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RESEARCH ACTIVITIES OF STUK 2000–2004

S. Salomaa, T.K. Ikäheimonen (eds.)

Säteilyturvakeskus
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Key words: research, radiation protection, evaluation, ionising radiation, non-ionising radiation

Abstract

The primary goal of STUK, the Finnish Radiation and Nuclear Safety Authority, is to protect people, society, environment and future generations from 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 2000–2004. The research and its organization scientific strategy and priorities, the impact of results, publications, and the functions of research laboratories are all reviewed. This report has been written to provide background material for an international evaluation of STUK research carried out in autumn 2005. A follow-up of actions taken after the first international research evaluation mission in 2000 will be provided. In 2004, STUK was also evaluated as one of the sectoral research institutes in Finland and the main conclusions from this mission will also be given.

SALOMAA Sisko, IKÄHEIMONEN Tarja K. (toim.). Säteilyturvakeskuksen tutkimustoiminta 2000–2004. STUK-A210. Helsinki 2005, 268 s.

Avainsanat: tutkimus, säteilysuojelu, toiminnan arviointi, ionisoiva säteily, ei-ionisoiva säteily

Johdanto

Säteilyturvakeskuksen (STUK) päämääränä on suojella ihmisiä, yhteiskuntaa, ympäristöä ja tulevia sukupolvia säteilyn haitallisilta vaikutuksilta. Säteilyturvakeskuksen tutkimustoiminta tuottaa säteilyn käyttöön, esiintymiseen ja vaikutuksiin liittyvää uutta tietoa. Tämä raportti on yhteenveto STUKin säteilysuojelututkimuksesta vuosina 2000–2004. 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 2005 aikana. Raportissa kuvataan myös edellisen, vuonna 2000 suoritetun tutkimuksen kansainvälisen arvioinnin suositusten pohjalta tehdyt toimenpiteet ja vuonna 2004 tehdyn kansallisen sektoritutkimuslaitosten rakenteellista kehittämistä koskeneen selvityksen johtopäätökset STUKin osalta.

Contents

Introduction

The Radiation and Nuclear Safety Authority (STUK) is a regulatory authority, research institution and expert organization, whose mission is to protect people, society, environment, and future generations from 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.

One 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 and independent reviews on the effectiveness and quality of research are carried out every five years. This is now the second time when 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 organization

The research carried out at STUK is related to radiation protection, covering both ionizing and non-ionizing radiation. 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 organizations outside STUK. However, the present review only covers the strategy, organization and results of radiation protection research carried out by STUK itself.

1.1.1 Brief history of STUK as a research organization

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, 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 exposure of the population to radioactive fallout and how the various 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 introducing guidelines for action levels, monitoring frequencies and mitigation measures. 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 made to build nuclear energy capacity in Finland, STUK's resources were increased by giving it greater research capabilities. The main research areas in 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-ionizing 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 needs 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 the other Nordic countries in radiation protection research. This co-operation has 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 advanced to 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 90s, 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 90s. In 1995, Finland joined the European Union and, ever since, STUK has played an active part in the research programmes of the European Union. The expansion of STUK functions is illustrated in Fig. 1.

1.1.2 Arrangements for setting and modifying the research strategy

The mission of STUK is protecting people, society, environment, and future generations from harmful effects of radiation. STUK is, besides a research centre, also a regulator and inspectorate. In addition, STUK has the role of an emergency preparedness organization in nuclear and radiation hazard situations. STUK

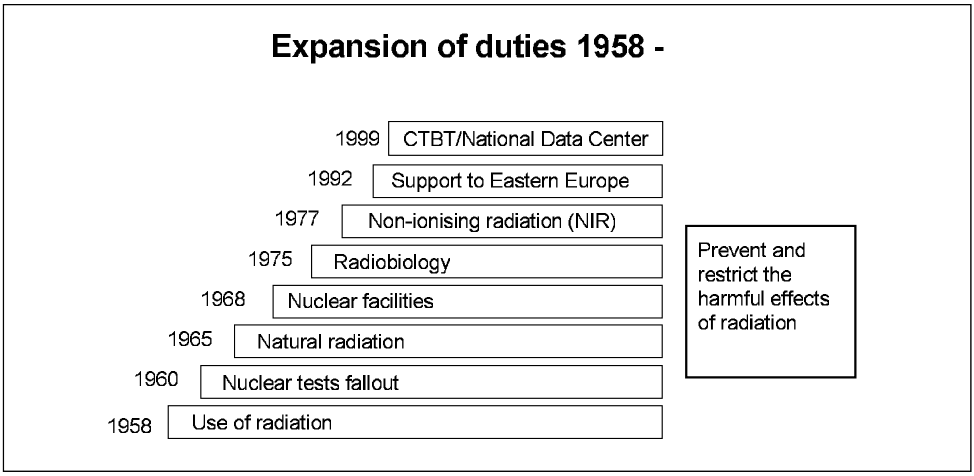


Figure 1. Expansion of functions of STUK.

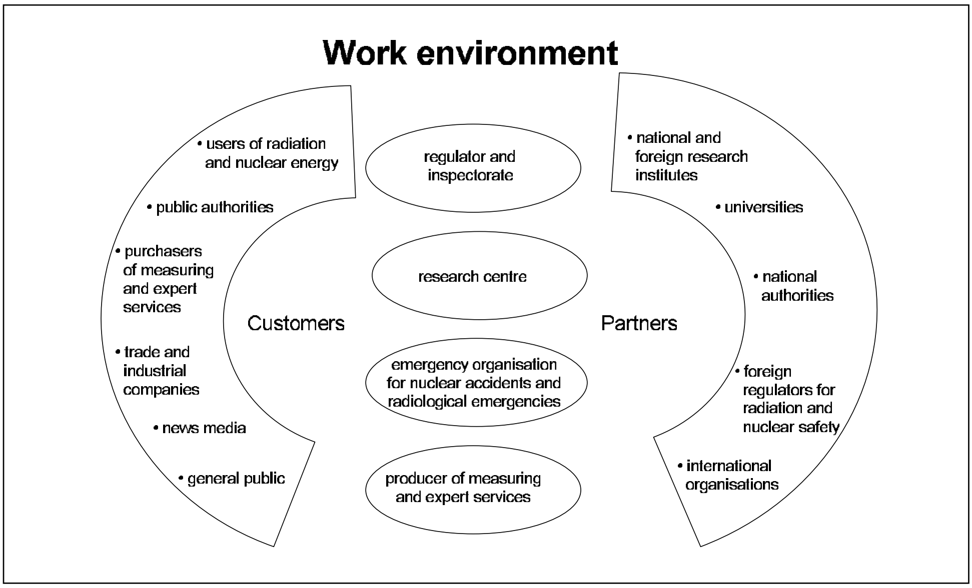


Figure 2. Work environment of STUK.

also produces expert services in surveillance of environmental radioactivity and metrology. STUK's areas of operation cover the whole range of radiation and nuclear safety and ionizing and non-ionizing radiation.

The multiple roles of STUK and the work environment involving different customers and partners are illustrated in Fig. 2.

STUK has one strategic plan that is updated every fourth year. The current strategy was updated in 2003 encompassing the period of 2003 – 2006. The strategy describes the mission, vision, success factors, values, operational environment, focus areas (effectiveness, processes and structures, development and functional capability, resources and financing), topics elaborated further in specific action plans and, performance indicators. The STUK level strategy is complemented by action plans prepared for all core processes, including research.

Process approach promoted by the standard ISO 9001:2000 was adopted in 2002. Extensive work has been done since then first by identifying and describing the main processes and then updating the respective manuals, and preparing flow charts. The work with the processes has continued several years. Now there exists, among other things, a table for core processes and support processes identifying outcomes of the respective process, process monitor, process owner and respective quality manual guide.

In addition to research, STUK has prepared action plans for: regulation of nuclear power plants, regulation of nuclear materials and nuclear waste, regulation of radiation safety – ionizing radiation, regulation of radiation safety – non-ionizing radiation, metrology, surveillance of environmental radioactivity, preparedness for emergencies, information and data management, public communication and rule making.

Vision of STUK is:

- The level of radiation safety and nuclear safety is high in Finland, and provides an outstanding standard for international benchmarking.
- STUK is well-known and respected as an expert organization, as an independent regulator dedicated to safety, and as an influential international actor.

Carrying out the STUK strategy, the success factors are:

- Our impact on maintenance and development of radiation and nuclear safety is effective and risk informed.
- Our safety regulations are in line with good international practice.
- Our research work is of high quality and focused on key issues of radiation protection.
- Our work processes are consistent, cost-effective and well-defined.
- Availability, quality, and speed of our services meet the expectations of our clients and partners.
- Quality and effectiveness of our work are improved continuously and systematically.
- Our staff is in good mental and physical condition.

- Our staff is professionally competent, well motivated, and has high work ethic.
- Our financial situation, work conditions and tools are in a good shape.

Basic values that direct STUK's operations are competence, openness and courage. According to these, decisions, positions and other measures are based on professional knowledge and competence; acting is open and honest, both towards stakeholders as well as in internal communication; problems are identified, as well as own views, and brought up rigorously. Responsibility for own decisions and acts is acknowledged and possible errors are corrected.

The strategy of STUK has been formulated according to Balanced Scorecard (BSC) and it covers the goals in effectiveness, the processes and structures, regeneration, working capacity and resources and financing (see Fig. 3). The focus areas are set according to main processes.

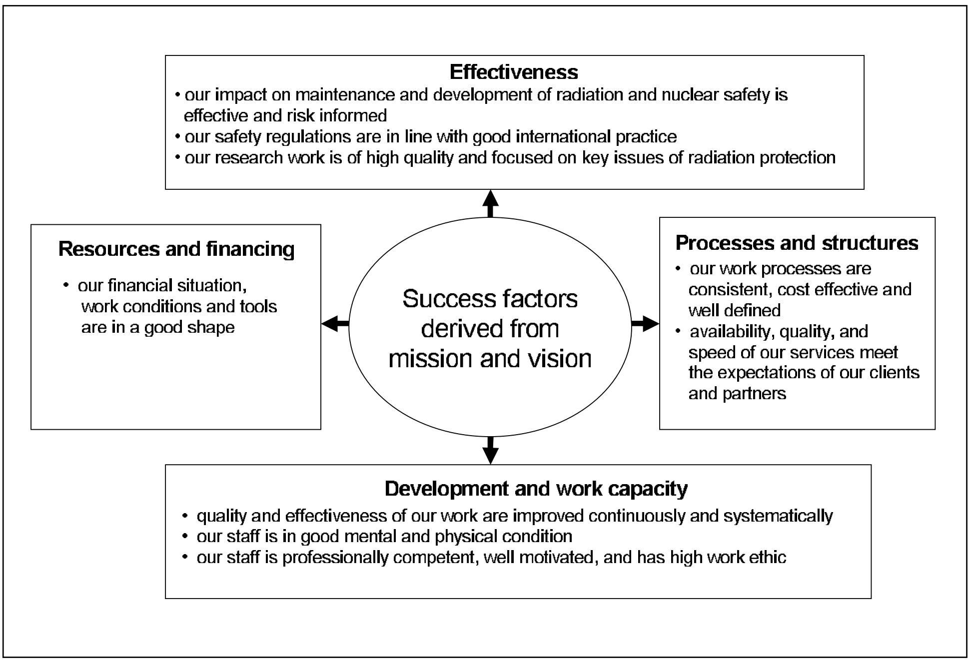


Figure 3. Success factors derived from mission and vision.

1.1.3 Changes in the operational environment

In the recent years STUK has identified the following challenges and possibilities in its operational environment:

- Renewal of international radiation protection principles
- Radiation protection of the environment
- EU directives and recommendations on radiation protection
- Development of medical diagnostics and treatment methods based on use of ionizing radiation
- Need to improve quality and competence in use of radiation
- Increased use of equipment that generate electromagnetic fields
- Need to improve radiation and nuclear safety in Central and Eastern Europe
- International terrorism
- EU directives and recommendations on radiation protection
- EU plans to harmonize safety requirements and regulatory practices
- Construction of a new nuclear power plant
- Major modifications at operating nuclear power plants
- Final disposal of spent fuel
- Formation of European Research Area, 6th framework program
- Development of technology used in information management and communication
- Changes in financing of radiation and nuclear safety research

1.1.4 Identifying priority areas for research

The research strategy is based on STUK's mission: to protect people, society, environment, and future generations from the harmful effects of radiation. For this purpose, research is carried out on radiation levels, effects of radiation and prevention of radiation hazards. When STUK decides which new projects are prioritized and funded, the following factors are taken into account:

- need of state-of-the-art knowledge
- importance of exposure to public health
- possibilities to limit radiation exposure
- societal need of the research and
- need to get basis for accounting specific Finnish circumstances in the definition of international safety requirements and safety limits

The main emphasis in research activities is to improve scientific level and effectiveness. The strategic focus areas are:

- project networks: universities and research institutes

- critical evaluation of results
- publication in various forums selected on basis of scientific value
- information on results to stakeholders
- active contribution to development of principles in radiation protection principles and criteria given in the publications of the ICRP and ICNIRP
- international co-operation on effects of radiation to plants and animals

The main areas of research are:

- Health effects of radiation; further research data is needed especially on risks of low doses, internal exposure and non-ionizing radiation; main focus areas in radiobiological research are genomic instability, mechanisms of carcinogenesis and biological dosimetry.
- Exposure of Finns to natural radioactivity is among the highest in the world; radon surveys and mitigation help to decrease the exposure.
- Preparedness for nuclear and radiation accidents; producing data on methods how to protect and restrict the harms of radioactive fallout and to develop methods that allow to follow and predict the radiation situation.
- Research supporting safe medical use of radiation; especially optimization of medical actions causing the greatest exposure.
- Research needed to develop radiation detection methods and dosimetry.

1.1.5 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. Publications in peer-reviewed international journals provide the means for communication with the scientific community, including risk assessment organizations. Studies that are of interest mainly at the national or local level are published in a national report series, STUK-A series, in Finnish and/or Swedish. Municipalities and counties are active users of STUK's environmental surveys and databases, such as radon in indoor air or radon or uranium in drinking water.

In addition to publications, new methods, improved study protocols, computer models and databases are products that enhance the capability of

STUK to carry out its mission. STUK research also contributes to improved safety procedures that are applied by the users of radiation, for example, in medicine. 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 STUK personnel.

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

1.1.6 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, non-targeted effects, individual susceptibility, molecular epidemiology), emergency preparedness (including terrorist and malevolent acts), and co-operation with neighbouring areas of Eastern Europe. EU directives on radiation protection and medical exposure to radiation will influence the course taken by research carried out at STUK. New research priorities also include studies on non-ionizing radiation, especially the effects of mobile phone frequency radiation. Possible effects of mobile phone radiation will be studied by proteomic approaches at the cellular level as well as using epidemiology. Radiation protection of biota will also be addressed in order to prepare for future environmental radiation protection guidelines. More information on future plans is available in the laboratory descriptions in Chapter 2.

Detailed descriptions of STUK research projects for the period 2000–2002 have been published in the STUK-A179 report (Salomaa 2000) and for the period 2003–2005 in the STUK-A202 report (Salomaa 2004). The plans include projects in the following areas: medical radiation, natural radiation, environmental transfer of radioactive substances and nuclear emergency preparedness, protection of the environment from the effects of ionizing radiation, health effects of radiation, and non-ionizing radiation. Each year, about 80 research projects are on-going and 10–20 of them are completed.

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

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

- applied research, deriving from the needs of the authorities and society or even those of stakeholders such as hospitals or industry
- problem-oriented basic research, which typically addresses the health risks of ionizing and non-ionizing radiation and mechanisms of radiation action on living cells

Applied research typically leads to more knowledge about exposures and better measurement and dose assessment techniques, and formulates improved procedures for users of radiation and tools for emergency preparedness. 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-ionizing radiation and natural radiation). Research work has a fundamental role in improving the calibration and accuracy of the measuring instruments of ionizing radiation, electromagnetic fields and ultraviolet radiation. Nuclear reactor regulation and nuclear materials regulation benefit 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 the 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 fundamental 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 organizations. However, the studies conducted on the Finnish population are also directly relevant at the national level.

The Department of Research and Environmental Surveillance has four main functions: research, environmental surveillance, emergency preparedness and services. The relations and synergies between these different functions are illustrated in Fig. 4.

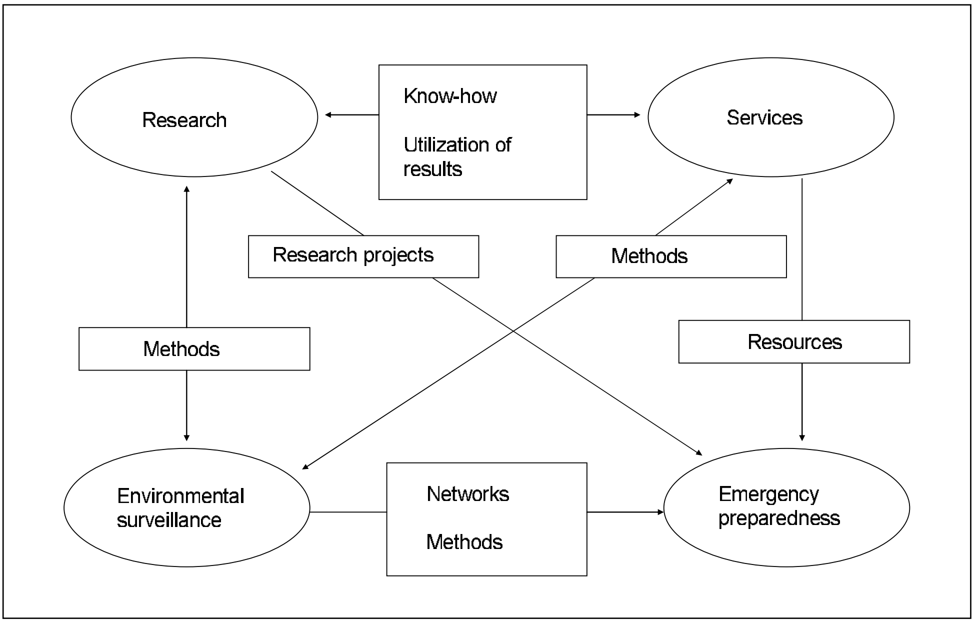


Figure 4. Synergies between the different activities of the Department of Research and Environmental Surveillance.

Research is conducted by all laboratories and many research projects involve experts from the different laboratories. All laboratories are also involved in emergency preparedness and all permanent staff members have a specific role in STUK's emergency organization. Five laboratories take part in surveillance of radiation in the environment. Radiation measurement services are provided by seven laboratories, with the largest programs related to radon, NPP environment and internal contamination. There are multiple contact points and synergies between the different activities. Environmental research, environmental surveillance and analytical services make use of the same sample treatment and analytical methods and know-how. Data generated by the services is also used for research purposes, as in the case of radon mapping or monitoring of the NPP environment. Research is generating new methods and technologies for use in radiation emergencies and environmental surveillance. Emergency preparedness benefits of the monitoring networks and routines. Last but not least, the income from the contracted services makes it possible to employ staff and buy equipment so that these extra resources are available in case of a radiation emergency.

1.1.8 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 specialization. In some areas, especially in those related to emergency preparedness and environmental radioactivity analyses, the lack of other research units with expertise in radiation protection is becoming problematic, since there should be more capacity in that field in case of severe fallout situations. In Finland, research related to ionizing radiation protection is carried out in the medical physics departments of universities/university hospitals, at the Technical Research Centre of Finland (VTT) and the Laboratory of Radiochemistry at the University of Helsinki. Research related to non-ionizing radiation protection is carried out at the Institute of Occupational Health and University of Kuopio.

During 2000–2004 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
- University of Oulu
- Helsinki University Hospital
- Kuopio University Hospital

- Tampere University Hospital
- Turku University Hospital
- 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 Institute (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
- Finnish Cancer Registry
- Centre for Metrology and Accreditation
- Lapland Regional Environmental Centre

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 most EU countries, all Nordic countries, the Baltic states (Estonia, Latvia and Lithuania, now EU Member States), NIS countries (Russia, Kazakhstan, Ukraine and Belarus), several Eastern European countries (Poland, Czech Republic, Slovakia, now EU Member States) and non-European countries such as the USA, Canada, Japan, China, Australia and South Africa. The foreign networks involve well over a hundred research institutes.

1.1.9 Impacts on the ministry level

Administratively, STUK comes under the Ministry of Social Affairs and Health. However, several other ministries (Fig. 5) deal with issues related to radiation and nuclear safety.

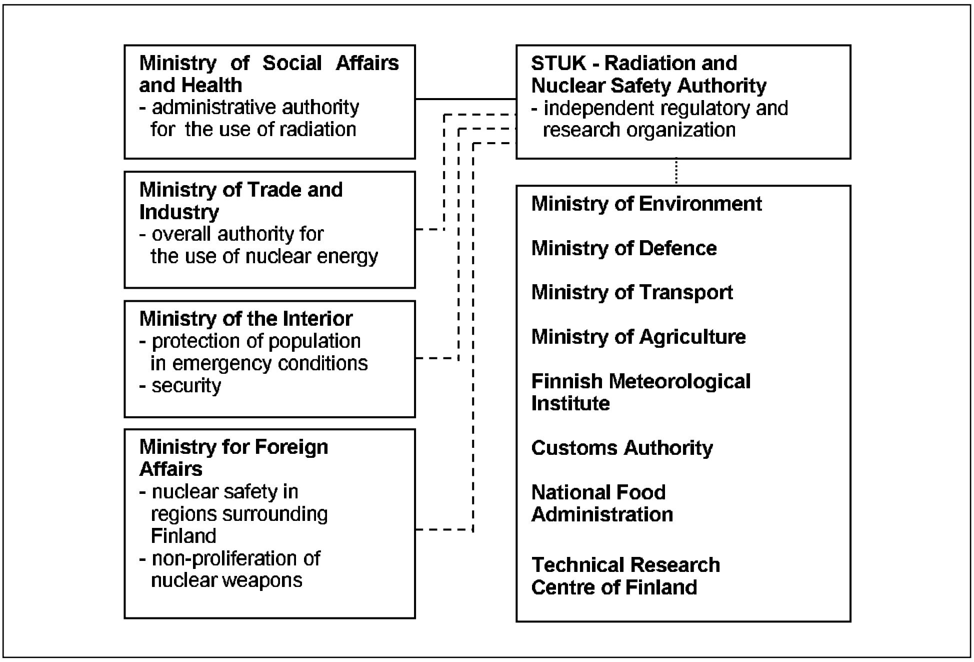


Figure 5. Co-operation between STUK and ministries and other governmental organizations.

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 Ministry of Trade and Industry, Ministry of Environment and Ministry of 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, the Advisory Board for Nuclear Energy and the Scientific Advisory Board for Defence.

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 ionizing and non-ionizing 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; protection of the environment
- **Ministry of Defence**
  Nuclear and radiological threats, emergency preparedness, mobile/airborne radiation measurements
- **Ministry of Agriculture**
  Agricultural radiation countermeasures, radionuclides in the food chain, forests

1.1.10 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 universities and professional level education and several STUK 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 organized 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.

Over the years, more and more attention has been paid on the exploitation and impact of the STUK research results. Exploitation plan is an integral part of the research project plan. At the international level, many of the research results are communicated via research networks or different working groups. Since Finland joined the European Union in 1995, STUK has obtained a strong position in European research programmes, especially in the Nuclear Fission programme. STUK has also given a considerable input in the development of radiation protection standards of the European Commission via Article 31 group and commissioned services of DG TREN (especially for natural radioactivity). STUK has also acted as a contracted support organization to the EC in radiation and nuclear emergencies (RESPEC project). During years 1997-2001 Finland hosted a WHO Project Office for Nuclear Emergency Preparedness, with STUK acting as the supporting WHO Collaborating Centre. STUK experts advised WHO in public health aspects of nuclear emergencies, such as preparation of Guidelines for Stable Iodine Prophylaxis. STUK also has representatives in the committees and working groups of OECD Nuclear Energy Agency (NEA). However, the lack of STUK's representation in international risk assessment organizations such as UNSCEAR or ICRP has caused 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 ionizing and non-ionizing radiation at the molecular level to daily monitoring of levels of radiation. This broad expertise has enabled also STUK's own technical product development whenever it has been needed.

