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ABSTRACT

The primary goal of STUK, the Finnish Radiation and Nuclear Safety Authority, is to prevent and limit the harmful effects of radiation. The research conducted by STUK yields new information related to the use, occurrence and effects of radiation. The present report summarises STUK's own research activities related to radiation protection in 1995 - 1999. The research and its organisation, scientific strategy and priorities, the impact of results, publications, and the functions of research laboratories are all reviewed. This has been done to provide as background material for an international evaluation of research to be carried out in autumn 2000.

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Avainsanat Tutkimus, säteilysuojelu, toiminnan arviointi, ionisoiva säteily, ei-ionisoiva säteily

JOHDANTO

Säteilyturvakeskuksen (STUK) päämääränä on säteilyn vahingollisten vaikutusten estäminen ja rajoittaminen. Säteilyturvakeskuksen tutkimustoiminta tuottaa säteilyn käyttöön, esiintymiseen ja vaikutuksiin liittyvää uutta tietoa. Tämä raportti on yhteenveto STUKin säteilysuojelututkimuksesta vuosina 1995 - 1999. Raportissa käydään läpi tutkimustoiminta ja sen organisointi, tieteellinen strategia ja painopistealueet, tulosten vaikuttavuus, julkaisutoiminta ja tutkimusyksiköiden toiminta. Yhteenveto toimii taustamateriaalina STUKin tutkimuksen kansainväliselle arvioinnille, joka tehdään syksyn 2000 aikana.

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INTRODUCTION

The Radiation and Nuclear Safety Authority (STUK) is a regulatory authority, research institution and expert organisation, whose mission is to prevent and restrict any harmful effects of radiation. The ultimate objective is to keep the radiation exposure of Finnish citizens 'as low as reasonably achievable' (the ALARA principle) and to prevent radiation and nuclear accidents with a very high certainty (Safety As High As Reasonably Achievable or the SAHARA principle). The confidence of the general public and stakeholders' views on the significance of STUK's operations in enhancing safety are also key indicators of the quality of its work.

A key objective of STUK research is to extend professional knowledge that supports regulatory operations and the maintenance of emergency preparedness. The quality of the research done is under continuous self-assessment, and internal procedures have been set up to promote continuous improvement. Peer review of scientific articles in international journals is used as an external quality measure. However, this is the first time that all STUK's research activities are being subjected to external review by international radiation protection experts and scientists.

1 RESEARCH

1.1 Research and its organisation

The research carried out at STUK is related to radiation protection. In addition, STUK experts also supervise nuclear safety research projects (safe use of nuclear power and nuclear waste management) commissioned by the authorities and conducted by organisations outside STUK. However, the present review only covers the strategy, organisation and results of radiation protection research carried out by STUK itself.

1.1.1 Brief history of STUK as a research organisation

The Institute of Radiation Physics, the predecessor of the Radiation and Nuclear Safety Authority (STUK), was founded as a research institute in 1958. Its functions had been defined earlier, in 1957, in the Radiation Protection Decree. They were primarily to monitor the safety of X-ray equipment and other radiation sources used in hospitals, to carry out the necessary radiation measurements related to radiation therapy, and to study the consequences of atmospheric nuclear tests for human health and the environment.

In the early years of STUK, research focused on developing radiation metrology and personal dosimetry, and on radioecological studies in the environment. Wider use of radiation in medicine and industry in the early 1960s forced STUK to develop more accurate methods of calibrating X-ray and radiation therapy machines, and also to develop its own dosimetry system for personal dose control. On the other hand, atmospheric nuclear tests in the 1950s and early '60s generated public pressure for research on how members of the public are exposed to radioactive fallout and how different radionuclides behave in the Finnish environment. These radioecological studies also led to the establishment of a separate laboratory in northern Finland to study more closely the behaviour of radionuclides in sub-arctic foodchains. The laboratory was founded in 1970 in Rovaniemi.

The first investigations on underground miners' exposure to high concentrations of radon and its progeny were performed in the 1970s. These studies led to regular monitoring of workers' exposure and guidelines for action levels, monitoring frequencies and mitigation measures were introduced. The first findings on exceptionally high levels of natural radionuclides in groundwater also date from the late '60s.

In the '70s, after a political decision had been taken to build nuclear energy capacity in Finland, STUK's resources were increased, giving it greater research capabilities. The main research areas at this period were the behaviour of radionuclides in the environment and their transfer to human body, the occurrence of radon and other natural radionuclides in underground and surface waters and in building materials, radon in houses and workplaces, and the development of new methods for radiation surveillance in the immediate surroundings of future nuclear power plants. The first experimental studies on radiobiology and non-ionising radiation were also carried out.

The nuclear accident at Chernobyl in 1986 had significant radiological consequences in Finland. The radioactive fall-out necessitated extensive investigations on public exposure to released radionuclides, the occurrence and behaviour of radionuclides in the environment, and on the effects on the health of exposed people. The need for experimental radiobiological research, use of modern biological dosimetry, and for epidemiological studies increased. More effort was put into developing of emergency preparedness tools, including automatic monitoring networks, environmental modelling and decision-aiding techniques. Research became more networked with domestic and foreign research institutes and the number of joint projects was increased.

STUK co-operates closely with other Nordic countries in radiation protection research. This co-operation can be said to have started even before the official establishment of STUK, that is, in 1957, when the Nordic Liaison Committee for Nuclear Energy Questions (NKA) was set up. Nordic research co-operation moved into a new phase in 1975, when a new co-operation forum, Nordic Nuclear Safety Research (NKS), was established. This co-operation takes place within four-year framework programmes.

The collaboration with the New Independent States of the former Soviet Union and Eastern European Countries increased considerably in the 90's, especially in nuclear safety but also in research related to the environmental and health effects of the Chernobyl accident and the former nuclear tests. The establishment of the National Data Centre related to the Comprehensive Nuclear Test Ban Treaty also promoted new research functions in the late 90's. At present, in addition to domestic and Nordic co-operation, STUK plays an active part in European Union research programmes, and engages in bilateral and multilateral research co-operation with countries such as the United States, Russia and Estonia. The expansion of STUK functions is illustrated in Fig. 1.

1.1.2 Arrangements for setting and modifying the scientific strategy

The scientific strategy is based on STUK’s mission: to prevent and limit any harmful effects of radiation. For this purpose, research is carried out on radiation levels, effects of radiation and prevention of radiation hazards.

STUK's current strategic plan was outlined in 1998 to cover the next four years. Since then, all departments have prepared more detailed strategic plans of their own. Departmental strategy plans include a description of their mission and vision, an evaluation of changes in the internal and external operational environment (in the form of a SWOT analysis), and strategic plans for different areas of action.

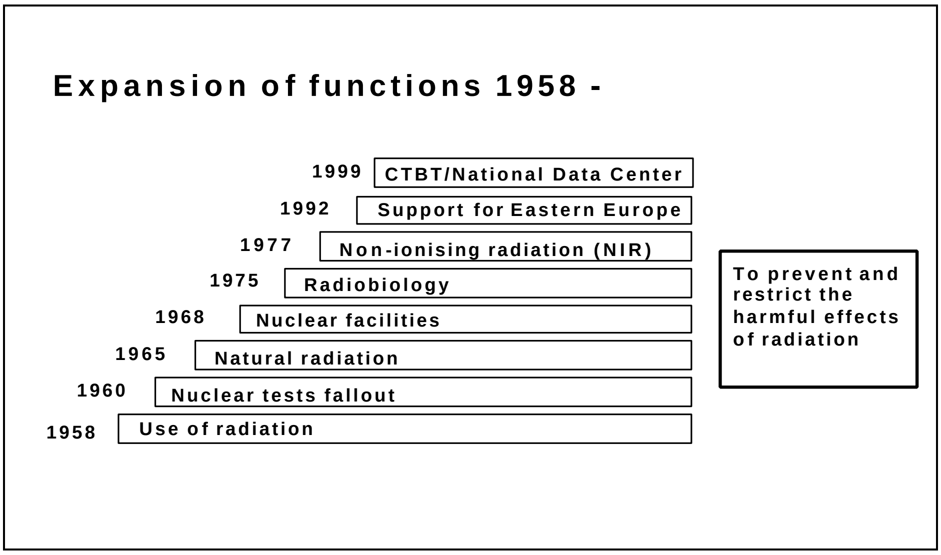


Figure 1. *Expansion of functions of STUK.*

The strategic plans are annually reviewed and revised jointly by management and staff, so that the planning period is always four years ahead. Research strategy is part of departmental strategy, and none of the departments under evaluation carries out research only. There is continuous input from other functional sectors, such as emergency preparedness, environmental surveillance of radiation and radiation practices regulation, which ensures that the research done supports the other functions of STUK.

1.1.3 Identifying priority areas for research

When STUK decides which new projects are prioritised and funded, the following factors are taken into account:

- Lack of knowledge in the study area
- Importance for public health: large numbers of people exposed/large individual doses
- National importance/special features of Finland
- Social demand for the knowledge

STUK’s research mission is to prevent and limit the harmful effects of radiation. The foundation for this is to gain information on the health risks for the public and workers from radiation. As knowledge about the exposure and risks grows, more emphasis will be put on prevention and limitation.

1.1.4 Dissemination of research results and transfer of knowledge and technology

As part of their self-evaluation seminars and development of procedures, STUK's departments have carried out an analysis of their stakeholders, products and end-users in different areas of action. The products and end-users of STUK research are described in Table I.

High-quality scientific publications are the key products of STUK research. They also form a solid basis for the conclusions and recommendations passed on to decision-makers and citizens. The highest-quality results are submitted to international journals for publication. Studies that are of interest mainly at the national level are published in national report series in Finnish and/or Swedish.

Table I. *End-users and products of STUK research.*

End-user	Product
decision-makers, citizens	conclusions, recommendations
scientific community - scientists at research institutes, universities - UNSCEAR, ICRP, BEIR, ICNIRP (risk assessment)	scientific publications
STUK as a regulatory and expert body	information to support and guide regulation and emergency preparedness, methods, equipment, models
municipalities, counties	reports, conclusions, recommendations
users of radiation	improved safety procedures
enterprises	support for product development
funding bodies (EC, Finnish Academy of Sciences, NKS, National Technology Agency)	progress reports
individual research units themselves	new methods, improved study protocols, computer models, databases

Although STUK carries out quite a lot of technical development work, relatively few patents have been registered so far. Over the years, there have been a few spin-off enterprises established by former personnel.

1.1.5 Scientific highlights: progress report on research

The main objective of the radiation protection research of STUK is to produce and extend knowledge about radiation effects on human health and the environment and about the behaviour of radionuclides in our living environment. The goal is to support the mission of STUK, i.e. to prevent and restrict any harmful effects of radiation. In that sense, the achievement of STUK research can be reviewed by looking how the results have supported the regulatory activities of STUK and what new knowledge the research has produced.

Detailed achievements produced by different units during the past five years are presented in chapter 2. The following review is a general summary of the outcome of STUK research and it is not strictly limited to results achieved during the last five years.

Radiation surveillance and emergency preparedness

Research and development action of STUK has resulted in most of the technical tools used for radiation surveillance and emergency preparedness at STUK. In the last few years, methods and techniques used for environmental radiation surveillance have gone through a thorough investigation in connection of the development of quality system of STUK. A new system for monitoring of ambient dose rate was built in 1998-1999 due to the Y2K problems, and the whole surveillance program of environmental radiation was revised in 1999.

Management of radiation situation after a nuclear accident has been a subject of research and development especially after the Chernobyl accident. The tools being in use in the Emergency Preparedness Centre of STUK have been developed in co-operation with other domestic research institutes (The Technical Research Centre and the Meteorological Institute). Implementation of the RODOS system at STUK is just going on and models of RODOS are under adaptation to the Finnish environment.

Exposure to natural radiation

Research on natural radiation resulted in the finding that naturally occurring radionuclides are the biggest source of the public exposure to radiation. Especially airborne radon in houses and natural radionuclides in household water are real radiation protection problems in Finland. STUK has estimated that the percentage of population exceeding the dose of 1.0 mSv due to indoor radon, drinking water, and natural gamma radiation is 64, 1 and 0.3% respectively. The annual dose of 10 mSv due to residential indoor radon concentrations is exceeded in the case of 2% of the population (or about 100.000 people).

During the last few years, STUK has concentrated on development of mitigation techniques and preventive measures in the both of these problems aiming at to restrict the radiation exposure. This work is performed in close co-operation with other research organizations and building authorities. Also the public information is an important part of this mitigation mission. At the same time, the survey to find and complete risk areas for occurrence of high concentrations of indoor radon and natural radionuclides in household water has been continued.

Epidemiological studies performed by STUK on health effects of exposure to indoor radon support the results obtained in studies in other countries. It is estimated that in Finland radon is associated in 100-600 new lung cancer incidents annually.

Radiation hygiene

Studies of radiation hygiene, i.e. radionuclide contents in human body, have indicated the population groups receiving higher radiation doses via ingestion than the population in average. Especially people in the northern Finland consuming great amounts of reindeer meat have been a subject of investigation. Lichen being the major source of nutriment of reindeers is a super effective gatherer of radioactive elements from air. The body burdens of the male reindeer herders increased, from 5.5 kBq to 13 kBq in 1988 after the Chernoblyl accident, but decreased to 4 kBq in 1997, when the last measurements on the group followed from 1961 were made. The mean annual effective dose for the male reindeer herders was about 0.4 mSv in 1988. The body burdens of female members of reindeer herding families, and the corresponding doses, were about one third of the values for the male reindeer herders.

Two other special groups have been investigated during the past few years; the one consists of people in Padasjoki in the Central Finland and the other in Viitasaari, also in the Central Finland. Consumption of great amounts of fresh water fish from small lakes and other wild natural products (mushrooms, berries etc.) in these municipalities which received relatively great fallout from the Chernobyl accident has been the reason for investigations. The results for the population groups and the special diet groups show that the body burdens within a certain fallout region are closely related to the differences in the composition of the diet and to the activity concentration of the foodstuffs consumed.

Recent studies on effects of other industrial pollution on dynamics of radionuclides in soil indicate that chemical industrial pollutants may change also the behaviour of radionuclides in the environment.

Contamination studies of workers at nuclear power plants have indicated clearly how important it is that workers pay close attention to their own working habits and to the industrial safety instructions.

Environmental transfer of radioactive substances

The main outcome of studies on radioecology is, in addition to produce results on contamination levels, to understand better the behaviour of radionuclides in the environment (terrestrial, lake and marine), and to provide necessary data and information for environmental models to be used for emergency preparedness purposes.

After the Chernobyl accident, radioecological studies of STUK have concentrated to measure and to estimate contamination levels of foodstuffs (agricultural, natural and semi-natural products), forests and timber products (being important to the Finnish national economy), to investigate the behaviour of radionuclides in the environment and possibilities to mitigate contamination levels in foodstuffs and forest products, and to develop environmental models.

The results show that radionuclide concentrations in agricultural products will decrease quite rapidly after the deposition compared with those in natural or semi-natural products (mushrooms, berries and game meat). The obvious reason for that is the effective fertilisation of agricultural land. Also the results in forest environment indicate the benefits of fertilisation for restoration of contaminated forests in a severe fallout situation. The availability of timber for the wood industry can be materially increased with long-term forest treatments. When there is multiple use of forests, pickers of wild berries and mushrooms, and hunters receive less radiocaesium through foodstuffs from fertilised forests than otherwise.

In the few last years, radioecological studies have resulted in special lake and forest models to be used within the RODOS system. These two environments are of special importance for Finland because lakes and forests cover a significant part of the Finnish territory. Studies on environmental dynamics of fallout radionuclides have also produced significant information on contamination processes of the Baltic Sea.

Radioecological and biological investigations in the environs of nuclear power plants have produced knowledge about local populations' exposure to released radioactivity and about the biological changes in the marine environment due to thermal effects of cooling water.

STUK was one of the first western laboratories getting opportunity to study radiological condition of the north-western Russia in early 1990's. The results indicated that the Russian arctic seas (White Sea, Kara Sea) are less contaminated than e.g. the Baltic Sea. Only the estuary waters and sediments of the great Dvina and Yenisey rivers showed slight elevations of antropogenic radionuclides due to large catchment areas.

Medical radiation

Research related to medical radiation has yielded new information on radiation protection in X-ray diagnostics and radiotherapy. In diagnostic radiation, priority areas have included the optimisation of x-ray examination techniques (including objective assessment of image quality), the examinations with high patient doses (CT, fluoroscopic procedures), the most radiosensitive patients (paediatric patients), non-symptomatic patients exposed to ionising radiation (mammography screening), performance of new imaging techniques (digital imaging) and assessment of patient dose and radiation risk.

The ability of humans to visually detect static low-contrast objects in the dynamic fluoroscopic image was assessed. The studies showed that humans can extract information in dynamic images (lasting a few seconds) with an efficiency that is close to their efficiency in observing static images. Image quality measurement methods and data are needed, e.g., in optimisation studies and quality assurance for fluoroscopy.

Patient dose and image quality was studied in pediatric fluoroscopy by theoretical calculations and clinical measurements. Contrary to common belief, the patient dose could be decreased without compromising the image quality in fluoroscopic examinations. As compared to specialised children's hospitals in Munich and London, patient doses in some Finnish University hospitals could be decreased by 35% on average without impairing image quality. The results have influenced the technical recommendations in the present draft EC quality criteria for pediatric fluoroscopy. In 1995, a survey of annual frequencies and practises of radiological examinations was carried out at all radiological clinics in Finland. Combined with patient dose assessment, they can be utilised for detailed assessment of collective dose from X-ray examinations and for focusing optimisation work effectively.

Development of reference doses and improvements in dose measurements are under way in order to fulfil European MED directive requirements. A PC-based Monte Carlo program for calculating patient doses in X-ray examinations was developed.

A boron neutron capture therapy (BNCT) facility started operation in Finland recently. STUK contributed in the characterisation of the mixed neutron and gamma radiation beam and development of dosimetry with TL dosemeters and twin ionisation chambers technique. Independent gamma dose measurement on a patient *in vivo* was made possible for the first time. The new methods have been adopted in several BNCT facilities and used for regulatory control of the Finnish BNCT facility.

A permanent function of STUK is the maintenance of the national standards for ionising radiation quantities, and provision of calibration and testing services for radiation measuring equipment for radiation protection, diagnostic radiology and radiotherapy. New calibration and measurement techniques for diagnostics and radiotherapy were developed.

Radiation biology and epidemiology

No statistically significant increase in minisatellite mutation frequency was observed among the children of Estonian Chernobyl clean-up workers. The cases and controls were children born to the same families after and before father's exposure at Chernobyl.

No increase in the incidence of leukaemia, thyroid cancer other cancers were observed among the Estonian Chernobyl clean-up workers. Neither did they have more thyroid nodules than control men of the same age. There was no increase in the rate of stable chromosomal aberrations in their lymphocytes. It was concluded that the recorded doses probably gave an overestimation of dose. However, the suicide rate was significantly higher among the Chernobyl clean-up workers as compared to register-matched control men in Estonia, showing that the clean-up workers suffered of stress and mental health problems.

The co-operation between European laboratories concerning the FISH technique has produced guidelines for its use in estimating the dose of past or chronic exposures. In this context follow-up of the Estonian radiation accident victims in Kiisa has provided and continues to provide information on the stability of translocations. Moreover, the FISH technique has shown its potential in identifying chronic exposure to low-LET radiation on the group level in nuclear power plant workers, whereas domestic radon exposure showed no effect on lymphocyte chromosomes.

The gene expression profiles in radiation-induced thyroid tumour cell lines are heterogeneous and no common gene pathway defect could be demonstrated. In general, the relative amount of all expression changes (up and down) was not dependent on the radiation type or dose. However, downregulation of p21 in many of these *in vitro* irradiation-induced tumour cell lines prevents p53 from inducing any G1 arrest, revealing that the p53 apoptosis pathway might be dysregulated irrespective of the p53 mutation status.

A register study of airline cabin crew revealed an excess risk of breast cancer among cabin attendants. Pooled cohort studies on pilots and cabin crew with other European countries are under way.

UVA radiation increased the adhesion of tumour cells in endothelium, and may therefore enhance the metastasis of tumours.

RF-EMF studies have preliminarily shown that short-term exposure of cells to low-level 900GSM signal causes changes in protein expression and protein phosphorylation. This indicates that cells respond to the RF-EMF signal in spite of its very low energy.

Microcavitation studies have shown that irradiating cells that contain light-absorbing particles with nano-second length laser pulses is a very efficient and selective method of killing cells. This laser technique might have applications in tumour therapy.

Non-ionising radiation

An exposure meter to measure pulse power density from scanning microwave radar units was designed, and four meters were constructed for the Finnish Defence Forces. An isotropic broadband (30 Hz to 3 kHz) magnetic field meter was designed and constructed to measure magnetic fields in a broad dynamic range (from 40 nT to 4 mT).

Several systems were developed for dosimetry of radiofrequency radiation and testing the radiation safety of mobile phones. An automated test system was developed to test the radiation safety of mobile phones, and primary standards were developed for the precise calibration of SAR probes. Waveguide-type exposure chambers were developed for *in vivo* and *in vitro* studies on biological effects of mobile phone frequency radiation.

In 1998 the International Commission on Non-Ionising Radiation (ICNIRP) published new recommendations for electromagnetic fields and waves. The exposure limits for the general public were adopted by the Council of the EU in 1999. The limits are appropriate for continuous sinusoidal fields, but in the case of broadband harmonic fields the recommendations are too strict, without any good biological justification. The new exposure assessment method proposed by the NIR laboratory is based on the principle of weighting the field strength or induced current density with a simple high- or low-pass function, respectively. The instantaneous peak value of the weighted exposure is kept below a peak value obtained directly from the ICNIRP guidelines. In addition to be less restrictive, these exposure measurements are much simpler, as time domain measurements can be used instead of complex spectral measurements.

At the beginning of the ‘90s STUK established a secondary national standard for the spectral UV-irradiance for the calibration of solar and other UVR measurements. The standard is based on a 1 kW quartz-halogen lamp calibrated against the NIST primary standard in the USA. To overcome the serious problems arising from stability problems with standard lamps and the large differences in UVR scales, the Metrology Research Institute at Helsinki University of Technology developed a new calibration traceability chain based on standard detectors instead of standard lamps in collaboration with the NIR laboratory. A recent comparison of detector- and lamp-based scales showed good agreement. A detector-stabilised portable lamp is under construction to transfer the new scale to solar UVR spectroradiometers.

Another significant advance was achieved in the field of broadband solar UV radiometry. A test and calibration method based on laboratory tests on the meters and calibration against a precision spectroradiometer for solar UV was developed. The accuracy of solar UVR spectroradiometry has been verified in frequent Nordic and European inter-comparisons of spectral solar UVR measurements. The first international inter-comparison of broadband UVR-meters, commissioned WMO, was carried out.

The effect of arctic ozone depletion and snow on UVR exposure in northern regions was examined, and the cancer risk of solar UVR in Finland was assessed. These studies suggested that the combination of springtime ozone depletion and high UVR reflection from snow considerably increase facial UVR doses during the winter in northern Finland.

1.1.6 Strengths and weaknesses, opportunities and threats

In 1998, during the preparation of departmental strategies for the different areas of action, STUK's internal and external operational environments were assessed using SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats). The following factors were identified for the units carrying out research.

Internal operational environment

The following factors were identified as **strengths:**

- multidiciplinary know-how
- modern, high-quality premises and equipment
- experienced and educated personnel
- good international reputation for research, emergency preparedness and environmental radiation surveillance
- good international networks
- highly motivated personnel, positive attitude to continuous development
- a good work ethics
- delegation of responsibility and resources

The following **weaknesses** were identified, and the aim set of systematically eliminating them during the planning period:

- the boundaries of the various areas of action are not clear to everyone, which complicates the process of working hours
- problems with human resources management and individual control of workload (too many projects, too many *ad hoc* tasks)
- not enough time to keep up with the literature and recent developments elsewhere
- working procedures not standardised or totally lacking, which hinders collaboration between units
- lacking or non-uniform quality procedures (eg. systematic follow-up of customer feed-back, external scientific evaluation)
- problems with the ability to co-operate, mutual envy
- the age structure, a large number of experts retiring over a short period, transfer of knowledge
- no representation in international risk assessment organisations (ICRP level)
- deficiencies in language skills (Russian, Nordic languages)

External operational environment

The research units will aim to make the best use of factors in the external operation environment (society, other STUK) seen as **opportunities:**

- Continuous social demand for knowledge concerning use and levels of radiation and the health risks of radiation (informing citizens, implementation of EU directives, environmental health action plan, etc.)
- EC 5th framework programme (Nuclear Energy, Quality of Life)
- international networking of research increases expertise and quality
- projects across departmental and unit boundaries increase expertise and heighten the impact of research
- new functions arising from the Comprehensive Nuclear Test Ban Treaty (CTBT)
- the rapid advances made by new research methods in molecular biology and information technologies offer new potential for studying the health effects of radiation and for making environmental surveillance more real-time and efficient
- the multidisciplinary know-how at STUK attracts new collaborators

The following external **threats** were identified. These will be taken into account in planning and the research units will try to prevent and control them as far as possible.

- cuts in the state budget
- new functions without new resources
- any decline in EC radiation protection funding
- expanding internal administration may increase overheads and reduce productivity and competitiveness
- if young scientists are not recruited from outside the retirement of experienced staff may turn out to be a problem within a few years

1.1.7 Research plans for the next five years

During the next few years, the main emphasis will be on projects supporting the Finnish national environmental health action plan (radon, UV), the health risks of radiation (low doses and genetic effects), emergency preparedness, and co-operation with neighbouring areas of Central and Eastern Europe. EU directives on radiation protection and medical exposure to radiation will also influence the course taken by research carried out at STUK. New research priorities also include studies on non-ionising radiation, especially the effects of mobile phone frequency radiation. As more and more emphasis is given to environmental protection, the criteria for the radiation protection of nature will also be addressed.

A detailed description of STUK research projects for the period 2000-2002 has been published in the STUK-A179 report (Salomaa 2000). The plan includes 84 projects altogether in the following areas: medical radiation (6), natural radiation (12), environmental transfer of radioactive substances and emergency preparedness (37), health effects of radiation (18), and non-ionising radiation (11). All of these are already under way and some are already at the reporting phase.

1.1.8 Interaction between research and STUK's work as a regulatory body

Radiation protection research includes research and development that is relevant in protecting people and the environment from the harmful effects of ionising and non-ionising radiation. The radiation protection research carried out at STUK follows two main lines:

- **applied research**, deriving from the needs of the authorities or even those of stakeholders such as hospitals or industry
- **problem-oriented basic research**, which typically addresses the health risks of ionising and non-ionising radiation

Applied research typically leads to more knowledge about exposures and better measurement and dose assessment techniques, and formulates improved procedures for users of radiation. Within STUK, it is the regulation of radiation practices that gains the most direct benefit from radiation protection research (especially research on medical radiation, non-ionising radiation and natural radiation). Research work has fundamental role in improving the calibration and accuracy of the measuring instruments of ionising radiation, electromagnetic fields and ultraviolet radiation. Nuclear reactor regulation benefits primarily from research yielding better emergency management and more exact monitoring of occupational exposure. Regulation of nuclear waste and materials makes use of research results produced by the CTBT radionuclide laboratory and also benefits from environmental impact assessment and research on natural radiation. Emergency preparedness and radiological situation assessment relies heavily on the competence of the radioecological and airborne radioactivity laboratories. These units also perform environmental surveillance in Finland, which is one of STUK's regulative activities. In many cases, the interaction between research and regulatory functions develops through international standards and regulatory guides.

The more basic type of research, which addresses health risks from radiation, has a more indirect connection with regulation, as it adds to the pool of knowledge used by the risk assessment organisations. However, the studies conducted on the Finnish population are also directly relevant at the national level.

The impact of STUK research on other authorities in Finland is discussed in chapter 1.1.10.

1.1.9 Co-operation with other research institutes and universities with related and overlapping interests

In Finland, STUK is the main - and in many areas the only - research institute conducting radiation protection research. There are therefore no real competitors at the national level. Expertise complementing STUK's know-how in radiation protection is actively searched via networking with other research institutes having their own specialisation. In some areas, especially those related to emergency preparedness and environmental radioactivity analyses, the lack of other research units with expertise in radiation protection is becoming problematic, as there should be more capacity in case of severe fallout situations. In Finland, research related to ionising radiation protection is carried out in the medical physics departments of universities/university hospitals, at the Technical Research Centre of Finland (VTT) and in the Radiochemistry Department of the University of Helsinki. Research related to non-ionising radiation protection is carried out at the Institute of Occupational Health and University of Kuopio.

During 1995-99 STUK has been collaborating with the following Finnish research institutes and universities:

- University of Helsinki
- Helsinki University of Technology
- University of Turku
- University of Tampere
- Tampere University of Technology
- University of Kuopio
- University of Lappeenranta
- University of Jyväskylä
- National Research and Development Centre for Welfare and Health (STAKES)
- National Public Health Institute
- Finnish Institute of Occupational Health
- Defence Forces Research Institute of Technology
- Statistics Finland
- Finnish Environment Institute
- The Finnish Forest Research Institute (METLA)
- National Veterinary and Food Research Insitute (EELA)
- Finnish Game and Fisheries Research Institute
- Finnish Meteorological Institute
- Finnish Institute of Marine Research
- National Food Administration in Finland
- Technical Research Centre of Finland (VTT)
- Geological Survey of Finland
- The National Emergency Supply Agency

In addition, technical development has been carried out with several companies and a number of domestic collaborators and corporations have acted as suppliers of samples or data.

The foreign collaboration is extensive and has become increasingly important after Finland joined the European Union in 1995. The collaboration network includes partners in practically all EU countries, all Nordic countries, the Baltic states (Estonia, Latvia and Lithuania), CIS countries (Russia, Ukraine, Belarus and Kazakhstan), several Eastern European countries (Poland, Czech Republic, Slovakia) and non-European countries such as USA, Canada, Japan and New Zealand. The foreign networks involve well over a hundred research institutes.

1.1.10 Impacts on the ministry level

Administratively, STUK comes under the Ministry of Social Affairs and Health. However, several other ministries (Fig. 2) deal with issues related to radiation and nuclear safety.

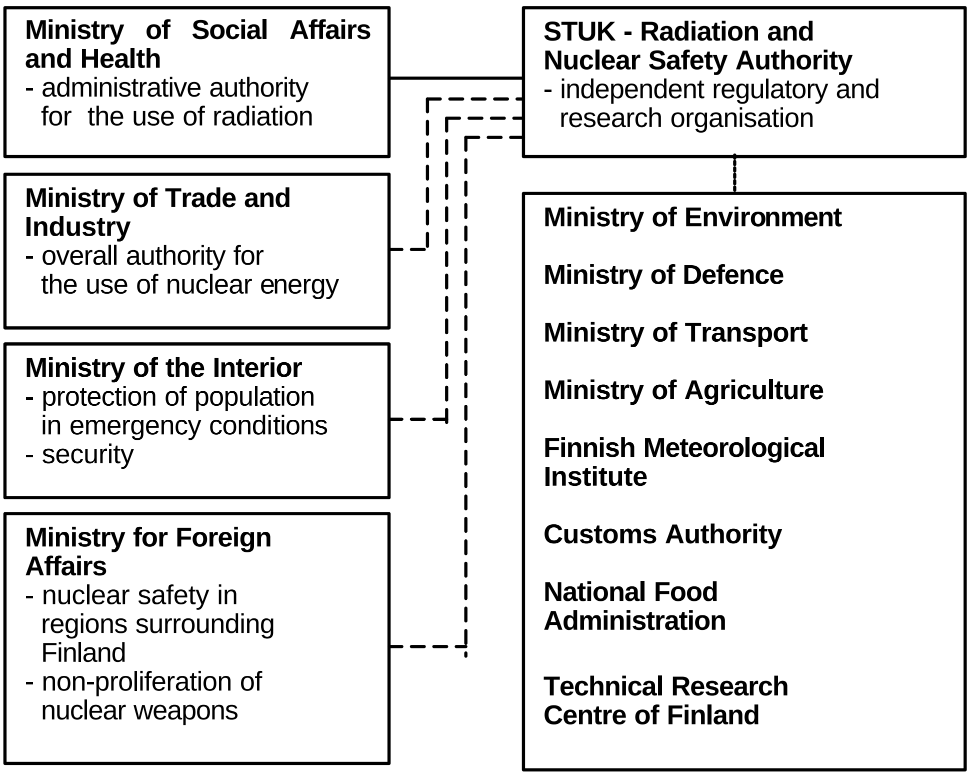


Figure 2. *Co-operation between STUK and ministries and other governmental organisations.*

Contacts with the different ministries at STUK level are provided within the STUK Board, which is chaired by the Ministry of Social Affairs and Health and has members representing the Ministries of Trade and Industry, Environment and the Interior. Other bodies facilitating the transfer of information between the governmental, institutional and industrial sectors are the Advisory Board for Radiation Safety, the Advisory Board for Nuclear Safety and the Advisory Board for Nuclear Energy.