As described in chapter 1.2.1, research results are distributed, besides 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 also publishes 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 also give lectures in various courses dealing with radiation, health effects or environmental protection, emergency preparedness or nuclear safety.

STUK has a close co-operation with educational institutions. In addition to joint research projects with universities, certain scientists of STUK act as permanent lecturers in universities. The new Radiation and Nuclear Safety book series has been welcomed as training material by several educational institutions.

1.2 Publications

The number of research publications in 1995–2004 is shown in Fig. 6. The publication categories include original publications (articles in international peer-reviewed journals); articles in the proceedings of international scientific meetings, and reports published in the institutes' own publication series. Publishing 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 2, after each laboratory description. The number of research publications shows an increasing trend over the years. During the years 1995–1999, an average of 28 original articles was published per year, whereas during 2000–2005 the average number of original publications was 35 per year. The increase is partly explained by internal training on scientific writing during year 2001. The high numbers of reports in years 2002 and 2003 partly reflect the preparation of the chapters for the new STUK book series.

About 60 experts at STUK have contributed to the new Radiation and Nuclear Safety book series (in Finnish). To date, five books have been published: Radiation and its detection (2002), Health effects of radiation (2002), Radiation in the environment (2003), Use of radiation (2004), and Nuclear safety (2004).

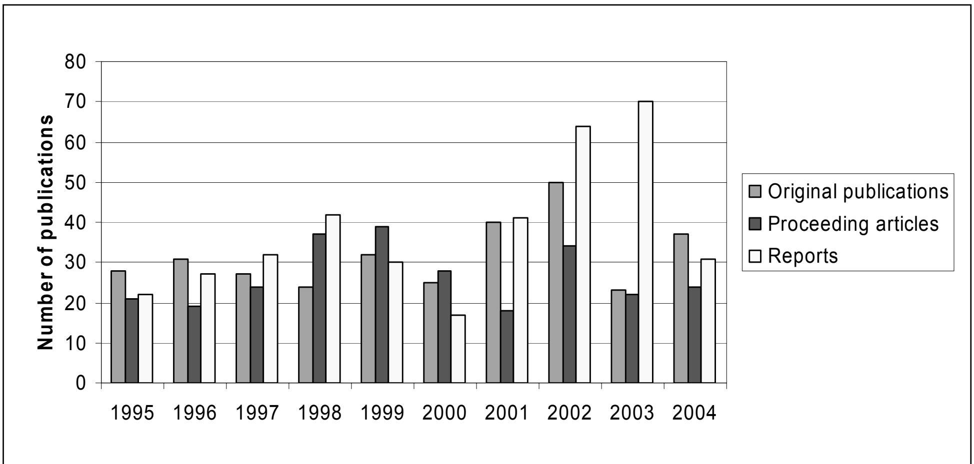


Figure 6. Number of research publications in the three publication categories during 1995–2004.

Two more books on non-ionizing radiation are in preparation, one dealing with electric and magnetic fields (to be published during 2005) and the other with optical radiation.

1.2.1 Actions to popularize research results

Many STUK research 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 popularized summary of the results to the Information Unit immediately after their publication in an article or report. The information officers make use of the summaries for press releases and information materials. Citizens are very interested in news dealing with radiation or nuclear safety, and the media takes up practically all STUK press releases. Training of scientists includes instruction on communicating with the media which is also practised in emergency exercises.

Scientific expertise on effects of radiation and its occurrence in the environment has increased the general credence to STUK. The past 20 years have demonstrated that the mass media and private citizens contact always experts of STUK whenever news or rumours on radiation appear. On the other hand, STUK itself has also placed resources on public communication in order to provide necessary information expeditiously and in a professional way. In 2004, STUK used 3.1% of its resources for public communication. STUK's communication is proactive, open, timely and understandable. Experts can be reached at any time, including nights, weekends and holidays via an information officer duty system.

There are several ways of popularizing 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 (the new book series)
- Internet pages (www.stuk.fi), which were improved and updated during 2004, including questions for experts and answers within two days
- About 9 000 visitors per month in the Finnish pages, 5 000 in the English pages
- Most popular were the radon pages, then research and pages of general knowledge on radiation
- 200–300 questions for experts per year were received as mentioned above

- Separate ultraviolet radiation, home and radon expert teams on the web received about 50, 50 and 150 questions per year, respectively
- Press releases and press conferences, interviews
- Training courses and lectures aimed at the stakeholders
- Information via telephone

1.3 Organization and resources

1.3.1 Organization

Most of STUK research is carried out by the Department of Research and Environmental Surveillance. In addition, research supporting the regulatory functions is carried out by the Department of Radiation Practises Regulation (metrology and dosimetry, use of radiation in medicine and industry) and the Laboratory for Non-Ionizing Radiation (electric and magnetic fields, optical radiation).

The organization of STUK is shown in Fig. 7 and those of Departments of Research and Environmental Surveillance and Department of Radiation Practises Regulation in Figs. 8 and 9, respectively.

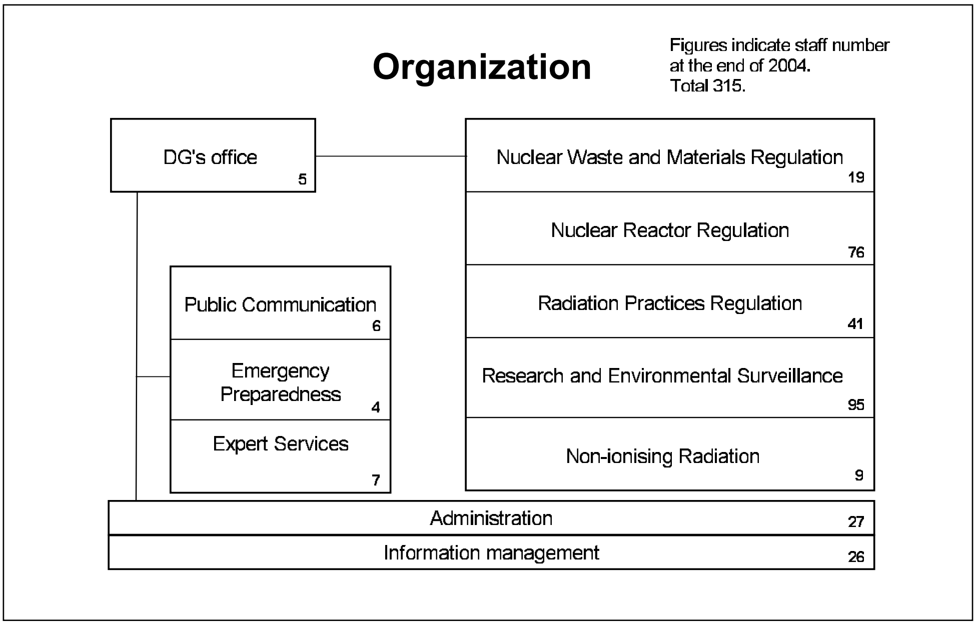


Figure 7. Organization of STUK.

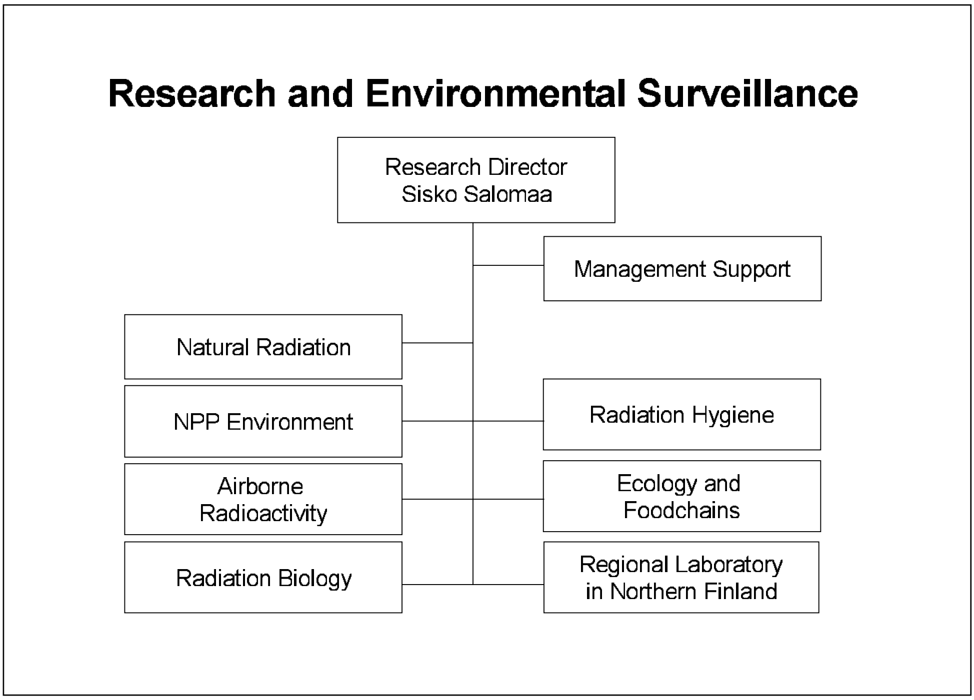


Figure 8. The Department of Research and Environmental Surveillance.

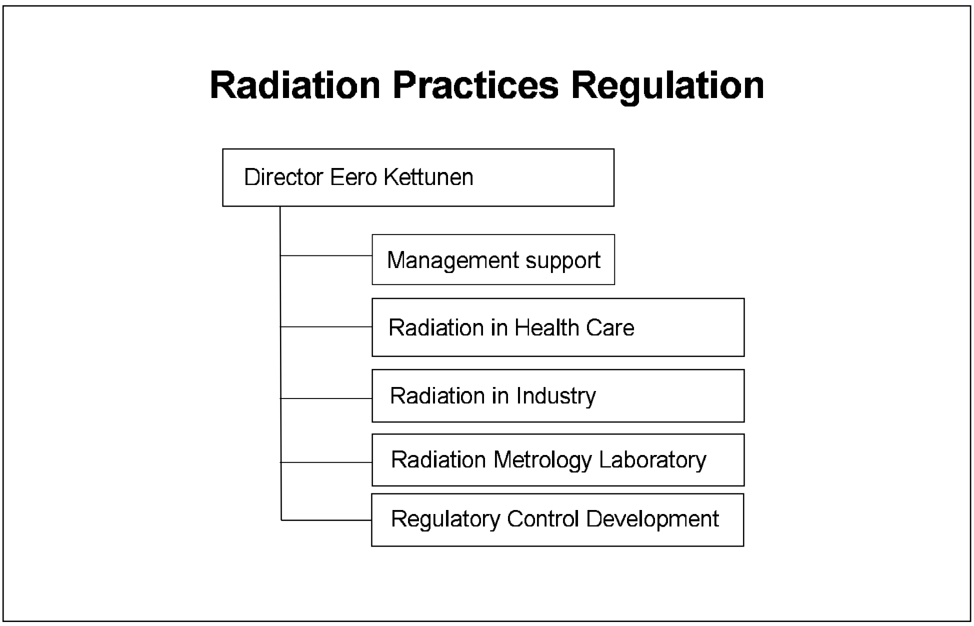


Figure 9. Organization of the Department of Radiation Practices Regulation.

At the end of 2004, there were seven laboratories in the Department of Research and Environmental Surveillance. Six of these were situated in Helsinki (Natural Radiation, Radiation Hygiene, NPP Environment, Ecology and Foodchains, Airborne Radioactivity, and Radiation Biology) and one in Rovaniemi (Regional Laboratory in Northern Finland). The Research Director is responsible for the overall conduct of research at STUK, as well as general administration, emergency preparedness and information dissemination of the department. The Deputy Director is responsible for conduct of environmental radiation surveillance, as well as expert services, finance, and quality management of the department.

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 the 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. Every laboratory has its own meetings to ensure the flow of information from the department and STUK level to the laboratory and between the laboratory personnel. Permanent work groups for sampling and pre-treatment, gamma spectrometric measurements and radiochemical analyses exist for treating the development, purchases, guides and substance of these areas. The groups consist of representatives from each relevant laboratory. 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.

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.

Quality Management System of STUK

STUK's quality system is based on international quality standards (ISO 9004: Quality management systems – Guidelines for performance improvements, and ISO/IEC 17025: General requirements for the competence of testing and calibration laboratories). The principles of the total quality management (the EFQM Excellence Model), are also applied.

The quality policy of STUK – "This is how we operate – quality policy of STUK" is the up-most document directing the quality system. The rest of the quality system is specified by other guides and orders of the STUK Quality Manual. The STUK Quality Manual is complemented by other STUK-level manuals as well as quality manuals and guides that are valid in different fields of STUK's activities. All the guides and plans are available on the Intranet.

In 1999 the quality policy of STUK was extensively defined and it was updated in 2003. The management of STUK is committed to observe the quality system and to continuously improve the quality of activities. Customer focus is an essential part of the quality of work.

Accredited processes

Accreditation of laboratory processes was awarded by FINAS (The Finnish Accreditation Service) in 1999 and was renewed in 2003 according the European Standard EN ISO/IEC 17025 standard. The accreditation field is "Test of radiation safety and related environmental sampling" (Test laboratory T167). Separate accreditation fields are:

- Advanced gamma spectrometric analyses (all gamma nuclides)
- Gamma spectrometric measurements (Cs-, I-, K-, U-, and Th-isotopes)
- Radiochemical analyses (tritium, Sr-, Pu-, Am- and Cm-isotopes)
- Direct measurement of people
- Airborne radon concentrations
- Natural radionuclide in water (Rn-, Po-, Pb- and U-isotopes)
- Chromosome analyses
- Sampling nearby nuclear power plants in terrestrial, air and marine environments

Since the accreditation has been adopted, external audits by FINAS have been performed yearly. In addition, internal audits of each separate accredited field have been carried out in order to ensure continuous developing of the laboratory processes.

One laboratory has also been certified by CTBT organization (Comprehensive Test Ban Treaty). Most of the requirements are based on standard ISO/IEC 17025. Some additional requirements are set for the safety of samples, measurement system and analysis of data.

Finland has signed in 1999 an international agreement on metrology (Mutual Recognition Arrangement, MRA). According to agreement, participants recognize each other's measurement and calibration certificates. The MRA presumes that the standard ISO/IEC 17025 is applied. The fulfilment of the agreement is coordinated in Europe by EUROMET. In 2003 STUK presented its ionization radiation dosimetry related quality system to EUROMET QS-forum. The quality system was accepted by the evaluators. In this connection, the principle of Self-Declaration is applied instead of accreditation.

1.3.2 Personnel

In 2000, the number of employees in the Department of Research and Environmental Surveillance was 102. In 2001, the Medical Radiation Laboratory was fused to the Department of Radiation Practices. During 2001–2004, the number of employees in the Department of Research and Environmental Surveillance varied between 91 and 96, depending on the number of fixed-term personnel and trainees working on projects. In addition, about 25 persons working at the Department of Radiation Practices Regulation and the Laboratory of Non-ionizing radiation use part of their time in research. The number of full person-years spent on research sector has varied between 61 and 72 during 2000–2004 (see Fig. 13, page 33).

The educational background of the staff in the units described above is illustrated in Figs. 10 and 11. Currently, 55 per cent of the permanent staff has 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. Twentyfive of the 96 persons with permanent positions have post-graduate level qualifications. Eighteen of them are doctors (Ph.D., MD.PhD. or Dr.Tech.) and the rest have a Licenciate's degree (Ph.Lic, Tech.Lic.). Six of the doctors are docents, i.e. lecturers in university departments. Seven Master's and two Licenciate's degrees and five Doctorates were completed in 2000–2004. In addition, two graduate level degrees were completed.

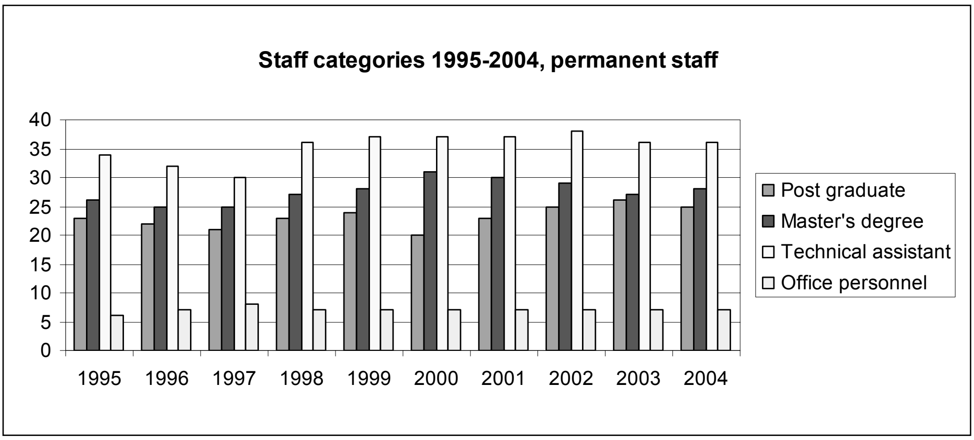


Figure 10. Staff categories 1995-2004, permanent staff of the units performing research.

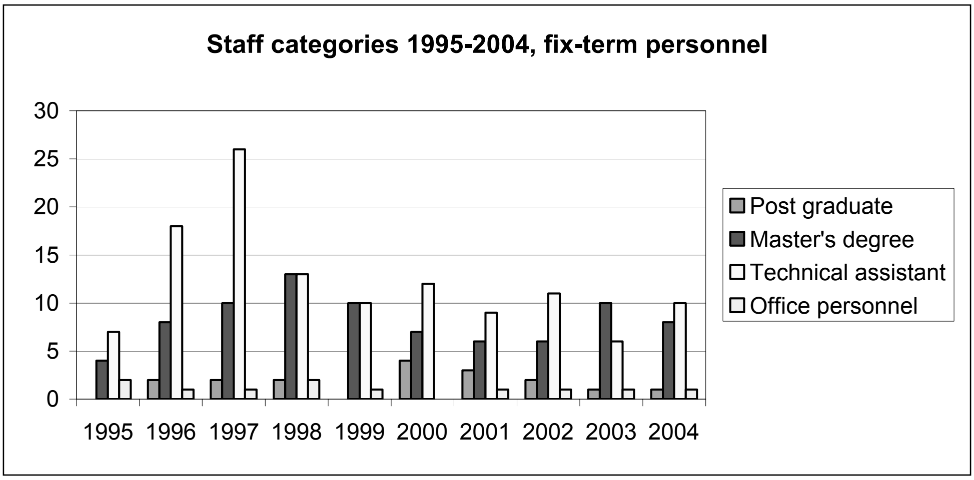


Figure 11. Staff categories 1995–2004, fixed-term personnel of the units performing research.

1.3.3 Recruitment of researchers

A large number of the permanent staff was engaged in the 1960s and the '70's when the functions of STUK were expanded due to the 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 a long experience, 15.9 years of experience in average in 2004, 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 total of 300 employees, some 130 will retire during the next ten years. Average age of the permanent staff was 47.4 years and that of the fix-term staff 35.3 years in 2004.

It takes several years to train a scientist in a specialized 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 specialized training are directly available for the posts. External funding and shared-cost contracts have enabled the employment of fixed-term personnel, including students aiming at a Master's degree or doctorate. Many of these project researchers have later been engaged permanently by STUK, resulting in a more balanced age structure. Nevertheless, transferring the knowledge of retiring experts to the new generation of radiation protection specialists continues to be a major challenge.

STUK started an extensive internal training programme on different aspects of radiation protection and nuclear safety in 2002, along with the publication of the new book series that has been used as training material (Paile 2002, Ikäheimonen 2003, Pöllänen 2004, Sandberg 2004, Tapiovaara 2005, and two more books to be published).

In Finland, there are no specialized PhD Schools in the field of radiation protection. However, post graduate training has been provided by the Doctorate School on Public Health, Doctorate School for Environmental Health and Doctorate School on Systems and Risk Analysis. Three staff members have attended the training for a European MSc in Radiation Biology during recent years.

1.3.4 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 25% of STUK's total costs. Planning of a new nuclear reactor unit in Olkiluoto has increased accounting of nuclear safety compared to research. The breakdown of STUK costs among the different action areas in 2004 is shown in Fig. 12.

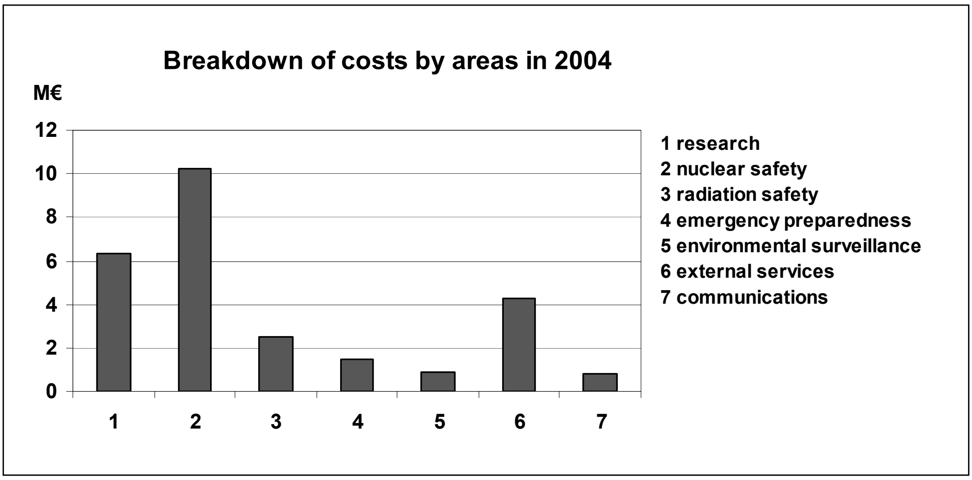


Figure 12. Breakdown of total STUK costs among the different action areas in 2004.

Research has been earlier STUK's biggest action area in terms of human resources, but during the last years, the portion of nuclear safety has become the largest one. About 20–24% of total human resources have been devoted to research purposes during the past few years, while earlier it was more than a quarter of the resources (Fig. 13). In addition to the fact that the volume of nuclear safety has increased, other reasons for the decreasing proportion are the increase in other actions, such as internal development projects of STUK, large expert service projects, writing of Radiation and Nuclear Safety book series, and large emergency preparedness projects that have taken time of the researchers.

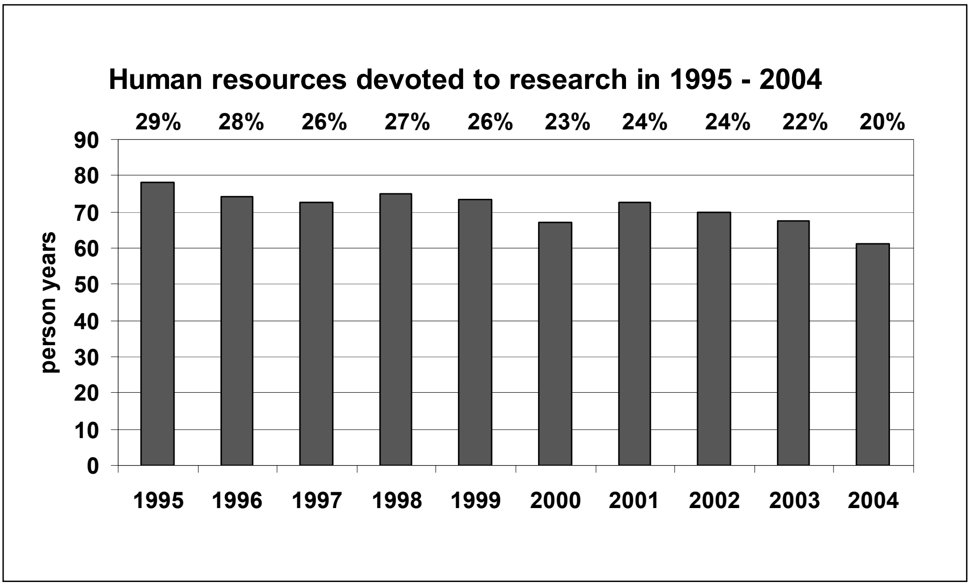


Figure 13. Person-years devoted to research at STUK in 1995–2004. The percentages in the figure indicate the proportions of STUK's total human resources.