Many STUK research results and development projects are of direct benefit to different ministries and authorities in Finland. STUK also collaborates actively with the research institutes of the different ministries. The most important ministries and authorities using research results are the following:

Ministry of Social Affairs and Health

Health risks of ionising and non-ionising radiation, preventive medicine, medical use of radiation, environmental health action plan, occupational health

Ministry of Trade and Industry

Nuclear safety, EC Nuclear Energy Programme, contacts with the IAEA, food industry and trade, industrial use of radiation

Ministry of the Interior

Emergency preparedness, environmental radiation surveillance

Ministry for Foreign Affairs

CTBT (Comprehensive Nuclear Test Ban Treaty) National Data Center and radionuclide laboratory

Ministry of the Environment

Radon in indoor air and drinking water, community planning, construction guidelines, environmental health action plan jointly with the Ministry of Social Affairs and Health, radioactivity in the Baltic Sea and the North East Atlantic, Radioactivity in the Arctic areas

Ministry of Defence

Emergency preparedness, mobile/airborne radiation measurements

Ministry of Agriculture
Agricultural radiation countermeasures, food research, forests

1.1.11 Impact on society

The results and conclusions of STUK research are passed on to the decision-makers and the society in several ways. The implementation involves several ministries and authorities at country and municipality level that have responsibilities related to radiation protection (health, environment, rescue service, community planning etc.). Books written by STUK experts are used in university and professional level education and several experts also have posts as university lecturers (docent). Advanced professional training in radiation protection is provided both at national and international level. Joint seminars and emergency exercises are organised with several stakeholder groups. Knowledge on radiation protection is also mediated via research networks and projects involving stakeholders and aim at improved procedures and practises or new methods to reduce the radiation exposure. This two-way communication also ensures that STUK receives valuable information and feedback from the key actors in the field. Information on research results and radiation protection is actively distributed to the general public and the stakeholders (see 1.2.1).

In recent years, more and more attention has been paid on the exploitation of the STUK research results. Exploitation plan is now an integral part of the project plan. At the international level, many of the research results are communicated via standardisation working groups. However, the lack of STUK's representation in international risk assessment organisations such as ICRP or UNSCEAR may cause some delay in the exploitation of Finnish knowledge by the international risk assessment society.

Expert knowledge of the research personnel of STUK covers all areas of radiation protection, i.e. from the basic research of health effects of ionising and non-ionising radiation at the molecule level to daily monitoring of levels of radiation. This broad expertise has enabled also own technical product development whenever it has been needed.

Scientific expertise on effects of radiation and its occurrence in the environment has increased the general credence to STUK. The past 15 years have demonstrated that the mass media and private citizens contact always experts of STUK whatever news or rumours on radiation appear. On the other hand, STUK itself has also put resources for public communication to be able to provide necessary information expeditiously and in a professional way. In 1999 STUK used 2.3% of its resources for public communication.

As described in chapter 1.2.1, research results are distributed, in addition to the scientific society, also to the general public by publishing a popularised summary of each research article or report. Regarding communication with radiation users and other stakeholders STUK scientists are submitting articles to professional journals in order to distribute latest news of radiation research and radiation protection. STUK is also publishing its own journal on radiation protection and nuclear safety (ALARA journal) which is more or less directed to the domestic radiation protection society. Experts of STUK are also giving lectures in various cources dealing with radiation or environmental protection, emergency preparedness or nuclear safety.

STUK also has a close co-operation with educational institutions. In addition to joint research projects with universities, some scientists of STUK act as permanent lecturers in universities.

1.2 Publications

The number of research publications in 1995-1999 is shown in Fig. 3. The publication categories include original publications (articles in international peer-reviewed journals); articles in the proceedings of international scientific meetings, and reports published in institutes' own publication series. Publication in international journals and for a wider audience is encouraged. Publications are used as a measure of research productivity. STUK has an internal impact score for different types of publications: 12 points for an original publication, 8 for a proceedings article, 4 for a report and 2 for an international meeting abstract or an article in a national professional journal. The result objective is that STUK publishes one original publication equivalent per researcher-year.

List of publications for the last five years is given in Chapter 3.

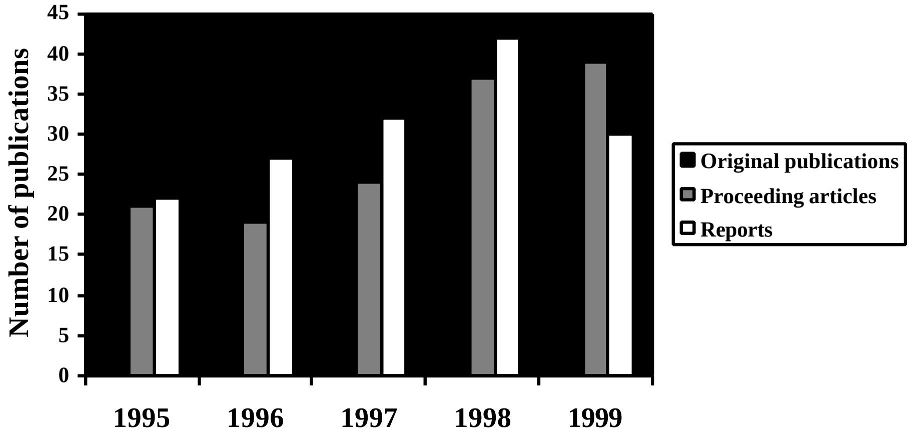


Figure 3. *Number of research publications in the three publication categories during 1995-1999.*

1.2.1 Actions to popularise research results

The research carried out at STUK is applied, and many of the results are of interest to citizens, decision-makers and stakeholders. STUK's information policy is open and proactive. In the case of research results, the routine procedure is to pass a popularised summary of the results to the Information Unit immediately after publication. Training of scientists includes instruction on communicating with the media and this is also practised in connection with emergency exercises. Citizens are very interested in news dealing with radiation or nuclear safety, and the media takes up practically all STUK press releases.

There are several ways of popularising results and of communicating with the public and stakeholders:

- Articles published in national professional journals, such as STUK's own journal, ALARA. These articles reach primarily the stakeholders.
- Information leaflets
- Books on radiation and nuclear safety
- Internet (www.stuk.fi)
- Press releases and press conferences, interviews

- Training courses and lectures aimed at the stakeholders

1.3 Organisation and resources

1.3.1 Organisation

The organisation of the Research and Environmental Surveillance department is shown in Fig. 4. There are eight laboratories, seven of which are situated in Helsinki (Natural Radiation, Radiation Hygiene, NPP Environment, Ecology and Foodchains, Airborne Radioactivity, Medical Radiation and Radiation Biology) and one in Rovaniemi (Regional Laboratory in Northern Finland).

There is also a management unit taking care of the department's administration, management of research and environmental surveillance, co-ordination of emergency preparedness and related research, secretarial and statistical work and database maintenance. The Research Director is responsible for general administration of the department and for conduct of research. The Deputy Director is responsible for conduct of environmental radiation surveillance and expert services.

In the Radiation Practices and Regulation department (Fig. 5), research is carried by two laboratories, the Non-ionising Radiation Laboratory and the Radiation Metrology Laboratory.

Management is founded on active interaction between management and personnel. The management holds regular briefings for the personnel on the objectives of operations, the principles guiding these operations and current development projects, and monitors operations by maintaining regular direct contact with the units. Other means of communication include the minutes of the STUK management group and department meetings, which are drawn up in an informative manner and are available to everybody over the Intranet. A Co-operation Group composed of representatives of the management and the personnel deals with matters that affect working conditions and other general matters of personnel policy.

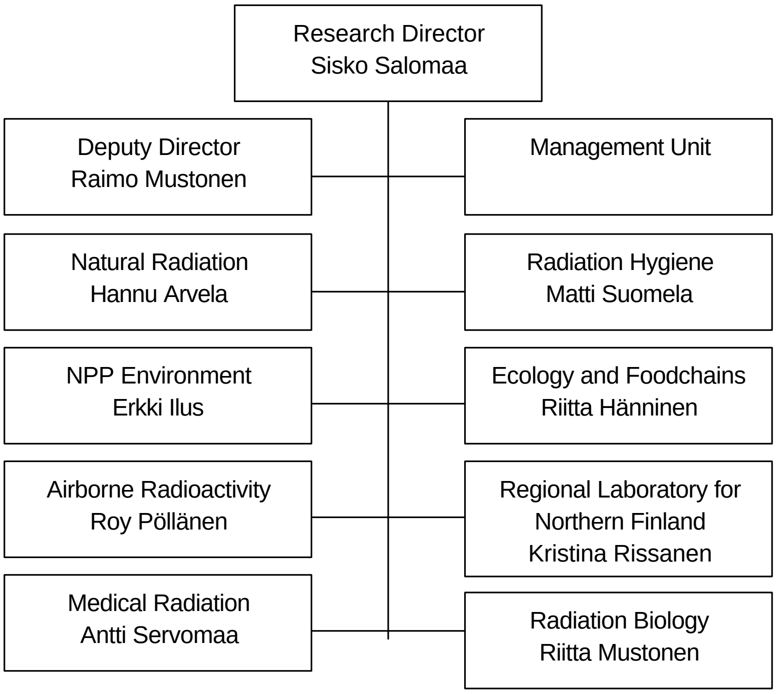


Figure 4. *Organisation of the Department of Research and Environmental Surveillance.*

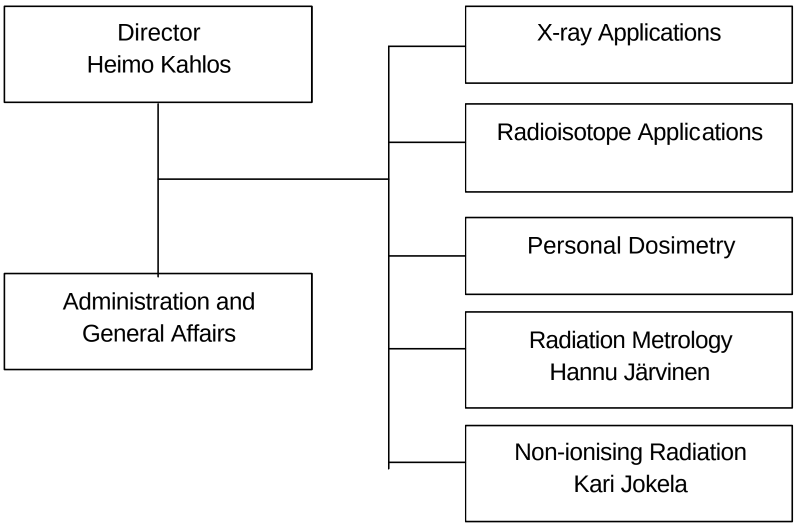


Figure 5. *Organisation of the Department for Radiation Practices Regulation.*

Orders, guides and written plans endorsed by the management are used to facilitate efficient direction and to ensure systematic work practices. They are included in quality manuals or form part of long-term strategy plans or annual action plans.

All supervisors are responsible for setting objectives for the unit they are heading, for systematic monitoring of results, and for creating the conditions for the work, including adequate supplementary training and a smooth flow of information on all relevant matters.

Both individual areas of responsibility and those of whole organisational units are documented in the quality manuals.

1.3.3 Personnel

In 1995-1999, the number of employees in the Department of Research and Environmental Surveillance varied between 87 and 107, depending on the number of fixed-term personnel and trainees working on projects. In addition, the Non-ionising radiation and Metrology laboratories of the Department of Radiation Practices and Regulation employed about twenty persons. The number of full person-years spent on research sector was 73 – 79 during the same period (see Fig. 9).

The educational background of the staff in the units described above is illustrated in Figs. 6 and 7. Currently, 54 per cent of the permanent staff have an academic degree at Master's level or higher. The scientists' educational background is almost entirely in the natural and life sciences, such as physics, nuclear physics, radiochemistry, chemistry, statistics, geology, genetics, biology, biochemistry, medicine, limnology and forestry. The technical sciences are also well represented. Twenty-four of the 96 persons with permanent positions have post-graduate level qualifications. Thirteen of them are doctors (PhD, MDPhD or DrTech) and the rest have a Licenciate's degree (PhLic, TechLic). Six of the doctors are docents, i.e. lecturers in university departments. Ten Master's and two Licenciate's degrees and three Doctorates were completed in 1995-1999.

1.3.4 Recruitment of researchers

A large number of the permanent staff were engaged in the 1960s and the '70's when the functions of STUK were expanded due to nuclear test fallout, discovery of the radon problem and the construction of nuclear power in Finland (see Fig. 1). As STUK is the main institution for research on radiation protection in Finland, there has been relatively little turnover of staff. This means that most of the staff has long experience and high competence in their research field. On the other hand, a large number of experts will be retiring in the next few years. Of STUK's 300 employees, some 90 will retire during the next ten years.

It takes several years to train a scientist in a specialised field. A university education alone does not provide adequate expertise in radiation protection and, as Finland has no other strong research institutes in radiation protection, very few scientists with specialised training are directly available for the posts. In the recent years, especially since Finland joined the European Union, external project funding has increased considerably at STUK. The shared cost

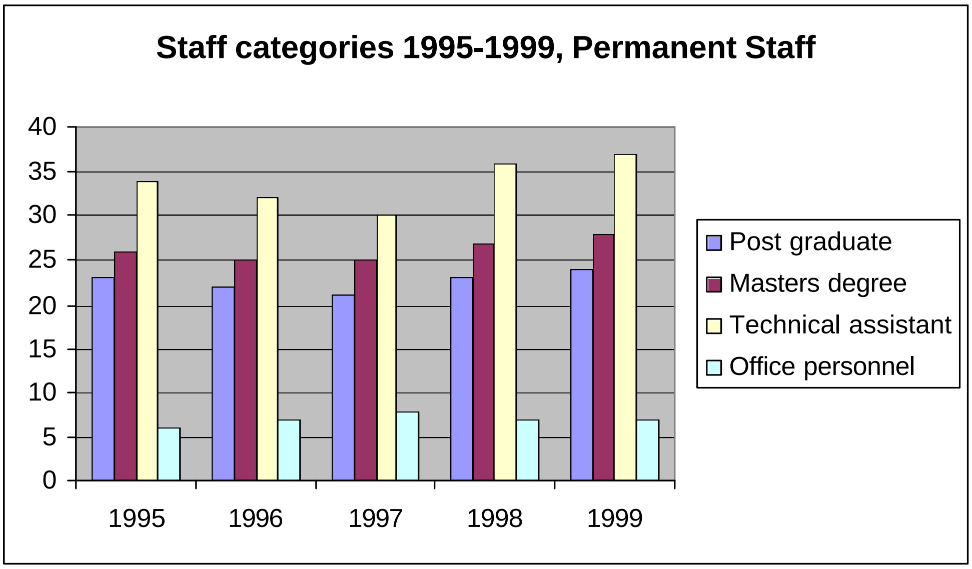


Figure 6. *Staff categories 1995-1999, permanent staff of the units performing research.*

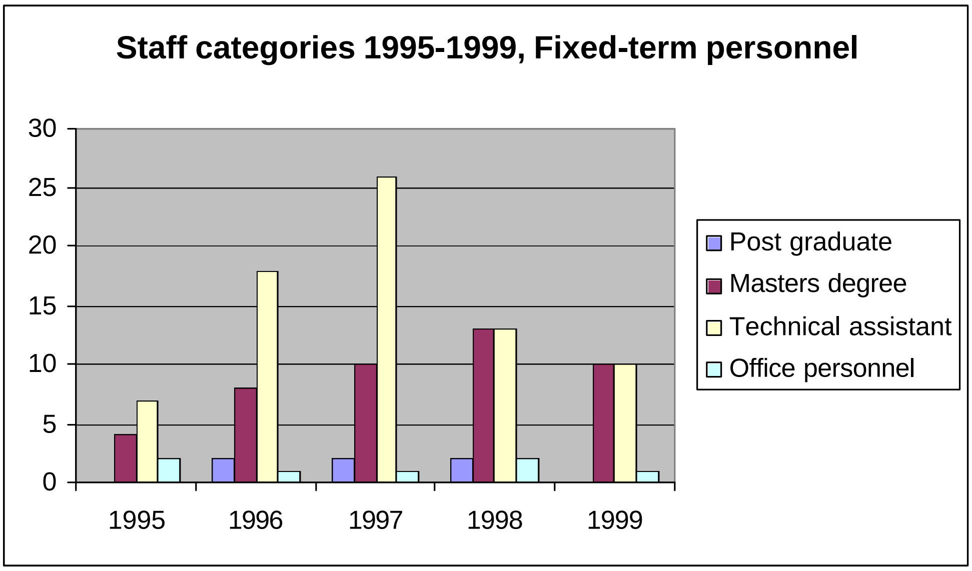


Figure 7. *Staff categories 1995 - 1999, fixed-term personnel of the units performing research*

contracts have enabled the employment of fixed term personnel, including students aiming at a Master's or doctorate. Many of these project researchers have later been engaged permanently by STUK, resulting in a more balanced age structure. Nevertheless, transfering the knowledge of retiring experts to the new generation of radiation protection specialists will be a major challenge.

1.3.5 Finance

All STUK activities are divided into seven action areas: research, nuclear safety regulation, radiation safety regulation, emergency preparedness, environmental surveillance of radiation, external services and communication. Costs are divided up among these action areas. Overheads from administration, internal services, renting expenses, etc. are also divided among the action areas according to internally agreed procedures.

During the past few years research has accounted for some 30% of STUK's total costs. The breakdown of STUK costs among the different action areas in 1999 is shown in Fig. 8.

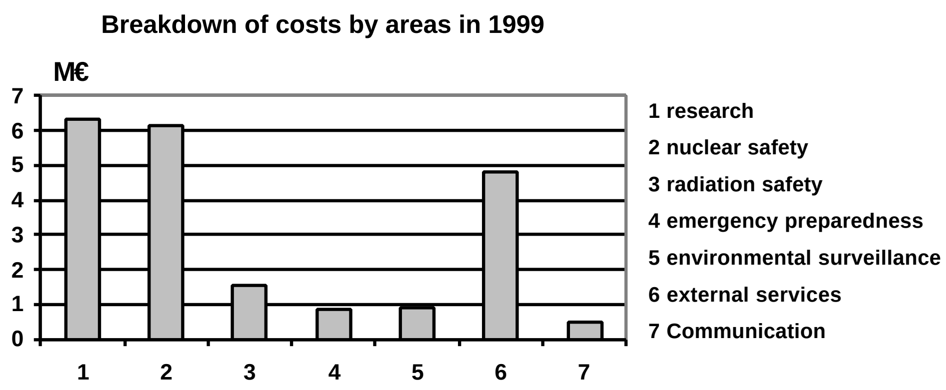


Figure 8. *Breakdown of total STUK costs among the different action areas in 1999.*

Research is also STUK's biggest action areas in terms of human resources. About one quarter of total human resources has been devoted to research purposes during the past few years (Fig. 9).

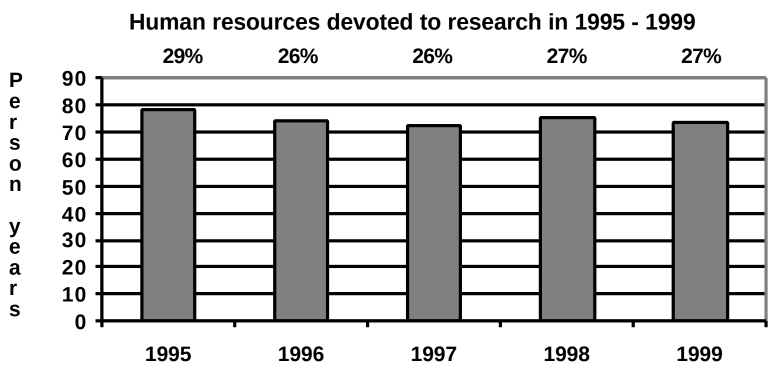


Figure 9. *Person-years devoted to research at STUK in 1995 - 1999. The percentages in the figure indicate the proportions of STUK's total human resources.*

The small variations in person-years reflect the number of temporary employees in short-term research projects. In 1999, 73.4 person-years were allocated to research.

The total cost of research has been around EURO 6 million during the past few years (Fig.10). Since 1995 total costs have increased slightly, due to higher overhead costs. Direct research costs decreased from EURO 3.4 million in 1995 to 2.7 million in 1999.

Most of the research funding comes from the state budget and the overhead costs shown in Fig. 10 are entirely covered from budget funding. Direct costs can be allocated to several funding sources. In Fig. 11, funding of direct research costs is divided among domestic and foreign sources. In addition to the state budget, STUK domestic research funding has been obtained mainly from the Academy of Finland and from the National Technology Agency (TEKES). The international funding has mainly come from the European Commission since 1995, when Finland joined the European Union. Other international sources include Nordic Nuclear Safety Research (NKS) and the US National Cancer Institute (NCI).

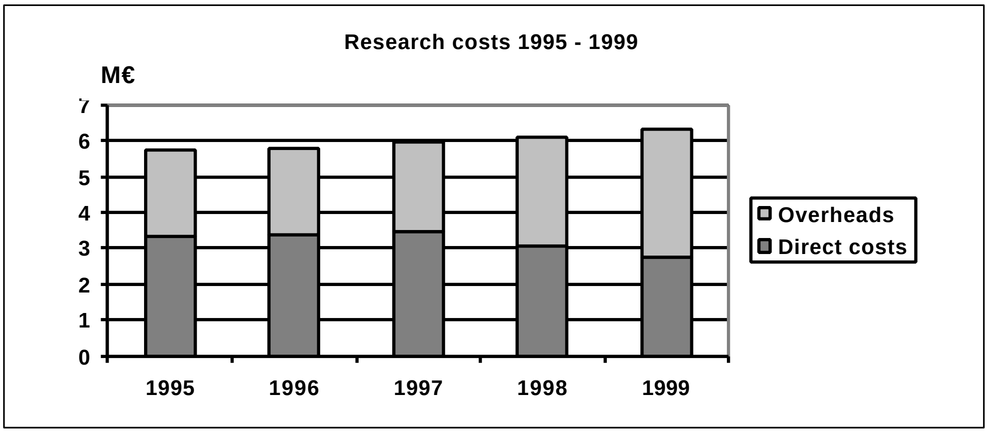


Figure 10. *Trends in research cost from 1995 to 1999.*

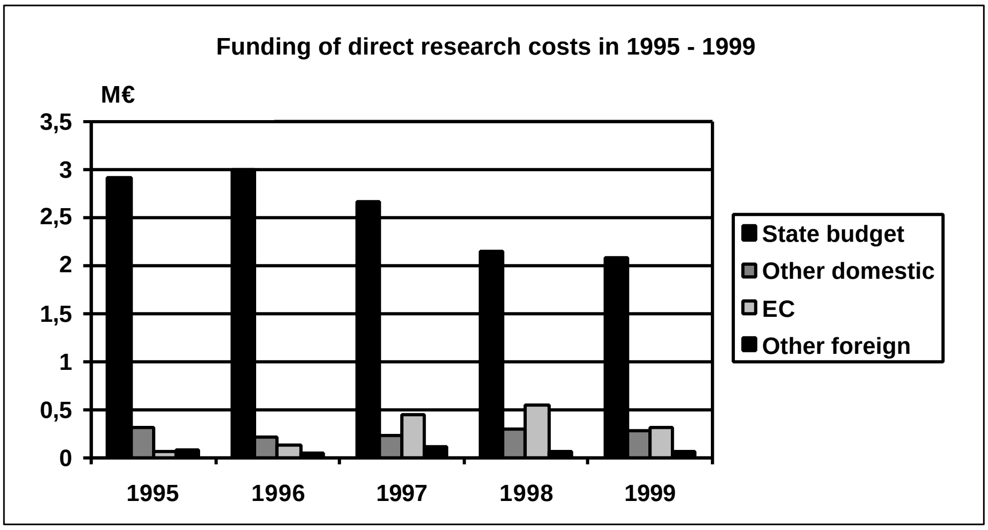


Figure 11*. Sources of research funding at STUK in 1995 - 1999.*

Research is divided into nine areas of focus:

- Nuclear safety
- Medical radiation
- Natural radiation
- Radioecology and emergency preparedness
- Health effects
- Metrology
- Non-ionising radiation (NIR)
- International co-operation (outside projects)
- Domestic co-operation (outside projects)

As mentioned above, STUK does not itself carry out the nuclear safety research projects (safe use of nuclear power and nuclear waste management) commissioned by the authorities. This research is conducted by organisations outside STUK, but supervised by STUK experts. Only a small fraction of the research done on nuclear safety is conducted by STUK itself, and this is included in the funding figures presented here.

In 1999, the total cost of research was EURO 6,321,000, broken down among the different research activities as shown in Fig. 12. Radioecology and research related to emergency preparedness accounted for 35% of the funding, followed by radiobiological and epidemiological studies of radiation effects.

1.3.6 Research facilities

STUK research is conducted at two different sites. Most of the research facilities are in one building in eastern Helsinki, the rest being at the regional laboratory in Rovaniemi, about 800 km north of Helsinki. The Regional Laboratory in Northern Finland specialises in studies on subarctic and arctic ecosystems.

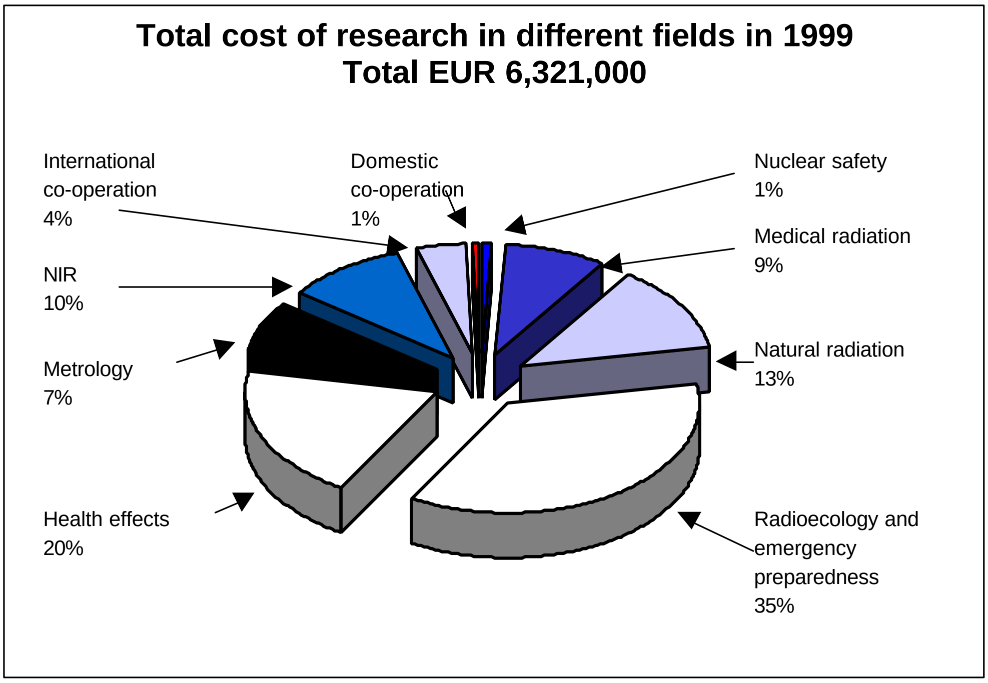


Figure 12. *STUK research cost in different research fields in 1999.*

The total floor area of the main building in Helsinki is about 14 500 m^2, of which about 4 600 m^2 comprises laboratory facilities with special structures and ventilation. The main building dates from 1994. The laboratory ventilation is isolated from the system ventilating the normal office rooms. The facilities comprise laboratories for pre-treatment of samples, radiochemical and biological treatment and analysis of samples, radioactive and X-ray measurements, non-ionising radiation, and calibration of measuring instruments. STUK has seven laboratory rooms for low-background radioactivity measurements (alfa, beta and gamma). These have been constructed using a special concrete containing an extremely low amount of natural radioactive elements (olivine rock and special cement), and are equipped with special ventilation systems (air-conditioning, excess filtering of incoming air, and exhaustion of radon exhaling from construction materials before radon enters the room air). The main building also contains one laboratory for X-ray studies and three laboratories for the calibration of radiation measuring instruments. The laboratory facilities for cellular biology are isolated from the other research facilities. Altogether 87 fume cupboards are available. The laboratory for handling high amounts of radioactivity is located in the sub-basement of the building.

Laboratories for non-ionising radiation are located in the ground floor except the solar UV-measurement chamber, which is on the roof of the main building. Measurements of electric and magnetic fields, device testing and calibration are performed in radio-laboratory including a microwave anechoic chamber of size 2,5 x 2,3 x 4 m^3. Measurements of optical radiation, device testing and calibration are performed in optical-laboratory, solar-measurement chamber on the fenced roof. The interior of both optical-laboratory and solar-chamber are black pained. The measurement site in optical-laboratory is also screened with black curtain from rest of the room.

The facilities of the Regional Laboratory of Northern Finland in Rovaniemi, for pre-treatment, radiochemical analysis and measurements of environmental samples, are located deep in the bedrock. The rooms for radioactive measurements (alfa, beta and gamma) are situated in a shelter and they are protected against electromagnetic pulses.

The specific technologies and equipment used at STUK are listed in the laboratory descriptions (chapter 2).

1.3.7 Supportive functions

Internal administrative support functions include the financial and personnel administration. The information services at STUK include a high-quality library, which acts as the central library for radiation and nuclear literature in Finland. On-line scientific databases are readily available via the internal computer network. The ADP unit supports the computer network services and hardware installations. All employees at STUK have their own computer connected to the network. The network acts as an essential communication route, offering not only e-mail and the Internet, but also the Intranet, an electronic library containing all the documentation related to the management and administration of STUK. STUK's web site provides information in Finnish, Swedish and English.

Internal training is provided to improve skills needed to use the software (office programs, database construction, programming), and in management and communication. Tailor-made courses are also organised to meet the needs of specific personnel groups. Training at outside organisations is actively supported. Occupational health care, STUK's own gym and organised fitness activities help in maintaining the physical and mental well being of the personnel.