The small variations in person-years reflect the number of temporary employees in short-term research projects. In 2004, 61.3 person-years were allocated to research.

The total cost of research has been around EURO 6–7 million during the past few years (Fig.14). Since 1995, the total costs increased slightly, along with the general cost index and due to higher overhead costs, until 2003. Direct research costs varied from EURO 2.7 million to 3.7 million between years 1995–2004.

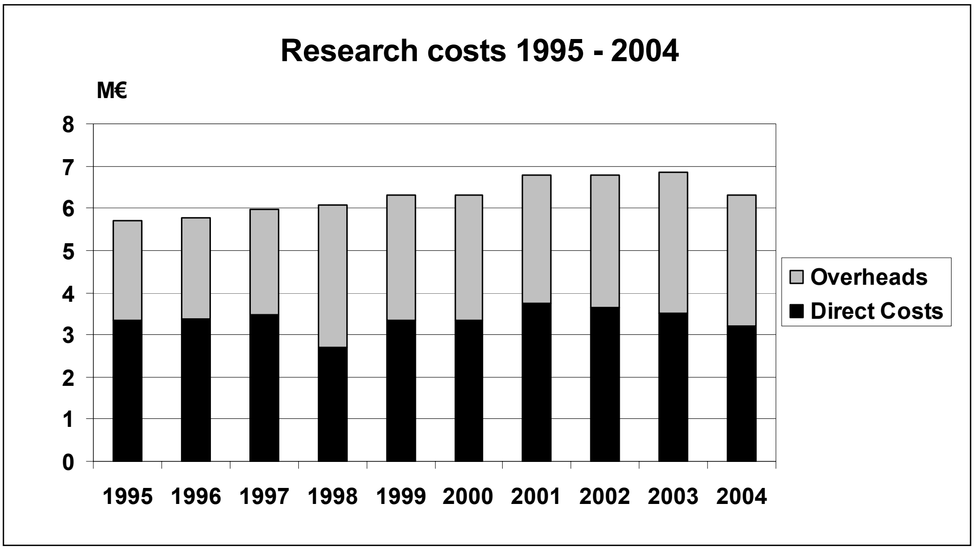


Figure 14. Trends in research costs from 1995 to 2004.

Sources of funding

Most of the research funding comes from the state budget and the overhead costs shown in Fig. 14 are entirely covered from budget funding. The overhead costs include administration, rents and internal services. Direct costs can be allocated to several funding sources. In Fig. 15, 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).

The proportion of research funding from the state budget has gradually declined over the years (Table II).

The proportion of external funding in financing STUK research has been 9–15% during 2000–2004. External funding covers about 600–1000 k€ yearly. In addition, a part of the training is carried out as shared-cost projects.

The role of income from services in funding is more remarkable than the external funding of research. Services provided by STUK consist of radiation measurements, calibrations, training, and expert services to be agreed case-by-case. In 2000–2004, STUK has received 4–8 times more income from services than from co-financed research projects. In 2004, the external funding in STUK

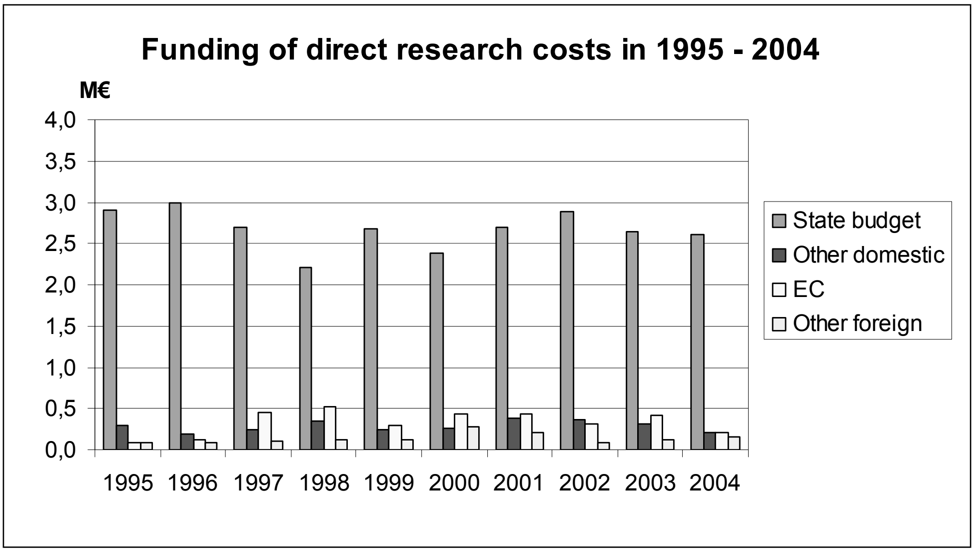


Figure 15. Sources of research funding at STUK in 1995—2004.

Table II. State budget for STUK, research costs and proportion of research costs from state budget in 2000—2004.

Year	State budget (k€)	Research costs (k€)	Research costs by state budget (k€)	Portion of research from total budget (%)
2000	9071	6299	5324	59
2001	10103	6780	5815	58
2002	10436	6768	5971	57
2003	11073	6845	5945	54
2004	10659	6313	5725	54

research was 588 k€, which is about 13% of the income from services in the same time (4520 k€).

Financial resources for the different sectors of research

For accounting, research is divided into nine areas of focus:

- Natural radiation
- Radioecology and emergency preparedness
- Health effects

- Metrology
- Medical radiation
- Non-ionizing radiation (NIR)
- Nuclear safety
- 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 organizations outside of 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 2004, the total cost of research was EURO 6,313,000, broken down among the different research activities as shown in Fig. 16. Radioecology and research related to emergency preparedness accounted for 37% of the funding, followed by radiobiological and epidemiological studies of radiation effects.

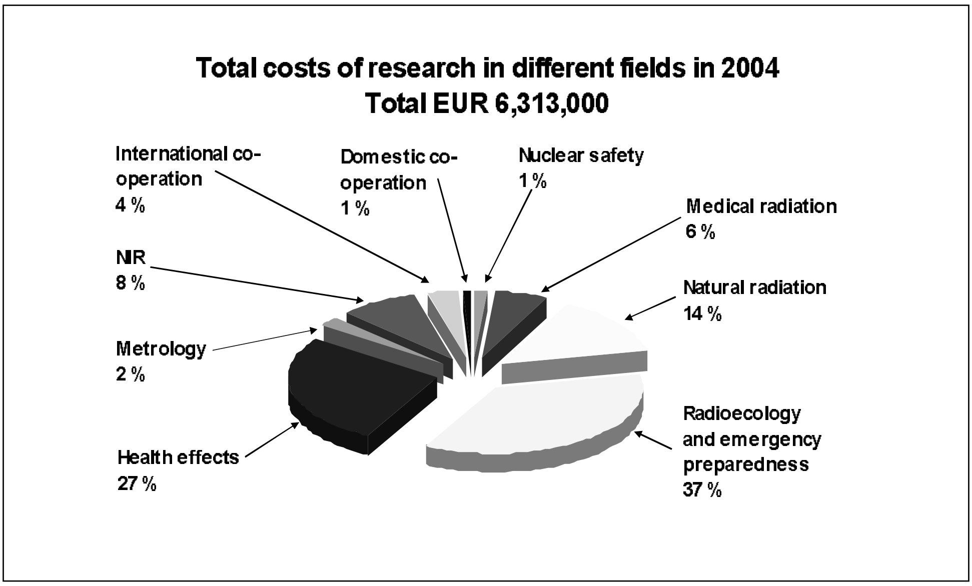


Figure 16. STUK research costs in different research fields in 2004.

1.3.5 Research facilities

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

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-ionizing radiation, and calibration of measuring instruments. STUK has seven laboratory rooms for low-background radioactivity measurements (alpha, 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 and molecular biology are isolated from the other research facilities. Altogether 88 fume cupboards are available. The laboratory for handling high amounts of radioactivity is located in the sub-basement of the building.

On the roof of the STUK main building, the air sampling station CINDERELLA filtrates radioactive substances from air, monitors radionuclides collected on the filter in real-time, changes the filter and performs on-site HPGe measurements of the filter automatically. CINDERELLA sends its spectral data to Linssi database where the analysis is performed. The results are available via www tools on the intranet of STUK. The initial analysis is fully automated; the final analysis is performed by an analyst who raises a "flag" of final results. CINDERELLA was built in 1995–1997, and globally it is the very first automated high-volume air-sampler which fulfils the criteria of CTBT monitoring. The automated analysis pipeline was designed in 2003–2005. CINDERELLA is now available commercially.

Laboratories for non-ionizing 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 × 2,3 × 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 painted. The measurement site in optical laboratory is also screened with a black curtain from the rest of the room.

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

For ensuring the high quality of analytical systems, considerable investments on specific technologies and equipment have been done during 2000–2004. A low background liquid scintillation spectrometry (Quantulus), a liquid scintillation spectrometer (Guardian), eight semiconductors for gamma spectrometers, three thin-window germanium detectors and two scintillation detectors have been purchased. Alpha measuring systems have been supplemented with new chambers and detectors. A mass spectrometer for protein analytics and a professional SAR assessment system for testing of mobile phones have been acquired. New analytical programmes for spectrometer and calculation systems were obtained. Emergency preparedness has been improved by designing and constructing a mobile laboratory van (SONNI). The older mobile laboratory unit was transferred to the Regional Laboratory of Northern Finland. Treatment of samples has been facilitated with a microwave digestion oven, a sample oxidizer and an atomic adsorption spectrophotometer. Two air samplers have been supplied and marine sampling has been improved with a new, modern seaworthy sampling boat. In addition, a large amount of smaller laboratory equipment has been purchased.

A new, uniform Laboratory Information Management System (LIMS) was installed and tailored for the use of all laboratories during 2003–2005. The system helps managing of all laboratory working, data management, reporting and quality assurance at the department.

1.3.6 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 support in the Information Management is provided by EDP-, DSS- and IS-units which support the computer network services, hardware installations and maintenance, data system services as well as information services. 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. A new Document Management System is under development.

During the last years, internal training on different aspects of radiation protection has been carried out. The training modules are based on the new Radiation and Nuclear Safety book series. Each year, about 4–6 training periods are arranged. Internal training is also provided to improve skills needed to use the software (office programs, database construction, programming), and in management and communication. Tailor-made courses are also organized to meet the needs of specific personnel groups. Twice a year there is a 2-day introductory course for new employees describing the different activities of STUK. Training at outside organizations is also actively supported. Occupational health care, STUK's own gym and organized fitness activities help in maintaining the physical and mental wellbeing of the personnel.

1.4 Summary of the previous external evaluations of STUK research and the actions taken as a consequence

1.4.1 International evaluation of STUK research activities in 2000

At the request of the Finnish Ministry of Social Affairs and Health, an international team of four experts evaluated STUK's research activities in 2000. The evaluation team familiarized with STUK's research activities by visiting STUK and examining the ample written material delivered to the team in advance.

The report, finalized in January 2001, states that STUK belongs to one of the leading research institutes in Europe or even in the whole world, when taking into account STUK's multidisciplinary scientific expertise and the usability of the study results. The team took notice, for example, of the age structure of STUK and the need for new researchers in the field, the small size of the laboratories and the need for enhancing the co-operation and more active publishing of study results. The team emphasized the national cooperation with universities and the international cooperation with the Nordic countries and the EU.

The recommendations concerning the research activities at STUK were carefully analyzed by the research units and management in 2001. The number of development actions taken in consequence of the evaluation of research activities is approximately 80. In the follow-up of the actions, it was concluded that 94%

of them had taken place already by 2002. A summary of the main development actions is given below.

It has been decided to perform an evaluation of research activities every fifth year. The aim is to keep STUK among one of the leading research institutes in Europe or even in the whole world and to maintain the research publications comparable with other corresponding institutes.

An organizational analysis was made. On the basis of the analysis it was decided to keep the low setup of organization. Research activities regarding the medical use of radiation were concentrated into one operational unit. Later on, emergency management functions (RODOS) of the Management Unit of the department of Research were fused in the Laboratory of Ecology and Foodchains in order to strengthen the long-term management of contaminated areas after nuclear accidents.

In order to improve collaboration between the STUK laboratories, three cooperation groups that dealt with measurements, were established (gamma and radiochemistry groups and a group dealing with sampling and pre-treatment of samples). In addition, a metrology working group was established to combine the metrology processes carried out by the departments of Radiation Practises Regulation and Research and Environmental Surveillance.

The cooperation with universities was enhanced by participating in graduate schools, giving guidance to university and thesis students and investing in further training of STUK staff.

The publication performance was improved by arranging courses in scientific writing and statistical analyses.

More attention has been paid to delivering the expertise along when important experts of STUK are retiring. This has been done by better documentation of research projects and improved databases, the new book series, internal training, mentoring and, in some cases, by employing new staff prior to the retirement of key experts.

Collaboration between the four research institutes under Ministry of Social Affairs and Health in risk assessment has been started, first by a joint seminar of the Advisory Boards on Radiation Safety and Health Risk Assessment of Chemical Agents. More recently, Institute of Public Health, Institute of Occupational Health and National Research and Development Centre for Welfare and Health and STUK have initiated a comparison of risk assessment processes in the different institutes.

The black spot is still the load of work. There are tasks in abundance and too many projects compared with the number of employees. Not even the evaluators could give clear advice on what should be left out. Almost everything seemed to be of importance and especially time series that bind the resources were supported strongly as an important input to the international scientific community. The tasks of STUK are rather determined by decrees and international agreements, which effectively limit the operational environment and make it difficult to give up any of the traditional tasks or aim at new directions without any additional resources. Also joining the EU has brought along quite a number of new obligations. At the same time, less and less of the budget funding is devoted for research.

1.4.2 Structural development of government research system

In 2004, the government of Finland launched an evaluation of the needs for structural development of governmental research systems, including universities, sectoral research centres and funding organizations. For this purpose, the topics for research and the organization and funding of research carried out by STUK was also evaluated, as STUK is one of the sectoral research institutes in Finland.

The main conclusions were that STUK has no overlapping research activities with other governmental research institutes, STUK is a well organised research centre and its research is cost- efficient. As compared to other governmental research institutes, the level of external funding is low, only about 15% of total funding.

During autumn 2005, the governmental R&D evaluation and development mission will continue, and prospects for increasing the external funding will be search.

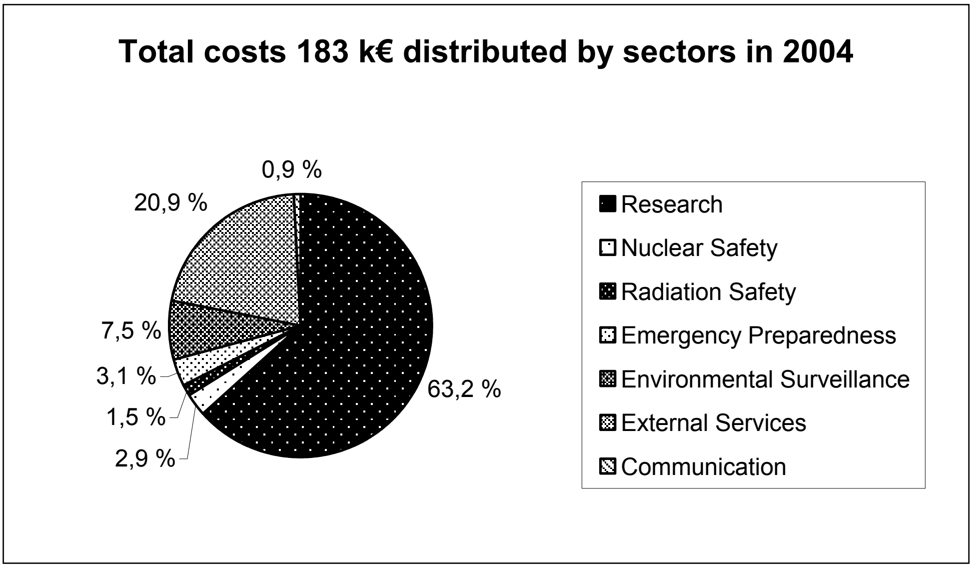
2 Laboratories

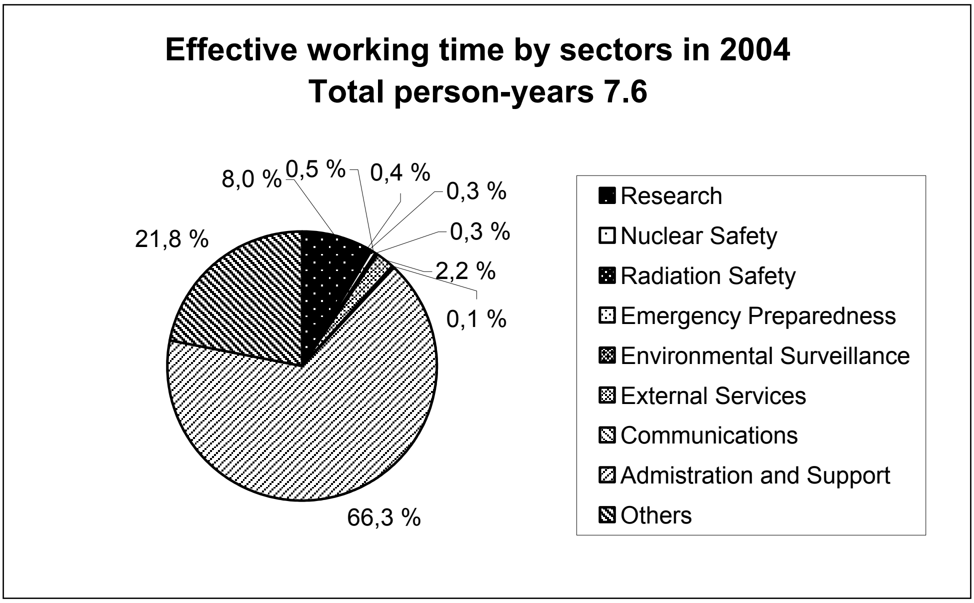
2.1 Department of Research and Environmental Surveillance, Management Unit

At the end of 2004, there were seven laboratories in the Department of Research and Environmental Surveillance. Six of these were situated in Helsinki (Natural Radiation, Radiation Hygiene, NPP Environment, Ecology and Foodchains, Airborne Radioactivity, and Radiation Biology) and one in Rovaniemi (Regional Laboratory in Northern Finland). The Research Director is responsible for overall conduct of research in STUK (core process owner), as well as general management of the department, emergency preparedness, and information. The Deputy Director is responsible for conduct of environmental radiation surveillance at STUK (core process owner), as well as expert services, finance, and quality management of the department.

The Management Unit has undergone considerable changes during the last five years and scientific and information management personnel has been moved into the laboratories and other units in order to integrate them more firmly with colleagues working on similar issues. Two scientists involved in the research on decision support systems for nuclear emergency preparedness (RODOS) and co-ordination of exercises have been moved to the Laboratory of Ecology and Foodchains in order to strengthen the preparedness for long-term countermeasures and management of radioactivity in contaminated areas, both in foodstuffs and environment. As a part of reorganization of information management activities at STUK, the data base expert services were moved from the departments into the STUK Information Management Unit.

The Research Director and Deputy Director also take part in administrative coordination of international research projects of strategic value to STUK. However, the scientific work of these projects is carried out in the laboratories, and therefore also the results of these projects are described in the context of the laboratory descriptions. Projects coordinated by the Research Director Sisko Salomaa include SEMIPALATINSK (Minisatellite mutations and biodosimetry of people living around the Semipalatinsk nuclear test site, Inco Copernicus), RADINSTAB (Genomic instability and radiation-induced cancer, EURATOM FP5), and NOTE (Non-targeted effects of ionizing radiation, Expression of Interest to EURATOM FP6 for an Integrated Project). The Deputy Director Raimo Mustonen has coordinated EVATECH project (Information requirements and countermeasure evaluation techniques in nuclear emergency management, EURATOM FP5) as well as a number of expert service projects carried out in the Baltic States and the Eastern Europe.


Total costs 183 k€ distributed by sectors in 2004
0,9 %
20,9 %
7,5 %
3,1 %
1,5 %
2,9 %
63,2 %
Research
Nuclear Safety
Radiation Safety
Emergency Preparedness
Environmental Surveillance
External Services
Communication


Effective working time by sectors in 2004
Total person-years 7.6
8,0 %
0,5 %
0,4 %
0,3 %
0,3 %
2,2 %
0,1 %
21,8 %
66,3 %
Research
Nuclear Safety
Radiation Safety
Emergency Preparedness
Environmental Surveillance
External Services
Communications
Admistration and Support
Others

2.1.1 Personnel

The Management Unit of the Department of Research and Environmental Surveillance takes care of the management, administration and secretarial support.

Sisko Salomaa, Ph.D. (genetics), research director

Raimo Mustonen, Ph.D. (physics), deputy director

Kari Sinkko, Ph.D. (physics), project manager of the decision support systems (moved into the Laboratory of Ecology and Foodchains on January 1, 2003)

Michael Ammann, M.Sc., scientist, RODOS expert (moved into the Laboratory of Ecology and Foodchains on January 1, 2003)

Jarmo Huovinen, M.Sc., data base expert (moved into the Information Unit on January 1, 2003)

Taina Ilus, M.Sc. (chemistry), statistician (moved into the Laboratory of Epidemiology and Biostatistics on January 1, 2005)

Secretaries: Anu Haglund, Seija Hämäläinen, Tuija Huotari, Jaana Joenvuori and Raisa Tiililä

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2.2 Natural Radiation

2.2.1 Key words and specific technologies

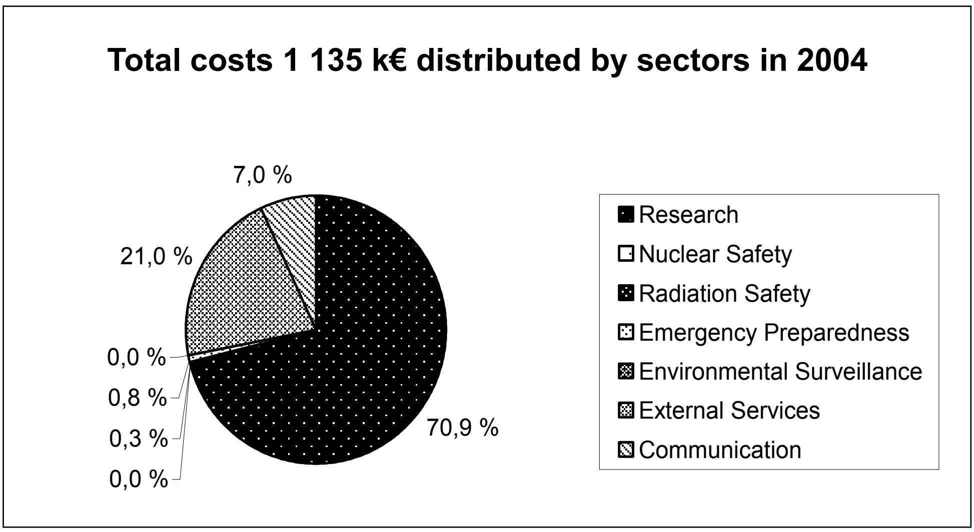
Key words

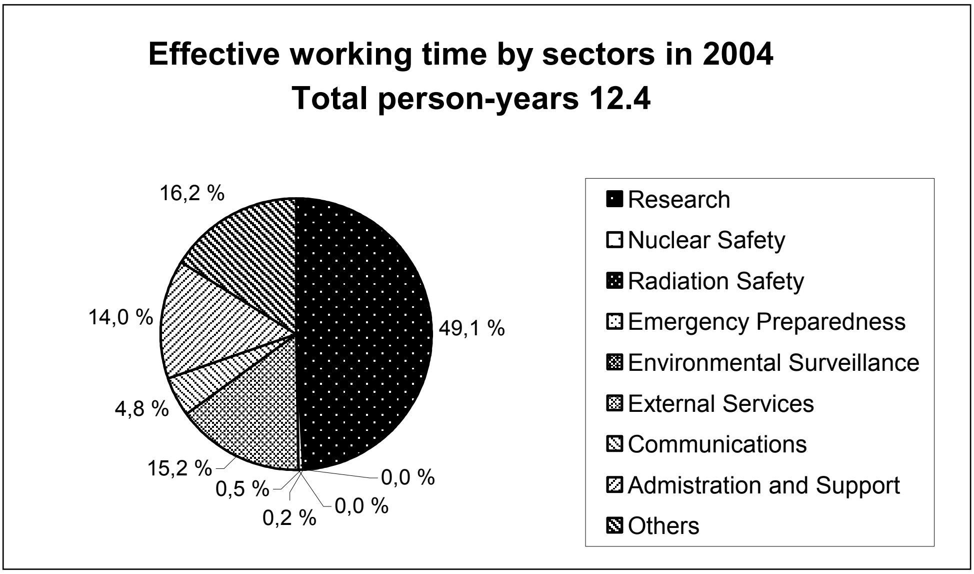
Natural radiation, radon, building materials, radioactivity, radon entry, home, workplace, municipality health authorities, building authorities, radon-safe building, survey, geology, soil, radon prognosis, risk mapping, indoor air, radon mitigation, emanation, air exchange, uranium, radium, ^{210}Pb,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

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





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,
- studies on mitigation of elevated indoor radon concentrations and on treatment methods of natural radioactivity in household water
- measurement services for indoor radon concentration and radioactivity in household water

Radon in indoor air

Scientists and authorities have been aware of radon as health hazard in residential buildings from the beginning of the 1980s. At that time scientists observed that direct influx from ground was the major source of radon in Finnish dwellings. Earlier radon was considered as a radiation problem related to radon bearing household water. From the early 80s onwards a comprehensive survey of radon in houses has been carried out. The late 80s represent a time of active measurements in Finnish municipalities. First national regulations concerning radon in indoor air were issued. STUK developed a methodology for making measurement plans and radon-prognoses in co-operation with the local authorities.

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. In 2000–2004, the NRL actively carried out research on practices in radon-safe building, on health studies and on surveys of natural radioactivity in household water outside of public water services.

Radon risk mapping

Since 1986, NRL has performed systematic indoor radon mapping jointly with the municipal health authorities in order to identify radon-prone areas. The NRL Radon Database “ART” includes information on indoor radon measurements made in 70 000 dwellings, building techniques and location of the houses, and the geology of the building sites.

The database is an invaluable tool in research and communication with the public. NRL maintains nationwide and regional maps and statistical summaries concerning indoor radon. Radon maps and statistical summaries show areas where the most active measures should be taken. This information is published on STUK Internet pages. It is used in national and municipal decision-making as well as for informing the media. NRL and STUK promote local radon campaigns providing local radon data for campaign information.

Studies on radon sources

The NRL aims at building a comprehensive view of the factors affecting indoor radon concentrations in Finland. Various projects aim at exploring the effect of building structure, soil properties, geological factors and soil uranium mapping data on radon concentration in the indoor air as well as the trends of radon concentration in new housing.

Since 2004 the effect of air permeability of the soil and gravel on the indoor radon entry has been studied using radon transport models. Highly permeable gravel under the slab enhances the soil gas flow into the house, and may multiply the radon entry rate. The results are also needed in decision making, in reasoning the requirements for radon-safe building, and in preparing training materials for building companies.

Mitigation studies

The surveys carried out in 1990s showed that the threshold of 400 Bq/m^3 is exceeded in 5% of all low-rise residential houses in Finland, altogether in approximately 60 000 houses. Based on international mitigation data, research made by Finnish universities and on STUK’s questionnaire study, STUK published a guide for indoor radon mitigation in 1995. This guide has been in wide use ever since. In 2000–2004 the NRL has continued gathering data aiming to improve the national guidance material.

Studies on radon prevention in new buildings

One of the key aims of the NRL has been promoting radon-safe building in co-operation with authorities and other researchers in Finland. This is highly important in Finland where the average indoor radon concentration in new buildings is higher than in buildings built before the 1970s, which is mainly due to the prevalent use of slab-on-ground foundation type. Development of radon-safe building has been carried out as multi-disciplinary work with construction and ventilation experts, and the Ministry of Social Affairs and Health carrying the responsibility for healthy indoor air issues.

As a result of these attempts, radon prevention work in Finland is counted today as a part of the work aiming at healthy indoor air.

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 the results of these, a large number of samples have subsequently been analyzed for uranium, radium, ^{210}Pb and ^{210}Po, using radiochemical methods. STUK's present survey work covers the 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 latest 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. The accreditation of the process for determining radionuclides in water was obtained in 1999.

Health studies

The NRL has had an active role in health studies, not only in exposure assessments, but also in epidemiological analyses. In 2000– 2004 the focus has been on multi-laboratory EU-pooling of the European case-control studies, and on the health effects of natural radionuclides in drinking water.

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, water treatment methods, health effects

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

Heikki Reisbacka, BSc (geology), scientist
Indoor radon measurement services, radon at workplaces

Pia Vesterbacka, 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

Tuomas Valmari, DrTech (physics), scientist
Studies on radon decay products, modelling indoor radon entry, indoor radon mitigation

Reko Simola, 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

Hanna Niemelä, assistant researcher
Indoor radon measurement services, 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 National Environmental Health Programme in the area of natural radiation.

Radon in indoor air

- Exploring the occurrence, exposure and health effects of inhaled radon at home and in work environment
- Providing information for decision-makers involved in regulatory work: STUK Radiation Practices Regulation, Ministry of Social Affairs and Health, Ministry of the Environment, municipal authorities
- Reducing exposure to indoor radon by remedial and preventive measures, research and development on the technology required
- Exploring the effect of soil, building materials and type of foundation on indoor radon entry rate
- Developing and maintaining the database for indoor radon concentration in Finnish dwellings
- Exploring the effect of house construction, soil and geological factors
- Evaluating methods for assessment retrospective radon exposure
- Developing radon-safe construction methods
- Developing guidance published by the authorities
- Developing the regulations and practices of building companies

Radioactivity in household water

- Exploring the occurrence, exposure and health effects of natural radioactivity (^{222}Rn, $^{234,238}U$, ^{226}Ra,^{228}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 utilized in mapping and planning regional water supply
- Studying the influence of bedrock type and groundwater quality on elevated radionuclide levels
- Exploring human exposure to lead (^{210}Pb) and polonium (^{210}Po) and the factors affecting their occurrence either as soluble ions or bound to particles

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 taking into account the Drinking Water Directive and the Commission's Recommendation
- Developing new, 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 safe and enduring methods for removing radon (^{222}Rn), uranium (^{238,234}U), radium(^{226,228}Ra), lead (^{210}Pb) and polonium (^{210}Po) from different type of ground waters

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 health effects, especially renal effects of uranium in collaboration with other research units.

2.2.5 Progress report on research over the last five years

Exposure to natural radiation
The NRL has carried out surveys of indoor radon, natural radioactivity in drinking water, gamma radiation both indoors and outdoors. The results from the surveys reported in 2000–2004 are presented below. A summary on exposure due to ingested water was presented at the 5th International Conference on High Levels of Natural Radiation and Radon Areas in September 2000 (Arvela 2002). The study presented a review on population distribution of annual doses from sources of natural radiation in Finland. The results were 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 3 000

dwellings. The percentage of population exceeding the dose of 1.0 mSv due to indoor radon, drinking water and natural gamma radiation are 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 Finnish population (total of 5.2 million).

Exposure to natural radioactivity in drinking water has been reported in many studies (Voutilainen et al. 2000, Mäkeläinen et al. 2001, Mäkeläinen et al. 2002, Vesterbacka et al. 2004).

Radon risk mapping

The NRL has continued to maintain the Radon Database which includes today the information of indoor radon measurements in 70 000 dwellings, the building techniques and location of the houses, and the geology of the building sites. The database is an invaluable tool in research work and communication with the public. The database has been utilized to provide data for the municipal authorities and especially for planning of new municipal "Radon bee" campaigns, launched in 2003.

In 90s STUK published several regional radon prognoses and the Radon Atlas of Finland with detailed municipal indoor radon data. The work carried out in 2000–2004 also aims at the publication of a revised Radon Atlas. This Atlas would include data of more than 100 000 households in the radon Database.

In the mapping strategy most attention should be focused on the Southern Finland. The search for high radon risk is easiest in areas of permeable soil types such as esker areas and other sand and gravel deposits (Voutilainen et al. 2000, Weltner et al. 2002).

A new countrywide random sample survey of indoor radon concentrations in Finnish dwellings will be launched in 2005–2006. The previous study was carried out in 1990–1991.

Radon exposure in homes and at workplaces

The total exposure to inhaled radon includes exposure received indoors at home and at work, as well as outdoors. These components were examined in a survey performed as a random sampling study. The survey was carried out as a questionnaire study on time spent daily at home, at work, and outdoors. Radon concentrations were measured at home, at workplace and using personal portable monitors. The times spent at home, at work and outdoors were 77, 14 and 9 per cent, respectively. The average concentrations at home and at work were 104 and 30 Bq/m^3. The mean radon concentration that Finns are exposed to was 88 Bq/m^3 using personal dosimeters and 85 Bq/m^3 using time-weighted measured concentrations. The correlation between the radon concentration at home and the personal mean concentration was strong (0.99), while the correlation between radon concentrations at home and at work was weak. The results of this study were reported in 2002 in the conference of Natural Radiation Environment NRE VII and have been published in the NRE VII Conference Book (Natural radiation Environment VII, Elsevier 2005).

The material was analyzed in co-operation with the Statistical Department of Helsinki University in a M.Sc. Thesis (Moisio 2004).

In the future, studies of radon at workplaces will be continued in more detail, including diurnal variation and radon levels at workplaces in different building types. A national study on radon concentrations outdoors is also in the study plan.

Modeling indoor radon entry

The aim of this study is to identify the most important properties of soil, building materials and types of foundation affecting the indoor radon entry rate.

In connection of a study aimed at detecting possible radiation-induced chromosomal aberrations, the factors affecting indoor radon concentration in 84 households among the participants were studied. The study area located in a region of enhanced radon concentrations. Type of substructure and soil permeability was the most important factors also in this study with a low sample quantity (Mäkeläinen et al. 2000, 2001).

Regional differences in radium concentration and radon emanation factor of sub-slab filling sand correlate remarkably with measured indoor radon concentrations. Filling sands were examined in a countrywide study (Vesterbacka and Arvela 2000).

Since 2004, the effect of air permeability of the soil and gravel on the indoor radon entry has been studied in the NRL using radon transport model RnMod3d (Risø National Laboratory, Denmark). Highly permeable gravel under the slab enhances the soil gas flow into the house, and may multiply the radon entry rate. Differences in radon emanation of the gravel were found to have a minor importance as compared to differences in air permeability. The model simulations have been used in reasoning the requirements for radon-safe building and in preparing training materials for building companies. The results of this recently started project will be reported in the next years.

Radon progeny and radiation dose

The Natural Radiation Laboratory has studied, in co-operation with the University of Helsinki, Department of Physical Sciences, Division of Atmospheric Sciences, the behaviour of radon decay products (radon progeny) in indoor air. In addition to indoor radon concentration data, information on radon progeny behaviour is also needed for dosimetric risk estimates. Most of the previous indoor air progeny studies have been carried out with aerosol particle number concentration higher than 2 000 cm^3, where the radiation dose is mainly due to the progeny attached to the aerosol particles. The first results, published as a Master of Science thesis, suggest that in Finland most of the dose originates from the unattached progeny (Kuuspalo 2002). Unattached progeny cause eightfold dose as compared to the aerosol-attached progeny.

The objective of the future studies is to find the range, variability and the main factors affecting the size and concentration (relative to the radon concentration) of unattached radon progeny in Finnish dwellings. The results are used for estimating conversion factor from radon gas concentration to radiation dose in Finnish dwellings with various ventilation types and indoor aerosol characteristics.

Remedial measures

In 1995, STUK published a report on radon remediation methods in Finnish dwellings. In 2002–2003 a questionnaire was sent to 1 000 households that had carried out radon mitigation after 1995 (Arvela 2001). The results will be utilized for further development of the guidance material. Experience on mitigation at workplaces is being collected from specific workplace studies. The results collected so far have been utilized in mitigation training.

The results from the mitigation studies in blocks of flats showed that high depressure in blocks of flats is one of the most important factor that increases the indoor radon levels in flats of the lowest floor (Arvela 2000d, 2001b). Commonly used mechanical exhaust ventilation and tight structures together create this excessive underpressure. Underpressure may also worsen the efficiency of otherwise effective mitigation methods, such as sub-slab-suction and radon well.

The NRL is planning to renew in coming years the present guides for indoor radon mitigation in co-operation with the Ministry of the Environment and building researchers.

Studies on radon-safe building

The studies of STUK have shown that the average indoor radon concentration in new buildings is higher than in buildings built before the 1970s. This is mainly due to the prevalent use of slab-on-ground foundation type. In the 1990s the NRL studied the functionality of the guidance given for radon-safe building. The study aimed at finding the main defects in design and implementation of radon-safe building and to find out how well the guidance on radon-safe building had been followed. Results were collected from 300 houses. The results clearly pointed out that the national guide issued in 1994 needed revising (Arvela et al. 2000a, Arvela 2000b, 2001a).

The results of the former studies gave rise to the project "Radon-safe building, moisture prevention and air exchange in a healthy building" (RAFO), 1998–2001, supported by the Finnish Technology Agency and led by STUK (Arvela et al. 2000c, 2001c, Arvela et al. 2002b). The project was part of the Finnish Environmental Research Programme (SYTTY), and focused on the development of the radon-safe building practices (Arvela et al. 2002). The project included studies on ventilation rate and underpressure in the test houses in Tuusula house fair area (Airaksinen et al. 2002). Differences in ventilation strategies affect remarkably radon entry into buildings.

As a result of the RAFO project, a new construction method for an airtight joint between the foundation wall and floor slab was developed for houses with slab-on-ground or houses with a basement. The construction prevents the flow of radon-bearing air from soil into the house. The practice is based on the use of reinforced bitumen felt in the floor joint.

The study group launched negotiations with the Ministry of the Environment and Building Information Ltd. in order to start the revision of the guidance material. A work group coordinated by STUK prepared a new guide for radon-safe building and was published as a RT Building Information File in 2003 (Risberg et al. 2003). As a second precautionary construction method, a radon piping should be installed below the slab. The piping can be utilized to reduce the indoor radon concentration and also the moisture in the floor slab and sub-slab gravel.

The publication of a new guide to radon-safe-building affected also the devel-opment of national building regulations. In Part B3 for substructures of the National Building Code, Finnish Building Regulations, published in 2004, radon safe-building is required as a main rule in the whole country and the guidelines of the B3 utilize the advice given in the RT Building File for radon prevention.

In the future STUK will carry out, in co-operation with building industry and authorities, a follow up study of the functionality of the new guide. STUK will also monitor the indoor radon concentrations achieved in new buildings. The developments so far have already resulted in improved radon-safe practices in building industry and in the municipal building permission process.

Natural radioactivity in private wells in Finland – a representative survey in 2001

The NRL launched in 2000 a new drinking water survey in co-operation with the Ministry of the Environment and local health authorities. Natural radioactivity in drinking water was determined in a population-based random study of 472 private wells, from 288 drilled wells and 184 wells dug in soil. The mean concentrations of ^{222}Rn, ^{226}Ra, ^{234}U, ^{238}U, ^{210}Pb and ^{210}Po in drilled wells were 460, 0.05, 0.35, 0.26, 0.04 and 0.05 Bq/l, and in wells dug in soil 50, 0.016, 0.02, 0.015, 0.013 and 0.007 Bq/l, respectively. Approximately 10% of drilled wells exceeded the radon concentration of 1 000 Bq/l and 18% exceeded the uranium concentration of 15 µg/l.

The mean annual effective dose from natural radionuclides for a drilled well-user was 0.4 mSv and 0.05 mSv for a user of a well dug in soil. The effective dose arising from ^{222}Rn was 75% from the total of all natural radionuclides for drilled well-users. As regards long-lived radionuclides, ^{210}Po and ^{210}Pb caused the largest portion of the effective dose. The dose arising from ^{238}U, ^{234}U and ^{226}Ra was only 8% of the total of all natural radionuclides. The results have been published in a STUK report (Vesterbacka et al. 2004a) and as an article in Radiation Protection Dosimetry in 2005.

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 the uranium series found in the water of drilled wells. The aim has been to find out areas with anomalously high radionuclide concentrations and to analyze the radionuclide composition to assess the radiation doses. Comprehensive summaries on the survey were published in 2001–2002 (Mäkeläinen et al 2001, Salonen and Huikuri 2002). The Radon Atlas of wells drilled into bedrock (Voutilainen et al. 2000) provides detailed municipal data on measurements. The maps in the Radon Atlas are based on a sampling of 9 200 drilled wells all over the country. Results of the nationwide survey, described in the previous chapter, was published in 2004.

Occurrence of natural radioactivity in Finnish groundwater was also examined in co-operation with Geological Survey of Finland (GTK) in the "One Thousand wells" project. This offered valuable information from simultaneous occurrence of natural radionuclides together with other stable elements. Results are published in GTK report (Tarvainen et al. 2001a, 2001b). Additionally, the data from this study will make it possible to evaluate the main parameters affecting occurrence of natural radionuclides in Finnish groundwater.

The database for radionuclides in drinking water covers practically all public 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 wells dug in soil layers is usually low, whereas in drilled wells there are anomalously high concentrations (tens of thousands of Bq/l) found mainly 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 oxidizing 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 making the most significant contribution to the dose, after 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, for 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.

The effect of water treatment on the presence of particle-bound ^{210}Po and ^{210}Pb in groundwater

The distribution of ^{210}Po and ^{210}Pb in various particle-size fractions in Finnish groundwater was studied at five private homes. Each site had water treatment equipment comprising either an ion exchange unit or a granular activated carbon (GAC) filter. Samples of both raw and treated water were filtered using pore sizes ranging from 450 nm to 100 kDa and the activity concentration of ^{210}Po and ^{210}Pb in the filtrate was determined. In untreated groundwater 86% of ^{210}Pb, on average, was found in the large particle fraction (>450nm). However, in Fe- and Mn-rich water with a high Fe/Mn ratio and in organic-rich water the majority of ^{210}Pb was found either in the intermediate particle (100 kDa – 450 nm) or small particle (<100 kDa) fractions. Compared to ^{210}Pb, ^{210}Po was bound more to the intermediate and small particle fraction. After water treatment, ^{210}Pb was found most frequently in the large particle fraction. The size distribution of particle-bound ^{210}Po was not as clear as that of ^{210}Pb, and in treated water ^{210}Po was more evenly distributed among the fractions. The ion exchange unit removed ^{210}Pb and ^{210}Po bound to the intermediate or small particle fraction, whereas the efficiency of the activated carbon filters in removing ^{210}Pb and ^{210}Po was independent of the particle size. Results are presented in a publication of Radiochimica Acta in 2005.

Sampling of ^{210}Pb in radon-bearing drinking water

The aim of this study was to develop a feasible method for ^{210}Pb determination in ^{222}Rn-rich drinking water. Special attention was paid to the ingrowth of excess ^{210}Pb from decay of ^{222}Rn in sample containers holding ^{222}Rn-rich water, taking into account the out-leakage of ^{222}Rn from sample containers. In addition, the varying ^{210}Pb activity concentration in the household water supply in one day was studied. The study was performed using water from eight test sites with wells drilled in bedrock. The results indicated that the in-growth of excess ^{210}Pb in the sample container plays an important role. ^{222}Rn concentration of 1 000 Bq/l produces approximately 0.08 Bq/l of ^{210}Pb in one day. Depending on the container material, the leakage of ^{222}Rn in two days from the sample container causes a relative decrease of 3–6% in the excess ^{210}Pb activity concentration compared to the situation with no leakage. The influence of sampling time had no significant influence on the activity concentration of ^{210}Pb in drinking water. The results were presented in LSC 2001 conference (Vesterbacka and Mäkeläinen 2002).

Studies supporting the legislation concerning natural radioactivity in drinking water

The EU drinking water directive (Council Directive 98/83/EC,) on the quality of water intended for human consumption was issued in 1998. The NRL has performed research to support the Ministry of Social Affairs and Health in the implementation of the directive into national legislation.

The report STUK-A182 (Mäkeläinen et al. 2001) gave the grounds for a proposition that was prepared for restricting and monitoring of the radiation exposure from radioactive substances in drinking water. STUK delivered the proposition to the Ministry of Social Affairs and Health in March 1999. The proposition introduced an action level of 300 Bq/l for radon concerning the waterworks. For other radionuclides except radon the action level proposed was a total dose of 0.1 millisieverts per year (mSv/a). This new proposition did not bring any notable changes in the monitoring practice, although the calculated doses will slightly change. The proposed guideline for radon in private wells was 1 000 Bq/l.

According to the present monitoring data, less than 200 Finns served by waterworks use drinking water with radon concentration exceeding 300 Bq/l. Approximately 1 000 waterworks consumers receive an annual dose that exceeds 0.1 mSv caused by other radionuclides than radon. About 20 000 Finns served by private wells use drinking water with radon concentration exceeding the STUK guideline of 1 000 Bq/l (Mäkeläinen et al. 2001, Vesterbacka et al. 2004).

The NRL also carried out a cost-benefit analysis in order to provide grounds for decision-making (Mäkeläinen and Turtiainen 2003). The NRL participated also in the WEKNOW meeting in order to provide basic information on natural radioactivity in drinking water for this EU project (Mäkeläinen et al. 2003). The project has created a Web-based European Knowledge Network on Water, WEKNOW.

Radioactivity in household water, development of analysis methods

The development of new analysis and measurement methods has enabled the completion of a large number of radionuclide analyses made at STUK in the last twenty-five years. The measurement methods are based on liquid scintillation counting (LSC) and alpha spectrometry. The LSC measurement method developed and introduced in 1979 for radon measurement offered significant improvements compared with the previous gamma spectrometric method. The method allows an automatic measurement of large sample series accurately with significant savings in labour costs. The method has thereafter been tested comprehensively at STUK, followed by acquisition of new, low-background LSC counters equipped with anti-coincidence guard counters and pulse-shape analysers (PSA). Application of PSA in LSC spectrometers has reduced the lower limit of detection for radon because of the low background in the alpha window. Recently, additional tests were made in order to test whether quenching corrections were required in measuring radon in water. The method was also compared with another LSC method used more commonly in the world. The results will be published as two articles in international journals in 2005.

The biggest advantage of the new LSC technology was gained when a new method was introduced at STUK in the beginning of 1990s to determine gross alpha and gross beta in water. The low-background LSC spectrometer, the Wallac QuantulusTM 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 and the calculation of the uranium and ^{226}Ra contents accurately enough for radiation protection purposes. Thus, no further analyses using time-consuming radiochemical methods are usually required. In certain conditions, 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 that used with the previous method. All these benefits have enabled nationwide surveys of natural radionuclides in groundwater.

During the period of 2000–2004 STUK has organized intercomparisons and presented international reviews on LSC techniques (Möbius and Salonen 2002, Salonen 2004).

Two degrees about portable LSC technique and uranium determinations using alphaspectrometry were completed at STUK, one thesis for Helsinki University (M.Sc.) and one final examination of a laboratory analyst for a vocational high school (Heinola 2001, Simola 2004).

Radioactivity in household water, measurement methods of polonium and radium

Commission Recommendation issued on December 20, 2001, on the protection of the public against exposure to radon in drinking water gave limits for radon daughter nuclides ^{210}Pb and ^{210}Po. In case of water from wells drilled into bedrock, 9% exceeds the ^{210}Pb limit of 0.1 Bq/l and, respectively, 4% of the ^{210}Pb limit of 0.2 Bq/l.