2 LABORATORIES

2.1 Department of Research and Environmental Surveillance, Management Unit

2.1.1 Key words and specific technologies

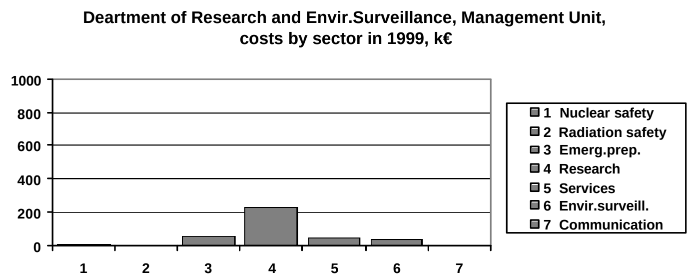
Key words

Emergency preparedness, protective actions, consequence assessment, training and exercises, decision support systems, environmental modelling, decision analysis.

Specific technologies

RODOS system, GIS systems, HP/ UNIX network.

2.1.2 Description of laboratory activities



The varied response to the Chernobyl accident both in and beyond the former Soviet Union above all demonstrated the need to plan countermeasures in advance, together with generally accepted procedures and models to ensure an integrated and harmonised response to any future accidents. The tasks facing decision-makers in emergency management are complex and highly stressful. During an incident, volumes of varied and continually changing data become available, risking an ‘information overload’. It is important, therefore, that they are provided with timely, easily comprehended summaries of relevant information. To understand what information is “timely, easily comprehended and relevant” requires a very clear understanding of the practical needs of decision-makers also in terms of the information provided by STUK and of the context in which they work. Thus, it is necessary to understand the factors, decision processes, organisational structures and interactions that lead to effective and informed responses to nuclear accidents.

To improve nuclear emergency management and decision support, we have taken part in the completion and customisation of the modelling in the European RODOS (Real-time, On-line DecisiOn Support System) system. RODOS is also used in training courses and exercises. In order to study and improve the applicability of the RODOS system for decision-making, a series of evaluation exercises based on hypothetical nuclear accidents has been organised with decision-makers and technical experts responsible for emergency management. STUK also co-ordinates the RODOS Users' Group (RUG) which provides a forum for the exchange of experiences between users of the RODOS-system. The aim of the User Group is to reinforce communication and feedback between users and model and system developers in order to improve the quality and efficacy of the system.

2.1.3 Personnel

The Management Unit of the Department of Research and Environmental Surveillance takes care of management and administration, secretarial and statistical support and database maintenance. In addition to research director and deputy director, there are five secretaries, a statistician and a system analyst. Two scientists in the Management Unit are involved in the research on decision support systems for nuclear emergency preparedness and co-ordination of exercises.

Research personnel:

Kari Sinkko, PhLic (physics), project manager of the decision support systems

Michael Ammann, MSc, scientist

2.1.4 Aims of research

The overall objective is to plan countermeasures in advance and secondly, to catalyse the development of future versions of decision-supporting systems that are better tailored to the decision-makers *practical* needs in terms of the information provided and interface design. Also, where appropriate, processes and procedures may be changed to take advantage of the full potential of decision-supporting system. Specifically, the project's objectives are as follows.

Objective 1. To identify and document the emergency management process with view to:

- understanding how decision-supporting system tools can better interact with and support the process;
- identifying modifications of the process which may lead to more effective use of decision-supporting system tools;

Objective 2. To better understand the needs of decision-makers at different stages in the management of emergency better, firstly, by

- clarifying what information decision-maker need and in what form;
- identifying the factors (radiological, socio-psychological, economic, etc.) which drive decision-making;
- exploring how these factors relate to the bases for international (generic) guidance on intervention;
- eliciting the relative importance of the factors in a range of accident scenarios and how these change during the course of an accident;

thus identifying and defining attributes and value trees that can be tailored into RODOS and other decision-supporting systems.

Objective 3. To improve the communication of uncertainties to the decision-makers and to support them in their task of explaining the uncertainties and risks to a wider public by:

- developing and testing graphical techniques in order to improve the decision-makers' understanding of the probabilities and values involved in the analysis;
- identifying how to present information on uncertainties via the decision-supporting system so that it supports known good practice in public risk communication.

Objective 4. To improve the economic modelling of the monetary costs of countermeasures and to identify more precisely the economic indicators that could be used in the decision-making process by:

- developing economic models that could be integrated into the decision-supporting systems based on existing models (probabilistic safety analysis codes and economic models);
- collecting economic data both to define appropriate data bases for the economic model and to develop the methodology for acquiring such data.

2.1.5 Progress report on research over the last five years

Completion and Customising of the Modelling in RODOS

The R&D work in the 'Completion and Customisation of the Modelling in RODOS' project under the auspices of the Nuclear Fission Safety Research Programme within the Commission's 4^{th} Framework Programme started at the beginning of 1997. The RODOS C project is one of the six separate, but fully integrated RODOS, contracts aiming to develop a real-time, on-line decision support system.

The work in the RODOS C project has been aimed to expand the applicability of the RODOS system to encompass all stages of an accident and all distance ranges in Europe, and also making improvements and customisations in existing methods. The following R&D areas have been developed:

- Completion and customisation of radiological modelling and their databases in natural and seminatural environments. Development of submodules for the estimation of internal and external doses in forest environments. Extension of the aquatic submodule to northern and mountainous conditions.
- Development of a computer-based training course for off-site emergency management in the later phase of a nuclear accident. Production of a guideline on the methodology of preparing and organising of nuclear emergency exercises. Application of the RODOS system in various exercise settings.

Work performed in the RODOS C project:

- The Forest Food Chain and Dose Module of the FDMF was developed jointly with IPSN. Integration of FDMF into the RODOS system was completed and validated in early 2000.
- The first series of Finnish decision conferencing has been completed and the reports published in the STUK report series in 1998 and 2000 (STUK-A159 and STUK-A173). An evaluation report on the exercises was issued at the end of September 1998.

RODOS Users' Group

A two-year Concerted Action, the RODOS Users' Group (RUG) commenced in September 1998. The Users Group provides a forum for the exchange of experience between different users of the RODOS system and those responsible for its development; this interaction is expected to improve both the quality and efficacy of the system and how it is used.

Work has included:

- Creation of a *WWW page* at STUK, December 1998.
- *First meeting of the RUG*, February 1999: close site and the early-phase issues of an accident, such as dispersion, early-phase countermeasures, links to meteorological networks, and review of the implementation status at emergency centres
- *Second meeting of the RUG*, September 1999: dispersion over great distances, issues in the intermediate phase of an accident, behaviour of contamination in rural and urban areas, foodstuffs
- *Third meeting of the RUG*, March 2000: 5^{th} Framework Programme proposals in the emergency management area (evaluation, contractual negotiations and managing accepted/ linked projects) and possible interaction between DSSNET (5^{th} FW project) and RUG, status of RODOS Version 4.0, User Guide, Final report, CDs and current and future RODOS installations (PL, Slovak Rep., Germany and others), conclusions of the first comparison exercise of the RODOS Users' Group, and plans for the second consequence assessment analysis of the RODOS Users' Group.

Finnish Decision Conferences: Later-Phase Protective Actions in Urban and Rural Environments

The following meetings (interview/decision conferences), which were assumed to be taking place at successive decision points in the evolution of the hypothetical accident, were organised: an interview analysis in order to shed light on urgent protective actions like iodine prophylaxis sheltering and evacuation, and meetings/a decision conference (STUK-A173). The meetings related to milk and milk products dealt with urgent measures to protect livestock (milk) and the decision conference with follow-up and more extensive countermeasures applicable to milk and milk products.

The decision-making process adopted in Finland for meetings concerning decisions on countermeasures applicable to foodstuffs/milk/milk products was worked out. The description listed participating organisations and their duties, especially who will prepare advice, who the stakeholders are, which the organisations are that will take the final decision, and who will implement actions.

The different ways of running the decision conferences were described and tested, depending on the participants and the expected phase of the accident. At the earlier conference only the value tree technique was tested. This was the starting point for a second series of experiments. However, how uncertainty handling could be incorporated into the process was also evaluated. One way was to work with utility functions and thus introduce risk attitudes explicitly. Another way was to model the uncertainties solely as ranges of outcomes. This approach applies the new interval methods PAIRS and PRIME (Salo and Hämäläinen 1992, 1997) and the related software's WINPRE and PRIME solver, developed by the Systems Analysis Laboratory.

EKO-5: planning early clean up. Nordic Nuclear Safety Research, NKS

The aim here was to work out guidelines to be used in planning early clean-up actions which have to be taken during the first three weeks in order to be meaningful. The work only considered actions reducing doses from external radiation in inhabited areas. A main target group for the written document (NKS/EKO-5 (96) 18) is those in charge of making plans for the actions to be taken in the case of a radioactive release, who are found at different levels in the preparedness organisations in each country.

EKO-4.1.1.c: decision-making in the later phase of an accident. Nordic Nuclear Safety Research, NKS

Issues concerning clean-up strategies in an urban environment after a very severe hypothetical reactor accident were discussed in a joint Nordic exercise. A decision conference was organised on the 30th and 31st August 1995 in Stockholm, Sweden. The conference was designed for those responsible for planning and deciding on protective actions in the Nordic countries after a nuclear accident.

The objectives of the conference were to create a shared understanding between the decision-makers and radiation protection community on concerns and issues related to decisions on protective actions after a nuclear accident. Another aim was to identify the values/attributes to be considered in setting intervention levels for clean-up actions in an urban environment and to demonstrate and explore the use of decision conferencing as a tool for decision-making on protective actions (STUK A-132).

2.1.6 Research plans for the next five years

STUK's research projects for the period 2000-2002 are described in detail in the STUK-A179 report (Salomaa 2000). A list of the projects to be carried out by the Management Unit is given below.

- Improvement, extension and integration of operational decision support for nuclear emergency management (DSSNET)
- Decision conferences: planning protective actions in urban and rural environment

2.2 Natural Radiation

2.2.1 Key words and specific technologies

Keywords

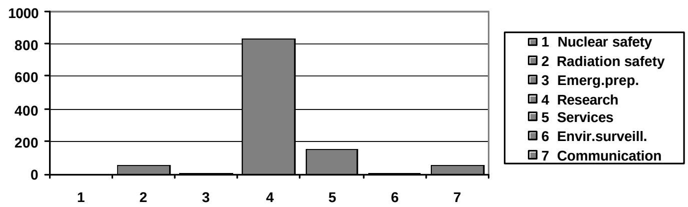
Natural radiation, radon, epidemiology, lung cancer, building materials, radioactivity, radon entry, home, workplace, municipality health authority, building authority, survey, geology, soil, radon prognosis, emanation, air exchange, uranium, radium, ^{210}Pb, ^{210}Po, risk mapping, indoor air, radon mitigation, water treatment, water purification, radon-safe building, household water, drinking water, drinking water regulations

Specific technologies

Alpha track, ionisation chamber, Lucas cell, gamma spectrometry, sub-slab suction, radon well, alphaspectrometry, liquid scintillation counting (LSC), low-background LSC spectrometry, alpha-beta discrimination, pulse shape analysis, ion-exchange, radon removal by aeration, granular activated carbon (GAC) filtration, uranium removal by anion exchange, radium removal by cation exchange, reverse osmosis, nanofiltration

2.2.2 Description of laboratory activities

Natural Radiation Laboratory, costs by sector in 1999, k€



The Natural Radiation laboratory is responsible for:

- research on occurrence and risks of radon in indoor air, natural radioactivity in household water and terrestrial and cosmic radiation, as well as mitigation studies
- measurement services for indoor radon concentration and radioactivity in household water

Radon in indoor air

Radon in dwellings first emerged as a radiation protection problem in Finland in connection with household water. Radon was first studied in houses with elevated (several tens of kBq/l) radon concentrations in their drinking water. Waterborne radon was therefore considered to be the main source of radon in indoor air. At the beginning of the 1980s, views totally changed when direct influx from soil was found to be the major source of radon in Finnish dwellings. From the early '80s onwards a comprehensive survey of radon in houses has been carried out. The late '80s were a time of active measurements in municipalities. STUK developed a methodology for making measurement plans and radon-prognosis in co-operation with local authorities. Strategies for seeking high indoor radon concentrations and variations in indoor radon concentration were studied.

In the '90s the NRL has focused on producing a representative nationwide survey of indoor radon, on health studies and on remedial and preventive measures.

Radon risk mapping

Since 1986, STUK has performed systematic indoor radon mapping jointly with municipal health authorities in order to identify radon-prone areas. The measurement plans illustrate the radon situation among the existing housing stock, whereas the prognosis maps show the radon potential of building land. Searching is easiest in esker areas and other sand and gravel deposits because they are easy to locate from geological maps. Radon mapping activities include:

- Measurement plans: In 1994 we completed the work of making first-stage radon measurement plans, and these now cover all of the 450 municipalities in Finland. We have also drawn up 'radon situation reports' which include maps of the radon situation in the municipality and recommendations for further measurements. These reports now cover about 200 municipalities. STUK's new product is a radon report, which includes statistics on indoor radon and household radon from drilled wells according to postcodes.

- Radon prognosis reports: We have compiled 10 radon prognosis reports which cover about 60 municipalities including five cities: Helsinki, Espoo, Vantaa, Tampere and Lahti.

Studies on radon sources

Natural radioactivity and radon exhalation from Finnish building materials were studied extensively in the '80s. In 1992 a guide was published, which forms the basis for the EU building material regulation published in 2000. In the '90s activity has been focused on regulatory measurements of industrial building materials and wastes. The effect of the sub-slab filling sand used has been studied using a countrywide sample, in co-operation with municipal building authorities. A study is underway of the contribution of radon in household water to indoor radon concentrations.

Studies on radon entry into dwellings and on temporal variations

The modelling studies have focused on the role in the entry process of diffusive and convective entry and climatic factors, and especially on variations in indoor radon concentrations. Former studies published in 1994 show the substantial effect of subterranean airflows on indoor radon concentration in esker areas.

Mitigation studies

The surveys of indoor radon concentration carried out by STUK in the '80s and '90s showed that the threshold of 400 Bq/m^3 is exceeded in 5% of all low-rise residential houses in Finland, altogether approx. 60,000 houses. The aim of the mapping work started in the mid 80's in co-operation with the municipal authorities is to identify these houses. One of the tasks of the NRL has been to survey the methods for and results of radon mitigation in houses with a high indoor radon concentration.

Studies on radon prevention in new building

Reducing of indoor radon concentration through research and co-operation with other authorities is one of the key aims of STUK. The nationwide indoor radon surveys and specific studies on the prevention and decision practices of municipal authorities have provided basic information on the direction taken by research in Finland. The prevalence of slab-on-grade construction is the main factor in the increase in indoor radon concentrations in Finland since the '50s. In 1994 the Ministry of Environment published guidelines for radon-safe slab-on-grade foundations.

Natural radioactivity in household water

The STUK Natural Radiation Laboratory has been studying the natural radioactivity of household water since the late '60s. Most of the water samples received for radioactivity measurements have been tested for radon, gross alpha and gross beta. Depending on these results a large number of samples have subsequently been analysed for uranium, radium, ^{210}Pb and ^{210}Po, using radiochemical methods. STUK's present survey work covers results from more than 1,000 waterworks and about 12,000 private wells. The database comprises the results of about 45,000 measurements or analyses.

Research on natural radioactivity in drinking water has included nation-wide surveys, mapping, and studies on health risks and on water treatment methods for removing radionuclides from water. Developing the radionuclide analysis methods based on the newest technology has been considered important in the interests of greater speed and lower costs. The accuracy of the methods has been established as good in international comparisons. Accreditation of the process for determining radionuclides in water was obtained in 1999.

Health studies

The NRL has had an active role in STUK health studies. Originally it was responsible for the exposure assessment in these studies, but its activities have now expanded into epidemiological analyses as well. In recent years the focus has been on multi-laboratory EU pooling of European case-control studies, and on the health effects of natural radionuclides in drinking water.

Results from two epidemiological case-control studies concerning indoor radon and lung cancer were published in the 1990s.

Other research activities

The Natural Radiation Laboratory has carried out surveys of gamma radiation both indoors and outdoors, and published the results in 1995. The laboratory has been responsible for the exposure estimates related to external gamma radiation due to both natural and Chernobyl-based radiation sources in epidemiological studies.

2.2.3 Personnel

Hannu Arvela, DrTech (physics), head of laboratory
management, occurrence, remedial measures and prevention of indoor radon concentrations

Laina Salonen, LicSc (radiochemistry), senior scientist
natural radioactivity in household water, treatment methods

Ilona Mäkeläinen, MSc (physics), senior scientist
occurrence, exposure, health effects, epidemiology, radon prognosis methods

Anne Voutilainen, MSc (geology), senior scientist
radon risk mapping, radon communication

Heikki Reisbacka, BSc (physics), scientist
indoor radon measurement services, radon at workplaces

Pia Huikuri, MSc (radiochemistry), scientist
radiochemistry, natural radioactivity in household water, treatment methods, measurement services

Tuukka Turtiainen, MSc (radiochemistry), scientist
gamma activity and radon calibration services, radon in indoor air, water treatment methods

Sirkka Hämäläinen, laboratory operator

natural radioactivity in household water, radiochemical analyses and database
Sointu Starck, laboratory operator
natural radioactivity in household water, radiochemical analyses and database

Mailis Vansen, laboratory operator
indoor radon measurement services, electrochemical etching

Eija Immonen, laboratory operator
indoor radon measurement services, database operator

Kaarina Aapro, laboratory operator
indoor radon measurement services, workplace database operator

2.2.4 Aims of research

General objectives

- Exposure to natural radiation due to elevated radioactivity concentrations in both indoor air and household water increases the risk of cancer. The objective of the NRL is to quantify the risks and to develop techniques for reducing exposure to natural radiation.
- The NRL aims to promote the research objectives set by the governmental Environmental Health Committee in 1998 in the area of natural radiation

Radon in indoor air

- Exploring the occurrence, exposure and health effects of inhaled radon in both home and work environment
- Providing information for decision-makers involved in regulatory work
- Reducing exposure to indoor radon through both remedial and preventive measures and research and development on the technology required
- Development of the methodology used in radon risk mapping
- Exploring the effect of house construction, soil and geological factors
- Evaluating retrospective radon exposure methods

- Developing radon-safe construction methods, guidance published by the authorities, and the regulations and practices of building companies; combining qualified moisture prevention with radon-safe structures in Finnish housing.

Radioactivity in household water

- Determining the occurrence exposure and health effects of radioactivity (^{222}Rn, $^{234,238}U$, ^{226}Ra, ^{210}Pb and ^{210}Po) in public and private groundwater sources in Finland
- Identifying the areas with elevated or high levels of radionuclides particularly in bedrock water to be utilised in mapping and planning regional water supply
- Studying the influence of bedrock type and groundwater quality on rising radionuclide levels
- Exploring human exposure to lead (^{210}Pb) and polonium (^{210}Po) and the factors affecting the soluble and particle-bound fractions of these radionuclides in various types of ground waters and the representativeness of the sample-taking methods
- Exploring the radon transfer factor from household water into the indoor air
- Providing the basis for new requirements and recommendations for radon and long-lived radionuclides in drinking water.
- Developing newer, time-saving or more accurate analytical methods for lead (^{210}Pb) and radium (^{226}Ra and ^{228}Ra)
- Developing and maintaining the database for radionuclides in household water in Finland
- Making recommendations on the most suitable methods for removing radon (^{222}Rn), uranium ($^{238,234}U$), radium ($^{226,228}Ra$), lead (^{210}Pb) and polonium (^{210}Po) from drinking water of different qualities

Health effects

- Assessing the lung cancer risk from exposure to indoor radon concentrations
- Assessing the cancer risk from exposure to natural radioactivity in household water
- Assessing the exposure and dose estimates from lead (^{210}Pb) and polonium (^{210}Po), through both inhalation and ingestion

- Assessing the toxic effects of uranium in collaboration with other research bodies

2.2.5 Progress report on research over the last five years

Radon risk mapping

One of the big challenges of the '80s was the creation of the STUK Radon Information System (RIS). Today, the system includes data on more than 54,000 houses, providing a good basis for radon mapping and research. The RIS comprises coordinates of the houses, geological data, construction data from questionnaires, and the results of indoor radon measurements.

The results of the radon risk mapping have been published in two STUK reports: Radon in dwellings in Finland (Voutilainen et al. 1997a) and the Radon Atlas of Finland (Voutilainen et al. 1997b). The former summarises the mapping work done with municipal health authorities. The latter contains detailed information on the radon situation in Finland. It provides radon maps of houses built on permeable or impermeable building sites province by province, and statistics on radon concentrations municipality by municipality. Some of the maps are also found on the Internet at www.stuk.fi. The methodology of radon mapping in municipalities is also discussed elsewhere (Voutilainen and Mäkeläinen, 1999). Information gained from measurement plans and prognoses has given decision-makers a more balanced view of the radon situation in municipalities and over the whole country.

The indoor radon prognosis method formulated at STUK utilises a multiplicative model to correlate indoor radon concentrations in low-rise housing with location and construction factors. Indoor radon concentrations in houses are adjusted for different substructure types. The substructures are then classified according to the probability of radon leaks. The soil types are classified according to the permeability, and the prognosis area is divided into homogenous sub-areas within each soil type class. The probability of exceeding 200 Bq/m^3 is then calculated for the house type at the highest risk in each sub-area and soil type.

The prognosis reports written in the early '90s were unpublished investigation reports commissioned by municipalities. STUK has published two radon prognosis reports concerning large high-risk areas: Eastern Uusimaa (Voutilainen and Mäkeläinen 1995) and the Province of Kymi (Pennanen et al. 1996). The method used in Finland has many advantages compared with prognosis methods based on purely geological data and soil gas measurements, for instance. The prognosis method used at STUK has been presented at several scientific meetings (Mäkeläinen et al. 1999b).

Radon-safe building - interviewing of municipal authorities

In 1998 a study was carried out to establish radon prevention practices in municipalities with a high indoor radon concentration (Voutilainen, Vesterbacka, Arvela 1998).

About three in four of the municipalities questioned demanded or recommended action on radon at least in part of the municipality, but only 30% of municipalities recommended this over the whole of their area. The most important prevention measure against radon, radon-tight foundation construction, was recommended only in a few municipalities.

The report's proposal for action is that radon-safe construction should be recommended to all builders in the area studied, regardless of the soil type. The technical radon plans should already be presented as drawings when the building permit is applied for. The success of radon-safe building should be verified by municipality using check-up measurements. Co-operation between the building and health authorities should be improved and the mutual obligations both clarified, and in the case of building authorities tightened, to ensure that healthier homes are built in Finland.

Modelling indoor radon entry, concentrations and variations

The model used to calculate the indoor radon concentration in houses with passive stack ventilation (natural, non-mechanical ventilation) combines the physics of diffusive radon entry, of air-flow from soil driven by the pressure difference, and of air infiltration (Arvela 1995a, 1995b). The model explains to a considerable extent the seasonal variations observed in indoor radon concentrations. Correction factors for annual average radon concentration are needed to adjust measurements taken over periods other than twelve months. The model predicts a typical correction factor of 0.9-0.6 for winter measurements over two months. Our new non-published analysis of seasonal variations measured in 1996-97 confirms the predictions. The model has been utilised to estimate the annual average radon concentration in connection with epidemiological studies, for instance.

Building materials

The European Commission published recommendations in the report "Radiological protection principles concerning the natural radioactivity of building materials (Radiation Protection No. 112, Luxembourg). The recommendations are based on the Finnish guidelines (ST Guide 12.2) and on the survey and proposal provided for the Commission by STUK.

Remedial measures

STUK published in 1995 a report on radon remediation methods in Finnish dwellings (Arvela 1995c). The report also serves as the main guidance on indoor radon mitigation, giving information on factors affecting the success of remediation and technical details. STUK has further collaborated in research into implementation of sub-slab suction (SSD) in Finnish dwellings, in collaboration with Helsinki University of Technology (HUT). SSD is the one of the most effective methods of radon remediation. The work has resulted in the production of a special technical guide on sub-slab suction in low-rise housing, intended for house owners, construction designers and authorities (Ministry of Environment 1996). A special report surveys results from 20 test houses and the experience gained in preparation of the guide (Kettunen, Rissanen, Viljanen and Arvela 1997). The collaboration continued in 1995-1998 in a joint research project on radon remediation in blocks of flats (final report under construction).

Prevention studies

In 1995-96 STUK carried out a questionnaire study on radon-safe building in Finland (Ravea and Arvela 1997). The study aimed at finding the main defects in design and implementation and to establish how far the guidance given on radon-safe building has been followed. Results were collected from 300 houses. In most of the houses with slab-on-grade the prevention relied solely on the installation of a sub-slab depressurisation system. Sealing, which should be an essential part of prevention according to the guide, was performed in only a low number of houses. In houses with an active sub-slab ventilation system, with crawl space or an edge-thickened slab, radon concentrations were low. In houses with piping but no fan, radon concentration was below the action threshold of 200 Bq/m^3 in only 45% of the houses. The corresponding median value in these houses was 220 Bq/m^3. Sub-slab piping without a fan had no great effect on radon concentration. Sealing measures were carried out in only about 30% of the houses and in many of these houses it was not done according to the guideline. If careful sealing work was done, however, good results were achieved without activation of the sub-slab piping. The importance of complete, careful sealing work should be stressed in advice and guides concerning radon prevention.

The results of this study gave rise to the project "Radon-safe building, moisture prevention and air exchange in a healthy building", supported by the Finnish Technology Agency and led by STUK (Arvela 2000a, Arvela, Kettunen, Kurnitski, Jokiranta 2000). The project is part of the Finnish Environmental Research Programme, and focuses on the development of the radon-safe building practices. The results achieved in this ongoing project have already promoted the revision of the present guidance material.

Surveys of radioactivity in household water

The laboratory has been conducting a systematic survey of natural radioactivity in household water since the late '60s. Practically all water supply plants and more than 1 000 private wells were studied in the '70s. In the last 20 years, special attention has been given to groundwater in bedrock because of the very high concentrations of radon and other radionuclides in uranium series from drilled wells. The aim has been to find areas with anomalously high concentrations and to analyse the radionuclide composition there to assess the radiation doses. The most recent comprehensive summaries on the survey were published in 1994 and 1999 (Mäkeläinen et al 1999a). The Radon Atlas of wells drilled into bedrock (Voutilainen et al. 2000) is a recent achievement. The maps in the Radon Atlas are based on a sampling of 9,200 drilled wells all over the country.

The database for radionuclides in drinking water covers practically all public the waterworks in Finland and 12,000 private wells, and contains results from about 45,000 measurements or analyses. The results indicate that the radioactivity in public groundwater sources and in dug wells in soil layers is usually low, whereas in drilled wells anomalously high concentrations (tens of thousands of Bq/litre) are mainly found in the uraniferous granite areas of southern Finland. Because Finnish bedrock waters are typically soft, and rich in bicarbonate or carbon dioxide, uranium is soluble under oxidising conditions and often occurs simultaneously with radon at high concentration levels. The long-lived radon progeny, ^{210}Pb and ^{210}Po often occur in radon-rich waters, and these make the most significant contribution to the dose after that made by radon.

The survey of bedrock waters is still of radiological significance because the number of bedrock wells used permanently in Finland is estimated at 70,000 - 100,000, whereas the total number of private dug or drilled wells in either permanent or leisure use is about 700,000. Drilled wells have become very popular in the last few decades. Finnish bedrock consists mainly of granitoids. Granite rock contains particularly elevated levels of uranium.

Dose from drinking water and reference levels

In 1998-1999 the NRL evaluated the doses from natural radioactivity in household water and the population groups exposed. The Ministry of Health and Social Affairs supported the study. The final report has now been delivered to the Ministry and is being prepared for publication (Mäkeläinen et al. 1999). It proposes that the maximum level of radon in private wells used permanently be set at 1000 Bq/l. It also includes information on radon, uranium, radium, ^{210}Pb and ^{210}Po concentration levels in public and private water sources, and doses and dose distributions among people using these waters. The results have been presented in summary at a Nordic Radiation Protection Meeting (Mäkeläinen et al. 1999a).

The dose from drinking water originates almost totally from naturally occurring radionuclides in the ^{238}U series, the most important nuclide being ^{222}Rn. Second comes ^{210}Pb, and third ^{210}Po. The mean dose received through ingestion of drinking water, weighted by age group, is 0.14 mSv per year. The users of private wells, who form 13% of the population, receive more than half of the total cumulative dose of 750 manSv. The most exposed group comprises users of wells drilled in bedrock, who receive 320 manSv though they comprise only 4% of the population. The calculated number of annual cancer incidences due to drinking water is very sensitive to the dose-conversion factors of ingested radon used, as it is to the estimated lung cancer incidences caused by radon released from water into indoor air.

Development of analysis methods

The development of new analysis and measurement methods has enabled a large number of radionuclide analyses to be made in the last twenty years. The measurement methods are based on liquid scintillation counting (LSC) and alphaspectrometry. The LSC measurement method first used to measure radon in water in 1979 offered significant improvements compared with the previous method, allowing accurate measurements of radon in water to be made in a large number of samples with savings in labour costs. The method has since been tested comprehensively following the acquisition of new, low-background LSC counters equipped with anticoincidence guard counters and pulse shape analysers at STUK (Salonen et al 1996). The original LSC cocktail was then replaced by an environmentally safe cocktail. Use of pulse shape analyses (PSA) in the low-background LSC counters made it possible to reduce the lower limit of detection (LLD) for radon to be about one order of magnitude lower than with a conventional LSC counter without PSA.

The biggest advantage of the new LSC technology was gained when a new method was developed to determine of gross alpha and gross beta in water (Salonen and Hukkanen 1997). The low-background LSC spectrometer, the Wallac Quantulus™ , equipped with an anti-coincidence guard counter and a pulse shape analyser permits the simultaneous spectral measurement of the gross alpha and gross beta activities, but also of the uranium and ^{226}Ra contents accurately enough for radiation protection purposes, and no further analyses using time-consuming radiochemical methods are usually required. The beta spectra provide valuable information on the nuclide contents, e.g. whether the beta activity is caused by ^{210}Pb, ^{228}Ra or ^{40}K. Sample preparation for the LSC method is also simpler than with the previous method. All these benefits have made it possible to collect a large quantity of data on the occurrence of radiologically significant nuclides in Finnish groundwaters.

Removal of natural radionuclides from household water

Research on removal of radon from drilled well water in Finland started in 1995. The objective of the study was to develop effective and simple radon removal equipment, which could reliably be used in private households.

As a result of the research, there are now four different kinds of aeration equipment on the market. In addition, two of the participating firms have gained the know-how and facility to sell proper granular activated carbon (GAC) filters for radon removal. Recently some other firms have also put effective aerators onto the market.

The equipment, the research methods and the results attained during the development of the equipment are described in the publication "Removal of radon from drilled wells—New aerators and implementation of granular activated carbon filtration" (Myllymäki et al 1999). In addition, recommendations and safety instructions have been issued for the purchase, installation, and disposal of the equipment. Also the joint European TENAWA project confirmed that aeration is an effective way to remove radon from well water. However, the project pointed out that more attention should be paid on the technical reliability of the used equipment.

The joint European TENAWA project proved that activated carbon filtration is a suitable method for removing radon from the water supplies of private households. Removal efficiencies are mostly over 95%. The levels to be removed should not exceed 5,000 Bq/L otherwise gamma radiation originating from the filters cannot be controlled by shielding. Activated carbon filtration is not a viable method for removing other waterborne radionuclides.

Strong base anion exchange resins are suitable for removing uranium on both a domestic and a waterworks scale. The removal efficiencies are over 95%. Strong acid cation exchange resins remove over 95 of waterborne radium. They can also be applied on both a domestic and a waterworks scale.

Nanofiltration and reverse osmosis are suitable methods for removing uranium, radium, lead and polonium simultaneously, but not for removing radon. After reverse osmosis the water requires secondary treatment in order to increase the hardness value.