The accuracy of ^{210}Pb determination via the spontaneous deposition of ^{210}Po on a silver disk and its alpha spectrometric measurement has been improved. The study focused on the storage conditions of the polonium-containing solutions, the tracer used in polonium analysis, the effect of the storage time and acid concentration on the ^{210}Po deposition. The intermediate precision and repeatability associated with the improved ^{210}Pb analysis of fresh groundwater samples were 5% and 14%, respectively. These improved values were achieved by using glass bottles as storage containers for the solution remaining from the first ^{210}Po deposition, by rinsing the sample container with concentrated hydrochloric acid after storage and by using different isotopes of polonium as the yield determinant tracer in the first and the second deposition. Less polonium adsorption onto the storage container walls occurred with HCl than with HNO3. The overall uncertainty in ^{210}Pb analysis was (11 ± 7)% at the 95% confidence level. The minimum detectable activity concentration was 0.1 mBq/l calculated from blank samples and 0.05 mBq/l using the background counts of the alpha spectrometer. Results are presented in publication of Analytica Chimica Acta in 2005.

Development of ^{228}Ra determination started in order to check the compliance with the requirements in the Drinking Water Directive (DWD). ^{228}Ra was determined via its daughter nuclide ^{228}Ac using gamma spectrometric measurement. Water sample (2 liters) was evaporated to the volume of 0.5 liters after which it was transferred into a counting container (Marinelli). The minimum detectable activity was 0.07 Bq/l for 0.5 liters of water with a counting of 1 000 minutes.

Treatment Techniques for Removing Natural Radionuclides from Drinking Water, TENAWA

TENAWA project (Treatment Techniques for Removing Natural Radionuclides from Drinking Water) was carried out on a cost-shared basis with the European Commission (CEC) under the supervision of Directorate-General XII, Radiation Protection Unit. TENAWA project was started because in several European countries ground water supplies may contain high amounts of natural radionuclides. During the project both laboratory and field research was performed in order to test the applicability of various equipment and techniques for removing natural radionuclides from drinking water. The measurable objectives of the project were: (1) to give recommendations on the most suitable methods for removing radon (^{222}Rn), uranium (^{238}U, ^{234}U), radium (^{226}Ra, ^{228}Ra), lead (^{210}Pb) and polonium (^{210}Po) from drinking water of different qualities (i.e. soft, hard, iron-, manganese- and humus-rich, acidic), (2) to test commercially available equipment for its ability to remove these radionuclides, (3) to find new materials, adsorbents and membranes effective in the removal of radionuclides, and (4) to issue guidelines for the treatment and disposal of radioactive wastes produced in water treatment. The final report was published as the STUK-A169 report (Annanmäki and Turtiainen 2000).

Radon could be removed efficiently (>95%) from domestic water supplies by both aeration and granular activated carbon (GAC) filtration (Turtiainen et al. 2000a, Turtiainen et al. 2000b). Defects in technical reliability or radon removal efficiency were observed in some aerators. The significant drawback of GAC filtration was the elevated gamma dose rates (up to 120 microSv/h) near the filter and the radioactivity of the spent GAC. Aeration was found to be a suitable method also for removing radon at waterworks (Salonen et al. 2002). The removal efficiencies at waterworks where the aeration process was designed to remove radon or carbon dioxide were 67–99%. If the aeration process was properly designed, removal efficiencies higher than 95% could be attained.

Uranium could best be removed (>95%) with strong basic anion exchange resins and radium by applying strong acidic cation exchange resins (Huikuri and Salonen 2000). Also, weak acidic cation resin, zeolite A, sodium titanate and manganese dioxide were found efficient in radium removal. Hydroxyapatite removed both uranium and radium. Simultaneous removal (>95%) of uranium, radium, lead and polonium could be achieved by nanofiltration and reverse osmosis. The side-effect of RO-technique was the quality of the effluent; the water becomes almost totally demineralized and therefore corrosive. Commercially available iron and manganese removal equipment removed variable amounts of radon (0–90%), uranium, radium, lead and polonium (0–100%) depending on the operation principle.

Lead and polonium could be removed only fairly effectively by ion exchange and GAC filtration (35–100%). It is expected that neither lead nor especially polonium would form intrinsic precipitates but they would be adsorbed on colloidal minerals and organics.

When different kinds of treatment methods are used to remove natural radioactivity from drinking water, wastes containing natural radioactivity will be produced. It is recommended that the annual dose to inhabitants from external gamma radiation of a GAC filter should not exceed 0.1 mSv. It is also recommended that the dose rate at a distance of 1 m from the GAC filter should not exceed 1 microSv/h. To achieve these aims the GAC filter should be installed outside the living facilities. It is also recommended that the wastes containing natural radioactivity in solid form be discharged into communal dumps, and wastes containing natural radioactivity in liquid form be discharged into the sewer.

Safe operation of domestic equipment for removing radionuclides from drinking water

In order to gain more information on long-term operation of the water treatment equipment, a new project was initiated in 2000. The National Technology Agency of Finland partly funded the project. The emphasis was laid on the safe operation of the treatment units and water quality monitoring. Another purpose of this research project was to compose a guidebook for consumers and water treatment companies.

Radon could be removed from the household water by aeration and by activated carbon filtration also in long-term operation. Aerators that were well designed and set up were able to remove constantly over 90% of waterborne radon. The best aerators achieved removal efficiencies that were nearly 100%. It was noticed, however, that setting up an aeration system requires thorough planning. Malfunctioning due to faulty mounting or failure of an aerator occurred nearly in one third of the households interviewed.

Also, activated carbon filtration removed radon efficiently. The removal efficiencies were over 90%, often nearly 100%. It was discovered that depending on the water quality and usage, the carbon batch inside the filter needs to be changed every 2–3 years. The radiation shield was found an impractical and risky solution to the radiation problem. Therefore, it was recommended that GAC units be installed in a separate building or by the well, not inside the dwelling.

It was also recommended that uranium be removed from drinking water by anion exchange, which is the most efficient removal method for this purpose. Typically, the removal efficiencies are nearly 100%. One exception was the socalled tap filter (faucet mounted filter) that has a removal efficiency depending on flow rate of water in the filter. It was discovered that high saline concentration in water may decrease removal efficiency of uranium. Changes in plumbing pressure or pH-value did not have any significant influence on uranium retention.

Removal efficiencies of lead and polonium varied a lot depending on the chemical form in which they occurred in the water. They could be reliably removed from water by reverse osmosis only. Other treatment methods, such as ion exchange and activated carbon filtration, removed lead and polonium only partly. Lead and polonium were removed more efficiently when they were bound onto smaller particles than larger particles.

Testing simultaneous removal of radon, iron and magnesium by two commercial devices gave promising results: radon removal efficiency was over 98%. Furthermore, it was found that certain fluoride removal equipment can be applied to simultaneous removal of uranium, radium, lead and polonium.

The results of the project were reported in STUK-A197 report which has served well both the needs of research and water treatment companies (Vesterbacka et al. 2003).

Natural radioactivity in household water from waterworks (VEERA)

The aim of the study is to gather information about concentrations and retentions of natural radionuclides in waterworks with classical water treatment processes. Also the retention of radionuclides in the distribution system was studied. The study was also aimed at giving information to health authorities for situations where natural radionuclide concentration at waterworks exceed the concentration limits given in the Drinking Water Directive and the Commission Recommendation, issued on December 20, 2001, on the protection of the public against exposure to radon. Especially the guide values for uranium in drinking water given by the World Health Organisation (WHO) have lead to considerations.

Altogether 17 waterworks with 46 catchments were studied. Waterworks selected had different kind of raw water source and a variety of water treatment processes. The most often used method was alkalisation, which did not significantly affect on radionuclides activity concentrations. Membrane filtration removed over 90% and sand filtration 10–20% of uranium. Sand filtration affected also activity concentration of polonium, and often over 70% of polonium was removed. Radon removal by aeration was typically between 70–85%. Radon concentration decreased in the water distribution system due to the radioactive decay. For the same reason, activity concentration of lead increased in the distribution system.

The results were reported as a STUK-A206 report (Hämäläinen et al. 2004) also as a M.Sc. thesis (Hämäläinen 2004).

Natural radioactivity in Finnish food

The Natural Radiation Laboratory has mainly focused on radioactivity in drinking water. In estimation of the exposure to natural radionuclides, the contribution of food is as essential as the contribution of drinking water, especially at lower exposure levels. The NRL carried out a literature study on radioactivity in the main elements of Finnish food. The results were published as a M.Sc. thesis

(Myllymaa 2004). The average annual dose due to natural radioactivity in food was estimated at 0.09 mSv. The contribution of ^{210}Po is as big as 64%, the rest originating mainly from radium isotopes and ^{210}Pb. The project will be continued in co-operation with the Laboratory of Ecology and Food chain.

Health studies of indoor radon

The NRL has had an active role in STUK's health studies. Originally it was responsible for the exposure assessment concerning these studies, but its activities have now also expanded into epidemiological analyses. In recent years, the focus has been on multi-laboratory EU pooling of European case-control studies. This study is the largest collaborative study concerning radon and lung cancer in homes so far, including 13 studies, of which two studies were performed by STUK and NRL. The results were published in 2004 in British Medical Journal, showing that collectively, though not separately, these studies show appreciable hazards from residential radon, particularly for smokers and recent ex-smokers, and indicate that it is responsible for about 9% of the deaths from lung cancer, and hence, 2% of all cancer deaths in Europe (Darby et al., 2004).

The work will continue with a world-pooling where respective studies from North-America and China will be pooled. Furthermore, retrospective radon monitors have been tested and used in the European project, and results of both a validation study and a pooled analysis of epidemiological studies with exposure assessment methods using both retrospective and traditional methods will be published in the future.

The two facts, first that there was a significant increase in lung cancer even below the current action levels and second that the dose response appears to be linear down to low doses, have lead to consideration for the need to re-evaluate the radon risk information given by STUK as well as the reference levels of indoor radon concentrations in Finland.

Cancer risk from the radionuclides in drinking water

Cancer risk from natural radionuclides occurring in drinking water was studied among people that had used water from private drilled wells during 1976 and 1980. A case-control study (cohort of 150 000 people) was performed due to exceptionally high concentrations of natural radionuclides (radon, uranium, radium, ^{210}Pb and ^{210}Po) in private drilled wells. About 700 water samples were collected from drilled wells of study persons and statistical analyses were performed to evaluate the cancer risks. The study was carried out jointly with the Laboratory of Radiation Biology (Epidemiology and Biostatistics since 2005) and in co-operation with the National Public Health Institute, the Geological Survey of Finland and the Finnish Cancer Registry (Auvinen et al. 2002). Publications on radon and stomach cancer and also water radioactivity and urinary organ cancer will be published in 2005 (International Journal of Cancer).

Health effects of uranium in drinking water

Chemical toxicity of natural uranium in drinking water is a more important health risk than cancer from radiation. About 200 000 Finns obtain permanently their drinking water from their own drilled wells that may contain elevated levels of uranium. Renal effects of uranium have been studied among Finns who have had chronic exposure to uranium through drinking water (Kurttio et. al 2002). Participants (n = 325) of two studies were selected from the laboratory database where all results on radionuclide analyses in drinking waters from nationwide surveys and services have been stored since the early 1970s. The participants were selected to represent a wide range of uranium intakes. In the first study, uranium was analyzed in drinking water and urine, and in the second study, also in hair and toenail samples using ICPMS. Nephrotoxic effect of uranium was evaluated by measuring kidney function from blood and urine samples. These studies have also enabled to examine the possible effect of uranium on bone metabolism and to assess the bio-kinetic model of uranium exposure using various bioassay samples and the uranium source using $^{234}U/^{238}U$ ratio. The studies have allowed the comparison of ICPMS and alpha spectrometric methods, and to study the matrix effect of the ICPMS method. The study was carried out jointly with the Laboratory of Radiation Biology and in co-operation with the National Public Health Institute, Tampere University Hospital, Turku University Hospital and Nuclear Research Center, Negev, Israel.

The first study has been completed (Kurttio et al. 2002) but the assessment of the results from the second study is under way. An article on renal effects of uranium will be written to be published in an international journal.

Estimation of human exposure to natural radionuclides, ^{238}U and ^{210}Pb by using direct and indirect methods

The project carried out together with the Radiation Hygiene Laboratory, see page 88 for detailed description.

Environmental impact during the life cycle of Finnish natural stone production—radiation dose assessment

In this study, environmental impact during the life cycle of natural stone production was investigated (Aatos et al. 2003). One of the points of interest was radiation. Natural stone samples from 23 quarries were surveyed for the radioactivity. One quarry was selected for a case study where the effective dose to the workers was assessed. The use of these stones in buildings was also evaluated with respect to the excess dose caused to the residents.

The annual effective dose from natural radionuclides to the workers of the investigated quarry was about 0.4 mSv. The largest proportion – about 50% – of the dose was due to external gamma radiation emitted directly from the rock. At the quarry where the activity concentration of the rock was the highest, the dose from gamma radiation was approximately 0.45 mSv/y. Therefore it is likely that the dose does not exceed one millisievert per year in any of the natural stone quarries in Finland. Hence, the quarries can be excluded from the list of workplaces where significant exposure to natural radiation may occur. From both the companies' and the authority's point of view the BSS-directive is complied with.

The effective dose from inhalation of particles at the quarry was small, less than 0.07 mSv/a. It is obvious that the outdoor air in the surrounding area contains even fewer particles originating from the rock. Therefore, the people living in the neighborhood do not receive any significant dose from inhaling particles of mineral origin. In comparison, the average indoor radon concentration in the private houses in the municipality is 265 Bq/m^3 that will cause an annual effective dose of 4.5 mSv per year for the residents.

Building materials can lead up to elevated doses. Therefore, the effective dose received from building materials is restricted by legislation. The European Commission recommends the activity concentration index as a screening tool for building materials. If the excess dose criterion is set to 1 mSv per year, the value of the index should not exceed one in bulk materials and six in superficial materials. Value one was exceeded in about half of the samples. Hence, these granitic stones are not suitable to be used in bulk amounts in dwellings. However, natural stones are mostly used as surface materials and the activity concentration indices were less than six in all samples. According to the dose assessments performed in three built environments these natural stones can be used safely as decorative stones.

2.2.6 Research plans for the next five years

The on-going research projects of the NRL have been described in STUK Research projects 2003–2006 (Salomaa 2004). They include:

- Indoor radon mapping and maintaining of national indoor radon database
- Radon sources and radon entry into buildings
- New country-wide random sample study of residential indoor radon concentrations

- Indoor radon mitigation and development of guides
- Radon remedies at workplaces
- Radon-safe building
- Unattached radon progeny and indoor aerosol concentration in Finnish dwellings and their effect on radiation dose
- Radon epidemiology
- Radioactivity in household water
- Methods and domestic equipment for removing radionuclides from drinking water
- Studying the influence of bedrock type and groundwater quality on rising radionuclide levels
- Studying the concentration of natural radionuclides in food supplies
- Studying natural and temporal variation in activity concentration of natural radionuclides in 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)
- Kidney toxicity of uranium in drinking water (JURMU)
- Radioisotopes in drinking water and cancer risk (JUORAAS)

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2.3 Radiation Hygiene

2.3.1 Key words and specific technologies

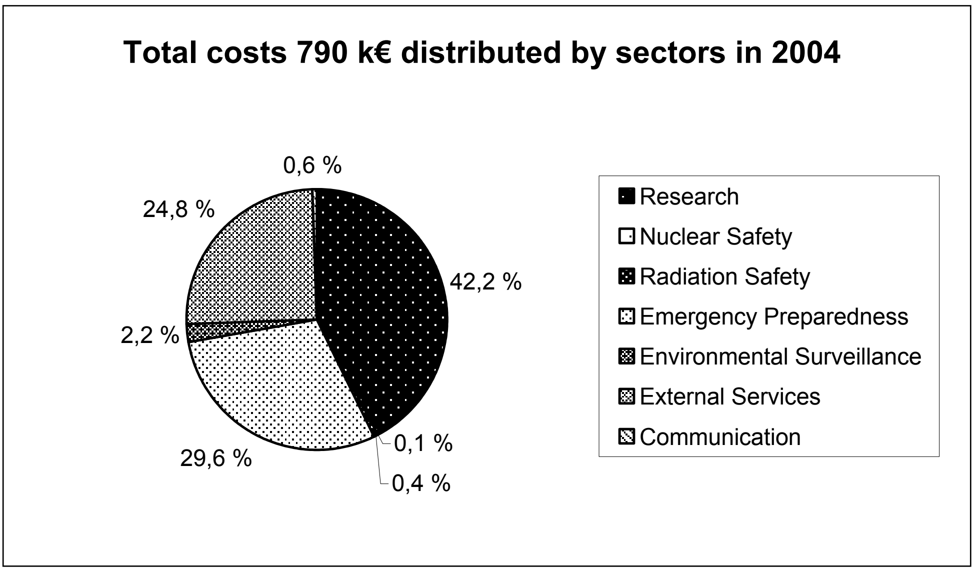
Key words

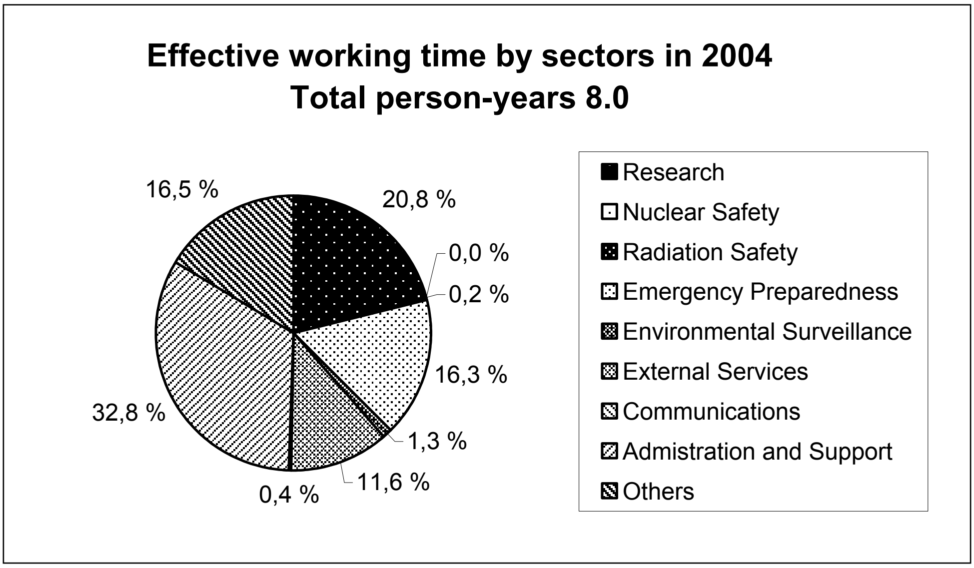
Internal radionuclide contamination, internal radiation dose assessment, whole-body counting, bioassay, internal contamination and radiation doses of workers, internal doses of population and population groups, nuclear bomb test and Chernobyl-derived contamination of population and of special dietary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

Specific technologies

Stationary whole-body counter with scanning techniques, mobile whole-body counter, lap geometry counters, thyroid counters, 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 of people (Rahola T, Suomela M. 2000). The laboratory is responsible for the gammaspectrometers placed in about 40 local laboratories around the country, for the calibration and maintenance of these instruments as well as registering the results from each laboratory. The intention is that the local laboratories would be prepared to measure local foodstuffs in emergency situations to assist STUK in creating an overview of the radiation situation in Finland. Lately also thyroid and surface contamination monitors have been added to the emergency preparedness equipment In 2004, the introduction of new gammaspectrometers was initiated for the local laboratories and the removal of the simple, old equipment was started. This is a new challenge for the laboratory personnel responsible for the technical maintenance of this new instrumentation and for the practical advice to the local staff.

A considerable part of the laboratory's activities consists of various 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 takes care of 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 waste for final repository at the NPP in Olkiluoto.

2.3.3 Personnel

Tua Rahola, MSc., head of laboratory
Management, radiation protection, internal dose assessment, radiohygienic and radioecologic studies, emergency planning and preparedness

Maarit Muikku, PhD, 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, dose assessment

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

Jarno Koikkalainen, laboratory engineer
National service for storing and conditioning of radioactive sealed sources waste, advising waste producers on safety questions, gammaspectroscopy of samples for emergency preparedness

Timo Hackzell, laboratory technician
Technical maintenance of laboratory equipment, testing of new equipment, especially for emergency preparedness

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

2.3.4 Aims of research

The main topics studied in 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 various 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 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 beta emitters ^{90}Sr, ^{3}H and ^{210}Pb.

2.3.5 Progress report on research over the last five years

^{137}Cs content and internal radiation doses of special population groups

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

Measurements on a statistically chosen (stratified random sampling) population group were started already in 1986 and were performed annually until 1993 and after that once, in 1996. The results of these studies have provided a good estimate of the 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 have been used to calculate the annual internal doses. The maximum internal doses due to the Chernobyl accident were received in 1987. Based on the measurements of the population group and the Helsinki reference group, taken annually from one to four times a year since 1965, the mean internal effective dose for the Finnish population was about 0.5 mSv for the first ten years and will remain 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 (Auvinen et al. 2001, Rahola et al. 2002, Puhakainen et al. 2003, Rahola and Muikku, 2004, Stradling et al. 2003, Suomela et al. 2003).

During the last five years the studies of the three special diet groups have continued, using the mobile whole-body counter. The first group, from Central Finland, represent a population consuming forest berries and mushrooms and especially a lot of freshwater fish caught in small lakes in a region with high fallout. The second group is a population consuming freshwater fish, game and other products from the wild. Reindeer meat is the primary radiocaesium source for the third group, reindeer herders from northern Lapland.

The results for the randomly sampled 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 another fallout region. The transport may decrease the body burdens in a high fallout area and increase them in a low fallout area. Many Finns also spend time at their summer houses, located far from their home residence, fishing and picking berries and mushrooms. This means that the gradient of the deposition levels in different fallout regions is steeper than the gradient of the mean body burdens of people residing in corresponding fallout areas. This is evident with the people residing in the Helsinki area, for instance. Another explanation for the variation of body burdens of radiocaesium lies in the different amounts of freshwater fish, wild berries and mushrooms consumed by people residing in various parts of the country. The concentration of radiocaesium in these foodstuffs reflects clearly the deposition level. As early as in 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, vary from year to year mostly because of the variation in 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 cesium in 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. In the study group, the difference in the body burdens in April and September was very small compared with the non-Sami reindeer herders that 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 1.7 kBq by 2005, when the last measurements of the group followed since 1961 were made. The mean annual effective dose for the male reindeer herders was about 0.4 mSv in 1988. The body burdens of the female members of reindeer herding families, and the corresponding doses, were about one third of the values for the male reindeer herders.

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

Contamination of workers at nuclear power plants

The Radiation Hygiene laboratory assesses the internal contamination of nuclear power plant workers. The laboratory started the assessments as a service task in 1978 when the first NPP with PWR type reactors began its operation. In 1980, the second NPP 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, ^{110}m 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 at the site with the nuclide-specific mobile whole-body counter of STUK. The workers routinely pass a portal monitor whenever they enter or leave the controlled area.When they start working at the power plant or when they leave the plant they are also measured with a non-nuclide specific whole-body monitor.

The studies have shown that the contamination levels depend greatly on the type of repair and maintenance work done during the outages. According to our experience 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 level of entering the measurement result into records in Finland. If a worker's body burden is much higher than the mean body burden, the person is remeasured and the radiation history established in order to estimate the radiation dose more accurately. If possible, such persons are 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 persons working together have been found to vary greatly, demonstrating 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 personal working habits.