In groundwater, uranium usually has the oxidation state +VI and it occurs in the form of anionic complexes. Lead and polonium are usually found bound in particles of different sizes.

With the exception of activated carbon, which needs to be aged for about three weeks before being disposed of, the wastes produced in water treatment methods were estimated to be low enough in radioactivity to be discharged into the sewer or into communal dumps.

Health studies

Two epidemiological studies on the health effects of radon in indoor air have been carried out. The first was published originally in a doctoral thesis (Ruosteenoja, 1991), and was later re-analysed and published as a journal article (Ruosteenoja et al. 1996). The study was conducted in a Finnish population residing in a high-exposure area. Relative risks of 1.8 and 1.5 for the incidence of lung cancer were observed for those exposed to concentrations of 95-185 Bqm^{-3} and more than 186 Bqm^{-3}, respectively. The increase was not statistically significant.

The second study on radon-induced lung cancer (Auvinen et al. 1996 and 1998 (Erratum) was conducted among a population that had lived for at least 19 years in the same detached house. The risk of lung cancer associated with indoor radon concentration was not statistically significant, but at 100 Bq/m^3 the risk estimate (OR 1.1, 95% CI 0.9-1.3) was very close to that previously reported in a Swedish study and also that obtained in a recent meta-analysis.

The data from both these studies will be pooled with other studies in a collaborative study of lung cancer and residential radon exposure. In the first stage the data will include findings from case-control studies in Europe and in the second stage similar data from North America as well. The study will be performed as an EU project within the Radon Epidemiology (see Appendix A).

The study on domestic radon exposure and the chromosomal aberrations was performed like the epidemiological studies, in collaboration with the Radiation Biology Laboratory (Lindholm et al. 1999). The study covered a total of 84 non-smoking individuals, divided into 3 groups according to radon concentration measurements performed in their homes: low (< 100 Bq/m3, mean 67 Bq/m3), medium (200-400 Bq/m3, mean 293 Bq/m3) or high radon concentration (> 800 Bq/m3, mean 1737 Bq/m3). The minimum residence in the present low-rise house was 10 years. Equal frequencies of translocations and other aberrations, e.g. dicentrics and complex rearrangements, were obtained in each group. The conclusion of the study was that chronic exposure to high concentrations of domestic radon did not increase the rate of stable or unstable chromosomal aberrations in peripheral blood lymphocytes detected in FISH chromosome painting.

With regard to theoretical carcinogenesis research, calculations to study the implications of a two-stage clonal expansion model for indoor radon risk assessment were performed (Castrén 1996, 1999). He concluded that case-control epidemiological studies overestimate the lifetime risk by an amount, which may rise to a substantial percentage.

Two epidemiological studies on the cancer risk from the radionuclides in drinking water and on the nephrotoxicity of uranium in drinking water are underway in co-operation with the KTL (National Public Health Institute), the GTK (Geological Survey of Finland) and the Finnish Cancer Registry.

Exposure to natural radiation

The NRL carried out surveys of gamma radiation both indoors and outdoors, and published the results in 1995. The laboratory has been responsible for the exposure estimates arising from external gamma radiation due to both natural and Chernobyl-based radiation sources in some studies. A review on doses from natural radiation was presented in a doctoral thesis in 1995 (Arvela 1995b) and in publications (Arvela et al. 1995).

A new summary including exposure due to ingested water will be presented at the 5th International Conference on High Levels of Natural Radiation and Radon Areas in September 2000 (Arvela 2000). The study will present a review on population distribution of annual doses from sources of natural radiation in Finland. The results are based on earlier representative surveys of gamma radiation outdoors and indoors, and on surveys of indoor radon concentrations and natural radioactivity in drinking water. The measurements of gamma radiation outdoors were based on a mobile survey on roads. The indoor gamma radiation measurements were carried out using TLD-dosemeters fixed to radon dosemeters. The long-term measurements of indoor radon concentration were performed using alpha track detectors in 3000 dwellings. The percentage of population exceeding the dose of 1.0 mSv due to indoor radon, drinking water and natural gamma radiation is 64, 1 and 0.3% respectively. The annual dose of 10 mSv due to residential indoor radon concentrations is exceeded in the case of 2% of the population (total 5.1 million).

2.2.6 Research plans for the next five years

The STUK research projects for the period 2000-2002 are described in detail in the STUK-A179 report (Salomaa 2000). During 2000-2004 more emphasis will be placed on health studies, preventive measures and assessing the exposure and dose estimates from radioactive lead and polonium. A list of the projects to be carried out at the Natural Radiation Laboratory is given below.

- Indoor radon mapping
- Radon in indoor air
- Total radon exposure of Finns (RATVA) (Nat.)
- Radon remedies at workplaces (Nat.)
- Radon-safe foundations, moisture prevention and air exchange in a healthy building (Nat.)
- Validation of the retrospective radon measurement method (RETRO) (Internat.)
- Pooled analysis of European case-control studies of radon and lung cancer (RADON EPIDEMIOLOGY)
- Radioactivity in household water
- Safe operation of domestic equipment for removing radionuclides from drinking water
- Household water as a source of radiation dose to Finnish people - the random-sampling survey (TAVES)
- ^{210}Pb in humans (jointly with the Radiation Hygiene Laboratory)
- Exposure to natural radiation in industry (NORMA)
- Impacts of natural stone production on radiation exposure
- Kidney toxicity of uranium in drinking water (JURMU)
- Radioisotopes in drinking water and cancer risk (JUORAAS)

2.3 Radiation Hygiene

2.3.1 Keywords and specific technologies

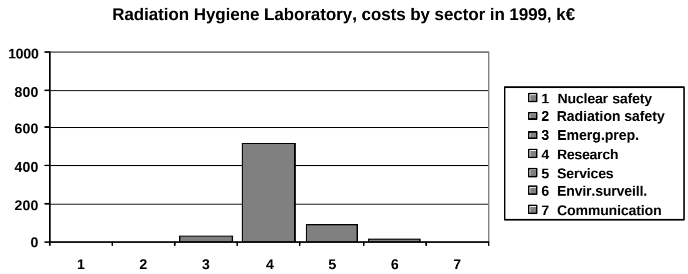
Keywords

Internal radionuclide contamination, radiation doses, whole-body counting, bioassay, internal contamination and radiation doses of workers, internal doses of population and population groups, nuclear bomb test and Chernobyl-derived contamination of population and special diet groups

Specific technologies

Stationary whole-body counter with scanning techniques, mobile whole-body counter, lap geometry counter, thyroid counter, partial body counter for low energy gamma emitters, liquid scintillation counters and gamma spectrometers for sample measurements, counter for foodstuff monitoring, surface contamination monitors, conditioning and storing service for radioactive waste (sealed sources of low or medium level)

2.3.2 Description of laboratory activities



The Radiation Hygiene Laboratory is responsible for surveillance and research on artificial and natural radionuclides in man. The radiation exposure for various population groups of people and for radiation workers is determined using direct and bioassay methods. The results are used to estimate and control internal radiation doses. Activities also include research on factors influencing internal radiation exposure with special emphasis on metabolic and radioecological aspects. One important function of the laboratory is to take part in emergency preparedness work in general and especially in the case of internal contamination.

A considerable part of the laboratory's activities consists of different expert services for enterprises. The most important are the control of internal contamination and estimation of the organ and total body doses of nuclear power plant and other radiation workers. The laboratory also deals with the waste handling of sealed sources of low or medium activity in Finland. In addition to advising waste producers, this includes receiving, conditioning and storing of waste for final repository at the NPP in Olkiluoto. Calibration work and registration of the results of the 50 local foodstuff laboratories are performed as forms of internal service maintenance.

2.3.3 Personnel

Matti Suomela, PhD., head of laboratory
management, radiation protection, radiohygienic and radioecologic studies

Tua Rahola, MSc., senior scientist
radiation protection, internal dose assessment, radiohygienic and radioecologic studies, emergency planning and preparedness

Marketta Puhakainen, Master of Pharmacy, scientist
radiation chemistry, bioassays, quality assurance

Eero Illukka, BSc., scientist
national service for storing and conditioning of radioactive sealed sources waste, advising waste producers on safety questions

Sauli Pusa, MSc., scientist
Maintenance and development of the whole-body counter systems, measurement methods, quality assurance

Tarja Heikkinen, MSc., assistant researcher
radiation chemistry, bioassays

Veikko Pohjalainen, laboratory operator
maintenance of laboratory systems, data operator

2.3.4 Aims of research

The main topics studied at the Radiation Hygiene Laboratory are:

- Differences in the body burdens of the population depending on various diets and residence (residential) areas. The implication of different foodchains for the body burden of different groups.
- Factors affecting the radiation doses of radiation workers.
- Behaviour of radionuclides in the body (biological half-lives of radionuclides)
- Development of direct measurement methods to determine of the amount of ^{210}Pb in the skeleton of people consuming water containing high amounts of radon and its progeny and inhaling radon-rich indoor air. Applying the results to retrospective dose estimation.
- Application of bioassay (urine analyses) methods to determine of beta emitters ^{90}Sr and ^{3}H and ^{210}Pb.

2.3.5 Progress report on research over the last five years

^{137}Cs content and internal radiation doses affecting the population

Changes in internal radiation doses affecting the population and special population groups getting more ^{137}Cs from the diet than the population in general have been studied using measurements performed annually. The diet of these special population groups includes a lot of fresh water fish, wild mushrooms and wild berries from areas with high ^{137}Cs deposition and in reindeer herding areas, reindeer meat. In addition a reference group representing people living in the Helsinki area was measured. Long-term follow-up studies are necessary in order to get representative dose estimates. The results also give information on where Finns receive the highest radiation doses.

Measurements on a statistically chosen (stratified random sampling) population group were already started in 1986 and were performed annually until 1993 and thereafter once, in 1996. The results of these studies have provided a good estimate of annual changes in internal body burdens caused by radiocaesium from the Chernobyl fallout among people (children, adult men and women) residing in different fallout regions and chosen according to the radiocaesium deposition level. The results were used to calculate annual internal doses. The maximum internal doses were received in 1987. Based on the measurements of the population group and the Helsinki reference group, which were taken measured annually from two to four times a year since 1965, the mean total effective dose for the Finnish population was about 0.5 mSv for the first ten years and will be somewhat over 0.6 mSv over the next 50 years after the accident. The highest mean dose, about 0.8 mSv, was received by men, the mean dose for children being about half and that for women about two thirds of the dose for the men in the population group. The results have also made it possible to estimate the age dependence of and total lifetime risk from the radiation doses from the Chernobyl fallout.

During the last five years the studies of three special diet groups have continued, using the mobile whole-body counter. The group from Padasjoki represents population consuming freshwater fish caught in small lakes in a region with high fallout and the Viitasaari group a population consuming a lot of freshwater fish and other products from the wild. Reindeer meat is a primary radiocaesium source for the group of reindeer herders from northern Lapland.

The results for the population group and the special diet groups show that the body burdens within a certain fallout region are closely related to the differences in the composition of the diet and to the activity concentration of the foodstuffs consumed. The latter reflects the deposition level in the food production area. The foodstuffs may be consumed by the local people living in the production area or transported to an another fallout region. The transport may decrease the body burdens in a high fallout area and increase them in a low fallout area. This means that the gradient of the deposition levels on the different fallout regions is steeper than the gradient of the mean body burdens of people residing in the corresponding fallout areas. This could be seen in the Helsinki area, for instance. Another explanation for the variation of body burdens of radiocaesium lies in different amounts of freshwater fish, wild berries and mushrooms consumed by people residing in different parts of the country. The concentration of radiocaesium in these foodstuffs reflects clearly the deposition level. As early as 1988 the intake of radiocaesium from wild products was higher than

that from agricultural products. The availability of products from the wilds, and consequently the intake of radiocaesium, varies from year, to year mostly because of variation in the meteorological and growing conditions. This variation is reflected in the body burdens.
Although the mean deposition of Chernobyl fallout radionuclides in Lapland was only about one tenth of that in southern Finland, the body burdens of Lapps are high because of the region's special foodchain - lichen-reindeer-man. In northern Lapland, reindeer meat is consumed in fairly even amounts throughout the year, as it is an integral part of the local culture and the difference in the body burdens in April and September was very small compared with the non-Sami reindeer herders who mainly consumed reindeer meat only after the autumn slaughter, and much less frequently in spring and summer. The difference in the dietary habits of Sami reindeer herders from northern Lapland and of non-Sami reindeer herders from the southern part of the reindeer herding district is also apparent in the whole-body counting results. The body burdens of the male reindeer herders increased, from 5.5 kBq to 13 kBq in 1988 after the Chernobyl accident, but decreased to 4 kBq in 1997, when the last measurements on the group followed from 1961 were made. The mean annual effective dose for the male reindeer herders was about 0.4 mSv in 1988. The body burdens of female members of reindeer herding families, and the corresponding doses, were about one third of the values for the male reindeer herders.

To be able to estimate internal doses from radon inhaled indoors, radon dosimeters were supplied to all volunteers in the groups in 1997. The results will be used to estimate the total annual dose.

Effect of Industrial Pollution on the Distribution Dynamics of Radionuclides in Boreal Understorey Forest (EPORA)

The objective of the EPORA project was to evaluate the potential effects of industrial pollution on the migration of radionuclides in soil, on association of radionuclides in different soil constituents and on transfer from soil to plants. The potential effect of industrial pollution on runoff of radionuclides and radiation doses was also studied. An assessment was therefore carried out in which measurements of fallout radionuclides - ^{137}Cs, ^{90}Sr and ^{239,240}Pu - and heavy metals were made for the first time to describe and analyse the concomitant consequences of industrial pollution and radionuclides for the items mentioned above. The project took place during a three-year period from the beginning of 1997 onwards and formed part of the 4th Framework Programme of the European Commission. The Head of the Radiation Hygiene Laboratory was responsible for co-ordination of the project. The laboratory also performed most of the radionuclide analyses, and the EPORA project engaged the most of its personnel resources during the period concerned. The project was also a member of an association with two other EC research projects, PEACE and LANDSCAPE, co-ordinated by the IPSN (Dr. H. Métivier). It was performed according to schedule, and this new subject for study was also included in the 5th Framework Programme.

The test area chosen in the surroundings of a copper-nickel smelter on the Kola Peninsula (NW Russia), where huge atmospheric emissions of copper, nickel sulphur from the smelter had continued the since 1930s. The above-mentioned radionuclides originated mainly from the worldwide fallout from nuclear bomb tests.

The results showed that the depth distribution in soil, residence half times and aggregated transfer factors of all three radionuclides depended on the degree of pollution. In the litter layer, for instance, the activity of all three radionuclides increased consistently from the reference site to the most polluted site, but in the root zone, the opposite effect was observed. In the organic layer, the exchangeable fractions of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu decreased with increasing pollution.

The studies of the transfer of ^{137}Cs and ^{90}Sr from the catchment soil to streamwater in runoff showed that the concentrations of these radionuclides depend more on the fraction of bogs in the catchment area than on the amount of pollution.

The external dose rate of ^{137}Cs, calculated from the depth profiles of its activity in the soil, was approximately 1.5 nGy h^{-1} for all the sites and did not depend on the chemical pollution. Related to the total activity per square metre, the dose rate of Chernobyl-derived ^{137}Cs was about 1.6 times higher than that of ^{137}Cs from global fallout, because the activity of Chernobyl-derived ^{137}Cs was concentrated closer to the soil surface than that of ^{137}Cs from global fallout.

In summary, it can be concluded that most of the radioecological quantities studied depended on the amount of pollution load at the various sites, though the effects were related to the type of soil/plant ecosystem or soil/runoff water system. The methodology applied can also be used investigate other polluted areas or to evaluate the efficiency of restoration procedures used in polluted areas.

Contamination of workers at nuclear power plants

The laboratory assesses the internal contamination of nuclear power plant workers. The assessments were begun in 1978 when the first nuclear power plant with PWR type reactors began to be used commercially used. In 1980 the second nuclear power plant with BWR type reactors started to operate and was included in the assessments. Varying but small amounts of activation and corrosion products (e.g. ^{51}Cr, ^{54}Mn, ^{58}Co, ^{59}Fe, ^{60}Co, ^{95}Zr-Nb, ^{110m}Ag and ^{124}Sb) and small amounts of ^{131}I have been detected mainly during outage periods for maintenance and refuelling of the reactor. During the annual outage a group of people representing workers with an elevated risk of internal contamination are measured with a mobile whole-body counter at the site.

The studies have shown that the contamination levels depend greatly on the type of repair and maintenance work done during the outages. Our experience has shown that, if the effective dose approaches 1 mSv, an incident has occurred. In an outage, less then 20% of the whole-body counted workers usually receive a dose >0.1 mSv, which is the recording level in Finland. If the body burden of a worker is much higher than the mean body burden, the person will be re-measured and the radiation history established so that the radiation dose can be estimated more accurately. If possible, such persons will be measured repeatedly over a longer period of time, to enable even more accurate estimation of the half-lives of the radionuclide in question and the resulting radiation dose. Studies to provide a rough estimation of the existence of radioactive particles in the working area have also been performed.

The body burdens of the persons working together have been found to vary greatly, showing the importance of radiation protection instructions and good individual working habits. The risks of being contaminated also vary, depending on the type of work. In addition to being useful for dose control these studies, also monitor radiation hygiene conditions in work areas, and specifically motivate workers to pay close attention to their own working habits.

Radionuclides in sewage water and sludge

Radionuclides in sewage water and sludge from wastewater treatment plants have been measured to find out which radionuclides originating from discharges from hospitals, nuclear weapons tests, the Chernobyl accident and nuclear power plants can be detected, and to estimate their possible effects on radiation hygiene in working conditions at the wastewater treatment plants. Their transport to the aquatic environment was also studied.

The studies have shown that the highest concentrations of radionuclides from medical use originate from ^{131}I radiation therapy. The maximum ^{131}I concentration measured in crude sewage was 94 000 Bq m^{-3}. This was detected only one day after administration of a typical therapy dose of 3700 - 7400 MBq. Only minor amounts of ^{131}I passed into sludge. Minor amounts of other radionuclides used in nuclear medicine can also be seen detected in communities where a hospital with a nuclear therapy unit is situated.

Radionuclides originating from nuclear power plants have been detected in the sewage sludge of wastewater treatment plants in communities near the Loviisa and Olkiluoto NPP sites. The radionuclides typically found are ^{51}Cr, ^{54}Mn, ^{58}Co, ^{59}Fe, ^{60}Co, ^{110m}Ag and ^{124}Sb. The same radionuclides are also found in atmospheric discharges from the power plants but the amounts do not correlate with the activities found in the sewage water or sludge of the waste water treatment plants studied or in local precipitation, some of which is transported to the wastewater treatment plants. The other possible source may be the activity carried by workers in their clothing or body, but further studies are needed in this field.

2.3.6 Research plans for the next five years

The STUK research projects for the period 2000-2002 are described in detail in the STUK-A179 report (Salomaa 2000). A list of the projects to be carried out at the Radiation Hygiene Laboratory is given below.

- ^{137}Cs body content and internal radiation doses affecting the population

- ^{210}Pb in man
- The NKS projects on assessment of internal doses
- Radionuclides in sludge at waterworks and wastewater treatment plants

2.4 NPP Environment

2.4.1 Key words and specific technologies

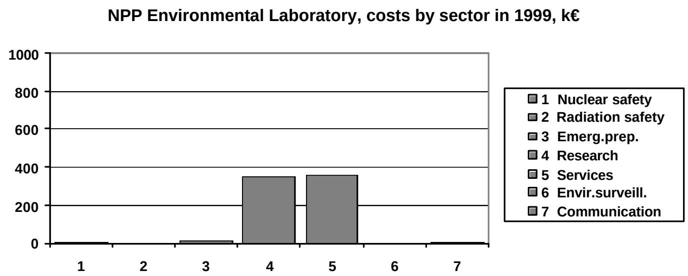
Key words

Environmental radioactivity, environmental monitoring of nuclear power plants, environmental effects of nuclear power plants, marine radioecology, terrestrial radioecology, Baltic Sea, quality assurance, development of methods, transuranics, dating of sediments, analysis of particles, emergency preparedness

Specific technologies

Low-level gamma-ray spectrometry, alpha spectrometry, beta spectrometry, radiochemical methods, liquid scintillation methods, dating methods, environmental sampling methods

2.4.2 Description of laboratory activities



Service studies and permanent environmental monitoring programmes

Environmental monitoring of radioactive substances in the environs of Finnish nuclear power plants is the main function of the NPP Environmental Laboratory. The laboratory does the work as charged service to the power plants. The environmental monitoring programmes of the Finnish nuclear power plants at Loviisa and Olkiluoto are relatively extensive, including together about 1000 samples/analyses per year. The NPP Environmental Laboratory is responsible not only for laboratory work, but also for designing the monitoring programmes and for most of the sampling and other field work in the monitoring. This work takes up about 50% of the working capacity of the laboratory and reduces its capacity to do scientific work. However, the extensive environmental data produced as a result of the monitoring programmes are valuable and have also been used for scientific purposes.

In addition, the NPP Environmental Laboratory is responsible for another permanent monitoring programme, which is not scientific work as such, though the results of the monitoring can also be used for scientific purposes. Radioactive substances in the Baltic Sea are monitored in international co-operation between all the Baltic Sea countries. The work is carried out under the auspices of the Baltic Marine Environment Protection Commission (HELCOM) and the NPP Environmental Laboratory is the Finnish partner in this co-operation. The Finnish contribution to this monitoring programme consists of about 120 samples/analyses annually from seawater, bottom sediments, fish and other biota.

Research

The laboratory has participated in several international research projects financed as part of Nordic nuclear safety research (NKS) and by the EC, and in many national research projects.

The laboratory has also co-operated in research projects with several research institutes in Europe and the USA.

It played a central role in developing and establishing the Q&A systems and accreditation of relevant analysis methods in the Research and Environmental Surveillance Department.

The laboratory has presented its research results at several international meetings and published them in national and international scientific journals.

Standardisation

- The laboratory has participated in the standardisation work of the Technical Committee IEC 45B: Nuclear Instrumentation of Electrotechnical Commission (IEC), by commenting and voting on draft standards for the National Committee.

Expert services

The laboratory has provided expert services as follows:

- for the IAEA Advisory Group, in the drafting the IAEA-TECDOC "Inventory of radioactive material entering the marine environment: Accidents and losses at sea involving radioactive materials"
- for the IAEA Advisory Group, in the drafting of the IAEA Safety Guide "Principles of source and environmental monitoring for radioactive discharges"
- As consultant to the IAEA, in the drafting of the Safety Report "Practical considerations in the design and operation of source and environmental radiation monitoring programmes and systems" and as a member of the IAEA Technical Committee reviewing the same draft.
- As a member of the Finnish delegation to the Inter-Governmental Panel of Experts on Radioactive Waste Disposal at Sea of the London Convention.

2.4.3 Personnel

Erkki Ilus, MSc (marine biology), head of laboratory
management, design and implementation of environmental radiation monitoring programmes, environmental effects of nuclear power plants, marine radioecology, thermal effects of cooling water discharged from nuclear power plants

Seppo Klemola, MSc (physics), scientist
gamma-ray spectrometry, airborne radioactivity, environmental monitoring of nuclear power plants

Tarja Ikäheimonen, MSc (radiochemistry), scientist
marine and terrestrial radioecology, especially for transuranic elements, radiochemical nuclide analytical methods, including alpha and beta spectrometry, environmental monitoring of nuclear power plants

Jukka Mattila, MSc (limnology)**,** scientist
marine radioecology especially sediment studies, environmental monitoring of nuclear power plants, dating of sediments

Vesa-Pekka Vartti, student at Helsinki University (radiochemistry), assistant researcher
radiochemical nuclide analytical methods, quality assurance

Kari Huusela, research technician
environmental sampling and field studies

Marjaana Ahonen, laboratory operator
pre-treatment of samples and radiochemical analyses

Eija Haakana, laboratory operator
pre-treatment of samples and radiochemical analyses

Aimo Kemppainen, laboratory operator
pre-treatment of samples and radiochemical analyses

2.4.4 Aims of research

Radiation monitoring in the environs of nuclear power plants and in the marine environment involves not only implementation of the permanent monitoring programmes, but also more profound research work focusing on details in different surveillance sectors.

The aims of the research carried out at the laboratory are:

- To develop the environmental monitoring programmes of Finnish nuclear power plants and to ensure that the conclusions based on the results of the monitoring programmes are correct.
- to develop the dose calculation models used in the monitoring programmes

- to assess the environmental impacts of Finnish nuclear power plants
- To assess the amount of radioactivity in the Baltic Sea and the radiological exposure of the population to radioactivity occurring in the Baltic Sea.
- to obtain knowledge about radionuclide processes in the Baltic Sea
- to develop analytical methods for environmental studies and emergency preparedness

2.4.5 Progress report on research over the last five years

Studies on the behaviour of radionuclides in the environs of nuclear power plants and the environmental effects of Finnish nuclear power plants

The environmental impacts of the two Finnish nuclear power plants have been assessed on the basis of some 25 years of experience. Their radiological impact on people living in their vicinity and on the environment in general has been insignificant (Ilus et al., 1997). Radionuclides of local origin are found in the terrestrial environment only occasionally, and in very small concentrations. On the other hand, samples from the marine environment regularly contain traces of local discharges, even at some distance from the power plant concerned, though only in low activity concentrations (Ikäheimonen et al., 1995, Klemola et al., 1998). The research carried out at the laboratory has focused on studying the indicator value of certain organisms or other sampling objects when radioactivity is being monitored (Ilus, 1995). Some indicator organisms, e.g. the seaweed *Fucus vesiculosus*, have been used with success in several national and joint Nordic studies. The most notable thermal effects of cooling water have been changes in winter ice conditions and certain biological effects in sea areas close to the power plants. The littoral vegetation has become more eutrophic and phytoplankton primary production has increased in the vicinity of the cooling water outlets.

The laboratory's expertise in the environmental monitoring of nuclear power plants, which derives from its long experience of extensive and versatile monitoring programmes, has also been used for national and international purposes. The laboratory has participated in the drafting and reviewing of a forthcoming IAEA Safety Guide and a coming IAEA Safety Report, which will provide guidance in the environmental monitoring of radioactive discharges. Several foreign experts have visited the laboratory (for periods of 1 week to 5 months) on IAEA fellowships. Recently, the laboratory's expertise was used in Environmental Impact Assessment procedures launched in Finland, connected with plans to build new nuclear power plant units at Loviisa and Olkiluoto.

Baltic Sea studies

The laboratory has been an important partner in the MORS (Monitoring of Radioactive Substances in the Baltic Sea) Expert and Project Group of the Helsinki Commission (HELCOM) since the Group started to work in 1986. All the Baltic Sea countries make a contribution to the joint international monitoring of radioactivity in the Baltic Sea, and the laboratory is the Finland's representative in this co-operation. Since the Chernobyl accident, the MORS Expert Group has published two joint assessment reports on radioactivity in the Baltic Sea (Ilus et al., 1995). The third Joint Report "Radioactivity in the Baltic Sea in 1992-1998" will be published at the beginning of 2001. The laboratory has been responsible for preparing and writing several chapters in the reports, especially those dealing with "The monitoring network", "Quality assurance", "Radionuclides in sea water", "Radionuclides in biota" and "Radionuclides in sediments".

In 1996, the European Commission initiated a comprehensive study of the radiological status of the Baltic Sea, the Marina Balt Project, to which experts from the MORS group participated and a few experts from outside the group contributed. The project involved quantifying the amounts of radioactivity reaching the Baltic Sea, modelling subsequent dispersion and transfer within marine compartments, assembling available environmental data and comparing these data with modelling results, identifying and quantifying pathways to man and, finally, estimating realistically the doses received by critical groups and by the population as a whole. The laboratory was responsible for quantifying the source terms. In this connection, a comprehensive study was carried out with the purpose of estimating discharges of Cs-137 and Sr-90 into the Baltic Sea by Finnish rivers after the Chernobyl accident (a joint study with the Laboratory for Ecology and Foodchains). A summary of the main results of the Marina Balt project was published in an international journal and the Final Report came off the press in April 2000 (Nielsen et al., 1999, Ilus & Ilus, 2000, Saxén & Ilus, 2000).

The most significant source of artificial radioactivity in the Baltic Sea is the fallout from the Chernobyl accident. The total input of Cs-137 to the Baltic Sea from Chernobyl has been estimated at 4700 TBq. Other important sources are global fallout from atmospheric nuclear weapons tests and discharges from nuclear reprocessing plants in Western Europe. In 1996, the decay-corrected cumulative sum values for Cs-137 and Sr-90 discharged from the local nuclear facilities were 1.7 and 0.7 TBq, respectively. During 1950-1996 the maximum annual dose to individuals from any critical group in the Baltic Sea area was estimated at 0.2 mSv y^{-1}. The total collective dose from man-made radioactivity in the Baltic Sea was estimated at 2600 manSv.

Marine radioecology studies supported by the NKS (Nordic Nuclear Safety Research)

During the last five years the Laboratory has been involved in two Marine Radioecology Projects supported by the NKS. In the 1994-1997 project the main emphasis was put on sediment research, in particular on the interaction between sediments and radionuclides, and the sedimentation processes. The laboratory's contribution to the project was divided into two national subprojects: 1) The sedimentation rate in the Baltic Sea and 2) Radionuclide processes in sediment and near-bottom water in varying redox conditions. So far a highly comprehensive study on sedimentation rates in different parts of the Baltic Sea has been carried out. The estimations were based on the vertical distribution of certain radionuclides (Cs^{137}, ^{210}Pb, $^{239,240}Pu$) in the sediments. The results showed that the sedimentation rate varies in the Baltic Sea over a very broad range. It was also concluded that more than one parallel method should be used to evaluate sedimentation rate, because of the unstable environmental conditions (Ilus et al., 1998).

The sediment data collected for the above study were also used to estimate the total inventory of ^{137}Cs bound in the Baltic Sea sediments. This study was made in co-operation with the Finnish Institute of Marine Research, by pooling all the data available. The total inventory of ^{137}Cs in the seabed was estimated at 2.14 PBq in 1996. The results were presented at an international symposium on marine pollution organised by IAEA-MEL, Monaco (Ilus et al., 1998).

The 1998-2001 Marine Radioecology project of the NKS deals with radioactive tracers in Nordic Sea areas. It is divided into two sections: a) Use of Tc-99 as a tracer for transport of contaminated water masses from the Irish Sea to Nordic waters, including the Baltic Sea, b) Use of radioactive tracers in studies of radionuclide processes and transport in the Baltic Sea, and in its catchment and adjacent areas. The laboratory's main interest is in the Baltic Sea, but it is also taking part in the Tc-99 survey being conducted in all Nordic Sea areas. For this purpose, bladder-wrack (*Fucus vesiculosus)* samples were taken along the Finnish coast in the summer of 1999. The results show that Tc-99 can be detected in small quantities in *Fucus* almost everywhere on the Finnish coast.

Studies in the Thule area (N.W. Greenland)

In January 1968, a US B52-bomber carrying 4 nuclear weapons caught fire and crashed on the ice in Bylot Sound off Thule Air Base in N.W. Greenland. The aeroplane and the nuclear weapons were totally destroyed in the subsequent explosive fire. Some of the weapons' plutonium was scattered over several square kilometres of ice. Based on surveys carried out in 1968, 1970, 1974, 1979, 1984 and 1991, it was estimated that the pollution remaining in the seabed in Bylot Sound as a consequence of the accident amounts to approximately 1.4 TBq (~0.5 kg) plutonium-239,240, 0.025 TBq plutonium-238, 4.6 TBq plutonium-241 and 0.07 TBq ^{241}Am.