Optimisation of Monitoring for Internal Exposure – OMINEX

OMINEX project was funded by the European Community under the 5th (EURATOM) Framework Programme (1998-2002). The aim of the OMINEX project was to provide advice on the design and implementation of internal dose monitoring programmes in the workplace in such a way that best use is made of available resources, while minimizing costs. Topics addressed include choice of monitoring method(s), (e.g. excretion monitoring vs. in vivo monitoring), choice of measurement technique (e.g. alpha spectrometry vs. mass spectrometry), monitoring intervals, measurement frequency, required measurement sensitivity and accuracy, measurement parameters needed to achieve this performance, the resulting uncertainty in assessed intakes and doses, and minimum detectable doses. The underlying approach to optimisation was to consider costs versus "benefits", the latter being quantified primarily by assessing the sensitivity or accuracy with which intakes and doses are determined from the results of particular monitoring methods.

Monitoring of the workforce in the nuclear industries is carried out primarily in order to demonstrate compliance with European Union Basic Safety Standards for the protection of the health of workers against the dangers arising from ionizing radiation. There is however no compilation of information on internal dose monitoring programmes currently in use in the EU countries. Such information can be collected either by requesting information directly from organizations about their monitoring regimes or by searching the open literature. Up-to-date information can only be obtained by carrying out a survey, but it is not always easy to obtain responses. Laboratory of Radiation Hygiene had the responsibility of contacting organizations and performing the survey. A STUK-A203 report was published.

Two questionnaires were designed; a one-page “pre-questionnaire” and a questionnaire on the design of internal monitoring programmes. Both questionnaires are formatted MS Word documents. The monitoring programme questionnaire covers direct (in vivo) and indirect (bioassay and air sampling) monitoring for internal exposure to fission and activation products, and to compounds of uranium, thorium, plutonium, americium, mixed oxide (MOX) fuel, and other actinides. Separate sections cover routine and special monitoring. Six types of operations were identified. Before sending out the complete questionnaire, the one-page “pre-questionnaire” was distributed in order to establish the radionuclides monitored and monitoring methods used. This information was then used to select those sections of the main questionnaire to be sent to the organizations. All persons that responded did not answer each question unambiguously thus making the analysis difficult in certain cases.

Databases for storage and reporting of all information gained were constructed. Responses to the monitoring programme questionnaire were collected into a Microsoft Access 97 database. The database contains 39 tables arranged according to the subtitles in the questionnaire starting with general aspects, such as type of operation, number of workers, monitoring practice and purposes of monitoring, followed by data on methods of monitoring of fission and activation products and actinides including also data on chemical form, calibration, MDAs, monitoring frequency and investigation levels. There are also questions on dose assessment and statistics. All results of the survey are compiled in the database and will be kept anonymous.

The survey provides a representative coverage of the six types of operation identified and a sufficient number of workers. A major conclusion is that, concerning particularly the actinides, a wide range of approaches to monitoring are in use. There is no consensus on primary monitoring methods. All organizations monitor workers to assess individual doses for making an entry in a legal dose record. A minority of the organizations does it to monitor engineering practices and standards and three thirds to reassure individual workers that they are not receiving any excessive doses. Two modes in the distributions can be noted, centred at 0.1 mSv and 1 mSv, not particularly dependent on the monitoring purpose. There are several instances of clearly inappropriate methods being used (e.g. nose blow screening for tritium exposures).

Cumulative distributions show that most organizations aim to assess doses down to 0.1 – 0.5 mSv. This is lower than is required by the EURATOM directive indicating that doses above 1 mSv should be assessed for Cat B workers. From the point of view of legislative requirements, it is not necessary to assess doses below 1 mSv (EURATOM Directive defines exposed workers as those workers who could receive doses in excess of the public dose limits). This could mean that some organizations are expending unnecessary efforts in assessing doses at ~ 0.1 mSv. Some organizations might have sensitive measurement systems for other purposes and, in that case, the effort is the same assessing a dose of 0.1 or 1 mSv. The legislative requirements consider the total dose not only the internal dose. For fission and activation products the external dose is normally higher and for the internal lower, in comparison. For actinides the situation is the opposite. (Etherington et al. 2003, Etherington. et al. 2004a, Etherington et al. 2004b, Le Guen et al. 2002, Rahola et al. 2003, Rahola et al. 2004)

Estimation of Natural uranium and ^{210}Pb in man, direct and indirect methods

In Finland drilled wells in bedrock represent a potential source of internal exposure due to enhanced levels of natural radioactivity of the decay chains of ^{238}U and ^{232}Th in the well water. Exposures to natural radionuclides in drinking water are usually chronic and persist for many years before they are recognised. Uranium and ^{210}Pb intakes of the study subjects have been evaluated from their drinking water, the analyses being performed over several years by the Laboratory of Natural Radiation.

However it is normally difficult to assess individual cumulative exposures of the afflicted persons with biokinetic models due to a number of reasons: activity concentrations in water may show great temporal variations, assumptions about individual water consumption rates have to be made and many biokinetic parameters are uncertain. Due to these difficulties in the usage of biokinetic models it would be useful to have a biological parameter in the human body itself which can give a more direct indication of cumulative exposure.

As uranium and its long-lived decay products are stored in the skeleton, they can be measured in vivo. At STUK, instrumentation consisting of four high purity broad energy Ge-detectors was constructed for the in vivo measurements. A number of measurements at the human head have been performed on persons who have consumed water with high activities of natural uranium and its decay products over several years as well as bioassay sample measurements of urine and hair. The study persons have been selected in co-operation with Laboratory of Natural Radiation from the drinking water da-tabase of STUK, which covers the results of radionuclide measurements from more than 7 000 drilled wells. Our study has shown that high concentrations of uranium and ^{210}Pb in hair strongly disturb the in vivo measurements. Therefore, in vivo skeleton measurements at the knee have been tested. The results show that the knee measurements can be used to determine extremely elevated levels of uranium in skeleton, but to measure an average uranium content in skeleton with the current measurement set-up is difficult. The study has been made in co-operation with GSF- National Research Center for Environment and Health, Institute of Radiation Protection, Neuherberg, Germany (Haninger et al. 2002, Muikku et al. 2003a, Muikku et al. 2003b, Wahl et al. 2002, Wahl et al. 2004).

The subjects who participated in the in vivo measurements were asked to collect urine samples and hair samples for determination of ^{nat}U and ^{210}Pb concentrations. An ICP-MS (inductively coupled plasma mass spectrometry) has been used for the determination of uranium concentrations in urine samples and hair samples. The natural uranium concentrations both in urine and hair samples of the studied subjects were significantly higher than the average values in the world. A radiochemical method to determine ^{210}Po content in urine and hair samples has been developed.

In order to get better knowledge of the natural uranium excretion, a study to probe further the excretion of uranium in human urine and hair of occupationally non-exposed Finnish subjects is also under way.

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 NPPs 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. A new EU directive on sewage sludge is in preparation. To use and dispose of sewage sludge needs regulation.

In the sewage sludge in communal wastewater treatment plants 32 different radionuclides both natural and man-made have been detected.

Radionuclides originating from NPPs have been detected in the sewage sludge of wastewater treatment plants in communities near the Loviisa (Puhakainen 2002) 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 and 2003-2005 are described in detail in the STUK-A179 and STUK-A202 reports (Salomaa). 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 on a long-term scale
- Total radiation dose to people in certain special groups
- Uranium and ^{210} Pb in man: direct methods, calibration and tests of various in vivo measurement set-ups using the new tissue-equivalent skull and knee phantoms¨
- Uranium and ^{210}Pb in man: indirect methods, probing the excretion in human urine and hair
- Nordic projects on assessment of internal doses
- Radionuclides in sludge and the concentration of radionuclides in ash after possible incineration of sewage sludge and other wastes
- Surface contamination including contamination of people and various decontamination methods

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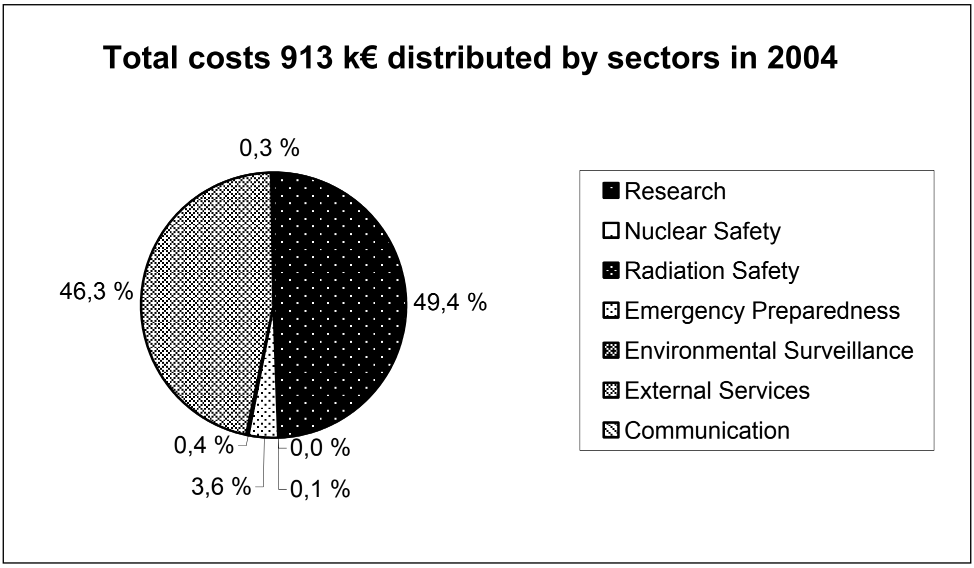
2.4 NPP Environments

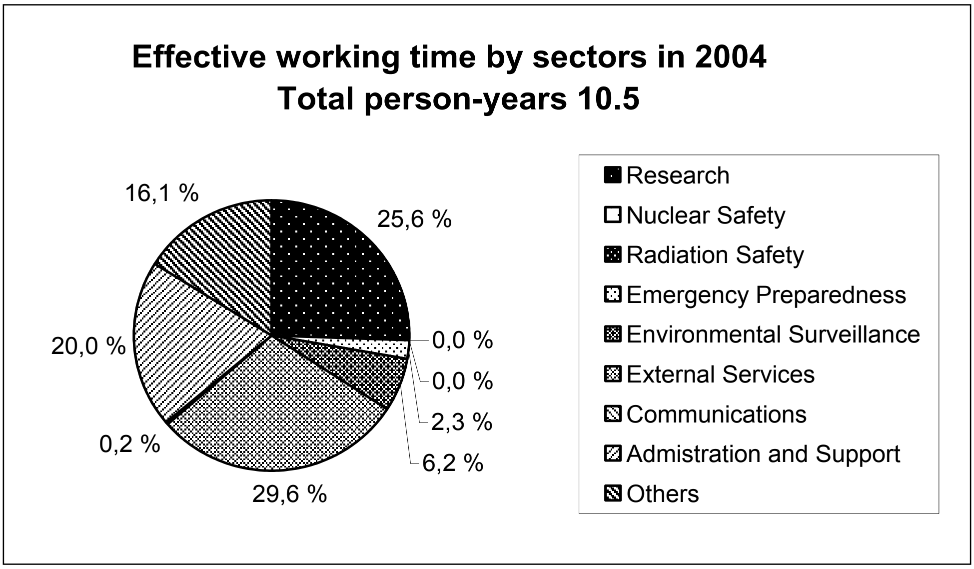
2.4.1 Key words and specific technologies

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, sediment dating methods, environmental sampling methods

2.4.2 Description of laboratory activities





Service studies and permanent environmental monitoring programmes

Monitoring of radioactive substances in the environs of Finnish nuclear power plants is the main function of the NPP Environmental Laboratory. The laboratory carries out the work as contracted 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 1 000 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 linked with the monitoring. This work takes up about 50% of the working capacity and reduces the capacity of the Laboratory to do scientific work. However, the extensive environmental data produced as a result of the routine monitoring programmes are valuable and have also been used as material for more comprehensive scientific studies.

In addition, the NPP Environmental Laboratory is responsible for another permanent monitoring programme. 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 in part by the 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.

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

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

Standardization

The Laboratory has participated in the standardiaztion 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 of the IAEA-TECDOC-1242 “Inventory of accidents and losses at sea involving radioactive material” published in September 2001.
- for the IAEA Advisory Group, in the drafting of the IAEA Safety Guide DS62 “Strategies for Monitoring Radionuclides in the Environment” to be published in the near future in the IAEA Safety Standard Series.
- 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.
- for the IAEA Safeguards, in coordinating analytical services of FINUVE organization (Finnish Nuclear Verification) and carrying out gammaspectrometric analyses of environmental and safeguards samples.
- as experts in the EC TWINNING Project LT2001 in guiding the personnel of the Lithuanian Radiation Protection Centre to develop and establish the Q&A systems and accreditation of relevant analysis methods in their institute.
- as experts in the EC PHARE Project ES-LV-PO/RA/01 in guiding the personnel of the Estonian Radiation Protection Centre to develop the Q&A systems in their institute.

2.4.3 Personnel

Erkki Ilus, Ph.Lic. (hydrobiology and limnology), 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

Tarja K. Ikäheimonen, Ph.D. (radiochemistry), senior scientist
Marine and terrestrial radioecology, radiochemical nuclide analytical methods, including alpha and beta spectrometry, environmental monitoring of nuclear power plants, quality assurance

Seppo Klemola, M.Sc. (physics), senior scientist
Gamma-ray spectrometry, airborne radioactivity, environmental monitoring of nuclear power plants, quality assurance

Jukka Mattila, M.Sc. (limnology), scientist
Marine radioecology, especially sediment studies, environmental monitoring of nuclear power plants, thermal effects of cooling water discharged from nuclear power plants, dating of sediments

Vesa-Pekka Vartti, student at Helsinki University (radiochemistry), scientist
Radiochemical nuclide analytical methods, including alpha and beta spectrometry, environmental monitoring of nuclear power plants, 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 environmental dose calculation models
- 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 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 impact of the Finnish nuclear power plants has been assessed on the basis of some 30 years of experience. The radiological impact of the NPPs on the people living in their vicinity and on the environment in general has been insignificant. 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 plants, though only in low activity concentrations (Ilus et al., 2002, Klemola et al., 2004). 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. 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 the primary production of phytoplankton has increased in the vicinity of the cooling water outlets.

The Laboratory's expertise in the environmental monitoring of NPPs, deriving from the 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. 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.

Forest ecosystem study in the environs of Finnish NPPs

The aim of the study was to provide new data on the occurrence, transport and accumulation of gamma-emitters, ^{90}Sr and transuranic elements in the forest environs of Finnish nuclear power plants (Ikäheimonen et al., 2003). The study was carried out during the years 2000–2002. A large number of soil, plant, berry and mushroom samples were collected in the vicinities of the Loviisa and Olkiluoto NPPs and analysed. Clear difference in distribution of ^{137}Cs, ^{90}Sr and ^{239,240}Pu were noticed between the two sites. The total amounts of ^{137}Cs, ^{90}Sr and ^{239,240}Pu in soil were about 1.3–3 times higher in Loviisa than in Olkiluoto. The observed activity ratios of the Cs and Pu isotopes clearly indicated to the Chernobyl fallout in these areas. The activity ratio of ^{134}Cs/^{137}Cs was about 0.07 in the year 2000 and 0.05 in 2001. These ratios were typical for the Chernobyl fallout taking into account the decay of the nuclides. The activity ratios of ^{238}Pu/^{239,240}Pu were clearly higher than those in global fallout, which indicates the contribution of the Chernobyl-derived Pu. In Olkiluoto, litter and humus contained trace amounts of ^{60}Co and ^{125}Sb originating from the local power plant. The highest concentrations of ^{137}Cs were found in mushrooms (up to 8 500 Bq/kg fresh weight). Aggregated transfer factors from soil to plants were calculated for various species. According to the results, ferns were good indicators of ^{137}Cs and ^{90}Sr, and the twigs of shrubs also for ^{90}Sr and ^{239,240}Pu (Ikäheimonen et al., 2003).

Study of coastal ecosystems in the environs of Finnish NPPs

A study of coastal ecosystems was carried out at Loviisa in 2000 and at Olkiluoto in 2001. Biota samples were collected from a broad variety of organisms at different levels of the ecosystem (from phytoplankton to water fowls, their eggs, etc.). The aim of the study was to compare the indicator value of different members of the aquatic ecosystem for gamma-emitting radionuclides, Sr and Pu in brackish water circumstances of the Finnish coast. The activity concentrations of ^{40}K were clearly highest in a filamentous green alga, *Cladophora glomerata*. ^{60}Co and ^{54}Mn were detected only at the lower trophic levels of the ecosystem. ^{60}Co was detected in phytoplankton, zooplankton, periphyton (maximum), macroalgae, in submerged vascular plants, and in mussels. ^{54}Mn was detected in zooplankton, periphyton, the bladder-wrack (*Fucus vesiculosus*) and in *Ranunculus baudotii* (maximum). ^{60}Co and ^{54}Mn were not detected in fish or birds or in their inner organs. The ^{137}Cs concentrations were highest in fish flesh. On the contrary, in fish-eating birds the highest concentrations were not in muscles but in liver and entrails. In birds' eggs the concentrations were very low; especially in egg shells. Among the lower organisms, the best indicators of ^{137}Cs were the polychaete worm *Marenzelleria viridis*, periphyton, the bladder-wrack and the relict crustacean *Saduria entomon*. The results of this project have been utilized in the INDOFERN and FASSET projects described below. The Sr and Pu analyses will be completed in 2005, and the results will be published in 2006.

Baltic Sea studies

The Laboratory has been an important partner in the MORS (Monitoring of Radioactive Substances in the Baltic Sea) Project Group of the Helsinki Commission (HELCOM). The Group started to work in 1986. All the Baltic Sea countries contribute to the joint international monitoring of radioactivity in the Baltic Sea, and the Laboratory acts as the Finnish representative in this co-operation. Since the Chernobyl accident, the MORS Group has published three joint assessment reports on radioactivity in the Baltic Sea. The fourth Joint Report "Radioactivity in the Baltic Sea in 1999–2004" will be published in the beginning of 2008. The laboratory has been responsible for writing several chapters in the reports, especially those dealing with "Sources of radioactivity" (Lüning & Ilus, 2003), "The monitoring network" (Ilus & Kotilainen, 2003), "Quality assurance" (Ikäheimonen & Mulsow, 2003), "Radionuclides in sea water" (Mulsow et al., 2003) and "Radionuclides in sediments" (Ilus et al., 2003).

The MOSSIE study

Some years ago, the MORS Group arranged an intercomparison exercise "MOSSIE" on sediment sampling methods and devices at four sampling stations in the Baltic Sea, using vertical distribution and total amounts of artificial radionuclides in the sediment samples as evaluation criteria. The intercomparison was attended by 11 sampling devices of different type. The results were published under the leadership of the Laboratory in Baltic Sea Environment Proceedings (Ilus et al., 2000), and they also constituted a part of a Licentiate's thesis (Ilus, 2001). Five criteria were used in choosing reference corers. The relative differences of each corer from the reference corer at each station were statistically considered. Based on this examination, a ranking list was drawn up for the corers. In general, the results showed marked differences in the total amounts of ^{137}Cs per square metre, even when the ^{137}Cs concentrations per kilogram dry weight were equal. This was assumed to be due to an edge effect, i.e. the inner walls of the coring tubes/barrels cause loss of material from the margin of the core.

The Marina Balt Project

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 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 ^{137}Cs and ^{90}Sr into the Baltic Sea by Finnish rivers after the Chernobyl accident (a joint study with the Laboratory for Ecology and Foodchains at STUK). The results of the Marina Balt project have been published in several reports (Ilus & Ilus, 2000, Saxén & Ilus, 2000, Ikäheimonen et al. 2000, Rissanen & Ikäheimonen, 2000, Saxén & Ilus, 2001).

The most significant source of artificial radioactivity in the Baltic Sea is the fallout from the Chernobyl accident. The total input of ^{137}Cs to the Baltic Sea from Chernobyl has been estimated at 4 700 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 ^{137}Cs and ^{90}Sr discharged from the local nuclear facilities were 1.7 and 0.7 TBq, respectively (Ilus & Ilus, 2000). During 1950–1996 the maximum annual dose to individuals from any Critical Group in the Baltic Sea area was estimated as 0.2 mSv/y. The total collective dose from man-made radioactivity in the Baltic Sea was estimated as 2 600 manSv.

Sediment studies and sediment dating

About one hundred sediment cores from the Baltic Sea have been dated in the Laboratory in several co-projects since 1995 dealing with estimation of recent sediment accumulation rates, discharges and spreading of organic pollutants, the history of cyanobacterial blooms and the nutrient flows in the catchments (Ilus et al. 2001, Poutanen and Nikkilä 2001, Isosaari et al. 2002). Sediment datings have been an essential part in these studies and as a partner of these projects the Laboratory has reached a good knowledge of sediment accumulation rates in different parts of the Baltic Sea. The projects have been mainly carried out as a co-operation with the Finnish Institute of Marine Research, the Finnish Environment Institute and the National Public Health Institute (Department of Environmental Health). The results have also been used in estimation of total amounts of ^{137}Cs activities in the Baltic Sea sediments (Ilus et al., 2003, Mattila & Ilus, 2002). Based on all the available data, it was estimated that the total inventory of ^{137}Cs in the seabed of the Baltic Sea in 1998 was 1 940 – 2 210 TBq. The highest total amounts of ^{137}Cs activities per m^2 were measured in the northern parts of the Bothnian Sea where the maximum value was 125 kBq/m^2.

Sediment dating results from the years 1995 – 2003 have recently been summarized and the data were presented in an international conference held in Monaco (Mattila et al., 2004, Mattila et al., 2005). At the stations of the Baltic Sea, the mean sediment accumulation rates ranged from 60 to 6 160 g/m^2/a. The highest accumulation rates were observed at the stations in the northern part of the Bothnian Sea, in river estuaries and in the eastern part of the Gulf of Finland. At the stations of the Bothnian Bay, Bothnian Sea, Gulf of Finland and Baltic Proper, the mean sediment accumulation rates were estimated to be 500, 1 200, 690 and 180 g/m^2/a, as the mean total amounts of ^{137}Cs activities were 9 000, 32 400, 13 200 and 2 600 Bq/m^2, respectively. According to these results, a strong correlation between the sediment accumulation rates and the total amounts of ^{137}Cs activities were obtained, which fact can be utilized in future sediment studies. The studies have also given valuable information about the variation in accumulation rates around the sampling stations, and sources of error related to sediment dating, sediment monitoring and sediment sampling. In the future, the sediment studies will be continued as small co-projects increasing the knowledge of Baltic Sea sediments in the Laboratory.

Studies of transuranic elements

Behaviour of transuranic elements in the aquatic environment in Finland

Studies on the determination of transuranic elements and their behaviour in the Finnish aquatic environment and in the Baltic Sea were started at STUK already in early 1970s. A Ph.D. thesis on this topic was published in 2003 (Ikäheimonen, 2003). The distribution of transuranic elements has been studied in order to clarify the possible sources and behaviour of these elements and the effect of the source on activity ratios in the aquatic environment. Developing of the analysis methods of ^{238}Pu, ^{239,240}Pu, ^{241}Pu, ^{241}Am, ^{242}Cm and ^{243,244}Cm was one part of the study. Great emphasis was laid on quality assurance during the entire research procedure to guarantee competent results, especially because of the very low-level concentrations and the small differences between them.

Concentrations of plutonium in the northern part of the Baltic Sea, in the Baltic Proper, the Gulf of Finland and the Gulf of Bothnia were low, i.e. at the level of the global fallout. However, the effect of the Chernobyl accident could be seen in the sediments. While most part of ^{239,240}Pu originated from the global fallout, the Chernobyl fallout could be seen in the activity ratios of ^{238}Pu/^{239,240}Pu and ^{241}Pu/^{239,240}Pu, and in the excess amount of ^{241}Pu. The portion of Chernobyl derived ^{241}Pu was 5.5 times higher than that originating from the global fallout at its highest. The peak of the Chernobyl fallout (1986) could be detected in the vertical distribution of the undisturbed sediments (Ikäheimonen, 2000, Ikäheimonen, 2003).

In Finnish freshwater fish, in the area of high transuranic fallout and in the water of Lake Päijänne, the Chernobyl derived transuranic elements were observed within few years after the accident as somewhat elevated concentrations. The annual maximum dose to people from transuranic elements in freshwater fish was insignificant, about 50 nSv/y, which is 0.001% of the total average annual dose to Finnish people (Ikäheimonen & Saxén, 2002, Ikäheimonen, 2003).

The concentrations in freshwater fish brings out incomplete knowledge of the behaviour of different isotopes of Pu, Am and Cm in a fresh fallout situation. Some results suggest the preferential uptake of ^{238}Pu when compared to that of ^{239,240}Pu in fish, and that the biological behaviour of Am and Cm is dissimilar in a fresh fallout situation (Ikäheimonen & Saxén, 2002, Ikäheimonen, 2003).

Transfer of transuranic elements from deposition to fish was higher than e.g. that from deposition to plant products. This means that in a possible serious fallout situation, the limit set by the EU for Pu and transplutonium elements in food, other than milk or liquid foods, would be first exceeded in freshwater fish and after that in reindeer meat, mushrooms and plant production. However, to exceed the EU limits, the deposition should be 3 000 times higher for Pu and 1 500 times higher for Am than the highest transuranic elements fall-out recorded in Finland after the Chernobyl accident (Ikäheimonen, 2003).

Transuranic elements in sediments of the Thule area

The Laboratory took part in an international expedition to the Thule area in 1997. Sediment samples from five sampling stations (80 samples altogether) were analysed for transuranic elements at the Laboratory (Ikäheimonen et al., 2002). Generally, the Pu concentrations in the area were from one to three orders of magnitude higher than the fallout level in other Arctic sea areas. The presence of large number of hot particles complicated the estimation of mean concentrations and total inventories. Samples with plutonium from the accident show significant variations in nuclide ratios of ^{238}Pu/^{239,240}Pu, ^{241}Pu/$^{238\ 240}$Pu, and ^{241}Pu/^{241}Am. This indicates that the Pu in Thule may originate from more than one source of a different quality. Particle isolation and activity measurements were also performed in co-operation with the Airborne Radioactivity Laboratory at STUK (Moring et al., 2001).

Nordic radioecology studies

The Laboratory has been involved in several Radioecology Projects supported by the NKS (Nordic Nuclear Safety Research). Short descriptions of each are given below.

<u>Marin radioecology project EKO-1</u>

In the EKO-1 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 in the deep area of the Hästholmsfjärden Bay, eastern Gulf of Finland. A highly comprehensive study on sedimentation rates in different parts of the Baltic Sea was carried out. The estimations were based on the vertical distribution of certain radionuclides (^{137}Cs, ^{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 the sedimentation rate, because of the unstable environmental conditions. The results of the two subprojects were published in the Final Report of the EKO-1 Project (Ilus et al., 2001a and Ilus et al., 2001b).

<u>Radioactive tracers in Nordic sea areas (BOK-2)</u>

The BOK-2.2 project dealt with radioactive tracers in Nordic Sea areas. It was divided into two sections: a) Use of ^{99}Tc as a tracer for transport of contaminated water masses from the Irish Sea to the 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 was in the Baltic Sea, but it also took part in the ^{99}Tc 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 showed that ^{99}Tc can be detected in small quantities in Fucus almost everywhere on the Finnish coast (Ikäheimonen et al. 2002, Ilus et al., 2002).

<u>Further technetium studies</u>

In 2003, the sampling of *Fucus vesiculosus* and some other plant and animal species was repeated along the Finnish coast, and in an inland area of Finland.

Samples for ^{99}Tc analyses were taken mostly from the same sites as in 1999 to follow up changes in the distribution pattern of ^{99}Tc, and to clarify the origin of ^{99}Tc found in *Fucus* along the Finnish coast. Several samples of terrestrial and aquatic plants were also collected from an inland area in the Finnish Lake District (Mänttä) that had been subjected to heavy Chernobyl ^{137}Cs fallout. The activity concentrations of ^{99}Tc in Fucus samples from the Finnish coast were smaller and more evenly distributed than in 1999. Small amounts of ^{99}Tc were also present in several samples taken from Mänttä. According to these results, the most important source of ^{99}Tc are probably the nuclear weapons tests carried out in the 1950s and 1960s. Another potential source of ^{99}Tc in *Fucus* on the Finnish coast might be the discharges from the Sellafield nuclear reprocessing plant (UK), but some results may also point to the contribution of the Chernobyl accident (Ilus et al., 2004).

New indicator organisms for environmental radioactivity (INDOFERN-project)

The objective of the INDOFERN project is to identify new indicator organisms and biomarkers for assessment of environmental radioactivity under normal and emergency situations. The mechanisms of uptake and accumulation will also be studied. Indicator organisms are valuable monitoring objects in emergency situations because they accumulate effectively, and often very rapidly, radioactive substances from their medium. Thus, they are able to give information about nuclide composition and dispersion of radionuclides at early stages of emergency situations. Since the Chernobyl accident, there are plenty of data on ^{137}Cs in biota, but other radionuclides have been left for less consideration. The aim is to get more information about other long-lived nuclides (^{90}Sr, Pu, Am) and about the most abundant discharge nuclides from the nuclear power plants (e.g. ^{60}Co). In addition, the usability of different organs or tissues of the organisms as indicators will be studied. The study yields new data on the occurrence, transport and concentrations of many important radionuclides in potential candidates of indicator organisms in a wide scale of Nordic ecosystems.

The INDOFERN Project is participated by eight laboratories representing all the Nordic countries; it is coordinated by the NPP Environmental Laboratory. So far, data have been collected from about 170 organisms. The idea in sampling has been to take the samples from relatively small areas where the environmental factors (type of soil, etc.) and the amount of radioactive deposition are likely homogenous, which makes it possible to compare the indicator value of different organisms. Special studies for the project have been carried out by the Laboratory in the terrestrial and aquatic environs of the Loviisa and Olkiluoto NPPs and in an inland area representing the highest deposition zone of the Chernobyl fallout in Finland (Mänttä). The planned duration of the project is 3.5 years and it will be concluded in the end of 2005. The results will be published in the Proceedings of the project's open Final Seminar and in a joint paper of the Project Group to be published in a respected scientific journal.

Radiochemiacal analysis in emergency and routine situations (RADCHEM-project)
The objective of the RADCHEM Project is to critically compare the reliability, repeatability, fastness, easiness and costs of radiochemical rapid methods, and the virulence, waste problems, etc. of the chemicals to be used. Based on this analysis, areas for further studies and the need to develop or modify the methods will be identified. The project is focused on those rapid methods for uranium, plutonium, americium, curium and strontium which can be applied both in emergency and normal situations. In addition, information will be collected about the methods used in the participating laboratories for neptunium and certain natural radionuclides. The aim is to establish active contacts and discussion between the Nordic laboratories and persons responsible for developing radiochemical methods. The project is participated by eight Nordic laboratories.

Laboratory measurements and quality assurance (BOK-1.1)
The objective of the project was to develop the quality of analysis of radionuclides, both for radioecology studies and emergency situations. To this purpose, two intercomparison exercises of alpha, beta and gamma-analysis on environmental samples were carried out. The Laboratory participated also in two intercomparison exercises of gamma spectrum analysis that were conducted to test the capability and rapidity of the method in emergency situations. Seminars on accreditation and measurement techniques were also arranged (Klemola, 2001).

8th Nordic Seminar on Radioecology
The 8th Nordic Seminar on Radioecology was held in Rovaniemi in 2001. The Laboratory was responsible for organising the seminar and for editing the Proceedings of the Seminar (Ilus, 2002).

Framework for Assessment of Environmental Impact (FASSET) and Environmental Risk from Ionising Contamination: assessment and management (ERICA)
The objective of the FASSET Project (2000–2004) was to create a framework for the assessment of environmental impact of ionising radiation in European ecosystems. The ERICA Project (2004–2007) is a sequel to the FASSET Project and its objective is to provide an integrated approach to scientific, managerial

and societal issues concerned with the environmental effects of contaminants emitting ionising radiation, with emphasis on biota and ecosystems. These vast projects have assembled a great number of European scientists from numerous research institutes. STUK has participated in both projects and the Laboratory has given contribution to the projects in the work packages responsible for providing scientific environmental data and scientific evaluation basis for the use of other work packages. The contribution of Erkki Ilus has been to select the indicator organisms for the Baltic Sea, to collect data on transfer factors of various radionuclides from water to biota in the Baltic Sea and to save them to a common data base.

Co-operation with the other laboratories at STUK

In the preceding evaluation of the research activities of STUK the Evaluation Panel recommended that "to achieve critical mass and to exploit potential synergism in analytical activities, close collaboration, concentration of radiological analyses in one laboratory, or integration of laboratories should be considered". The NPP Environmental Laboratory's opinion is that a laboratory of about 10 persons is certainly most effective and the working climate in a small group is always better than in larger units. The tight timetable of the main task of the Laboratory (monitoring programmes of the power plants) and the pressing working pace in the Laboratory speaks in favour of a small group which takes a personal responsibility and is able to keep the tight timetable in taking care of the sample flow and in reporting the results to the customers.

Close collaboration with all laboratories has already now been implemented, e.g. in gamma spectrometric analyses and in the use of all other analytical equipment. The co-operation between the laboratories has been taken care in three permanent Working Groups: (1) WG for Sampling and pretreatment, (2) WG for Radiochemical analyses and (3) WG for gammaspectrometry. All the laboratories are represented in these Working Groups, which are working actively.

Close co-operation between the laboratories has also been implemented in several joint projects, e.g. with the Laboratory of Ecology and Foodchains, the Laboratory in Northern Finland, the Laboratory of Airborne Radioactivity and the Laboratory of Natural Radioactivity.

<u>Long-lived radionuclides in lake ecosystems and their storage in bottom sediments of lakes</u>

One of these joint projects was the project "Behaviour of long-lived radionuclides in lake ecosystems and their storage in the bottom sediments of the lakes" carried out as co-operation between the Laboratory of Ecology and Foodchains and the

NPP Environmental Laboratory. The results of the first part of the project were published recently (Ilus & Saxén, 2005). The amount and vertical distribution of Chernobyl-derived ^{137}Cs in the bottom sediments of certain Finnish lakes were investigated. The depth profiles of ^{137}Cs in the sediments showed considerable variety in the lakes studied. The size and shape of the ^{137}Cs peak did not always correlate with the amount of the deposition in the area, but on the other hand, reflected differences in sedimentation processes in different lakes. The total amounts of ^{137}Cs in sediments varied from 15 to 170 kBq/m^2 at the sampling stations studied. In most of the lakes, the total amounts of ^{137}Cs in sediments were about 1.5–2 times higher (in one case 3.2 times higher) than in local deposition. Compared with the total amounts of ^{137}Cs at the same stations in the late 1960s and 1970s, the values were now at their highest, about 60-fold. The most important factors affecting ^{137}Cs values in sediments were the local amount of deposition and the type of the lake and the sediment, but in addition, there was a number of other factors to be considered.

The second part of this project is focused on transport of fallout nuclides (principally ^{137}Cs) and on the significance of sedimentation processes in small lakes, in which the ^{137}Cs concentrations in fish have remained high since the Chernobyl accident. The aim is also to consider transport of radioactive substances from fallout to different parts of the lake ecosystem in lakes with easily restrictable drainage areas. Two lakes were selected as study objects and samples of water, sediment and vegetation from the lakes, and samples of soil and vegetation from the terrestrial environments were taken in 2003. A publication is under preparation.

Age and radioactivity in fish

The third ongoing joint project with the Laboratory of Ecology and Foodchains is focused on the correlation between the age and radioactivity in fish. The fish species to be studied are pike and perch, and the material will be collected from Loviisa and Olkiluoto, from 2–3 lakes and from one additional coastal area. The project is planned to terminate in 2007.

Radioactivity of wood ash in energy industry and its radiation effects

The Laboratory has also participated in a project coordinated by the Laboratory of Ecology and Foodchains with the objective to improve the assessment of wood ash radioactivity and to facilitate safe handling and use of ash. The effect of the origin and composition of wood fuel on variation of radioactive caesium content in ash were examined. Typical ^{137}Cs activities found in fly ash were 1 000–5 000 Bq/kg. Naturally occurring radionuclides, such as ^{40}K, ^{226}Ra and ^{232}Th also contribute to the total radioactivity in ash (Vetikko et al., 2004).

Transuranic elements in the Arctic sea areas

Study of transuranic elements in the Arctic Sea areas (Barents, Kara, Petshora, Laptev and White Sea) were continued in close co-operation with the Laboratory in Northern Finland. Concentrations of the Pu isotopes were low in sediments, fish and algae samples from Barents, Kara and Petshora Seas, as well as in the outlets of the Rivers Ob and Yenisey. The Pu isotope ratios in sediments showed that the main source of TRUs has been the global fallout. In the Kola Bay, the concentrations of transuranic elements in sediments were low too, but the elevated ^{238}Pu/^{239,240}Pu ratios indicate that an other source, apart from the global fallout must exist (Ikäheimonen, 2003).

Depleted uranium

In 2001, the Laboratory participated in comprehensive analysis of three projectiles suspected of being composed of depleted uranium (DU). The study was carried out in co-operation with several laboratories of STUK and also other institutes (VTT Chemical Technology, Finnish Defence Forces Technical Research Centre).

The aim of the study was to identify and quantify the radioactive materials present in the projectiles and to estimate the possible skin dose. Analyses of the projectiles were carried out by different complementary methods, such as alpha spectrometry, gamma-ray spectrometry, mass spectrometry and electron microscopy, in order to verify the results obtained. The NPP Environmental Laboratory was responsible for the alpha and gamma-ray spectrometry analyses.

Shape and density of the projectile was challenging for the calibration of a HPGe spectrometer. With the help of semi-empirical efficiency transfer method the activities of the uranium isotopes were obtained and ^{235}U/^{238}U mass ratio 0.0025 ± 0.0005 could be calculated. A routine analysis using chromatographic resins for the separation of U and possible Pu and Am+Cm was performed on the DU sample. ^{238}U, ^{236}U, ^{235}U and ^{234}U were identified in the alpha spectra of the U-fraction. The presence of ^{236}U reflects the use of reprocessed fuel. No transuranium elements were detected (Pöllänen et al., 2003).

Development of methods

Computerized 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. The method utilizes a computer code for the calculation of detector efficiencies. The code was tested together with a number of other corresponding software in the EUROMET project 428 examining efficiency transfer results for Ge gamma-ray spectrometers. The test showed that the method gives detection efficiencies with deviations comparable to the other semi-empirical methods participating in the project. The final results of the project were published in 2001 (Lépy et al., 2001).

Carbon-14

As a part of the environmental monitoring programmes of the Finnish NPPs a method to analyse ^{14}C from environmental samples was introduced. Organic samples are combusted to water and carbon dioxide with Perkin Elmer 307 Sample Oxidizer. Water and carbon dioxide are trapped to specific cocktails and the samples are measured with a low background liquid scintillation counter. Environmental levels of ^{14}C in Finland are planned to be monitored more widely in 2005.

Nickel-63 in NPP's discharge waters

A new method to analyse ^{63}Ni from discharge waters of NPPs was developed in the Laboratory. The method is based on the dimethylglyoxime (DMG) precipitation with Eichrom's Nickel-resin. The method was tested with discharge waters from the Finnish NPPs with promising results, but it is not yet routinely used in the Laboratory.

Quality Assurance

The Laboratory has played a central role in developing and establishing the quality systems and accreditation of relevant analysis and sampling methods in the Department of Research and Environmental Surveillance at STUK. The accreditation was awarded in 1999 and renewed in 2003 according to the EN ISO/IEC 17025 standard. The accredited fields of testing comprise the tests of radiation safety and the related environmental sampling methods, gammaspectrometric analyses, radiochemical analyses of tritium and the analysis of radioactive strontium and transuranic elements in environmental, foodstuff and biological samples.

The Laboratory has participated in several national and international inter-comparison exercises and proficiency tests organised by the IAEA, NPL (National Physical Laboratory, UK), NIST (National Institute of Standards and Technology, USA), NKS (Nordic Nuclear Safety Research) and HELCOM/MORS. The results have shown very good quality of analytical methods used in the Laboratory.

Theses

During the 5-year period, academic dissertations have been finished in the Laboratory as follows:

Tarja K. Ikäheimonen, Ph.D. thesis, 2003 (Ikäheimonen, 2003)
Erkki Ilus, Ph.Lic. thesis, 2001 (Ilus, 2001)
Timo Töyri, M.Sc. Pro gradu thesis, 2003 (Töyri, 2003), summer assistant

One Ph.D. thesis (E. Ilus, Impacts of Finnish nuclear power plants in aquatic environment including the thermal effects of cooling water, 30 years of experience) and one M.Sc. pro gradu thesis (V-P Vartti, Technetium-99, its origin, mobility in the marine environment and research in the marine environment of the Finnish coastal areas) are in preparation.

Dissemination of expertise and information

Training

The Laboratory hires every year 1–5 students as short-term trainees. While utilizing extra work power the Laboratory gives an opportunity for the students to familiarise with the field and methods of environmental radioactivity studies.

In 2001, the Laboratory arranged a one-month training of an IAEA trainee under the IAEA fellowship.

Editing the series of books “Radiation and nuclear safety”

Scientists of the Laboratory contributed in editing of the series of books “Radiation and nuclear safety” (in Finnish: Säteily ja ydinturvallisuus) published by STUK, as the editor of the first volume “Observation of radiation” (Ikäheimonen, 2002), and by writing or co-writing three chapters: “Radiation detectors” (Klemola, 2002) “Determination of radioactivity” (Ikäheimonen et al., 2002) and “Radioactive substances in the Baltic Sea” (Ilus in Saxén et al., 2003)

2.4.6 Research plans for the next five years

The research projects of STUK for the period of 2003–2005 are described in detail in the STUK-A202 report (Salomaa, 2004). 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 2005 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 Project Group is continuous.

- Coordination responsibility in the NKS INDOFERN Project. To be concluded in the end of 2005.
- Partnership in the NKS RADCHEM Project. To be concluded in the end of 2005.
- Partnership in the EC ERICA Project. Duration of the project: March 2004–February 2007.
- Forest ecosystem study in the environs of Finnish nuclear power plants. To be finalized in 2006.
- Study of coastal ecosystems in the environs of Finnish NPPs. To be finalized in 2006.
- Ecosystem study in the Mänttä area. To be finalized in 2006.
- Ecosystem study in two small lakes with continuously high concentrations of Chernobyl ^{137}Cs in fish; co-operation project with the Laboratory of Ecology and Foodchains (Saxén). To be finalized in 2006.
- Participating in the EU/EURANOS project in the part of delivering the Handbook for emergency response to radiation incidents.
- Participating in the other studies of cleaning environment after an radiation accident.

2.4.7 List of Publications

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2.5 Ecology and Foodchains

2.5.1 Key words and specific technologies

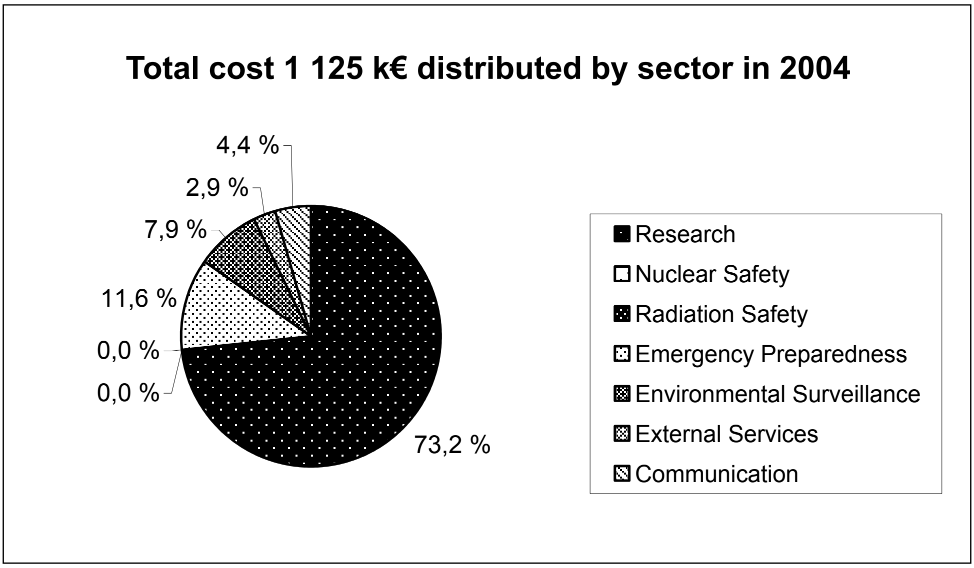
Key words

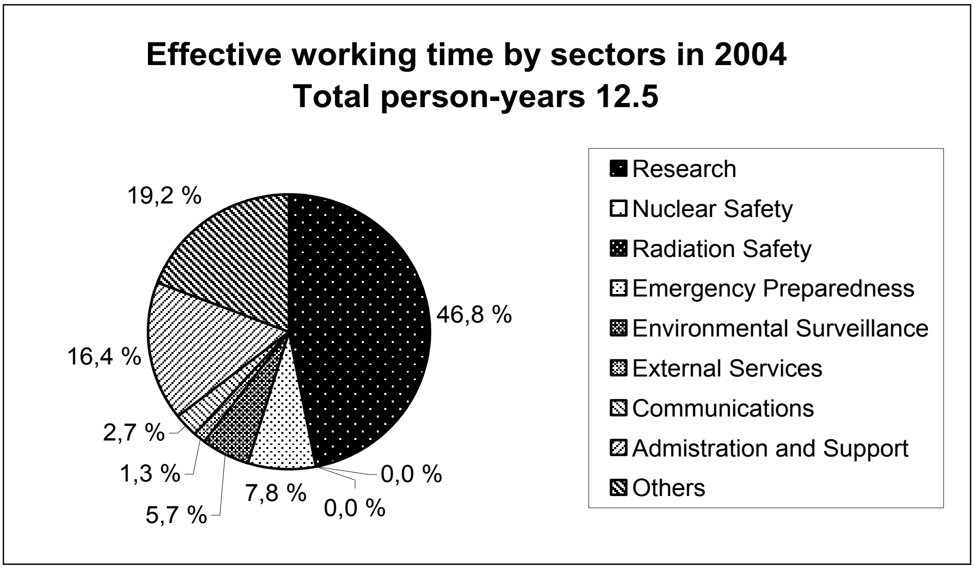
Forest radioecology, freshwater radioecology, agricultural radioecology, exposure pathways, environmental modelling, countermeasures, radiation protection of the environment, radionuclides in the foodchain, environmental monitoring, nuclear emergency management, decision support, multiattribute risk analysis, stakeholder involvement

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, RODOS system, GIS systems

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, to assess exposure from radionuclides in the environment through various pathways, to plan countermeasures for agriculture and forestry, and to plan rehabilitation strategies for contaminated inhabited areas
- to improve nuclear and radiological emergency management and decision support, including the decision analysis and the development of decision support system tools
- to perform surveillance of artificial radionuclides in deposition, foodstuffs, drinking water and surface water
- to improve environmental monitoring systems and to develop food monitoring strategies
- to participate in the development of environmental radiation protection systems
- to perform service analyses on radioactivity in foodstuffs, and to give certificates of radioactivity concentrations for export products, and
- to provide expert services on emergency planning and preparedness.

Research projects are carried out in co-operation with other institutes either nationally, as joint studies with the other Nordic countries, within the framework of the EU, or otherwise internationally. The Laboratory has multidisciplinary connections and scientific co-operation in Finland, particularly with the Finnish Forest Research Institute and Helsinki University of Technology.

Assessment of exposure from radionuclides in the environment

The Laboratory is responsible for the execution of the programmes monitoring artificial radionuclides in deposition, foodstuffs and surface and drinking water. The monitoring results are reported annually in the STUK-B report series and delivered to the European Commission on a regular basis.

Besides monitoring, which is a minor aspect of activities, the Laboratory also examines the distribution and transfer of radionuclides in terrestrial and aquatic environments. Both agricultural and forest environments are included in the research of terrestrial field.