In 1997 a new expedition went to the site of the Thule accident. The laboratory was re-presented in an international team of scientists invited to join the expedition (Dahlgaard et al., 1999, Ryan et al., 1999). Risø National Laboratory, Denmark led the sampling cruise, and the NPP Environmental Laboratory was responsible for sediment sampling. The laboratory has received about 100 sediment samples taken during the cruise and the samples will be analysed for a and ß nuclides of plutonium. The samples are also being checked by gamma-spectrometry, with the object of searching for fractions with plutonium particles. The particles will then be separated and their activity, size and composition will be analysed in co-operation with the Laboratory for Airborne Radioactivity.

Computerised gamma-ray spectrometry efficiency calculations

To simplify the efficiency calibration of germanium detectors, a simple and fairly accurate semi-empirical method has been used in the laboratory. This utilises a computer code for the calculation of detector efficiencies (Klemola & Ugletveit, 1997). The method and the code were validated in a project organised under the auspices of the International Committee for Radionuclide Metrology (ICRM). Good overall agreement was achieved between the experimental and calculated efficiencies of the detectors studied and volume sources in the energy range of 60-1800 keV.

The code was further tested in the EUROMET project 428. The test showed that our method gives detection efficiencies with deviations comparable to the other semi-empirical methods included in the project.

The applicability of the method was also demonstrated in an exercise studying optimum sample geometries for large and medium-sized germanium detectors. The results showed that the optimum cylindrical beaker shape is obtained when the diameter of the beaker is four to five times greater than the height of the sample. On the other hand, the Marinelli-type beaker was almost always found to give the highest count rate at any given energy level (Klemola, 1996).

In the most recent study, the validity of the method for low energy gamma rays was tested. Due to the low energy of the naturally occurring radionuclide ^{210}Pb, 46.5 keV, the attenuation of gamma rays in the sample needs special consideration. A computer program was used to transfer full-energy peak efficiencies of a standard geometry measured to various heights and densities of sediment samples. The ^{210}Pb concentrations obtained were compared with those of ^{210}Po, which was assumed to be in equilibrium with lead and analysed by alpha spectrometry. The results show good overall agreement and argue for extension of the method to low energies.

Improved gamma spectrometric analysis
Nordic Nuclear Safety Research (NKS) sub-project EKO-3.2.5.

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

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

Nordic Nuclear Safety Research Final Summary Report, NKS (97)FR 10p

Modern methods for analysing strontium in environmental samples in emergency and normal situations

The laboratory has developed a good and effective method for separating strontium from environmental samples (Ikäheimonen & Vartti, 1999). It is based on extraction chromatography using a special reagent (*Sr. Spec resin*). Two versions of the method were modified: a) a rapid method for emergency situations and b) a new method for normal monitoring work. All kinds of environmental samples could be analysed with the method. Measuring techniques were developed for rapid measurement of ^{89}Sr and ^{90}Sr using different combinations of several types of equipment. The new method significantly shortens the normal time needed to analyse strontium. It also makes the analysing process more pleasant and safe. In emergency situations rapid information about the level of strontium activities in the environment can now be obtained faster than before. The method was tested in international intercomparison studies.

A new method for analysing ^{241}Pu in environmental samples

A radiochemical method for determining ^{241}Pu in environmental samples was developed in the laboratory (Ikäheimonen, 2000). The method is based on liquid scintillation measurement of ^{241}Pu with a pulse shape analyser after Pu separation. Both alpha spectrometric measurement and liquid scintillation counting were needed. Instead of the pure ^{241}Pu standard, the efficiency calibration was performed using the ^{3}H standard. The detection limit of the method is very good, 0.007 Bq per sample. The advantage of the new method is that the samples are easy to prepare. Both alpha and beta emitting plutonium isotopes and Am and Cm isotopes, if needed, could be analysed from the same sample. The method was tested by comparing the results with the results of the ingrowth method and various reference materials.

A new method for analysing ^{99}Tc in environmental samples

A new method for analysing ^{99}Tc in marine samples was developed in the laboratory. The method is based on extraction chromatography using a special reagent (*TEVA resin*). After pre-treatment, Tc is extracted into the resin, which is measured with a liquid scintillation analyser. Yield measurements were performed gammaspectrometrically with a short-lived ^{99m}Tc tracer. The method is suitable for several kinds of environmental sample, though the pre-treatments are different. The effectiveness of the method for ^{99}Tc is about 85% and the detection limit is 0.003Bq per sample. The method was tested in an international intercomparison of seaweed samples. This new method and the results obtained using it will be presented at an international conference in October 2000.

Study of plutonium in the environment

The behaviour of plutonium and occurrence of its isotopes in the environment have been studied in different research programmes in the laboratory. The spread of ^{241}Pu in the air and its deposition in Finland were studied after the Chernobyl accident. Pu-241 was clearly present in the Chernobyl fallout in Finland. Pu was unevenly distributed and the mean radioactivity ratio of ^{241}Pu/^{239,240}Pu was calculated to be about 70. The impact of the Chernobyl accident was also visible in the Pu concentrations and Pu isotope ratios in Baltic Sea sediments (Ikäheimonen, 2000). Pu concentrations and ratios were also used to date sediments (Ilus et al., 1998).

In addition, occurrence of plutonium isotopes in the Arctic has been studied. Plutonium concentrations in moss, lichen, algae, fish and sediment samples from the Barents, Petshora and Kara Sea areas, and from the Kola Bay and certain islands have been monitored for several years. The concentrations of plutonium in the Arctic areas studied were generally low and originated from the global fallout resulting from nuclear weapon tests or discharges from reprocessing plants in Western Europe. However, some of the higher isotope ratios of Pu in the Kola Bay near the Atomflot area and in the outlet of Kola Bay to the Barents Sea indicate fresh releases from the facility or from waste storage vessels lying in the area (Ikäheimonen et al., 1997, Rissanen et al., 1997, 1998).

Developing laboratory techniques to identify radioactive particles

The laboratory is a partner in a study aiming to estimate hazards related to radioactive "hot" particles that may be released in a nuclear accident. The results are reported in more detail by Airborne Radioactivity laboratory (Pöllänen et al., 1999).

2.4.6 Research plans for the next five years

The STUK research projects for the period 2000-2002 are described in detail in the STUK-A179 report (Salomaa 2000). A list of the projects to be carried out by the NPP Environmental Laboratory is given below. The list consists of research projects that are in progress or will begin in 2000 and are planned to continue for several of the next five years.

- Monitoring radioactive substances in the Baltic Sea. International co-operation carried out by the HELCOM/MORS Expert Group is continuous.
- Partnership in the NKS Marine Radioecology project "Radioactive tracers in Nordic Sea areas". Duration of the project 1998-2001.
- Partnership in a provisionally approved EC project "FASSET - Framework for Assessment of Environmental Impact". Duration of the project 2000-2003.
- Forest ecosystem study in the environs of Finnish nuclear power plants. Duration of the project 2000-2003
- Study of coastal ecosystems in the environs of Finnish nuclear power plants. Duration of the project 2000-2003
- Study of Thule sediments. Duration of the project 2000-2001.

2.5 Ecology and foodchains

2.5.1 Key words and specific technologies

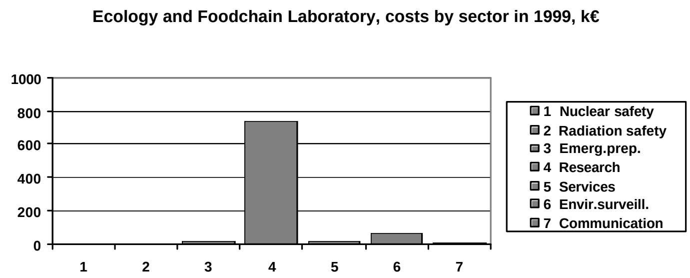
Key words

Forest radioecology, freshwater radioecology, agricultural radioecology, radiation exposure pathways, countermeasures, bioenergy, exposure modelling, food chains, radiation protection of the environment, long-term behaviour of radionuclides, radionuclides in foodstuffs

Specific technologies

Gamma, beta and alpha spectrometry, liquid scintillation counting, atomic absorption spectrometry, radiochemical methods for ^{3}H, ^{14}C, ^{89,90}Sr, ^{239,240}Pu, ^{210}Pb, ^{226}Ra, ^{210}Po, sampling of soil, deposition and forest vegetation

2.5.2 Description of laboratory activities



The responsibilities of the Ecology and Foodchains Laboratory are:

- to carry out research on radionuclide distribution and transfer in the environment, assessment of exposure from radionuclides in the environment and countermeasures in agriculture and forestry
- to perform surveillance of radioactivity in deposition, foodstuffs and surface water and to assist the customs authority related to import control of foodstuffs
- to perform service analyses on radioactivity in foodstuffs and to give certificates of radioactivity concentrations for export products

Assessment of exposure from radionuclides in the environment

Laboratory for Ecology and Foodchains is to make estimates of the Finnish population's internal radiation exposure through food chains. Accordingly, monitoring of radioactive material in the environment is continuous. The laboratory is responsible for the execution of programmes monitoring artificial radionuclides in deposition, foodstuffs and surface and drinking water.

Besides monitoring, which is a minor aspect of activities, the laboratory also does research on the behaviour and transfer of radionuclides in terrestrial and aquatic environments. Both agricultural and forest environments are included in the research of terrestrial field. In addition to its own sampling activities, it obtains samples for monitoring programmes and research projects from other organisations or institutes.

The laboratory's research projects and monitoring results have generated large databases that facilitate estimation of radiation doses to the population via foodstuffs from terrestrial (agricultural land and forests) and aquatic environments. The radiation dose via foodstuffs is now low. About 75% of the ingestion dose is contributed by products from nature, such as mushrooms, forest berries and freshwater fish, while the main foodstuffs from agriculture, much more of which are consumed than natural products but which are almost totally uncontaminated, contribute only about one quarter of the dose.

Radioecology and modelling

- forest ecosystems
- aquatic ecosystems
- agricultural ecosystems
- development of environmental transfer and dose models
- validation of terrestrial and lake models

Research projects are carried out in co-operation with other institutes either nationally, as joint studies with other Nordic countries, within the framework of the EU, or otherwise internationally. Radioecological research projects and development of environmental models complement each other.

Both are needed to estimate radiation doses and plan countermeasures in an emergency situation. The main research projects are described in section 2.5.5.

The laboratory carries out sample treatment, and gammaspectrometric and radiochemical analyses. It has the readiness and the equipment for sampling soil, wild food products, forest vegetation and deposition. Various assignments and analyses are done according to guidelines documented in the laboratory handbook. The laboratory also performs analysis services for industry.

Management and restoration of large-scale surface contamination, emergency preparedness

- analysis of countermeasures and development of strategies for agricultural land and foodstuffs and seminatural ecosystems
- development of emergency response arrangements and radioanalytical methods
- organisation of and participation in emergency exercises
- advice, education and information for local food and environmental laboratories

When needed, the laboratory helps to clarify of radiation problems in the fields of food and water supply and the forest industry.

In order to develop intervention and restoration strategies, we are contributing for instance to a Nordic Nuclear Safety Research (NKS) project on agricultural and forestry countermeasures. The main objective of the project is to prepare a Nordic handbook on countermeasures and to assess their feasibility in Finnish and Nordic production conditions. The project aims to achieve better understanding of the differences between Nordic countermeasure strategies and to be able to explain them. The work is contributing to developing the network between the individuals within Nordic agricultural and food authorities and radiation protection institutes who will be involved in mitigating the effects of a nuclear accident. Countermeasure strategies are documented in a Nordic handbook, which also provides background information on goals and the relevant arrangements within the agricultural and foodstuff area.

Communication and training

- information bulletins to the public on radionuclides in foodstuffs
- communication with stakeholders
- training of stakeholders: industry, agricultural and environmental health authorities
- organisation of seminars on management of foodstuffs following a nuclear emergency

Laboratory staff has given lectures at emergency preparedness seminars organised by the Food Pool of National Supply Agency and the Finnish Food and Drink Industries' Federation. The participants were from the food industry and the agricultural authorities. Presentations on radioactive contamination of foodstuffs have been given to interest groups such as farmers, hunters and medical staff.

The personnel of the radiation measurement laboratory of Kiirguskeskus, Estonia, have been trained at STUK. The training covered measurement techniques and quality assurance arrangements. Training has been arranged for staff at local foodstuff and environmental laboratories, who would be responsible for measuring locally produced foodstuffs in case of an emergency.

A Finnish seminar on radioactivity in forests and the effects of fertilisation on radioactive contamination was organised in 1999 in collaboration with the Finnish Forest Research Institute in Tampere, Finland. Information is given to the public based on the results of monitoring programmes and research projects. In addition to topical bulletins, a brochure on radionuclides in foodstuffs has been prepared.

2.5.3 Personnel

Riitta Hänninen, PhD (physics), head of laboratory
management, countermeasures, radiation protection, communication with stakeholders, emergency planning and preparedness,

Aino Rantavaara, MSc (radiochemistry), project manager
radioecology of agricultural and seminatural ecosystems, dose assessments, models, analysis of countermeasures, dietary surveys, radiochemistry

Ritva Saxén, MSc (radiochemistry), senior scientist
freshwater radioecology, radiochemistry, quality system of the laboratory, radiation protection of the environment, analysis of countermeasures

Virve Vetikko, MSc (biology), scientist
ecology, environmental management, radioecology of forests, data analysis, modelling

Eila Kostiainen, BSc (radiochemistry), assistant researcher
radioecology of agricultural and seminatural ecosystems, analysis of countermeasures, radiochemistry, gamma spectrometric analysis

Olli Taskinen, PhLic (forestry), scientist
forest management, bioenergy, forest ecology, diet assessment, statistical modelling

Ulla-Maija Hanste, assistant researcher
Radiochemical analysis ($^{89,90}Sr$, ^{14}C, ^{210}Pb, ^{226}Ra, ^{210}Po), a and ß measurements

Tuula Korttinen, laboratory operator
reception of samples, sample preparation

Ulla Koskelainen, BSc, assistant researcher
sample preparation, gamma spectrometric analysis, databases and data analysis on aquatic environment

Ulla Välikangas, laboratory operator
sample preparation, gamma spectrometric measurements, ^{210}Po analysis

Ulla Yli-Arvo, laboratory operator
radiochemical analysis ($^{89,90}Sr$, ^{14}C, ^{3}H, $^{239,240}Pu$), a and ß measurements

2.5.4 Aims of research

- To have the tools and capability to give advice concerning intervention in a large surface contamination situation originating from a radiological accident

- To assess individual and population exposure from man-made radionuclides in the environment and from use of natural resources

The Laboratory for Ecology and Foodchains works in the field of radioecology (transfer and distribution of radioactive material in the environment), assessment of individual and population exposure to radiation, and countermeasures. With regard to radiological accidents, the aim of research is to develop information, methods and capabilities for:

- monitoring radioactivity in the environment and in foodstuffs through laboratory measurements,
- making radiation exposure assessments,
- giving advice on intervention measures in a situation of large surface contamination and
- communicating with various stakeholders.

The target covers both the present situation caused by the Chernobyl accident and preparedness for radiological accidents in the future. The work of the laboratory encompasses several pathways and activities that cause human exposure from radionuclides in the environment: agricultural, seminatural and aquatic foodchains, external exposure and use of natural resources as raw material for construction, industry and energy production.

Radiation protection of the environment has recently been addressed. At present, one aim of the research done is to develop a framework for the assessment of environmental impact, i.e. impacts on organisms and ecosystems. The framework will contribute to judging compliance with environmental quality targets and communicating environmental consequences.

2.5.5 Progress report on research over the last five years

An integrated approach to radionuclide flow in semi-natural ecosystems underlying exposure pathways to man (LANDSCAPE)

The laboratory for Ecology and Foodchains collaborated with eight other European institutes in the LANDSCAPE project, under the 4th Framework Programme in the Nuclear Fission Safety Programme of the EC.

The primary aim of the project was to obtain a basis for forming reliable assessments of man's exposure to radiation under different time scales from radionuclides in plant and animal products of some representative seminatural ecosystems in Europe (SSI Report 99:19). The objective was to investigate the flows of radionuclides within and between the soil, vegetation and animals in forest ecosystems.

To achieve the objectives, both field experiments and modelling were carried out in the course of the project.

The role of the Finnish partners was to quantify the influence of forest management and primarily fertilisation, on radiocaesium distribution, and to assess fertilisation as a possible countermeasure. The laboratory for Ecology and Foodchains worked with the Finnish Forest Research Institute to investigate the effects of fertilisation on ^{137}Cs distribution and budget in two pine-dominated stands in Finland. The experiments also provided information on the general dynamics of radiocaesium in forest vegetation and soil. The results of the Finnish experiments were included in a geographical comparison, with the results from other countries. In addition, a special survey of the seasonal variation in radiocaesium and potassium in conifer needles was carried out in Finland. It showed that in general the seasonal variation in radiocaesium follows the pattern for potassium, but the two are not completely identical.

Radiocaesium uptake in vegetation can be reduced by site-specific nutrient fertilisation on nutrient-poor sites. Dry mass accumulation can be increased by fertilisation, especially in stemwood. The results showed that the reduction in Cs uptake cannot be explained by growth response alone, but that it is also related to root uptake (SSI Report 99:19).

The results indicate the benefits of fertilisation for restoration of contaminated forests in a severe fallout situation. The availability of timber for the wood industry can be materially increased with long-term forest treatments. When there is multiple use of forests, pickers of wild berries and mushrooms, and hunters receive less radiocaesium through foodstuffs from fertilised forests than otherwise.

The results of the study motivate further research on the applicability of forest management methods as countermeasures in a fallout situation. Such methods provide ways to following the principles of sustainable forestry, as the treatments do not drastically change the ecosystem.

Completion and customisation of the modelling in RODOS (RODOS customisation), C.1.1. The development of a submodule for estimating internal and external exposure from contamination in forests

Forest model

The laboratory for Ecology and Foodchains, with IPSN Cadarache, France, has developed a submodule for the RODOS system to estimate human radiation doses after an accidental contamination of forested areas in Europe. The project was carried out under the 4th Framework Programme of the EC. The module calculates the dry and wet deposition and time-dependent distribution of radionuclides in forests, and also the radiation doses received externally and through ingestion. Internal doses received through wild foodstuffs, and external exposure from radionuclides distributed in forests can be predicted for periods of between one day and 50 years after the day of deposition. Doses to the population and its subgroups can be calculated by age and by the way in which it uses forests and forest products.

The Forest Food Chain and Dose Module was developed as an integral part of the RODOS system. The program uses the same database as the main module, which deals with transfer of radionuclides in agricultural crops and the subsequent doses. Special sections for the parameters unique to the forest module were added to this database. For the current module, default sets of calculation parameters were derived for two radioecological regions, namely northern and central Europe, with their forest vegetation zones and plant and game animal species. For these regions, parameters for three types of forest are available in the database to include variation in activity concentrations and doses due to different conditions. The model parameters further include data for estimating human exposure due to the consumption of wild food products or time spent in the forest for either work or leisure activities.

The program itself begins by calculating deposition to forest from data on air concentrations and activity deposited in rain, provided by the Atmospheric Dispersion Module of RODOS. The time-dependent transfer processes between trees, understorey vegetation and soil are then modelled to provide input data for calculating concentrations in foodstuffs and external dose rates. The program calculates ingestion doses from isotopes of iodine, caesium, strontium and plutonium in wild berries, mushrooms and game meat. The seasons when these food products are available, radionuclide losses during cooking, and consumption rates are specified for each radioecological region.

External doses are derived through kerma rates caused by radiation sources in the crown layer, in trunks, in ground layer vegetation and in the soil. Nuclides emitting gamma radiation are used to calculate the kerma rate. In all, the contributions of some 50 radionuclides to the external doses can be estimated using the forest module. The exposed subjects represent different age groups of the population, forest workers, hunters, and berry and mushroom pickers. The model endpoints are calculated for a grid of locations defined for the geographical area of interest. All doses are given for three different forest types, which may differ from one radioecological region to another.

Using the forest module clarifies the significance of forests as sources of radiation, and as an assessment tool for the early phase it gives support for realistic intervention. The module is generally applicable throughout Europe, and its adaptability to local conditions improves the accuracy of long-term predictions. Non-experts, too, are able to use the module. (RODOS, Final Report [internal of the project])

Regional lake model

A regional model on the transfer of radiocaesium from deposition to freshwater fishes was developed and validated in co-operation with the Technical Research Centre of the Finland. In the long term, transfer of radionuclides from deposition to fish is affected by the hydrological and chemical quality of the water and the quality of the catchment area. In addition, contamination and decrease of the contamination of fish occur at different times and different rate's depending on the feeding habits of the fish. The lake model developed therefore consists of a catchment model, a lake model and a fish model. The model was developed on the basis of data produced on the transfer of ^{137}Cs into various types of fish in various types of lake in various types of catchment area. The model was then validated by means of another independent set of data. The model will support decision-making when long-term effects and radiation doses to people after a serious accidental deposition situation are estimated. The model is being implemented as a part of the RODOS system. (RODOS, Final Report [internal of the project])

Radionuclide distribution and transfer in the environment

Long-term distribution of radionuclides in lakes

The deposition from Chernobyl, which was unevenly distributed, significantly contaminated the lakes in southern Finland. The spatial variations and temporal changes in ^{137}Cs content in fish from some dozens of lakes have been determined, and the radiation doses caused in Finland by eating freshwater fish have been estimated. Besides uneven deposition, several environmental factors have caused variation in the ^{137}Cs content of fish. The results show that the transfer is up to 10 times more effective into predatory than into non-predatory fishes. Environmental factors, such as nutrition level, the lake water residence time, the type and size of the catchment etc cause differences varying by a factor of up to 50 to transfer coefficients from deposition into fish. So far, the results also show that certain fishing areas in Finland are more vulnerable to radioactive contamination than others.

The dynamics of the long-lived radionuclides ^{137}Cs and ^{90}Sr in a large lake basin important for both freshwater fishing and drinking water, located in an area of high deposition, were studied. The results show that these two nuclides behave in a different way in the aquatic environment, ^{137}Cs moves quickly from the water phase to bottom sediments, while most ^{90}Sr remains in the water phase and moves with the water flow. Also after entering the bottom sediment, ^{90}Sr is more mobile than ^{137}Cs, and it is found in deeper sediment layers than ^{137}Cs, which remains in the surface sediment. The distribution of ^{137}Cs between water and sediment was shown to have stabilised within two years of the deposition, when more than 90% of ^{137}Cs was in sediment and the rest in water. In the case of biota, ^{137}Cs transfers into the edible tissue of fish, while ^{90}Sr enters the bone tissue. The ecological half-lives of ^{137}Cs in several species of fishes were determined. The runoff from a catchment area with peat bogs was higher than the runoff from other types of catchment. Transfer parameters were derived from the results and a dynamic transfer model was developed for ^{137}Cs and ^{90}Sr. (Saxén et al. 1996 and 1997, Moring at al. 1997)

Transfer of radionuclides through rivers to the Baltic Sea

Total amounts of ^{90}Sr and ^{137}Cs discharged from Finland to the Baltic Sea during 1986-1996 were estimated. The estimation was based on the ^{90}Sr and ^{137}Cs content in water from five large rivers discharging into the Baltic Sea from Finland and in other surface waters and on data of water discharge by those rivers and from Finland as a whole. Only six times more ^{137}Cs than ^{90}Sr was discharged into the Baltic Sea from Finland during 1986-1996, although deposition of ^{137}Cs was about hundred times higher than that of ^{90}Sr. The reason is that most ^{137}Cs is effectively removed from water into bottom sediments of water courses or retained in the soil of the catchment area, while ^{90}Sr remains in the water phase and runoff of ^{90}Sr from the catchment into the water is also relatively higher than for ^{137}Cs. This emphasises the importance of ^{90}Sr in the case of radiation doses from surface waters and of ^{137}Cs in that of doses via pathways from catchment soil, lake sediments and biota after a fallout situation. Most of the ^{137}Cs deposited in catchment areas was retained there and only 1-3% was removed by rivers to the Baltic. The fraction removed was much higher for ^{90}Sr. River discharges from Finland to the Baltic Sea were significantly higher than releases from nuclear power plants and research reactors. (Saxén and Ilus, 2000, in press)

Comparison of the mobility of fallout derived from weapons tests and Chernobyl

The mobility of fallout derived from weapons tests and Chernobyl was compared by fitting different models to measurements of both pre and post Chernobyl ^{137}Cs activity concentrations in five major Finnish rivers. It was shown that there was no significant difference in the temporal changes in ^{137}Cs mobility from these two sources during the years after the fallout. Transport parameters derived from weapons test measurements gave good predictions of the long-term contamination of these rivers by Chernobyl fallout. Changes in ^{137}Cs activity concentrations in rivers since Chernobyl have declined as a result of slow sorption to clay minerals in catchment soils. This study shows that weapons test fallout also exhibited this slow decline over time. Rates of decline in ^{137}Cs activity concentration 10 years after fallout correspond to effective ecological half-lives in the range of 10-30 years. (Smith et al. 2000)

Assessment of exposure in Finland from the Chernobyl accident

Variations in radiation exposures: food contamination levels

A nation-wide foodstuffs programme has provided information on the radiation situation in Finland. The conclusions are that the contamination of foodstuffs in Finland is low, with the exception of wild produce in the areas, which received high radiocaesium deposition following the Chernobyl accident. The results of this programme are used to estimate radiation doses to people, including assessment of variability in diets and food production areas.

A set of databases has been constructed to help with assessing radiation doses via ingestion:

- databases on radioactivity (^{137}Cs, ^{134}Cs, ^{90}Sr) in soil, fodder, agricultural products (milk, meat, cereals, vegetables, garden produce), wild produce (game meat, wild berries, mushrooms)
- databases on production of foodstuffs, product yields
- data on human consumption rates, animal diets

Wild food consumption habits

The use of wild food is a significant pathway for internal radiation doses, as wild food contains higher concentrations of radionuclides than its cultivated counterparts. Use of wild berries, freshwater fish, wild mushrooms, game and wild herbs by Finnish households and individuals was assessed in two separate mail surveys. Consumption showed clear regional differences, in addition to high intra- and inter-household variation. The 10% of most wild food consuming households used several times more wild food than in average households. The importance of food processing and consumption of mushrooms for ^{137}Cs intake was noted (Markkula et al., 1997).

Model validation

Validation of Environmental Model Predictions (VAMP), multiple pathways scenario

An extensive scenario for model validation based on multiple dose pathways for ^{137}Cs in Finland analysed after the Chernobyl accident was provided for the IAEA Co-ordinated Research Programme VAMP. Environmental conditions in the test area (southern Finland) and data on production of foodstuffs, consumption rates, exposure conditions and observed test endpoints were derived. The pathways were ingestion, inhalation and external exposure (Rantavaara et al., 1996).

VAMP, Lake Scenario

Several European lakes were selected by the aquatic working group of VAMP for the validation of existing transfer models. STUK produced data files for the project on one lake from which fish and water were sampled and analysed frequently after the Chernobyl accident. This lake represents a special type which would be extremely vulnerable after a large surface contamination situation in the Nordic countries and which differs greatly from the lakes in central and southern Europe.

Radiation exposure from use of bioenergy

Radionuclides are concentrated in the ashes from bioenergy plants, and the resulting concentrations depend on the fuel contamination, ash content and combustion technique of the plant. The contamination levels of peat, wood and ashes have been estimated in three separate studies carried out in the Chernobyl fallout area in Finland. Peat has rather high levels of natural radionuclides, but is only weakly contaminated by the Chernobyl fallout as long as the surface peat is not used. The contamination found in wood was low and did not indicate any need for countermeasures. The bark showed ten times higher contamination. Due to the low ash content of bark and wood, the pure ash shows high ^{137}Cs content in the highest deposition region. The ashes from bioenergy plants were only moderately contaminated as the plants get their fuel from extensive areas and typically use not only wood but also peat and sludge. The activities found did not exceed the present guidelines. (Helariutta et al., 2000)

2.5.6 Research plans for the next five years

The research of the Ecology and Foodchains during the next five years will be focused on forest environments, long-term dose assessments, emergency preparedness, aquatic environments and radiation protection of the environment.

Forest research

For assessment of influence of countermeasures on forests and forest products a submodule to the Forest Food Chain and Dose Module in RODOS will be developed. It will improve and make more effective the usability of the RODOS system in emergency preparedness plans and exercises.

Radiation exposure due to the wood energy production will be assessed. The need for that is emphasised by new concepts of wood energy and the use of more contaminated forest biomass components like needles and small branches. The study aims at defining the most critical phases of the wood energy production from the radiation protection point of view, formulating the assessment procedures, assessing the current situation and defining the strategies to reduce exposure.

Variation in the radioactivity of timber due to differences in site types will be assessed based on timber received at sawmills and on samples from commercial forests. The new information is for the needs of the forestry sector, and for the development of calculation methods for dose assessments.

The database on radiocaesium in forest vegetation in forest types lacking domestic data will be completed. The significance of Pu contamination in forests as a dose contributor will be assessed.

Dose assessment

Long-term radiation doses for Finnish people via foodstuffs will be assessed, including the nuclear weapon test period and the period after the Chernobyl accident. As far as possible, the doses through the main pathways will be estimated for ^{137}Cs, ^{90}Sr and ^{131}I. Internal radiation doses caused by ^{14}C will also be estimated after analysing temporal changes of ^{14}C in some foodstuffs starting from the nuclear weapon test period up to present. Factors such as diet and regional variations relevant for the estimation of doses from foodstuffs will be studied.

Emergency preparedness

The basic emergency preparedness in the field of foodstuffs is continuously maintained by food chain studies and surveillance in Ecology and Food Chains. By assessing of countermeasures for mitigation of the possible effects of radioactive fallout on various types of environments the emergency preparedness is under continuous development.

A network of groups in five European countries to estimate options for managing contaminated agricultural land and foodstuffs and to evaluate practicable restoration strategies following nuclear accident will be formed in a project FARMING under the 5th Framework Programme of the EC.

A decision conference will be used for the evaluation of later phase countermeasures applicable to milk and dairy products .

Aquatic research

The object of the freshwater research is to study the factors affecting transfer of ^{137}Cs into fishes and especially the reasons for which ^{137}Cs in fish stays high for exceptionally long time. The majority of radionuclides transferred into lakes are gradually transferred into and finally stored in bottom sediments. To estimate how long the radionuclides deposited will be in the biological cycle long-term gathering of radionuclides into bottom sediment, the effect of eutrofication and humic substances on the sinking of the radionuclides to the bottom sediment will be studied.

Radiation protection of the environment

During recent years it has been recognized that the principles of the ICRP are not sufficient on all occasions to protect organisms other than humans from the harmful effects of radiation. In an EU -project, FASSET, the missing framework for radiation protection of organisms will be created in typical European environmental conditions. The existing criteria for the protection of the environment against other harmful substances, for instance chemicals, will be considered.

The STUK research projects for the period 2000-2002 are described in detail in the STUK-A179 report (Salomaa 2000). A list of the projects to be carried out by the Ecology and Foodchains Laboratory is given below.

- RODOS migration
- Development of food and agriculture restoration management strategies (FARMING) - Networked stakeholder groups at European level.
- Decision conferencing: milk
- Radiation protection of the environment, Framework for Assessment of Environmental Impact (FASSET, EU)

- Assessment of radiation exposure from wood energy
- Radioactivity of timber
- Forest radioecology and distributions of ^{137}Cs
- Behaviour of long-lived radionuclides in lake ecosystems and their storage in the bottom sediments of lakes
- ^{137}Cs and ^{90}Sr in freshwater fish
- Long-term exposure assessment
- Radiation doses to the population from depositions resulting from nuclear weapon tests and the Chernobyl accident
- Plutonium in forests
- ^{14}C in foodstuffs
- Development of food monitoring and regional food production data collection programmes for assessment of population exposure

2.6 Airborne radioactivity

2.6.1 Key words and specific technologies

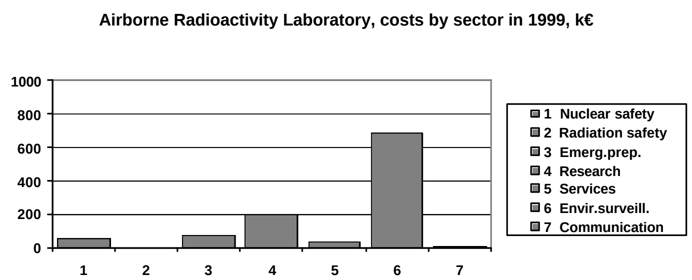
Key words

Airborne radioactive material, radiation monitoring, external dose rate, atmospheric transport, mobile radiation measurement, radioactive particles, particle analysis, fallout mapping, dose estimation, emergency preparedness.

Specific technologies

Computer codes for calculating atmospheric transport, dispersion and doses of radioactive substances, nation-wide external dose rate monitoring and information system, nation-wide surveillance of airborne radioactive material, automated sampling and alarm systems, environmental surveying using mobile equipment, mobile laboratory for environmental monitoring, satellite positioning, desktop mapping and data transfer, unmanned aerial vehicles in sampling and plume mapping, gamma-ray spectrometry, autoradiography, imaging, analyses of individual radioactive particles.

2.6.2 Description of laboratory activities



The responsibilities of the Airborne Radioactivity Laboratory are:

- research on radioactive particles and their atmospheric transfer and deposition

- development of tools for emergency preparedness (mobile and field measurements, sampling stations etc.)
- monitoring of external radiation and radioactivity in air
- task related to the CTBT (Comprehensive Test Ban Treaty) radioactivity measurements

Environmental radiation monitoring

The laboratory is responsible for monitoring external dose rates and airborne radioactive substances. The nation-wide dose rate monitoring network consists of about 290 stations equipped with GM tubes. In 1999-2000 we made a major contribution to the preparation of a real-time radiation monitoring and information system known as USVA. USVA utilises up-to-date web technology in disseminating radiation data and other related information.

In Finland there are eight sampling stations, which monitor airborne radioactive substances using equipment developed at STUK. Most of the samplers are manually operated, but the one on the roof of the STUK building in Helsinki is fully automated: it filters radioactive substances from the air, monitors radionuclides collected on the filter in real-time, changes the filter, prepares the samples for on-site high-resolution gamma-ray analysis and reports the data on the STUK www-pages.

Emergency Preparedness

Emergency preparedness is founded on an evaluation of the scenario of potential releases of radioactive material into the environment. In the middle of the ‘90s we prepared comprehensive internal reports on possible nuclear accident scenarios and their radiological consequences. These reports are used as a guideline in preparing the tools needed in emergency situations.

The laboratory co-operates closely with the Finnish Meteorological Institute (atmospheric transport and dispersion), the Ministry of the Interior (external dose rate monitoring) and the Finnish Defence Forces (air sampling and fallout/plume mapping using aerial vehicles). A number of field measurement and information transfer systems developed by the laboratory are now in operational use in STUK.

Research

The research carried out at the laboratory covers studies related to the behaviour of airborne radioactive material. The radiological hazards caused by (particulate) radioactive substances and the development of techniques for analysing different environmental samples are currently major topics. Results are typically published in scientific journals.

Technical development of the tools needed for external dose rate monitoring, monitoring airborne radioactive substances and environmental monitoring in general have been one of the laboratory's major tasks. Such tools are used primarily in emergency preparedness and management, and in in-field real-time radiation measurements using moving or mobile systems. Results are typically published in the STUK report series and at scientific conferences.

The Airborne Radioactivity Laboratory co-operates with several Finnish universities and research institutions. Publications have also been prepared jointly with other laboratories in the Department of Research and Environmental Surveillance.

Nuclear safety

STUK is one of the IMS (International Monitoring System) radionuclide laboratories according to the CTBT (Comprehensive Nuclear Test Ban Treaty). The necessary laboratory functions were set up in the laboratory in 1999. After certification the laboratory will analyse samples collected by the air monitoring stations. The station on the roof of the STUK main building operates as a prototype version of the monitoring stations. The Airborne Radioactivity Laboratory studied and developed different techniques for analysing the samples. The laboratory organised an international radionuclide-monitoring workshop at STUK at 1996.

Expert services

Many of the systems prepared by the laboratory are partly designed/prepared/financed by co-operation partners. An example of such expert services are Remote Monitoring Field Trial organised in co-operation with Sandia National Laboratories, in which the STUK roof laboratory was fitted with equipment that allows comprehensive remote monitoring of the station. Another example is the development work done in the IAEA Action Team on air sampling and particle analyses. Results from the expert services are typically published in the STUK report series.

Information

The results achieved in research and technical development are routinely processed using standard STUK communication procedures. For example, results of the external dose-rate monitoring at 8 stations are displayed via videotext and on STUK's www pages.

2.6.3 Personnel

The Airborne Radioactivity Laboratory was established in 1992, when the number of posts was five. In 1996, national external dose rate monitoring was added to laboratory's responsibilities and in 1999 CTBT laboratory functions were started. On June, 2000, the laboratory had altogether 12 permanent and fixed-term posts, distributed as follows:

Roy Pöllänen, PhLic (physics), acting head of laboratory
management, airborne radioactive particles, particle analysis techniques, aerosol physics.

Harri Toivonen, DrTech (nuclear physics), head of laboratory
currently on temporary leave to work for the CTBTO (Comprehensive Nuclear Test Ban Treaty Organisation), Vienna.

Juhani Lahtinen, MSc (eng.), senior scientist
development, cooperation within and maintenance of the nation-wide external dose rate monitoring system, dose rate monitoring, atmospheric transport, emergency preparedness and analysis of radiation threats.

Mikael Moring, MSc (eng.), scientist
Internal development of the CTBT laboratory, environmental radiation monitoring, laboratory and particle analysis techniques, gamma-ray analyses, mobile radiation measurements.

Kaj Vesterbacka, MSc, (physics), inspector
development and maintenance of the radiation monitoring information system, gamma-ray analyses, software development.

Erkki Katerma, eng., inspector
development and maintenance of the nationwide external dose rate monitoring network, control and automation, the external dose rate network.

Mikko Leppänen, eng., inspector
maintenance and development of the nation-wide external dose rate monitoring network, maintenance of the external dose rate network.

Suvi Ristonmaa, MSc (physics), scientist
development and maintenance of the radiation monitoring information system, emergency preparedness.

Tarja Ilander, system analyst
development of tools needed in environmental monitoring and preparedness, system design, programming, emergency preparedness.

Arto Leppänen, MSc (physics), scientist
development and maintenance of the nationwide monitoring system for airborne radioactive substances, gamma-ray analyses, system design.

Riitta Kontro, eng., research assistant
maintenance of the network of air samplers, data management.

Tuomas Valmari, MSc (eng.), scientist
radioactive aerosols, aerosol research, expert services.

Kari Kurvinen, MSc (physics), scientist
radiation detection and surveillance by unmanned aerial vehicles, radiation meters, mobile measurements.

2.6.4 Aims of research and technical development

The priority areas for research and technical development in the Airborne Radioactivity Laboratory are as follows:

- Development of tools needed at the STUK emergency centre in the early phases of a nuclear accident and identification of radiation hazards (calculation of atmospheric transport, dispersion, deposition and doses). In a nuclear emergency these tools would enable to estimates of the short-term consequences of releases and the dissemination of calculation results to different teams in the preparedness organisation.
- Development of tools needed for automatic and manual real-time monitoring of external dose rate and airborne radioactive substances. In a nuclear accident, automatic monitoring systems, accompanied by manual devices, should give a reliable and rapid picture of the radiation situation and facilitate correct countermeasures.
- Development of mobile radiation monitoring techniques and instruments (mobile laboratory, aerial vehicles, etc.), development of field monitoring techniques and methods needed to transfer field radiation data to STUK headquarters. Mobile radiation monitoring techniques with a positioning system make it possible to collect data from areas without radiation monitoring stations. Wireless data transfer enables transfer of radiation data and position data independent of location.
- Research related to release, characteristics, transport, dispersion, deposition and radiation threats related to radioactive particles in a nuclear accident. This is close to basic research and provides a scientific background for estimating hazards caused by radioactive substances. The results of these studies are utilised by STUK's expert services, for instance.
- Development of the laboratory assay methods needed to characterise the radioactive materials present in environmental samples. Sophisticated analytical methods for sample analysis are developed, especially in order to characterise the individual radioactive particles present in the sample. Results are utilised in different safeguard applications, for instance.

2.6.5 Progress report on research over the last five years

The following considers scientific and technical highlights in the priority areas for research and technical development.

Tools for emergency preparedness and short-term consequence estimation in a nuclear accident

In 1993 STUK, with a major contribution by the Airborne Radioactivity Laboratory, prepared a comprehensive internal report on evaluation of different scenarios of potential releases of radioactive material into the environment. Parts of that report have since been published. In 1996-1997 the report was accompanied by a second internal report dealing with the evaluation of hazards caused by plutonium. These reports have been used as a basis for designing the tools needed in emergency preparedness and consequence analyses.

The Finnish Meteorological Institute and the Technical Research Centre of Finland, partly in co-operation with STUK, have developed several systems be used in a nuclear accident to estimate the atmospheric transport and doses of radioactive materials. The Airborne Radioactivity Laboratory often prepared the interfaces between these systems and those used by STUK in a nuclear emergency. The main technical highlights are:

- Involvement in specifying and utilising the computer code known as TRADOS, a long-range atmospheric transport, dispersion and dose model. The code has been widely used in emergency preparedness exercises and in research. A new system known as SILAM will soon be in full operational use.
- Preparation of the gaussian-type computer code known as AINO for calculating atmospheric transport and doses. The code is in routine use in emergency preparedness exercises.
- Development of tools for visualising and disseminating different data, e.g. results of dose calculations or fallout mapping. Www-based tools are designed primarily for the use by the preparedness organisation and are routinely used in exercises.

Automatic and manual real-time monitoring

The laboratory operates a nation-wide network of external dose rate monitoring stations equipped with GM tubes. The detectors are controlled by a software, which is able to poll stations, receive alarms, store measured dose rate values and change the data acquisition parameters. The alarm limit of the stations is set at 0.4 μGy h^{-1}, which means a radionuclide concentration of approximately 100-1000 Bq m^{-3}, depending on the nuclide in question.

USVA is a new Finnish radiation monitoring information system, developed and operated by the Airborne Radioactivity Laboratory. It replaces the non-y2k-compatible SVO+ system. Modern www-technology is used in USVA to visualise the external dose rate data accumulated by the nation-wide network. Other information, such as weather data, trajectories, data from mobile radiation monitoring patrols etc., will also be shown by the system in the near future. Various Finnish authorities and institutes and the Defence Forces currently use USVA.

We also operate a network of 8 aerosol sampling stations. Three of the stations are equipped with a real-time radiation monitoring and alarm system. Studies have shown that on-line monitoring of external dose rate near an aerosol filter is a sensitive method for detecting artificial radioactive materials in the filter. Simulations indicate that a warning level of less than 10 Bq m^{-3} for artificial radionuclides can be attained. This concentration means to an ambient dose rate of approximately 1 nGy h^{-1}, which is about 2 orders of magnitude below a typical natural ground-level dose.

We have developed an automated high-volume aerosol sampling station for environmental radiation monitoring. The filters are automatically changed, prepared and analysed and manual operation of the station is only occasionally needed. The station, on the roof of STUK headquarters, is equipped with instruments that enable real-time radiation monitoring and alarm, weather monitoring and comprehensive remote monitoring of the station and the data. The station also has an electrically cooled gamma-ray spectrometer and an automated data analysis system. The duty cycle of the station is 1 d sampling, 1 d decay, 1 d counting. Typical detection limits are 1 - 10 μBq m^{-3}. It is possible to minimise the detection limit by selecting optimum decay and counting times. The station automatically reports the monitoring results on the STUK www-pages. The station is a prototype version of those that will be used in the CTBT/IMS monitoring system; a commercial version produced by a Finnish company already exists.

Mobile radiation monitoring and field measurement techniques

An advanced mobile laboratory for environmental radiation monitoring was designed and manufactured by the Airborne Radioactivity Laboratory in the mid '90s. The vehicle is equipped with a gamma-ray spectrometer and dose rate meters and a satellite navigation system. It also has a telecommunication system that allows radiation measurement data and positioning data to be sent to headquarters. The laboratory has an aerosol sampling system as well as radiation meters. It is able to perform air sampling and total beta and/or gamma ray analysis, gamma-ray analyses for environmental samples, in-situ gammaspectrometry for plume and fallout and dose rate measurements while moving.

The vehicle has been built mainly for emergency situations but it can also be used for other applications. The mobile laboratory was successfully used in the Nordic RESUME95 exercise, which was organised in Finland mainly by the Airborne Radioactivity Laboratory. It was also used in the international INEX-2-FIN exercise, in which several hundred coordinate-labelled dose-rate measurements and several gammaspectrometric analyses were performed in the field. Our team also participated in a Nordic exercise organised in Gävle, Sweden, in 1999.

For mobile radiation monitoring patrols and in-field measurements in general, it is often necessary to combine location information and measurements. In addition, wireless real-time data transfer is needed to map radiation levels at locations not covered by fixed stations. Software known as SAHTI has been developed for this application, and is used by the advanced measuring vehicle. SAHTI is also used at two central fire and rescue stations where the system is fitted into cars used by local rescue officers. It was used successfully to search for radioactive sources in Estonia. SAHTI has turned out to be a useful tool in emergency preparedness and is able to produce reliable measurements immediately after an accident.

The Airborne Radioactivity Laboratory contributes actively to the Finnish programme of safeguards support to the IAEA by providing expert services and research. One of the areas in focus is field measurement techniques, where we have specifically studied the feasibility of different radiation measurement systems. Special emphasis is put on the combination of radiation measurements, data acquisition, satellite navigation, and desktop mapping and wireless data transfer. The use of dose-rate meters, low- and high-resolution gamma-ray spectrometers, beta counting, autoradiography and X-ray fluorescence spectrometry have been investigated and found to be suitable for monitoring in the field.

Radioactive particles in a nuclear accident

The Airborne Radioactivity Laboratory has a programme for estimating the hazards related to radioactive 'hot' particles that may be released in a nuclear accident. The programme is focuses on the release and characteristics of radioactive particles, their transport in air, particle detection and possible radiation threats. The scientific highlights of the programme are as follows:

- The existence of radioactive particles cannot be considered unique to the Chernobyl accident. Their presence in the environment was also identified in earlier nuclear accidents.
- The characteristics of radioactive particles reflect the properties of the source material. Although complicated physical and chemical phenomena during the release may affect particle characteristics, it is possible to calculate the properties of individual particles in certain cases. These calculations are needed for a complete risk assessment of the particles.
- In a severe nuclear accident, large (aerodynamic diameter more than 20 µm) and highly radioactive particles (activity more than 100 Bq) may be transported hundreds of kilometres in air before deposition. The transport of radioactive particles differs from that of gaseous species. Air parcel trajectories are not necessarily sufficient to identify the areas that may receive radioactive materials.
- In the Chernobyl accident, the effective release height may have been considerably higher than reported previously (up to 2 km) or particles may have been lifted up to higher altitudes in deep convective cells.
- The composition of the particles has a crucial influence on the radiological hazard. The presence of short-lived nuclides in particles emitted from low burn-up fuel in particular, contributes substantially to skin beta dose rates. The contribution of gamma rays is negligible.
- The specific activity of 'monoelemental' particles, such as Ru particles, found in the environment after the Chernobyl accident may be higher

than those composed mainly (in terms of mass) of bulk U by a factor of about 100. Ru particles are almost entirely composed of fission products.

- Unlike particles composed mainly of bulk U, the volumetric activity of Ru particles emitted from low burn-up fuel may be much higher than that emitted from high burn-up fuel. Thus, the radiological risks from particles originating from high burn-up fuel are not necessarily the greatest.
- Even individual particles may represent a radiological hazard. When deposited on the skin, they may produce a basal cell beta dose that rapidly exceeds the ICRP annual dose limit for the public (50 mSv averaged over 1 cm^2 at a depth of 70 µm). If a Ru particle larger than 8 µm in diameter is deposited onto skin this dose may be exceeded in one hour. For U particles, the dose refers to an aerodynamic diameter of about 30 µm.

In a severe nuclear accident, highly radioactive particles may thus be a potential health hazard even far from the source. The radiological risks differ from those in a uniform exposure. Even if their numerical concentration is low, it is possible that some people may receive a hot particle deposited, for example, on the skin. Neglecting the particulate nature of the release plume may lead to underestimation of the significance of hot particles.

In 1997-1999 the Airborne Radioactivity Laboratory took part in the research project known as RAFF, supported financially from by the European Commission. The release of radionuclides from overheated uranium fuel, properties of fuel particles and their behaviour in the environment were studied. Our contribution was to develop and supplement computer codes for calculating particle characteristics and transport in air, and to identify the radiation threats. Experimental methods were also developed in order to characterise the particle properties. One of the main highlights of the programme was the finding that the release of radioactive particles can be demonstrated even using a small-scale facility. In 1998 we organised a workshop on the scientific issues related to the RAFF project.

Development of laboratory assay techniques

In traditional laboratory analyses the radioactive species are almost always considered as 'becquerels', more or less evenly distributed in a sample. Present thinking in radiation safety assessment, monitoring and analysis does not properly take into account the particulate nature of radioactive releases. Since radiological hazard is determined by the presence of radioactive material in the particles, it is of utmost importance to characterise particles thoroughly.

A range of assay methods is needed for the complete characterisation of radioactive particles. The information that can be obtained by analysing the particles depends on the method of analysis. Information collected from inactive parts of the particle may be as valuable as that collected from active parts. Together, they may provide valuable data, e.g. about the origin of the particles. This information may be extremely useful in certain safeguards applications, for example. Radioactive particles isolated from an environmental or swipe sample may function like a fingerprint, e.g. in tracing secret nuclear programmes or other illegal activities.

The Airborne Radioactivity Laboratory started research analysing individual radioactive particles in 1997. One of the main objectives was to find new methods that would supplement conventional analyses based on radiation detection. These 'new' methods are including electron microscopy and mass spectrometry. Another goal is to define systematic laboratory procedures for particle analysis. The advantage of identifying of radioactive particles in a bulk sample and isolating/analysing them subsequently in a laboratory makes it possible to achieve results that are otherwise inaccessible owing to the interference of non-relevant bulk particles. The phases of a particle analysis are:

1. Identification of the possible presence of individual radioactive particles in a sample.
2. Isolation and separation of the radioactive particles from a sample that may contain billions of uninteresting inactive background particles.
3. Analysis of particle characteristics using different laboratory methods.
4. Interpretation of the analysis results and comparison with calculated particle properties.

The experience on particle analysis revealed that radioactive particles should not be necessarily considered as 'becquerels' distributed homogeneously in the sample. Routinely used laboratory procedures are not appropriate for particle analyses. Several complementary (experimental and calculative) methods are needed to achieve complete characterisation of radioactive particles. Different analysis methods have also been tested on bulk samples. In the framework of the FINUVE organisation, the Airborne Radioactivity Laboratory is able to assist the IAEA in various technical and analytical issues.

2.6.6 Plans for research and technical development in the next five years

At present, the emphasis in research and technical development is on developing the tools needed for emergency preparedness and monitoring, studies related to behaviour of airborne radioactive material and development of laboratory analysis techniques. The laboratory strives to make full use of the potential of modern technology to develop real-time radiation monitoring systems and other tools to support emergency preparedness. The areas of research and technical development to be highlighted in the next five years are:

- The results of the SILAM and VALMA calculations will be integrated to STUK decision-making process to facilitate rapid and timely countermeasures in a nuclear accident. SILAM is a modern tool developed by the Finnish Meteorological Institute to estimate real-time atmospheric transport and dispersion of radioactive material. The Technical Research Centre of Finland recently developed a tool known as VALMA for rapid transport and dose calculations using either SILAM particle files or a simple Gaussian model.
- Utilisation of modern (wireless) data communication systems in environmental radiation monitoring. Development of www-based technologies for presenting the monitoring data. This will ensure extensive real-time dissemination of the data and facilitate timely decision-making.
- Utilisation of modern radiation measurement systems in environmental radiation monitoring. Some of the fixed stations for monitoring airborne radioactive materials are to be equipped with detectors that allow remote on-line radionuclide identification. This will enable fast concentration-based protective action in a radiation situation.

- Evaluation of recent developments in monitoring noble gases and, possibly, launching such monitoring.
- Development of mobile and field radiation monitoring techniques. Special emphasis will be put on the strategy of surveillance, which will be re-evaluated. The possibility of making mobile real-time measurements in a nuclear accident is of vital importance in estimating the level of contamination, especially in areas where no fixed monitoring systems exist. A new mobile laboratory for emergency preparedness and environmental monitoring will be constructed.
- Development of radiation surveillance using unmanned aerial vehicles.
- Studies related to the behaviour of radioactive aerosols. This is a research area that combines two well-known branches of physics - aerosol physics and radiation physics. It will also produce basic data for estimating the hazards caused by radioactive aerosol particles. In addition, development of laboratory analysis techniques will benefit.
- Research on laboratory techniques for analysing radioactive particles present in environmental samples. These techniques can be used to estimate the origin, time of release and possible formation and transport mechanisms of the particles.

The STUK research projects for the period 2000-2002 are described in detail in the STUK-A179 report (Salomaa 2000). A list of the projects to be carried out by the Airborne Radioactivity Laboratory is given below.

- Analysis of fission-bomb particles detected in marine sediments in Thule
- Radiation surveillance by unmanned aerial vehicle

2.7 Regional Laboratory in Northern Finland

2.7.1 Key words and specific technologies

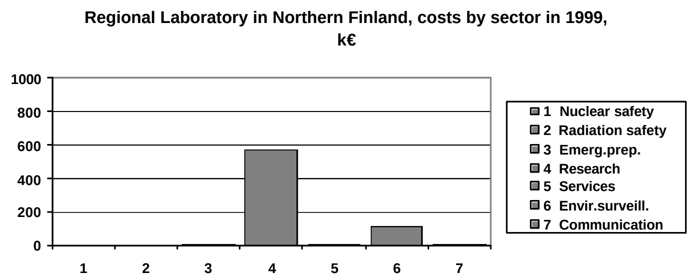
Key words

Environmental radioactivity in northern Finland, terrestrial radioecology, arctic and subarctic foodchains, monitoring of foodstuffs produced in northern Finland, radioactivity in Russian arctic sea areas, emergency preparedness, quality assurance

Specific technologies

Low-level gamma spectrometry, alpha spectrometry, beta spectrometry, radiochemical methods, environmental sampling methods, surveillance of airborne radioactive material and fallout in Finnish Lapland, nation-wide external dose rate monitoring USVA

2.7.2 Description of laboratory activities



STUK's Regional Laboratory in Northern Finland covers the northern half of Finland, that is the two northernmost provinces of Lapland and Oulu. The goal of the laboratory’s research is to study the transport and accumulation of radionuclides in arctic and subarctic food chains, and in locally produced foodstuffs. The laboratory has several permanent sampling areas and an extensive network of research institutes, laboratories, authorities, enterprises, private persons, etc. that co-operate in collecting samples and information in northern Finland.

The Regional Laboratory in Northern Finland is especially designed for emergency situations. The 635 m^2 laboratory is located 18 metres underground and it is equipped with EMP shield, filters, aggregates, etc.

The laboratory contributes to nation-wide radiation monitoring in Finland by analysing airborne and fallout radioactive substances sampled at three locations in Finnish Lapland, and it also has access to the USVA radiation monitoring information system. Most of the laboratory's other operations also support emergency preparedness.

Since 1993 radioecological research has been expanded to the arctic sea areas and shores of NW Russia. In 1993-1997 the laboratory participated in four sampling expeditions in Russian arctic seas (Barents Sea, Pechora Sea, Kara Sea, White Sea and Kola Bay) and in several terrestrial sampling projects on the Kola Peninsula. The laboratory's sample bank today contains 1700 samples from NW Russia.

The laboratory has participated in several international research projects financed by the EC, the Ministry for Foreign Affairs, by Ministry of the Environment and Nordic Nuclear Safety Research (NKS).

It has co-operated in research projects with several research institutes in Europe, Russia and the USA, presented research results in several international meetings and published results in national and international scientific journals and reports.

2.7.3 Personnel

STUK's Regional Laboratory in Northern Finland was established in 1970 at premises of the Agricultural Research Station of Lapland. At that time, it had a staff of two persons. Since then, the number of posts has gradually increased, partly as a consequence of the Chernobyl accident.

Today, the number of permanent posts is eight:

Kristina Rissanen, MSc (radiochemistry), head of laboratory, senior scientist
management, terrestrial radioecology in northern Finland, transport and accumulation of radionuclides in arctic and subarctic foodchains, especially

the foodchain lichen - reindeer - man, radioactivity concentrations in locally produced foodstuffs, diet of the Sami population, gammanuclide and plutonium concentrations in Russian arctic sea areas and Kola Peninsula, environmental sampling and field studies, quality assurance at the laboratory, ^{90}Sr analyses

Jarkko Ylipieti, laboratory engineer
land surveyor, data processing, MapInfo maps and their use in representing analysis results, development and maintenance of GPS databases of samples and analysis of results, gammaspectrometric measurements and maintenance of aerosol and fallout sampling

Pertti Niskala, student at Oulu University (physics), assistant researcher
gammaspectrometric measurement and calibration, airborne radioactivity, nation-wide external dose-rate monitoring system, mobile radiation measurement, quality assurance of gamma measurement in Rovaniemi

Marko Junttila, student at Oulu University (chemistry), senior laboratory assistant
radiochemical plutonium analyses, quality assurance of plutonium analyses in Rovaniemi, quality assurance of laboratory equipment

Tuula Virtanen, laboratory operator
radiochemical analyses

Hannele Koukkula, laboratory operator
pre-treatment of samples, radiochemical ^{90}Sr analyses

Eva Palosaari, laboratory operator
radiochemical plutonium analyses, maintenance of the sample bank

2.7.4 Aims of research

Population groups living in arctic and subarctic regions are more vulnerable to accidental releases of radionuclides due to their higher dependence on natural and seminatural foodstuffs, e.g. reindeer and wild food, than most people in temperate areas. The radionuclide transfer factors are higher for these special arctic foodchains and in this nutrient-deficient environment.

The aims of the research carried out at the Regional Laboratory in Northern Finland are:

- to increase knowledge about radioecological processes in arctic environments in order to improve dose assessments and emergency preparedness
- to develop practical countermeasures against radioactive contamination of arctic foodchains, e.g. reindeer
- to improve the preparedness in northern Finland by collecting the data on local food production and consumption necessary in an emergency situation
- The aim of joint EC projects in Russian arctic sea areas is to further develop a model which predicts the behaviour and fate of radionuclides in estuarine and marine environments, and which also includes modelling the transfer of radionuclides to marine biota in an accident situation.

2.7.5 Progress report on research over the last five years

The arctic foodchain: lichen - reindeer - man

The arctic foodchain lichen-reindeer-man accumulates radiocaesium most intensively in a fallout situation. The effects of the Chernobyl accident were minimal in northern Finland, because the fallout only affected the very southernmost redieer herding areas. However, ^{137}Cs and ^{134}Cs concentrations in lichen and reindeer have been monitored regularly in the Finnish reindeer herding area ever since the 60´s, due to the global fallout caused by the atmospheric nuclear tests. Today, the average ^{137}Cs concentrations in reindeer meat, 200 Bq/kg, is lower than before the Chernobyl accident, when it was 300 Bq/kg. There is a distinct difference in the rate of decrease between overgrazed areas and areas where lichen is still available. High concentrations around 4500 Bq/kg have still been measured in wild reindeer shot in Perho, Ostrobothnia, where the Chernobyl fallout was 10-20 times higher than in Lapland and there are only a few animals grazing on almost intact lichen fields.

Locally produced foodstuffs

Radiocesium concentrations are also monitored regularly in freshwater fish, farm milk, mushrooms, wild berries and garden vegetables, and sporadically in game. ^{137}Cs concentrations have now fallen to pre-Chernobyl levels. Consumption of these basic foodstuffs used to be estimated by interviewing the Sami families reporting for to wholebody counting. The Sami population whole body measurements were discontinued in 1997.

Russian Arctic Seas 1993-1996 (EC projects ARMARA and ARCTICMAR)

The surface sediments analysed by STUK cover a large part of the Russian arctic seas: from the White Sea to the Yenisey estuary in the Kara Sea, from the sea area between Svalbard and Franz Joseph Land to the Laptev Sea. The $^{238}Pu/^{239,240}Pu$ ratios in the Barents, Pechora, Kara and White Sea suggest that global fallout is the main source of plutonium. Concentrations of antropogenic gamma radionuclides were very low, and higher ^{137}Cs concentrations and $^{137}Cs/^{239,240}Pu$ ratios were noted only in the estuary sediments of the Dvina and Yenisey rivers, indicating an excess input of radiocesium via riverine transport from the large catchment areas of these rivers. Fresh ^{60}Co contamination was detected to the northeast of Kolguev Island near a dumping site in the Pechora Sea and in algae in the Kola Bay.

Kola Bay 1995, plutonium and cobalt release

^{137}Cs concentrations in the Kola Bay do not differ from those in the Barents Sea. Small amounts of the corrosion product ^{60}Co were detected in all the sediment samples between Atomflot, a civilian nuclear icebreaker base, and the Barents Sea, and in algae samples outside the Nerpa shipyard and in algae resembling dead coral in sediment layers along the Polarnyi transect.

The high $^{238}Pu/^{239,240}Pu$ ratios (0.10 - 0.18) in sediment layers outside and to the south of Atomflot indicate a certain amount of fresh release from the nuclear icebreaker facility or from the storage vessels located off it. Certain large greenish ^{137}Cs particles were identified as flakes of paint, probably originating from the radioactive waste storage vessels lying off Atomflot. According to Russian colleagues, loose paint flakes are hosed off into the bay before the rusting vessels are repainted. Because these paint flakes contaminated with ^{137}Cs were found in the same sediment layers as the most elevated plutonium isotope ratios, the probable source of the fresh release is the storage vessels, not Atomflot.

Bioconcentration factors in arctic sea biota

Thanks to STUK co-operation with the Murmansk Marine Biological Institute, a large collection of biota samples were obtained in 1993-1996. Gammanuclide concentrations were determined in 250 benthic fauna samples, in the most common fish species, in sea birds and in seal pups. In all the biota samples the ^{137}Cs concentrations were very low, below the detection limit 0.3 Bq/kg f.w. in half of the benthic fauna samples. The bioconcentration factors for ^{137}Cs usually varied from 20 to 100. Higher concentrations and bioconcentration factors were found in *Sipunculida*, *Nephthys* and tubes of *Polychaeta* species, all of which belong to the phylum *Annelida*.

Higher concentration factors were determined for ^{239,240}Pu, usually in the shells of molluscs; e.g. *Mytilus edulis* in Ostrov Nokuyav, CF 1360. On the other hand, CF 1340 was calculated for the soft parts of the filter feeder bivalvia *Tridonta borealis*, CF 1750 in the carnivore hermit crab *Pagurus pubescens* and CF 980 in the filtrate feeder sea cucumber *Cucumana frondza*, all sampled at the Pechora Sea. The highest bioconcentration factors for ^{239,240}Pu (2770+/-560) were found in the carnivore *Ophiuroidea* brittle star *Stegifiura nodosa*, collected in the Pechora Sea. In dissected starfish from the Kola Bay, plutonium was found to be concentrated in the body wall.

Arctic and Baltic salmon

As research to support the Russian arctic sea projects, ^{137}Cs concentrations have been analysed in two salmon populations: salmon caught in the River Teno, which drains into the Norwegian Sea, and salmon caught in the Rivers Tornionjoki, Kemijoki and Simojoki, which drain into the northern part of the Gulf of Bothnia, which is a part of the Baltic Sea. In salmon originating from the Baltic Sea the ^{137}Cs concentrations are one hundred times higher than in Teno salmon originating from the Arctic Ocean. In the River Teno, ^{137}Cs concentrations decreased from 1988 to 1998 with a 6-year biological half-life. There was no correlation between the cesium concentration and the age, weight or sex of the fish. There was no difference in the ^{90}Sr and ^{239,240}Pu concentrations in the bones or flesh of these two salmon populations.

The hundred times higher ^{137}Cs concentrations, about 30 Bq/kg in 1998, in the salmon originating from the Baltic compared with the Arctic salmon are a result of several factors: during the '60s and especially after the Chernobyl accident, several Finnish and Swedish rivers transported fallout radionuclides from large catchment areas into the Baltic Sea, which has a small water mass and low salinity compared with arctic seas.

^{137}Cs concentrations were low in all arctic sea fish, sea bird and seal pup samples, and $^{239,240}Pu$ concentrations were usually below the detection level. Detailed analysis results for the biota are presented in the STUK ARMARA project report, which will be published later.

2.7.6 Research plans for the next five years

The following list consists of research projects in progress or to begin during 2000. The projects are described in more detail in STUK-A179 report (Salomaa 2000).

- The ARCTICMAR EC project will continue until September 2001
- Partnership in EC project "Fasset - Framework for Assessment of Environmental Impact", in 2000 - 2003
- The AMAP phase 2, Trends and Effects Programme will continue until 2003, i.e. both the International Radioactivity Expert Group and the National Implemention Plan
- Mushrooms and soil samples from the Kivalo research area of the Finnish Forest Research Institute 2000 - 2001
- Countermeasures for reindeer in a fallout situation, jointly with the Reindeer Research Station of the Finnish Game and Fisheries Research Institute. Wholebody counting of living reindeer 2000 - 2002
- Wild reindeer in Perho and Kuhmo, joint project with the local game management area. Linked to the Fasset project 2000 - 2003
- A salmon project jointly with the River Teno Fisheries Research Station/Utsjoki and with the Botnian Bay Fisheries Research Station, Simo 2000 - 2003
- Seals from the Svalbard and Greenland area, joint project with the AkvaPlan Niva, Tromsø 2000 - 2002.

2.8 Medical Radiation

2.8.1 Key words and specific technologies

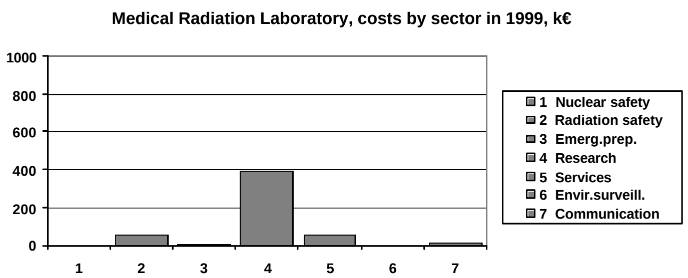
Key words

Ionising radiation, radiation protection, diagnostic x-ray imaging, quality assurance, optimisation, patient dose, image quality, radiation risk, performance of x-ray units, education, training, standardisation.

Specific technologies

X-ray dosimetry and spectrometry, patient dose estimation, radiation risk estimation, visual assessment of image quality, objective assessment of fluoroscopic image quality, performance measurements.

2.8.2 Description of laboratory activities



Research

The laboratory is responsible for research on radiation protection in medical radiology. For this purpose it has:

- participated in European research projects financed by the EC,
- participated in national research projects
- co-operated in research projects with research institutes in Europe and the USA
- developed methods for quality assurance (QA) and performance measurements

- developed computer programs for patient dose and radiation risk assessment
- developed theory and methods for measuring the objective image quality of fluoroscopic images
- studied the optimisation of x-ray imaging (image quality and dose) theoretically and experimentally.

Education and training

The laboratory has given the following education and training in radiation protection and quality assurance in diagnostic radiology:

- courses for the radiological personnel of hospitals, institutes and companies in Finland
- courses in Estonia
- lectures in international courses financed by the IAEA and EC
- lectures for radiography students in the social and health care units of polytechnics
- special courses in patient dose determination for specified groups
- supervision of a doctoral thesis and of several M.Sc theses in Finland and Estonia
- participation in the STUK project of writing a book on radiation protection.

The European Medical Exposure Directive (MED) faces the medical use of radiation with many new functions, specifically quality assurance, patient dose measurement, staff education and training, and clinical audits. The laboratory has organised courses on radiation protection and quality assurance for some ten years now. The radiation protection legislation and official requirements, QA guides, patient dose and radiation risk, performance of equipment, optimisation of imaging techniques and QA at hospitals are among the subjects lectured on at courses. The annual number of participants has been about 100-200 from various hospitals, polytechnics and companies. The lectures have been printed as STUK reports and distributed to the participants.

Standardisation

The laboratory has participated or been involved in:

- the standardisation work of the IEC subcommittee 62 B (Medical Imaging Equipment), in working groups and the National Committee,
- the ICRU working group 'Mammography - assessment of image quality'
- preparation of the rules and guidance issued by STUK for diagnostic radiology.

Expert services

The experience that the laboratory has gained in research work, QA and performance measurements can be utilised in specific areas where no other national resources are available. The laboratory has provided expert services in diagnostic radiology for:

- QA measurements for x-ray units
- acceptance tests for x-ray units
- calibration of radiation monitors and x-ray tube voltage measurement devices
- assessment of the shielding of x-ray examination rooms
- attenuation measurements of protective materials
- dose and risk assessment for exposed pregnant women
- inspections of the radiation protection and QA in x-ray departments.

2.8.3 Personnel

Antti Servomaa, PhD (physics), Docent, head of laboratory
patient dose and radiation risk, quality assurance, optimisation, education and training

Matti Toivonen, PhD (physics), senior scientist
metrology, dosimetric methods: TLD, BNCT dosimetry, patient dose assessment, optimisation studies on x-ray examinations, member of the editorial board of Radiation Protection Dosimetry (since 1998)

Markku Tapiovaara, MSc (physics), senior scientist
theory of imaging physics, optimisation of imaging techniques, patient dose assessment, performance of x-ray units, expert services, standardisation

Tuomo Komppa, LicPhil (physics), senior scientist
dosimetry in diagnostic radiology and radiotherapy, patient dose assessment, radiation risk assessment, standardisation

Juhani Karppinen, MSc (physics), scientist
performance and QA measurements of CT, fluoroscopy and digital imaging units, expert services, inspections of radiological units in hospitals, patient dose measurements

Teuvo Parviainen, senior radiographer, inspector
radiation protection and QA measurements of radiological units, education and training in radiation protection, expert services, inspections of radiological units at hospitals, patient dose measurements

2.8.4 Aims of research

The laboratory's current research focuses mainly on matters stressed in the European Medical Exposure Directive (MED) 97/43/Euratom:

- optimisation of x-ray examination techniques, including objective assessment of image quality
- examinations with high patient doses (CT, fluoroscopic procedures)
- the most radiosensitive patients (paediatric patients)
- symptomless patients exposed to ionising radiation (mammography screening)
- performance of new imaging techniques (digital imaging)
- assessment of patient dose and radiation risk.

Research results are utilised in QA measurements and guides, in inspections and in expert services.

2.8.5 Progress report on research over the last five years

Relationship between objective and visual image quality in fluoroscopy

Image quality is the factor limiting patient dose reduction in diagnostic radiology. Therefore, in order to be able to work at as low doses as possible, methods for assessing image quality are necessary. Most commonly, assessment is based on subjective visual observation of test images, a methodology which suffers from inaccuracy, variability of results, and other problems.

We had already developed a system for measuring of the objective quality of fluoroscopic images (Phys. Med. Biol. 38, 71-92 (1993), Phys. Med. Biol. 38, 1761-1788 (1993) and Phys. Med. Biol. 40, 589-607 (1995)). This method is based on statistical decision theory, and measures the actual information content in the real-time fluoroscopic image, within the context of a specified detection task. The measurement is made from the video signal of the x-ray equipment, using a PC and a frame grabber board. The result of the measurement is expressed as the square of the ideal observer's signal-to-noise-ratio, SNR^2, in an image sequence of a given length, or as the accumulating rate of the SNR^2. Although it was known that these measures depict the objective quality of the image data, it was not known how far the results would correspond to the amount of information that could be extracted by a human observer of the images.

In this study, the ability of humans to visually detect static low-contrast objects in the dynamic fluoroscopic image was assessed. Human performance was measured using the two-alternative-forced-choice method. From the measurements, we obtained the human observer's SNR at the decision level, thus allowing human efficiency in utilising information to be calculated.

Human performance was seen to improve along with the SNR of the ideal observer, i.e. when the thickness of the test detail was increased, when the image noise was lowered, and when the length of the image sequence duration was increased. However, the *efficiency* of human observers decreased slowly when the image sequence duration increased. The slowness of this decrease was a surprise; we had expected the efficiency to decrease rapidly when the length of the image sequence exceeded the time scale of visual temporal averaging (a few tenths of a second). The efficiency of human observers was found to be 30–40% when the image data were displayed with a high display contrast, and 15–25% when the image data were displayed at the lower display contrast typical of clinical settings. These data show that humans can extract information in dynamic images (lasting a few seconds) with an efficiency that is close to their efficiency in observing static images.

The ideal observer's SNR^2 in the image sequence was seen to be closely connected to the performance of human observers. Measurements of the accumulating rate of the ideal observer's SNR^2 can therefore well be used to assess image quality in fluoroscopy. Consequently, meaningful, accurate, reproducible and objective results of image quality can be obtained. Such measurement methods and data are needed, e.g., in optimisation studies and quality assurance for fluoroscopy. (Tapiovaara 1997)

Optimisation of imaging techniques in paediatric fluoroscopic examinations

Patient dose and image quality were studied in paediatric fluoroscopy. The study comprised two parts: theoretical calculation of optimal imaging conditions and clinical measurements of dose rate and SNR^2_{rate} at six hospitals.

In collaboration with Linköping University and the Royal Marsden NHS Trust, we studied optimal examination techniques in paediatric fluoroscopy using Monte Carlo computational methods. The results were ascertained experimentally by using a PC-based image quality measurement system. This was used to measure the detectability of iodine contrast material details in fluoroscopic images of phantoms of differing sizes. Contrary to common belief, the patient dose rate could be decreased without compromising image quality when the x-ray tube voltage was adjusted to a value lower than usual, the x-ray beam was heavily filtered, and an antiscatter grid was added to the system (except for the smallest patient size, corresponding to newborn). The paper describing this work in was highlighted in a special commentary article Physics in Medicine and Biology and was also put on the journal's free web pages.

In addition to the above-mentioned calculations and laboratory measurements, further dose and image quality measurements were made at all the three Finnish university hospitals that have specialised x-ray departments for paediatric radiology, and at one university hospital where the same equipment is used for examining both adults and children. Measurements were also made at specialised children's hospitals in Munich and London. In the measurements, it was found that, the doses could be decreased by 35% on average without impairing image quality. It was also noted that the dose and image quality levels at the Finnish hospitals were much higher than at the reference hospitals abroad: if the Finnish hospitals were content with these hospitals' image quality hospitals, their dose rates could in principle be decreased by a factor of 3-6, depending on patient size. During the project, this was tried at two Finnish hospitals. According to their radiologists, image quality remained sufficiently good for examination purposes, even though dose rates were decreased by 30–80%, depending on the hospital and patient size. Technical limitations in the x-ray equipment reduced the dose savings to somewhat less than could be expected from theoretical reasoning. The paper describing these measurements is currently being published in Radiation Protection Dosimetry. The results have also influenced the technical recommendations in the present draft EC quality criteria for paediatric fluoroscopy. (Tapiovaara et al. 1999, Tapiovaara et al. 2000)

Annual frequencies of x-ray examinations for adult and paediatric patients

A survey of the annual (1995) frequencies and practices of radiological examinations among paediatric and adult patients was carried out at all radiological clinics in Finland. The total number of x-ray examinations was 4.2 million, which makes 0.83 examinations per head of population. The number of paediatric x-ray examinations was 351 000, making 0.34 examinations per person in the population under 16 years of age. The annual frequencies, types and practices of paediatric and adult x-ray examinations in Finland were studied in detail. The results give a general picture of the distribution of all examinations between various hospital types, examination types and age groups. Combined with patient dose assessment, they can be utilised in detailed assessment of collective radiation doses from x-ray examinations, and for focusing optimisation work effectively. The project was financed by the EC. (Articles in STUK-A152, STUK-A163)

Patient dose measurements for paediatric radiographic, fluoroscopic and CT examinations

Patient doses in paediatric radiographic, fluoroscopic and CT examinations were measured at selected university hospitals and other central hospitals in Finland. The purpose was to collect supplementary data for the development of reference doses and dosimetry for various ages and sizes of

paediatric patient. The European MED directive states that patient doses must be determined regularly and compared with reference doses. The results of the project provide basic data for the establishment of national reference dose levels. They can also be used for the assessment of collective doses and radiation risks. The project was financed by the EC.
For paediatric radiographic examinations, the dose-area product (DAP) was measured for each radiographic projection separately, and the entrance surface dose (ESD) was calculated. The measurements were made at four university hospitals, and the total number of projections was about 900. For paediatric fluoroscopic examinations, the dose-area products were measured at three university hospitals, and the number of patients was 217. A fluoroscopic examination typically involves both fluoroscopy and radiographic imaging.

Computed tomography (CT) is used less frequently on children than on adults, but it still comprised about 2.5% of all paediatric x-ray examinations in 1995 in Finland. Data on clinical CT practice were gathered by means of a questionnaire over two months at six central hospitals. Both helical CT and conventional axial CT examinations were included. The total number of CT examinations in the survey was 114 among paediatric patients, and 228 among adult patients. The paediatric CT examinations comprised head, abdomen, spine, lung and pelvis examinations. Examinations of the head were the most common paediatric CT examinations. (Servomaa et al. 2000, articles in STUK-A152, STUK-A163, STUK-A174)

Nordic patient reference doses in adult x-ray examinations

The Medical Exposure Directive (97/43/Euratom) requires national patient dose reference levels to be established for medical exposures. Within the framework of Nordic radiation protection co-operation the task group “X-ray Diagnostics” has collected dose-area products for five conventional examination types in the Nordic countries. The results show that the examination techniques are rather similar in the five Nordic countries, where the dose-area products were measured at 143 hospitals or laboratories. Combining the results from various countries increases the statistical reliability of the data. The Nordic recommendations for patient dose reference levels will be published in European Radiology. They are also being utilised in issuing European recommendations. (Gron et al. 2000, Saxebøl et al. 1998, Saxebøl et al. 1996)

PCXMC - A PC-based Monte Carlo program for calculating patient doses in x-ray examinations

In medical radiology, the air kerma at the patient entrance surface (ESD) and the kerma-area product (DAP) in the X-ray beam are common patient dose descriptors that can be readily measured. However, they are not sufficient for evaluating the radiation risk from the X-ray examination or for comparing the radiation detriment from different examinations. Therefore, methods are needed for the calculation of conversion factors from ESD or DAP to the effective dose and doses in various organs. We have developed a PC program (PCXMC) that is capable of providing such data.

PCXMC is a Monte Carlo program for calculating patients' organ doses and the effective dose in medical x-ray examinations. The anatomical data of the human-mimicking phantoms in the program are based on the mathematical hermaphrodite phantom models of Cristy (1980), which describe patients of six different ages: new-born, 1, 5, 10, 15-year-old and adult patients. Furthermore, the phantoms are adjustable to mimic patients of an arbitrary weight and height. PCXMC also allows free adjustment of the x-ray projection and other examination conditions of projection radiography and fluoroscopy. All organ doses calculated by PCXMC relate to the patient entrance air kerma (mGy, free-in-air, without backscatter) at the point where the central axis of the x-ray beam enters the patient. The user must supply the program with this datum or the dose-area product.

Monte Carlo calculation of x-radiation transport is based on stochastic mathematical simulation of the interactions between photons and matter. This simulation has been formulated in PCXMC in a standard manner. Photons are emitted (in a fictitious mathematical sense) isotropically from a point source into the solid angle specified by the focal distance and the x-ray field dimensions, and monitored while they interact with the phantom according to the probability distributions of the physical processes that they may undergo: photo-electric absorption, coherent (Rayleigh) scattering or incoherent (Compton) scattering. PCXMC does not consider any other interactions, because the maximum photon energy is limited to 150 keV. A large number of individual photon histories is generated, and estimates of the mean values of energy depositions in the various organs of the phantom are used for calculating the doses in these organs.

The program runs in a PC under Windows 95/98/NT. The Monte Carlo simulation time depends on the accuracy required and on the speed of the PC, but typically takes only a few minutes in a PC with a 200 MHz Pentium processor.

The data calculated by PCXMC have been compared with the organ dose conversion factors calculated in NRPB by Jones and Wall (1985) and Hart et al. (1994, 1996). In general, the agreement between the results of PCXMC and NRPB is good, and the differences between them typically fall within the statistical error that arises from the finite amount of photons simulated.

PCXMC is available to other users too. So far, about 50 programs have been sold worldwide. Web pages describing the program are available at the Internet address http://www.stuk.fi/pcxmc/. (Tapiovaara et al. 1997, Servomaa et al. 1998)

Radiation risk assessment for patients of various ages

A radiation risk assessment system, based on the modified relative risk model published in the BEIR V report (1990), has been coded in a PC program, together with Finnish demographic and cancer statistics. The program can be used to calculate lifetime risk estimates, such as the *risk of exposure-induced death* and the *loss of life expectancy*, when the radiation doses to specified organs and organ groups are known. The risk estimates are calculated as a function of the age at exposure, and an average risk to the exposed population is calculated according to age distribution. The program has been used to estimate the risks to patient from various X-ray examinations, and also the risks from Chernobyl fallout in Finland. (Servomaa et al. 1995, Komppa et al. 1996, Karppinen et al. 1995, articles in STUK-A152, STUK-A163)

Calculation of shielding in x-ray department

The new occupational dose limits have set new requirements for the shielding of operating rooms in x-ray departments. Earlier methods were based on the use of the maximum exposure values to assess shielding of the examination room. A PC-based calculation method has been developed for assessing shielding requirements for diagnostic x-ray rooms. It takes into account the real examination frequency, exposure parameters, projections and leakage radiation from the x-ray tube housing. The program has been utilised to assess the shielding requirements for diagnostic examination rooms in hospitals. (Karppinen 1997)

Development of boron neutron capture therapy (BNCT) dosimetry with TL dosemeters

The aim of the project was to develop and verify a method suited to characterisation of the mixed neutron and gamma radiation beam and measurement of patient doses in vivo using detectors which do not perturb the radiation field significantly and which can be calibrated directly against standards of dosimetric quantities.

A sandwiched thermoluminescent dosemeter (TL dosemeter) with a thin active layer of active ^{6}LiF:Mg,Ti material on a passive basis was selected for neutron detection and a ^{7}LiF:Mg,Cu,P detector for gamma detection because of its special microdosimetric characteristics (sensitivity inversely proportional to the ionisation density of radiation). These detectors were calibrated against the air kerma (gamma radiation) and neutron fluence (activation of gold) standards. Algorithms were then derived for the separation of neutron and gamma induced signals from both detectors. Calculated kerma factors were used for the conversion between neutron fluence and the absorbed dose of neutron radiation just as in dosimetry with gold sheets. In gamma dosimetry, the above-mentioned goals were achieved completely, and some characteristics of the TL dosemeters exceed the corresponding characteristics of gold sheets (better local resolution and smaller perturbation of neutron field). For these reasons, and because independent gamma dose measurement on a patient *in vivo* was thus made possible for the first time. The method has since been adopted at several BNCT facilities. The method and the studies made during its development have been published. (Aschan et al. 1999a, Aschan et al. 1999b, Aschan et al. 1999c)

2.8.6 Research plans for the next five years

The STUK research projects for the period 2000-2002 are described in detail in the STUK-A179 report (Salomaa 2000). A list of the projects to be carried out at the Medical Radiation Laboratory is given below. The present work plan extends up to 2002. After that it is likely that the research will focus on the assessment of patient dose levels in various examinations, on the optimisation of x-ray imaging and on the development of QA programmes.

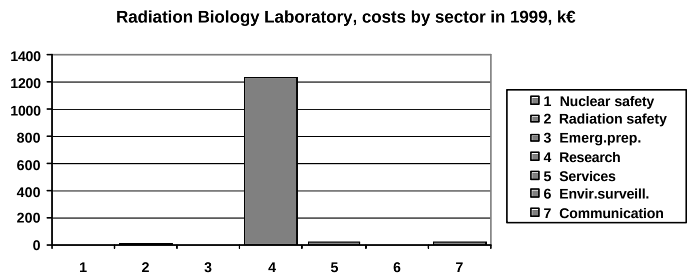
- Development of a method to follow up X-ray examination frequencies and patient doses
- Measures for optimising radiological information and dose in digital imaging and interventional radiology (DIMOND III)
- Further development and application of the PCXMC patient dose calculation program
- A computer program for radiation risk assessment
- Performance measurements of X-ray diagnostic units
- Objective methods for measuring the image quality of radiographs
- The relationship between measured and visual image quality

2.9 Radiation Biology

2.9.1 Key words and specific technologies

- radiation biology, molecular biology, molecular cytogenetics, biodosimetry, epidemiology, health effects, radiation-induced cancer, hereditary effects, risk assessment
- ionising radiation, non-ionising radiation, cosmic radiation, UVA/UVB, RF-EMF, mobile phones, radon, uranium, drinking water, drilled wells
- thyroid cancer, secondary sarcomas, radiation-induced genomic instability, individual radiosensitivity, minisatellites, mutations, p53 mutations, protein kinase C, apoptosis, gene expression, protein expression, kidney function, chromosomal aberrations
- SSCP, DNA sequencing, cDNA expression array, differential display, two-dimensional gel electrophoresis, immunohistochemistry, Western blotting, Southern blotting, Northern hybridization, FISH chromosome painting, Giemsa staining, single cell gel electrophoresis, PCC (premature chromosome condensation)

2.9.2 Description of laboratory activities



The responsibilities of the Radiation Biology Laboratory are:

- research on the biological and health effects of ionising and non-ionising radiation
- biological dose assessment by chromosomal analysis
- assessment of medical consequences of radiation exposure

Research

The research of the Laboratory covers broadly biological effects by ionizing radiation, non-ionizing radiation and radiation epidemiology. Current topis in studies of ionizing radiation are gene expression in radiation-induced cancer, hereditary effects by radiation, radiation-induced genomic instability, individual radiosensitivity and biodosimetry for reconstruction of radiation dose. Biological effects and health hazards of mobile telephones and UV radiation are presently the main research areas in non-ionizing radiation. In epidemiology, cancer risk from different radiation sources, like mobile phones, radon, cosmic radiation or radioisiotopes in drinking water, is being studied.

Laboratory is actively participating international and national reseach programmes and collaborating with research institutes in Europe, USA and Kazakhstan. The laboratory has 25 ongoing reseach projects from which 16 are international collaboration studies. Funding for research projects come from both national (Academy of Finland, National Technology Agency, Finnish Cancer Registry, Ministry of Social Affairs and Health) and international (EC Framework Programmes, EC Inco Copernicus, Nordic Cancer Union, and National Cancer Institute) funding agencies. Nine out of 16 international projects are currently financed by EU.

Expert services

Biological dose assessment by analysis of dicentric chromosomes is performed in cases of suspected overexposure to radiation. The dose assessment method is accredited.

2.9.3 Personnel

Biological effects of ionising radiation (molecular biology, molecular cytogenetics, biodosimetry)

Riitta Mustonen, PhD (genetics), head of laboratory
management, biological effects of radiation, including radiation-induced cancer; hereditary effects and radiation-induced genomic instability; individual radiosensitivity and risk assessment

Wendla Paile, MD (medicine), senior scientist
health effects of radiation, emergency preparedness, iodine profylaxis, deterministic effects

Carita Lindholm, PhD (genetics), senior scientist
molecular cytogenetics, chromosomal aberrations, FISH chromosome painting, retrospective dosimetry

Mikko Luokkamäki, PhLic (genetics), scientist
molecular biology, DNA sequencing, cloning, single cell gel electrophoresis

Anne Kiuru, McS (genetics), scientist, doctoral student
molecular biology, molecular cytogenetics, minisatellite mutations, P53 mutation analysis, SSCP, individual radiation sensitivity

Eeva Romppanen, MSc (biochemistry), scientist, doctoral student
molecular biology, thyroid cancer, cDNA expression array, differential display, DNA sequencing, Northern hybridization

Aki Salo, MSc (biology), doctoral student
molecular biology, radiation-induced genomic instability, cDNA expression array, differential display, single cell gel electrophoresis, Northern hybridization

Armi Koivistoinen, MSc (genetics), assistant researcher
molecular cytogenetics, chromosome aberrations, FISH chromosome painting

Marjo Perälä, BSc Engineer (food processing), research assistant
cDNA expression array, differential display, Northern hybridization, cloning, SSCP

Marja Huuskonen, technician
DNA extraction, gel electrophoresis, DNA sequencing

Radiobiological effects of non-ionising radiation (biochemistry, molecular biology)

Dariusz Leszczynski, PhD, DSc (biochemistry), research professor
molecular biology, biological effects and health safety of non-ionising radiation, UVA/UVB, RF-EMF, mobile phones

Riikka Pastila, MSc (biochemistry), scientist, doctoral student
molecular biology, UVA/UVB, melanoma, metastasis, adhesion molecules

Sakari Joenväärä, MSc (biochemistry), doctoral student
molecular biology, RF-EMF, mobile phones, protein expression, protein phosphorylation, apoptosis, protein kinase C

Pia Kontturi, technician
two-dimensional gel electrophoresis, immunohistochemistry, flow cytometry

Health effects of ionising and non-ionising radition (epidemiology)

Anssi Auvinen, MD, PhD (medicine, epidemiology), research professor (part-time affiliation), professor of epidemiology at University of Tampere
radiation epidemiology, neoplasms, radiation-induced hereditary effects

Päivi Kurttio, PhD (environmental sciences), senior scientist
epidemiology, uranium, drinking water, drilled wells, neoplasms, kidney function

Tiina Salminen, MSc, scientist (public health), doctoral student
epidemiology, mobile phones, electromagnetic fields, brain neoplasms

Katja Rämö, BSc (public health), trainee
epidemiology, airline personnel, breast neoplasms

2.9.4 Aims of research

The general aim is to study the mode of action of ionising and non-ionising radiation and to evaluate the consequences of the health effects of radiation for risk assessment.

The aim of radiation biology is to study the effects of ionising radiation on different endpoints at DNA, gene and chromosomal level, particularly those clarifying the mechanisms of radiation-induced carcinogenesis, radiation-induced genomic instability and individual radiosensitivity (gene expression, gene mutation analysis, apoptosis, DNA breakage and rejoining), or those describing possible hereditary effects on children from exposed parents (minisatellite mutations), or those that can be used for biological dose estimation (dicentrics, translocations).

The aim of non-ionising radiation research is to study different endpoints at gene, protein or cellular level, particularly those that describe the mechanisms of pro-metastatic effects of UVA radiation (solar- and solarium-derived) and those that determine the extent of cellular response to RF-EMF emitted by mobile communication devices.

The aim of radiation epidemiology is to assess radiation risks, particularly those that are not well-known (scientific relevance) or are of major concern in Finland (public health relevance). In the case of ionising radiation, they include the effects of low doses and internal exposures, as well as outcomes other than cancer. In the case of non-ionising radiation, they include radiofrequency electromagnetic fields and the health effects of UVA.

2.9.5 Progress report on research over the last five years

Biological effects of ionising radiation (molecular biology, molecular cytogenetics, biodosimetry)

The hereditary effects of paternal radiation exposure were studied by determining the frequency of radiation-induced heritable minisatellite mutations among the children of Estonian clean-up workers (liquidators). The cases and controls were children born to the same families after and before the father´s exposure at Chernobyl. Minisatellite mutations were studied using eight minisatellite probes in a method based on Southern blot. Paternal minisatellite mutations were detected in approximately the same number of case children as control children. In this study we did not observe any statistically significant increase in minisatellite mutation frequency among the children of radiation-exposed fathers (Kiuru et al. manuscript in preparation).

Our studies on gene expression in radiation-induced thyroid carcinogenesis using DD-RT PCR and cDNA expression array, demonstrate that the gene expression profiles are heterogeneous and no common gene pathway defect could be demonstrated. In general, the relative amount of all expression changes (up and down) is not dependent on the radiation type or dose. However, downregulation of p21 in many of these *in vitro* irradiation-induced tumour cell lines prevents p53 from inducing any G1 arrest, revealing that the p53 apoptosis pathway might be dysregulated irrespective of the p53 mutation status. (Romppanen et al. 3 manuscripts in preparation).

The co-operation between European laboratories concerning the FISH technique has produced valuable guidelines for its use in estimating the dose of past or chronic exposures. In this context follow-up of the Estonian radiation accident victims in Kiisa has provided and continues to provide information on the stability of translocations (Lindholm et al. 1996, 1998). Moreover, the FISH technique has shown its potential in identifying chronic exposure to low-LET radiation on the group level in nuclear power plant workers (Lindholm et al. 2000), whereas domestic radon exposure showed no effect on lymphocyte chromosomes (Lindholm et al. 1999). Doctoral thesis on retrospective dosimetry (C. Lindholm).

In studies concerning the mechanisms of chromosomal aberration formation, a non-random distribution of radiation-induced breaks was found along a set of chromosomes identified using the painting technique (Luomahaara et al. 1999, Kiuru et al. 2000). Using PCC assay, exchange-type aberrations were observed soon after irradiation of different cell cycle stages (Sipi et al. 2000).

Molecular epidemiological approaches have been used to study the significance of p53 mutations for individual radiation sensitivity. p53 mutations in human head and neck cancer cell lines were shown to be associated with increased radiosensitivity and capacity to repair sublethal damage (Pekkola-Heino et al. 1996, Servomaa et al. 1996, Pekkola-Heino et al. 1998). In addition, mutations or overexpression of p53 were not shown to predict survival among secondary rectal cancer patients who received radiation therapy for uterine cancer (Hirvikoski et al. 1999, Servomaa et al. in press).

Studies on genomic instability have indicated that the incidence of cytogenetically abnormal rogue cells show a large variability between studies and individuals and that no correlation between long-term radiation exposure and the occurence of rogue cells was demonstrated (Mustonen et al. 1998). Irradiation of CHO cell lines previously used in bystander effect studies, showed that radiation induces less micronuclei but more single strand breaks in G6PD deficient cell line compared to wild type cells. G6PD enzyme is important in defence against radiation-induced oxygen radical attack and cells lacking the enzyme seem to be lethally damaged immediately after irradiation (Salo et al. manuscript in preparation).

Biological effects of non-ionising radiation (biochemistry, molecular biology)

Apoptosis induction studies using rat leukocytes and rat smooth muscle cells (for review see Leszczynski 1996) have demonstrated that: (i) PKC inhibition induces cell cycle arrest at the G1/S boundary followed by cell apoptosis (Leszczynski 1995), (ii) PKCα depletion using antisense-oligo showed that this isozyme is involved in cell cycle progression but not in apoptosis (Leszczynski et al. 1996) and (iii) PKCζ and δ depletion using antisense-oligo was shown to induce cell apoptosis (Leszczynski. et al. 1995 abstract).

UVA-studies (Leszczynski et al. 1995; Leszczynski et al. 1996, Pastila & Leszczynski, manuscript in preparation) have shown that: (i) UVA activates PKC signaling pathway in leukocytes, (ii) UVA induces MHC antigen expression in PKC-dependent manner and (iii) UVA increases the adhesion of tumor cells to endothelium.

RF-EMF studies have preliminarily shown that short-term (1h) exposure of cells to a low-level (2 SAR) 900GSM signal causes changes in protein expression and protein phosphorylation; this indicates that cells respond to the RF-EMF signal in spite of its very low energy. (Joenväärä & Leszczynski, manuscript in preparation). A report on the possible health effects of mobile phones was prepared at the request of the Finnish Ministry of Social Affairs and Health (Jokela et al. 1999).

Microcavitation studies carried out at Harvard Medical School, Boston, MA, USA, have shown that irradiating cells that contain light-absorbing particles with nano-second length laser pulses is a very efficient and selective method of killing cells, and one that might have applications in tumor therapy. (Leszczynski 1999).

Photodymamic Therapy (PDT) studies at Harvard Medical School, Boston, MA, USA, have shown that PDT treatment of vein grafts prevents restenosis by eliminating smooth muscle cells by apoptosis and by generating of mechanical barrier that prevents migration of cell from adventitial areas to media and intima areas of the blood vessel wall. (Heckenkamp at al. 1999, Heckenkamp et al. 1999, Overhaus et al. 2000).

Health effects of ionising and non-ionising radition (epidemiology)

The health effects of Chernobyl fallout in Finland have been assessed (Auvinen et al. 1995, Auvinen et al., submitted). A collaborative project has evaluated radiation doses (Rahu et al. 1998), thyroid nodularity (Inskip et al. 1998) and cancer risk among Estonian Chernobyl clean-up workers (Rahu et al. 1998). A study of airline cabin crew revealed an excess risk of breast cancer among cabin attendants (Pukkala et al. 1996). Collaboration with the U.S. National Cancer Institute has explored the effects of residential EMF on risk of childhood leukemia (Hatch et al. 1999, Baris et al. 1999, Auvinen et al. in press) and the effects of radiotherapy for benign disorders on cancer risk (Ron et al. 1999) and the risk of thyroid cancer in relation to occupational exposure to low doses of radiation is being analysed. Studies on cancer risks from natural radioactive materials in well waters and the effects of uranium in well waters on the kidney will be completed.

2.9.6 Research plans for the next five years

Radiobiological effects of ionising radiation (molecular biology, molecular cytogenetics, biodosimetry)

Four main topics are foreseen in radiobiological reseach at STUK during next few years: mechanisms of radiation-induced carcinogenesis, mechanisms of radiation-induced genomic instability, interindividual variation in response to ionising radiation and biodosimetry.

Gene expression studies will continue in our research on radiation-induced carcinogenesis. Two genome-wide expression methods (cDNA Expression Array and differential display) will be applied in studies of radiation-induced primary human tumour cell lines derived from thyroid carcinomas from Belarussian children. The results will be compared with previous data obtained using cell lines from *in vitro* radiation-induced human thyroid tumours. Our project on radiation-induced genomic instability will aim to identify genes playing a pivotal role in the induction of genomic instability. The project will also study how genomic instability can be transmitted to cells that are not directly hit by irradiation ('bystander effect').

Two projects related to interindividual response to ionising radiation will be carried out: the first study will address the question of factors affecting the individual responses of cancer patients who develop secondary sarcomas after radiotherapy and the second study will focus on comparing the individual dose-response of different endpoints in lymphocytes to ionising radiation (chromosome aberrations, apoptosis, DNA breakage and rejoining).

In biodosimetry, the ongoing project assessing exposure among population exposed to chronic radiation at the Semipalatinsk nuclear test site in Kazakhstan will be completed. In another international collaboration study between six European laboratories, the aim is to achieve consensus on how to use FISH chromosome painting analysis in retrospective biodosimetry. Studies on persistence of translocations, control levels in unexposed individuals and methods of calibration will continue.

Radiobiological effects of non-ionising radiation (biochemistry, molecular biology)

Studies of the possible health effects of mobile communication devices will focus on proteomic approach to determine the mechanism of action of RF-EMF. Using two-dimensional gel electrophoresis, the proteins and phosphoproteins generated in cells exposed to RF-EMF and control cells at different points of time will be identified. Futhermore, the persistence of any protein expression changes will also be determined. Changes in gene expression will be determined using cDNA arrays.

Studies on the effects of UV radiation on melanoma metastasis will continue in animal studies and in human volunteers' to confirm the pro-metastatic effects of UVA observed *in vitro*.

Health effects of ionising and non-ionising radiation (epidemiology)

The role of mobile phones in the etiology of brain tumors will be assessed in a major collaborative study coordinated by the IARC. The same material will be used to evaluate the risk associated with medical x-rays in a Nordic collaborative study. A pooled analysis of European studies of indoor radon and lung cancer is in progress coordinated by the NRPB. A pooled analysis of cancer mortality among nuclear industry workers is under way with IARC coordination. Cancer incidence and mortality among pilots and cabin crew are being studied in a Scandinavian/European collaborative effort. The effects of radionuclides in drinking water on the risk of bladder and kidney cancer and leukemia are being studied. The effects of ingested uranium on kidney function are being investigated. Cancer risk from ingested radionuclides among reindeer herding Sami is studied in collaboration with Swedish and Norwegian researchers (coordinated by STUK). A larger cohort of Chernobyl clean-up workers is being established covering all the Baltic countries. The effects of Chernobyl on adult leukemia and thyroid cancer will be explored. Collaboration is planned with scientists at the Belarussian Center for Medical Technology and Institute of Oncology, to study the effects of Chernobyl fallout.

The STUK research projects for the period 2000-2002 are described in detail in the STUK-A179 report (Salomaa 2000). A list of the projects to be carried out by the Radiation Biology Laboratory is given below.

- Genomic instability and radiation-induced cancer (RADINSTAB)
- The use of FISH techniques for retrospective biological dosimetry (COD)
- The significance of individual radiation sensitivity for secondary cancer
- Inter-individual differences in the yield of radiation-induced chromosome aberrations
- Radiation-induced changes in gene expression
- Minisatellite mutations and biodosimetry of the population around the Semipalatinsk nuclear test site (SEMIPALATINSK)
- Radiation-induced heritable mutations in humans
- Mobile phones and the risk of brain tumours (INTERPHONE)

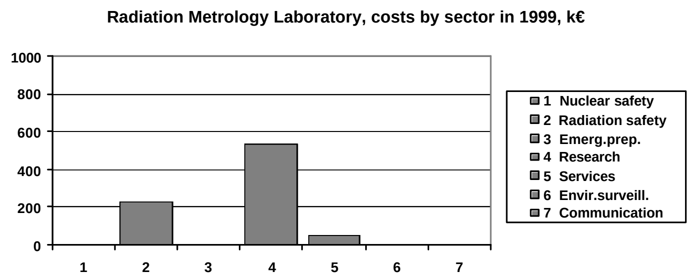
- Pooled analysis of European case-control studies of radon and lung cancer (RADON EPIDEMIOLOGY)
- Cancer risk among nuclear workers (LOWDOSERISK)
- Cancer risk among airline personnel (ESCAPE, NoESCAPE)
- Cancer among Sami people (Lapps)
- Kidney toxicity of uranium in drinking water (JURMU)
- Radioisotopes in drinking water and cancer risk (JUORAAS)
- Chernobyl fallout and adult leukemia
- Brain tumors and X-ray examinations
- Leukemia incidence in the vicinity of nuclear facilities
- Radon and lung cancer: an analysis using additive generalised linear models (RALMA)
- Health risk assessment of wireless communications (LaVita)
- Risk evaluation of potential environmental hazards from low energy electromagnetic fields (EMFs) exposure using sensitive *in vitro* methods (REFLEX)
- Biological effects of microwave radiation emitted by mobile phones
- Effects of UV on melanoma metastasis (SYTTY)
- Follow-up chromosomal aberration frequencies among accidentally exposed subjects
- Cytogenetic biomarkers and human cancer risk (CancerRiskBiomarkers)
- Cancer incidence among Baltic Chernobyl clean-up workers

2.10 Radiation Metrology Laboratory

2.10.1 Key words and specific technologies

Radiation dosimetry, standard dosimetry, calibration techniques, quality audit for radiotherapy, quality control for radiotherapy

2.10.2 Description of laboratory activities



The responsibilities of the Radiation Metrology Laboratory are twofold: (1) maintenance of the national standards for ionising radiation quantities, and provision of calibration and testing services for radiation measuring equipment for radiation protection, diagnostic radiology and radiotherapy, and (2) regulatory control of radiotherapy activities in Finland, including preparation of regulatory guides, issue of licences, inspections, comparative measurements, etc.

The research carried out at the laboratory is related to these two areas of responsibility, i.e., (1) research on standards and calibration techniques for ionising radiation quantities and (2) research on dosimetry and quality assurance techniques to ensure the safety of radiotherapy.

It is important to recognise that only a small part of the total number of man-years available at the Radiation Metrology Laboratory can be devoted to research. The time allocated for research averaged between 1 and 1.5 man-years/year.

2.10.3 Personnel

Hannu Järvinen, MSc (eng.), head of laboratory
management, quality management, regulatory activities in radiotherapy, standard dosimetry

Antti Kosunen, PhD (physics), senior physicist
research and development of standard dosimetry, measurement and calibration techniques, quality assurance, inspections of radiotherapy units at hospitals

Ilkka Jokelainen, MSc (physics), physicist
calibration, testing and irradiation services, research on calibration techniques, inspections of radiotherapy units at hospitals

Petri Sipilä, MSc (physics), senior physicist
regulatory activities in radiotherapy, inspections of radiotherapy units at hospitals, research and development in radiotherapy dosimetry and radiation safety

Ritva Parkkinen, Lic.Phil. (physics), medical physicist
inspections of radiotherapy units at hospitals, research and development in radiotherapy dosimetry and radiation safety at radiotherapy

Harri Lindroos, technician
calibration, testing and irradiation services, quality control of laboratory equipment

Ilkka Aropalo, technician
installation and maintenance of laboratory equipment, calibration, testing and irradiation services

2.10.4 Aims of the research

The research of the Radiation Metrology Laboratory aims solely at supporting the needs of regulatory activities. The national standards maintained by the laboratory are mainly secondary standards, as the development of primary standards is not considered feasible because of the small resources available. The research on standards therefore concentrates on applying the secondary standards for calibrations, i.e. in the development of optimum calibration techniques. The research on radiotherapy dosimetry and quality control techniques aims at developing and supporting the methods used in inspections carried out by STUK at radiotherapy clinics, and more generally, at supporting the development of quality assurance and safe procedures in radiotherapy.

2.10.5 Progress report on research over the last five years

The most important research objects and achievements over the period of last five years have been as follows:

- Development of techniques for the dosimetry of epithermal neutron beams, for the verification of doses to patients in Boron Neutron Capture Therapy (BNCT). Mainly, the characteristics of a twin ionisation chamber technique have been studied. The methods have been adopted into use in the regulatory control of the Finnish BNCT facility.
- Development of a new technique for the calibration of radiotherapy plane parallel chambers in high-energy electron beams. The accuracy of electron beam dose measurements has been improved by 1-2% thanks to introduction of the new method. The new technique and facilities are now routinely used in calibrations.
- Comparisons of the present air kerma-based and new direct-absorbed doses with water calibration techniques used to calibrate radiotherapy dosimeters at ^{60}Co gamma beam. The research has improved understanding of the associated uncertainties and provided useful insights for implementation of the new techniques.
- Development of measurement techniques for independent control of the whole radiotherapy process. Special phantoms have been developed to check the accuracy of radiotherapy treatment planning systems (TPS) and the transfer of CT-data to the TPS. The techniques have now been adopted as a routine tool in the regular inspections made in radiotherapy practices.
- Development of techniques to measure dose distributions in irregular and stereotactic fields of radiotherapy. The results have brought in new knowledge on the uncertainties of different techniques and improved the methods used in regulatory control measurements.

- Testing on the characteristics of a new type of personnel dosimeter. The results have shown the potential value of the new technique in personal dosimetry.
- Development of standardised methods to specify of dose delivery in radiotherapy. Through a number of scientific enquiries and discussions, consensus was reached between the Nordic countries, which has since largely been adopted also by the International Commission on Radiation Units and Measurements. This work was done in Nordic co-operation through a working group of the Nordic Association of Clinical Physics, which was chaired by a representative from the Radiation Metrology Laboratory.
- Development of a Quality System (QS) for a Secondary Standard Dosimetry Laboratory (SSDL). A number of Quality Control (QC) techniques have been investigated to establish an optimum QC program for an SSDL. The work was carried out as a part of a Co-ordinated Research Project of the International Atomic Energy Agency (IAEA). The results provide detailed guidance not only on the QC program but also on development of the overall QS to conform to an appropriate international standard (ISO 17025).

2.10.6 Research plans for the next five years

The STUK research projects for the period 2000-2002 are described in detail in the STUK-A179 report (Salomaa 2000). A list of the projects to be carried out by the Radiation Metrology Laboratory is given below.

- Independent verification of dosimetry in BNCT (based on the application of microdosimetric techniques; as a partner in an EU-funded research project)
- Comparative measurements in radiotherapy (special emphasis on new radiotherapy techniques such as multileaf collimators, intensity modulated treatments, and stereotactic treatments)
- Quality Assurance of electronic portal imaging devices (EPID) (for use as a dosimetric tool)
- New calibration techniques for dosimeters in diagnostic radiology (choice of radiation qualities, optimum calibration of dose area product meters, etc)
- Calibration techniques for brachytherapy sources

- Use of direct-absorbed doses in water calibrations for radiotherapy dosimeters
- Characteristics of new types of personal dosimeter

2.11 Non-Ionising Radiation Laboratory

2.11.1 Key words and specific technologies

Non-Ionising Radiation (NIR), low-frequency electric (E) and magnetic (H) fields, radio-frequency EM fields, microwaves, infra-red radiation, visible light, ultraviolet radiation (UVR).

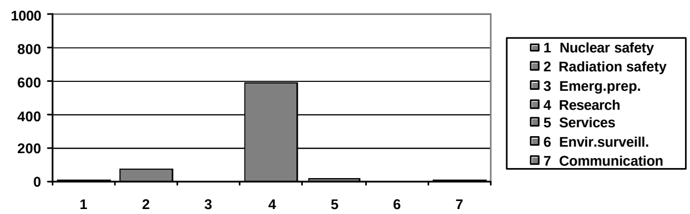
Power lines, magnetic resonance imaging (MRI) devices, electronic article surveillance devices (EAS), metal detectors, high-frequency heaters, broadcasting stations, mobile phones, base stations, microwave dryers, radars, lasers, sunlamps and sunbeds, UV-phototherapy, solar UVR.

EM field measurement techniques, exposure measurements, metrology, calibration, primary and secondary standards, traceability, Helmholtz-coil, TEM transmission cell, waveguide chamber, anechoic chamber, calibrated antenna, automated test system for specific absorption rate (SAR), calorimetry, *in vitro* exposure chamber, *in vivo* exposure chamber, quartz-halogen lamp, detector-based calibration, filter radiometer, portable calibrator, radiometry, UVR dosimetry, broadband UV-radiometers, spectroradiometers, solar UVR measurements.

Electrophysiology, interaction mechanisms, numerical EM-field dosimetry, experimental RF-dosimetry.

2.11.2 Description of laboratory activities

NIR Laboratory, costs by sector in 1999, k€



The Non-Ionising Radiation Laboratory

- carries out regulatory functions under the radiation protection legislation
- carries out research and technical development work to serve the needs of radiation safety, regulation and biological studies
- develops radiation protection standards
- disseminates public information on NIR
- provides expert services.

The regulatory functions include

1) preparation of proposals for radiation safety legislation and regulations,
2) preparation of safety guidelines (STUK guides),
3) supervision of NIR-emitting appliances and their use (e.g. high-power radars, broadcasting stations and laser shows) and
4) market control of sunlamps and sunbeds.

Typical expert services include:

1) calibration of EM field meters
2) calibration of solar UVR monitors
3) calibration of UVR meters in medicine and environmental research
4) exposure measurements and safety assessments on the EM fields of high-frequency heaters, base stations, microwave dryers, broadcasting stations, radar units, etc.
5) measurements on phototherapy devices, sunbeds and UV-lamps

These functions are not considered in more detail in this report, where the main focus is on research and other activities closely associated with the experience gained from research.

The laboratory started to do NIR research in the early ‘80s. The research was initially financed by STUK, but around the beginning of the ‘80s and ‘90s external funding and strict project work became increasingly important. The other STUK laboratories have since followed the same course. External funding has been provided by the Academy of Finland, Finnish Work Environment Fund, National Technology Agency (TEKES), European Union,

European Space Agency, FGF (Forschungsgemeinschaft Funk, Germany) and National Agency of Medicines.
In the EM field range the development of new types of exposure meter and measurement method in the frequency range 30 Hz - 10 GHz were the main topics up to the mid ‘90s. This work was motivated by the lack of suitable commercial meters for exposure assessments. New instruments developed include broadband electric and magnetic field meters, different radio frequency (RF) and microwave meters and induced body current meters.

The laboratory does not make any measurement without adequate calibration. Because no calibration services were available for EM field exposure measurements, it had to develop the calibration systems needed, such as Helmholtz coils for magnetic field meters, TEM transmission cells for RF field meters and calibrated horn antennas for microwave radiation meters.

Exposure studies based on measurements and theoretical calculations have been conducted for broadcasting stations, high-frequency heaters, radar stations, video displays, industrial induction heaters and MRI devices.

Since the publication of the new ICNIRP guidelines in 1998 a good basis has existed for exposure assessments dealing with relatively low-frequency electric and magnetic fields. The exposure assessment of broadband fields, however, is difficult because the present exposure standards can be only used for sinusoidal fields. The NIR laboratory has suggested adoptation of new method based on the spectral weighting of the field and limitation of the weighted peak field strength by the International Non-Ionising Radiation Committee (ICNIRP) for the restriction of broadband fields.

The safety problems associated with mobile telecommunication have been an important new topic of the research in the last six years. The laboratory has developed an automated SAR test system, waveguide based calibration systems for SAR probes and exposure chambers for *in vitro* and *in vivo* experiments. The SAR assessment is based on measurements and numerical simulations.

Precise measurements of solar UVR are needed to estimate the environmental and health consequences of global ozone depletion. Accurate calibration and test systems have been established for spectroradiometers and broadband UVR meters. Currently, the NIR laboratory calibrates the broadband solar UVR meters operated by the Finnish Meteorological Institute. The accuracy of the calibrations and solar UVR measurements is verified by frequent international inter-comparisons. The effects of ozone depletion and snow on human UVR exposure and the cancer risk associated with ozone depletion have also been examined within the national climate change programme (SILMU).

The safety of sunlamps, sunbeds and UV phototherapy equipment is another important research area in the optical range. The UVR doses received by users of sunlamps and sunbeds have been investigated, and the population exposure compared with the exposure to solar UVR. The emission characteristics of appliances and distribution of different types on the markets have also been surveyed.

2.11.3 Personnel

Kari Jokela, Dr. Tech., research professor , head of laboratory

Lauri Puranen, Lic. Tech, Project manager, EM studies

Tim Toivo, MSc (technology), scientist, doctoral student, EM studies

Ari-Pekka Sihvonen, BSc, assistant researcher, EM studies

Reijo Visuri, MSc, physicist (on leave), optical radiation safety

Lasse Ylianttila, MSc (technology), scientist, optical radiometry

Laura Huurto, Phil.Lic., medical physicist, medical use of NIR

Valpuri Jalarvo, BSc, assistant researcher

Kari Keskinen, technician

2.11.4 Aims of research

- To study exposures to NIR and compare them with exposure standards and current knowledge on thresholds of biological effects

- To examine the biological and biophysical basis of exposure limits
- To develop experimental and theoretical methods for exposure assessment
- To develop precise standards for the calibration of instruments used for exposure measurements
- To provide well characterised exposure systems for biological research
- To study the biophysical interaction mechanisms of NIR
- To obtain quantitative and reliable data for the dissemination of public information

2.11.5 Progress report on research over the last five years

Development of EM field exposure measurement instruments

An exposure meter to measure pulse power density from scanning microwave radar units was designed, and four meters were constructed for the Finnish Defence Forces (Puranen and Jokela 1996).

An isotropic broadband (30 Hz to 3 kHz) magnetic field meter was designed and constructed to measure magnetic fields in a broad dynamic range (from 40 nT to 4 mT). The next objective is to develop a magnetic field meter which measures the weighted peak value (Jokela 2000b) in the frequency range below 100 kHz.

RF-dosimetry

An automated test system was developed to test the radiation safety of mobile phones, employing automated scanning of SAR probes in a liquid phantom (Puranen et al. 1997). In contrast to most existing SAR test systems, the system is extremely economical thanks to its use of an inexpensive scanner based on a commercial device originally developed to measure dose distribution in the beam of a radiotherapy appliance.

For the precise calibration of SAR probes, primary standards were developed for the 900 MHz (Jokela and Puranen 1998) and 1800 MHz mobile phone frequency ranges. The standards are based on waveguides chambers partly filled with the lossy liquid used in the SAR test system. The precise value of SAR at the calibration point was determined by measuring accurately the temperature increase in and specific heat capacity of the liquid. The thermal calibration was verified with numerical simulations. Comparison of the calibrations with the RF dosimetry laboratory of ETH (Eidgenössische Technische Hochschule, Switzerland) verified that the accuracy of the STUK SAR standards (± 5%) compares well with the best SAR standards in the world. Next, the SAR calibrations will be extended to the frequency range 20-450 MHz.

To measure electric field in SAR calibrations, it is necessary to know accurately the exact conductivity of the liquid. An accurate device stripline system to measure conductivity within an uncertainty of under ± 3% was developed in collaboration with the radiolaboratory of Helsinki University of Technology (Sihvonen et al. 2000).

A waveguide-type exposure chamber was developed for the University of Kuopio to be used in the national research programme on the effects of mobile phones on mice (COST 244). Altogether 25 mice are placed inside the waveguide at the same time (Puranen et al. 2000). The animals are restrained in a plastic tube in order to maintain the same coupling to the microwave field. The exposure level is the same as that caused by typical mobile phones in the human head. The experimental dosimetry, based on calorimetric and electric field measurements, was verified by numerical calculations carried out by VTT (Technical Research Centre of Finland). STUK and the University of Kuopio provided the dielectric model of a mouse used in the calculations. Numerical wholebody SAR values were under 40% smaller than the measured values, which is a good result. The *in vivo* project continues. A large radial waveguide in which the rats live in unconstrained conditions is under development.

For *in vitro* exposures at STUK and the University of Kuopio, two waveguide chambers were developed at 900 MHz. Efficient water-cooling makes it possible to achieve high SAR values up to 10 W/kg without significant heating. The SAR values are determined with FDTD calculations, which are verified with measurements taken by miniature thermal and (in future) electric-field probes. The improvement of *in vitro* dosimetry will continue.

The most intense exposure to RF fields arises in the vicinity of industrial high-frequency heaters that operate at 13 MHz and 27 MHz (Puranen et al. 1995). An exposure assessment method based on measurements of induced current densities and electric field has been developed (Jokela et al. 1995c; Jokela and Puranen 1999). The main result of the study was a large current probe, which enabled measurement of the distribution of the induced current throughout the body. It was shown by measurement that the induced current decreases far less as a function of the distance from the heater than the maximum electric field does. Preliminary investigations were carried out to study the relationship between the induced current and SAR.

MRI study

The safety of patients examined with magnetic resonance imaging (MRI) and operators of the appliances was studied (Huurto and Toivo 2000). In the first part of the study the number of MRI examinations, hazards, accidents and side effects associated with MRI were surveyed by questionnaire. MRI workers' exposure to static magnetic field was assessed by measuring the fringe fields around a representative sample of MRI equipment and compared with the exposure limits. In the second part of the study the accuracy and applicability of the measurement methods specified by the International Electrotechnical Commission (IEC) were tested. The measurement method for gradient fields was tested in the laboratory and using MRI appliances, and a calorimetric method for measuring the SAR value was tested in the laboratory.

Broadband electric and magnetic fields

In 1998 the International Commission on Non-Ionising Radiation (ICNIRP) published new recommendations for electromagnetic fields and waves. The exposure limits for the general public were adopted by the Council of the EU in 1999. The limits are appropriate for continuous sinusoidal fields, but in the case of broadband harmonic fields the recommendations are too strict, without any good biological justification. The new exposure assessment method proposed to the ICNIRP by the NIR laboratory is based on the principle of weighting the field strength or induced current density with a simple high- or low-pass function, respectively. The instantaneous peak value of the weighted exposure is kept below a peak value obtained directly from the ICNIRP guidelines (Jokela 2000a, Jokela 2000b). The biological justification of the proposition was verified with electrophysiological model calculations. In addition to be less restrictive, these exposure measurements are much simpler, as time domain measurements can be used instead of complex spectral measurements.

The new exposure assessment method has been tested with exposure measurements carried out for different sources of broadband magnetic fields, including electronic article surveillance devices (EAS), metal detectors MRI devices and high-power industrial sources. A joint study with the University of Kuopio has started to systematically study the exposure of cashiers to magnetic fields from near-by EAS devices. New instruments will be developed to facilitate broadband exposure measurements.

UV radiometry

At the beginning of the ‘90s STUK established a secondary national standard for the spectral UV-irradiance for the calibration of solar and other UVR measurements. The standard is based on a 1 kW quartz-halogen lamp calibrated against the NIST primary standard in the USA. To overcome the serious problems arising from stability problems with standard lamps and the large differences in UVR scales, the Metrology Research Institute at Helsinki University of Technology developed a new calibration traceability chain based on standard detectors instead of standard lamps (Kärhä et al. 2000), in collaboration with the NIR laboratory. A recent comparison of detector- and lamp-based scales showed good agreement (Jokela et al. 2000). A detector-stabilised portable lamp is under construction (EC contract SMT4-CT98-2242) to transfer the new scale to solar UVR spectroradiometers.

Another significant advance was achieved in the field of broadband solar UV radiometry. A test and calibration method based on laboratory tests on the meters and calibration against a precision spectroradiometer for solar radiation was developed. Outdoor calibrations are necessary because it is difficult to simulate the angular and spectral characteristics of the sun and sky in a laboratory. The accuracy of solar UVR spectroradiometry has been verified in frequent Nordic and European inter-comparisons of spectral solar UVR measurements. The first international inter-comparison of broadband UVR-meters, commissioned by the World Meteorological Organisation (WMO), was carried out (Leszczynski et al. 1997; Leszczynski et al. 1998). The quality assurance procedure developed by the laboratory for broadband UVR meters has been adopted by the WMO (Webb et al. 1998).

UVR exposure and risk studies

The effect of arctic ozone depletion and snow on UVR exposure in northern regions was examined (Jokela et al. 1995a; AMAP 1998), and the cancer risk of solar UVR in Finland assessed (Taalas et al. 1996; Huurto et al. 1996). These studies suggested that the combination of springtime ozone depletion and high UVR reflection from snow considerably increases facial UVR doses during the winter in northern Finland.

A questionnaire was carried out to estimate population exposure to UVR from sunbeds and sunlamps. Demographic data was collected, as well as information on patterns of use of sunbeds and sunlamps, on attitudes towards solar UVR and sunbathing, and on colours of eye, hair and skin, in order to assess individual sensitivity to UVR and risk of skin cancer (Jalarvo 2000). The results showed that the total exposure of the population to UVR from sunbeds and solaria is small (1%) compared with the exposure from solar UVR, but there is a group of heavy users who receive significant UVR doses from artificial tanning. The use of sunbeds and sunlamps also starts at a relatively young age. In the second part of the study, the UVR safety of tanning saloons was surveyed in collaboration with local health authorities. Most sites surveyed did not fully comply with the existing safety requirements.

Artificial UVR is used in the treatment of psoriasis and other skin diseases. Long-term phototherapy is associated with increased risk of squamous cell carcinoma, so it has become necessary to monitor and restrict the cumulative UVR doses received by patients. A study was carried out in which the radiation characteristics, use and quality assurance practices of UV phototherapy appliances were surveyed. The UVR spectra and dose rate of UV phototherapy appliances were measured and the broadband UV radiometers used at hospitals were calibrated. The final report also gave recommendations for the quality assurance of phototherapy units and instructions on assessing the UVR doses of patients (Huurto et al. 1998).

2.11.6 Research plans for the next five years

The STUK research projects for the 2000-2002 period are described in detail in the STUK-A179 report (Salomaa 2000). A list of the projects to be carried out by the Non-Ionising Radiation Laboratory is given below.

- Development of exposure systems for animal and cell culture studies
- Improving the accuracy of ultraviolet radiation measurement
- New antennas and measurement methods for 3rd generadion cellular systems (NAMS)
- The ASTE project: EMC & Safety of Multimedia Terminals
- The combined effects of electromagnetic fields with environmental carcinogens (CEMFEC)
- Use of sunbeds in Finland
- Restricting exposure to broadband and pulsed electric and magnetic fields

Optional new research plans

The biophysical interaction mechanisms of 900 MHz RF fields with cells will be examined in co-operation with the Radiation Biology Laboratory to elucidate effects observed in STUK cell studies.

The RF fields emitted by the base stations of mobile phones will be measured and compared with the fields emitted by other sources. The objective is to provide quantitative data for the increasing public discussion on the health effects of base stations and mobile phones.

Exposure measurement methods for the near fields of base stations will be developed.

The derivation of SAR distribution in the body from induced current distribution at 27 MHz will be examined, using FDTD calculations and dielectric models of the human body.

The accuracy of power density calibrations at 0.9 GHz will be improved and a new standard developed for the 1.8 GHz frequency.

A calibration standard will be developed for the low-frequency electric field strength (50 Hz–10 kHz).

The effects of harmonic frequencies on exposure to intense electric and magnetic fields in the vicinity of power lines will be investigated. Other low frequency and broadband exposures to be surveyed arise from digital mobile phones, welding, induction heating, switched power sources, electrolysis etc. Due to the new recommendations of the ICNIRP and the EU Council, there is a much greater need for assessment of exposure to low frequency and broadband electric and magnetic fields.

A broadband magnetic field meter that shows the weighted peak magnetic flux density will be developed.
The long-term stability of solar UVR measurements and calibrations will be monitored.

New versions for the detector-based portable calibrator will be developed.

Exposure systems and a method for determining UVR doses will be devised for human and *in vitro* UVR studies.

UV lamps marketed in Finland for cosmetic or medical purposes will be measured and classified using their spectral irradiance. This will facilitate comparison between the original and replacement lamps used in sunbeds and phototherapy devices.

Exposure models and dose assessments will be developed and provided for epidemiological studies of the health effects of solar and artificial UVR.

3 LIST OF PUBLICATIONS (last five years)

The publication list includes original scientific articles published in peer-reviewed journals, proceedings articles, extended abstracts of international scientific meetings, books/book articles and scientific reports published in different institutes' or organisations' publication series. The publication list does not include conference abstracts, articles in domestic professional journals, internal project reports or popularised papers. The publications are listed for each laboratory separately to give a comprehensive view of their production.

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3.2 Natural radiation

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