The Laboratory's research projects and monitoring programmes have generated large databases that facilitate the estimation of radiation doses to the population via foodstuffs from terrestrial and aquatic environments. The average radiation dose via foodstuffs from artificial radionuclides is at the present below one per cent of the average annual radiation dose of a Finnish person, which is about 4 mSv including all sources. About 75% of the ingestion dose is contributed by wild food such as mushrooms, forest berries, game meat and freshwater fish, while the main agricultural products contribute only about one quarter to the dose. For persons consuming a lot of natural products the radiation dose via foodstuffs may be more than ten times the average.

Radioecology and modelling

- forest ecosystems
- aquatic ecosystems
- agricultural ecosystems
- development of environmental transfer models, countermeasure models and dose assessment models

Radioecological research projects and development of environmental models complement each other. Both are needed to estimate radiation doses and to plan countermeasures in an emergency situation. The modelling activities are described in section 2.5.5.

Management and restoration of rural and inhabited areas after large-scale radionuclide contamination

- analysis of countermeasures and development of restoration management for agricultural land, foodstuffs and forests

- emergency management and rehabilitation strategies for contaminated inhabited areas
- development of emergency response such as radiation monitoring strategies and national monitoring systems for radioactivity of food, and radioanalytical methods
- organization of and participation in emergency exercises.

The Laboratory is prepared to give advice on radiation problems in the fields of food and water supply and the forest industry. Both private and governmental organizations responsible for emergency preparedness on food, forestry and environmental sectors are an important part of the Laboratory's national network.

The Laboratory is developing the national food monitoring system to ensure countrywide resources for the assessment of radiation situation. This includes measuring equipment, monitoring strategies and guidance, and training. The task is carried out in collaboration with the Radiation Hygiene Laboratory and the Airborne Radioactivity Laboratory of STUK.

Nuclear emergency management and decision support systems

Planning in advance both possible countermeasures and the decision-making process for the early and later phases could ensure rational and transparent decisions for management of any future nuclear accident.

Openness, transparency and participation by the key players are all important factors for balanced decision-making on public issues. Decisions should be understood, accepted and supported by both the population and decision-makers. The objective is also to develop methods to include the concerns of all key players openly and equally in the decision taken. The approach applied employs a group process where responsibility is placed on participants to assimilate information and to provide judgements. It has a clear structure based on the Decision Analysis.

Expert services

The Laboratory provided consultancy services in the field of emergency preparedness within several EU funded projects. The projects transferred Western European practices in the field of emergency planning and training for the regulatory authorities of several Eastern and Central European countries. In addition, the implementation of the RODOS system has been supported in four countries.

Communication and training

Communication and training include:

- information bulletins to the public on radionuclides in foodstuffs
- communication with and delivery of information to the media
- communication with stakeholders, customers and interest groups
- training of stakeholders: industry, and agricultural and environmental health authorities, and
- organization of seminars on emergency management and other issues related with the activities of the Laboratory.

The laboratory staff has given lectures and has communicated with various stakeholder groups on emergency planning. Lectures have been given at emergency preparedness seminars. The participants were from the food industry, the agricultural authorities and interest groups such as food safety researchers and authorities, farmers and hunters. Training has been arranged for staff at local foodstuff and environmental laboratories responsible for measuring locally produced foodstuffs in a fallout situation.

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, assessement models, analysis and development of countermeasures, dietary surveys, radiochemistry

Kari Sinkko, PhD (physics), project manager
Decision support systems for nuclear emergency management, planning of protective actions, countermeasures for inhabited areas

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

Michael Ammann, MSc (eng.), scientist
Decision support systems for nuclear emergency management, environmental modelling

Eila Kostiainen, BSc (radiochemistry), scientist
Radioecology of agricultural and seminatural ecosystems, analysis of countermeasures, radiochemistry, gamma spectrometric analysis

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

Ulla-Maija Hanste, assistant researcher
Radiochemical analysis ($^{89,90}Sr$, ^{14}C, ^{210}Pb, ^{226}Ra, ^{210}Po), alfa and beta 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 and maintenance of a database for forest research, gamma spectrometric measurements

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

2.5.4 Aims of research

Key areas of the research activities of the Laboratory are:

1. Improvement of nuclear and radiological emergency preparedness and decision support, including the decision analysis and the development of decision support system tools. The aim 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 environmental contamination and
   - communicating with various stakeholders and interest groups, including the media.

2. Quantification of environmental transfer of artificial radionuclides through experimental studies, designed also for purposes of dose assessment, modelling, and planning of emergency response, particularly for agricultural and freshwater ecosystems and forests. Research projects produce information for short and long-term response to large-scale radioactive fallout situations.
3. Assessment of individual and population exposure from man-made radionuclides in the environment and in foodstuffs, and from the use of natural resources (e.g. timber and peat) as raw material for construction, industry and energy production.
4. Participation in the development of radiation protection of the environment.

2.5.5 Main results over the last five years

Main results of the studies carried out by the Ecology and Foodchains Laboratory are described under the following themes: emergency preparedness, radioecology and dose asessment, and radiation protection of the environment. The research projects for the period 2003–2004 are described in detail in the reports STUK-A-179 (Salomaa 2000) and STUK-A202 (Salomaa 2004).

Nuclear emergency management and decision support systems

Planning of protective action and development of decision support

This work was undertaken in order to develop methods and techniques for evaluating systematically and comprehensively protective action strategies in the case of a nuclear or radiation emergency (Sinkko 2004, Sinkko et al. 2004). This was done in a way that the concerns and issues of all key players related to decisions on protective actions could be aggregated into decision-making transparently and in an equal manner. An approach called a facilitated workshop, based on the theory of Decision Analysis, was tailored and tested in the planning of actions to be taken (Hämäläinen et al. 2000a; Mustajoki et al. 2001). The work builds on case studies in which it was assumed that a hypothetical accident in a nuclear power plant had led to a release of considerable amounts of radionuclides and therefore different types of protective actions should be considered. Altogether six workshops were organised in which all key players were represented, i.e., the authorities, expert organizations, industry and agricultural producers (Ammann et al. 2001; Hämäläinen et al. 2000b; Sinkko et al. 2001). The participants were those responsible for preparing advice or presenting matters for those responsible for the formal decision-making. Key players or stakeholders comprise responsible administrators and organizations, politicians as well as representatives of the citizens affected and other persons who will and are likely to take part in decision-making in nuclear emergencies.

The objectives and attributes considered in a decision on protective actions were discussed in many occasions and were defined for different accident scenarios to come. In the workshops intervention levels were derived according to justification and optimisation principles in radiation protection. Insight was also gained in what information should be collected or subject studied for emergency management. It was proved essential that the information is in a proper form for decision-making. Therefore, methods and models to assess realistically the radiological and cost implications of different countermeasures need to be further developed. In the consequent assessments, it is necessary to take production, economic, demographic and geographic information into account.

The experience gained strongly supports the format of a facilitated workshop for tackling a decision problem that concerns many different key players. The participants considered the workshop and the decision analysis very useful in planning actions in advance. They also expected a similar approach to be applicable in a real situation, although its suitability was not rated as high as for planning. The suitability of the approach for the early phase of an accident was not seen as good as a conventional managerial approch. It is concluded that a facilitated workshop is a valuable instrument for emergency management, and in exercises, revising emergency plans and identifying issues that need to be resolved.

All participatory methods, when practiced in advance, create a network of key players ensuring that they are better prepared for an accident situation. Facilitated workshops provide the participants with a forum for structured dialogue to discuss openly the values behind the decision.

<u>EVATECH, Information requirements and countermeasure evaluation techniques in nuclear emergency management</u>

EVATECH was a research project aiming for enhancement of quality and coherence of response to nuclear and radiological emergencies in Europe. The project was coordinated by STUK and it was carried out within the key action "Nuclear Fission" in the fifth Euratom Framework Programme in 2001–2005. The objective was to improve the decision support methods, models and processes in ways that take into account the expectations and needs of different stakeholders participating in decision-making of protection of members of the public and workers in a nuclear emergency situation. The project had ten partners from seven European countries.

The project was divided into four work packages dealing with; (1) development of evaluation tool(s) for the decision support systems (RODOS and ARGOS) that enable to find out the most practicable protective actions in a reliable and transparent way, (2) description of emergency management processes in a few European countries by a modern process modelling technique to clarify the decision making processes and to find out the best practices, (3) development of methodologies to conduct scenario-focused decision-making workshops with participation of relevant stakeholders, and (4) arranging of national decision-making workshops in seven participating countries to identify feasible countermeasures to clean-up contaminated urban environments after a nuclear accident.

In 2003, a decision on the new evaluation software to RODOS was made. Instead of continued development of the integrated evaluation subsystem (ESY) built within a Motif environment for RODOS, it was decided to adopt a generic Java-based multi-attribute evaluation tool (Web-Hipre, HIerarchical PREference analysis in the World Wide Web), developed at Helsinki University of Technology (HUT). A standard Windows-based multi-attribute evaluation tool VISA (Visual Interactive Sensitivity Analysis) was decided to be used with the other decision support system ARGOS.

The processes of management of nuclear emergencies were surveyed and documented in the UK, Belgium, Germany and Slovak Republic. Modern process modelling techniques were used to produce a generic model to describe the emergency management processes in these countries. The modelling was done to survey, document and compare the duties and emergency management processes in several countries and to define information and other support needs at various stages of the process. The objective was also to study whether information and decision support systems can be used more effectively and to identify differences between the countries, understanding the structural reasons for these and to suggest practices which might be shared.

A training seminar on facilitated workshops was arranged at STUK in 2003. The objective of the seminar was to introduce the participating experts to decision analysis and facilitated workshops, and to train them to conduct this kind of workshops where representatives from various organizations gather around the same table to find the most practicable countermeasures in an emergency situation. Nine national workshops on clean-up actions in inhabited areas took place between November 2003 and May 2004 in all the seven participating countries.

Completion and Customisation of the Modelling in RODOS

The work in the RODOS Customisation project of the 4th FP aimed at expanding the applicability of the RODOS system to encompass all stages of an accident and all distance ranges in Europe and at making improvements and customizations in existing methods. In addition to completion and customization of existing radiological models, a Forest Foodchain and Dose Module FDMF was developed in co-operation with STUK and IPSN (Institut de Protection et de Sûrete Nucléaire, France; Rantavaara et al. 2001), and a regional lake model was developed with the Technical Research Centre of Finland (RODOS Final Report [internal of the project]). Integration of FDMF into the RODOS system was completed and validated in early 2000.

The following data was provided, adapted and maintained:

- geographic maps
- demographic and production data
- inventory and source term database
- parameter database for the food-chain module
- real-time connection to weather masts of the Finnish NPPs
- numerical weather prediction data for Finnish and neighbouring NPPs

The RODOS system has been installed in the emergency centre of STUK and was used both by players and planners of emergency exercises. The players used it to assess doses and other consequences of the accident and advantages and disadvantages of interventions, and the planners used it to prepare exercise scenarios and to simulate measurements. The use of RODOS in training and exercises is an ongoing activity.

<u>RODOS Migration – Improved modelling for forest contamination</u>

The aim was to improve the forest food chain and dose model FDMF of RODOS (Rantavaara et al. 2001) for more practical applicability and to extend the model with an assessment of countermeasure implications.

The new forest model FDMF allows simulating the fate of radionuclides in the forest ecosystem. It gives the contamination of forest products as a function of time and also shows their spatial distribution on geographical maps. Radiation doses for different population groups resulting from their use of forests and forest products can be assessed. The modelled dose pathways are ingestion of wild berries, mushrooms and game meat, and external exposure received during the time spent in forests.

The purpose of forest countermeasure model LCMforest is to provide the radiation protection community with a tool that allows the assessment, evaluation and planning of countermeasure strategies. The user can choose between various countermeasure options, specify the intervention area and the timing, and receives an evaluation of the performance of the strategy in terms of averted dose and costs.

The countermeasure assessment model LCMforest provides the user with a tool for assessing either the dose saving potential of various countermeasures or the availability of acceptable timber. Model outputs of both FDMF and LCMforest are maps, tables and time plots. Whenever possible, costs are attributed to countermeasures. Only such countermeasures have been modelled that are not in conflict with the principles of sustainable forestry. Twelve countermeasure options are available in LCMforest: access restriction; banning mushrooms, berries, game meat; intensifying processing of mushrooms, berries, game meat; applying soil improvement measures, and timed felling.

In the early phase of a large-scale fallout situation, both access to forests and use of wild food products may need temporal restrictions. Considering the contamination dynamics of trees and giving an intervention value for activity concentration in wood, the timing of felling operations can be modified and thereby harvesting of otherwise unacceptably contaminated timber can be avoided. The availability of acceptable timber can be improved with practicable remedial measures which are activated at certain times after the contaminating deposition. For access restrictions and for measures related with wild foods, user-defined intervention criteria will set the timing.

To provide European-wide coverage, FDMF and LCMforest can be adapted to new radioecological regions by extending the parameter database, as also in other food dose models of RODOS. Adaptation to local conditions is important especially for the assessments of the radioactivity of timber.

RODOS Users Group

Prior to 1998, the development of RODOS, a decision support system designed for the management of nuclear emergencies, had been carried out almost entirely by research scientists and engineers. The end-users had little or no input into this development. To redress this situation, the RODOS Users Group (RUG) was established in 1998 under a Concerted Action Contract between the European Commission and STUK. The main objectives of this group were to encourage the emergency management community to use such a system, to provide a forum for end-users to share their experience in the use of such systems and to provide feedback from the end-users to the model and system developers in regard to operational problems and required improvements.

Exercises based on fixed accident scenarios proved to be an appropriate means of highlighting issues that needed to be discussed between users and developers and to stimulate and motivate the end-users to maintain and further develop the system. Such exercises also promoted further activity in the field of emergency management.

The organization and administration of realistic exercises are time consuming, laborious and expensive. It is therefore very important that the maximum benefit is achieved from such exercises. The use of analytical evaluation methods could be better employed for assessing an exercise and analysing the results. It would be useful in this context to formulate a framework that could provide scientific levels of merits and guarantee the full documentation of the work and effort invested. The workload in designing future exercises for RODOS could be reduced by taking all opportunities to use RODOS in international exercises.

Users with expertise and a responsibility in the field of emergency management have to be familiar with the relevant models used in the decision support system (DSS). They also have to be aware of the level of reliability of the calculated results and the limits and conditions applying to the model predictions. It is therefore essential that good co-operation exists between end-users and the R&D community developing the system. The RUG provided a forum for the end-users that enabled to communicate about their requirements to the developers, to receive advice and demonstrations of the latest additional features to the system. It is seen essential that the end-user can contribute to the development of models used in RODOS and other DSSs, and perhaps in the future, become more involved in the R&D aspects of these systems.

<u>DSSNET, Improvement, extension and integration of operational decision support systems for nuclear emergency management</u>

The overall objective was to create an effective framework for better communication between the community of institutions involved in operational off-site emergency management and the many RTD institutes. The aim was to get feedback from end users to further develop the decision support systems (DSS) for making practical improvements of emergency response in Europe. The specific objectives of the network included:

- to ensure that future RTD is more responsive to users' needs,
- to inform the user community of new developments and their potential for improving emergency response,
- to improve operational decision support systems by utilizing feedback of operational experience,
- to identify how information and data exchange between countries can be improved,
- to promote greater coherence among operational decision support systems and to encourage shared development of new and improved decision support systems features, and
- to improve the practicability of operational decision support systems.

Thirtyseven institutions from 21 countries of East and West Europe have been members of the network, with about half of them responsible for operational emergency management.

To stimulate the communication and feedback between the operational and the RTD community, five problem-oriented emergency exercises were performed. They covered various time phases of an accident and extended from the near range to farther distances with boundary-crossing transport of radionuclides. Working Groups were established in order to evaluate the experience gained with decision support systems and the information exchange between them. STUK took care of user interfaces, results and interaction with decision-makers. The other Working Groups were: exchange of data and information relevant for decision-making, system functions, networks and processing of on-line data, European database and hydrological problems.

Five emergency exercises provided valuable insight and lessons for operators and users of decision support systems. The feedback received on operational aspects of decision support systems was largely translated into operational improvements. Questionnaires were developed, distributed and evaluated by the Task Leaders of the Work Packages. The results were important input to RTD projects running in parallel, such as RODOS Migration, DAONEM, EVATECH and MODEM.

Stakeholders of the food supply chain in the FARMING network project

Stakeholders of the food supply chain ’from field to table’ were invited to collaborate under the FARMING (Food and Agriculture Restoration Management Involving Networked Groups) Thematic network in the 5th FP of the EC. About twenty Finnish organizations nominated their representatives to the group which comprised of professionals from industrial life and civil servants of authorities responsible for safety of food. Also interest groups of farmers, food industry, logistics operators, consumers, media and nature conservation organizations were involved.

The objectives were establishing a sustainable stakeholder group engaged in planning of emergency preparedness and evaluation of practicability of a set of countermeasures and waste disposal options suggested for intervention after radionuclide contamination of food production systems. Belgium, Finland, France, Greece and United Kingdom (coordinator) participated in the project, the results of which are shown in the internet (www.ec-farming.net).

The Finnish stakeholder group had annual seminars in 2001–2003. The working process was iterative; the topics of presentations and discussions supported knowledge base needed in evaluation of countermeasures and intervention strategies. Additionally, the Finnish group related the implementation of protective measures to the functional network of the food supply since the first seminar which included a scenario exercise in 2001. The seminar results were reported annually as project deliverables.

The stakeholder discussions on countermeasures, particularly on using the criteria for practicability, gave emphasis on the need for realistic cost estimates for implementation. A local context and an actual timing of radionuclide contamination of the food supply chain were needed. To improve the use of resources in agricultural economics research in planning of emergency response, a collaborative case study was activated. The objective of the study was comparison of costs for a few feeding options suggested for milk producing farms in a hypothetically affected area (Rantavaara et al. 2005a). Maintaining milk production was shown to be profitable even in the worst lack of clean feed, if a market for clean feed was possible to be created in a short time after the contamination.

Communication at different levels and stages from field to fork was emphasised, and a need for consumer education considered. The stakeholders' customer magazines were the main channel for dissemination of findings of the FARMING network to the stakeholders linked with the member organisations.

The partners from different parts of Europe emphasized the influence of their special production conditions on the content of intervention. Thereby the Finnish group considered the northern regions (Root et al. 2005). The evaluation results from the five countries revealed distinct differences, understandable through cultural, climatic, historic or other national and regional factors (Nisbet et al. 2005).

The Finnish stakeholder group achieved in three years a reasonable level of competence for coping with the radiation protection and radioecological background knowledge of importance in order to plan efficient response to contamination problems at various stages of the food supply chain. Consideration of local actors in training, and in planning and implementation of intervention was seen necessary for a successful response to accidental contamination of food production systems (Rantavaara et al. 2005b).

<u>Development of agricultural countermeasures</u>

STUK contributed to a systematic description of agricultural countermeasures in data sheet format under Nordic collaboration (Andersson et al. 2000, 2002). Later, corresponding collaborative approach resulted also in more general views on emergency preparedness in agriculture (Brink and Lauritzen 2002).

Preventing contamination of food under industrial processing from airborne radionuclides

Use of unfiltered air in pneumatic transport, drying or during roasting of foodstuffs can imply a risk of contamination during passage of a radioactive plume. Such conditions were theoretically examined for a cereal mill, and aerosol physics of radioactive particles involved in the process was applied for simulation of foodstuff contamination. Finally, some basic recommendations were given for food industry for coping with an unexpected risk of contamination (Valmari et al. 2004).

Radioecology and dose assessments

Radioecology of forest management – development of methodology for sustainable remediation of contaminated forests

The current knowledge resulting from experimental studies on soil improvement as a remedial method for contaminated forests is sufficient to confirm significant reduction in radionuclide contamination of trees and understorey vegetation. Growth conditions including soil type and nutrient status, and also species structure and development stage of a tree stand cause variation in observed remedial effect.

A number of test results from collaborative analyses of field experiments carried out by STUK and the Finnish Forest Research Institute during the 1990s have been published. Considerable reduction in the radiocaesium contamination of trees, particularly in debarked woody parts, has been measured in field conditions in boreal coniferous forests. New findings were related to harrowing of forest floor (Rantavaara and Raitio 2002), mineral fertilization of pine stands and understorey birch on various sites (Aro et al. 2002, Kaunisto et al. 2002a, 2002b), and effect of fertilization on underground wood fractions (Aro and Rantavaara 2002). Also radioactive strontium was considered in testing the effect of harrowing and/or liming on the uptake of radionuclides by young pines.

Effect of ash fertilization and/or prescribed burning on radiocaesium in wild berries was observed in the next few years after the treatments (Levula et al. 2000). All treatments showed a net reduction in activity concentrations of lingonberries, and the effect was most pronounced and of long duration with the highest dose of ash per surface area of soil.

Costs and profits in production of timber were compared based on a real forest area and a hypothetical contamination with ^{137}Cs. The net current value of timber covered well the costs for fertilization. Production of timber was more profitable after a remedial fertilization of soil than without soil improvement also because of a more advantageous timing of harvest (Rantavaara et al. 2002a).

Management methods filling the criteria of sustainable forestry have been recognized in Finland and several other countries. As far as remedial management is based on good practices of forestry applied today, the ongoing programme for research and development of methodology will provide acceptable tools.

The usefulness of forest management for remediation after a radionuclide contamination has been reviewed for national forestry experts (Aro and Rantavaara 2003) and for the Nordic radiation protection society (Rantavaara and Aro 2003), and brought into a Nordic co-operative context where radioecological background, preparedness and available tools for, and the state of management of forest remediation in Northern Europe were compiled (Hubbard et al. 2002).

Radioactivity of wood ash generated in energy industry

A survey for assessment of radioactivity in ash from biofuel power plants located in different parts of Finland was carried out in the late 1990s (Rantavaara and Moring 2001). The results suggested a more specific study on various types of wood fuels and ashes. The new project aimed to improve assessment of wood ash radioactivity and to suggest instructions for safe handling and use of ash. The effect of origin and composition of wood fuel on variation of ^{137}Cs content in ash was examined. Practical guidance was developed to estimate ash radioactivity based on information on the type of fuel, on ^{137}Cs deposited in 1986 in wood procurement area and on combustion technique. ^{137}Cs activity found in fly ashes was 1 000 – 11 000 Bq/kg. Naturally occuring radionuclides ^{40}K, ^{226}Ra and ^{232}Th, contributed less than ^{137}Cs to human external exposure to radiation in areas affected by the Chernobyl fallout.

The estimated radiation doses received by workers during ash handling were clearly lower than the action level 1 mSv/a. Internal radiation dose (from inhaled ash) is minor as compared to external dose from ash located nearby. The handling or use of ash may have to be modified, if the key radionuclides in ash, referred to in the STUK guide ST 12.2, cause doses approaching action levels for workers or members of the public. Materials with higher activity can be used, when shown that the action level for the public, 0.1 mSv/a, is not exceeded. If necessary, the dose can be effectively reduced by a soil layer on top of the ash. A 10 cm layer of soil reduces the external dose from a large pile of ash to one third. Examples on the sufficient thickness of the soil layer covering radioactive ash have been given in the report STUK-A200 (Vetikko et al. 2004).

Ash fertilization has a clear mitigating effect on the transfer of ^{137}Cs from the soil to trees and other vegetation. This is caused by potassium in ash through reducing the uptake of ^{137}Cs by plants. The reduction is significant for all soluble ^{137}Cs in the soil, derived either from ash or earlier accumulated fallout.

The observed long-term effect of ash fertilization is reduction of radiocaesium activity in trees and other forest products.

The results of the study can be used at combustion plants for assuring radiation safety of workers handling ash, and for planning of commercial ash products. The project was conducted in co-operation with Finnish energy and forest industries.

Plutonium in forests (under the Nordic Nuclear Safety research, NKS)

Levels of Pu contamination on a pine-dominated site in Central Finland were assessed. Soil depth profile samples, fractions of Norway spruce (*Picea abies*), samples of wild berries, dwarf shrubs and edible mushrooms were collected from the site, and mixtures of moose meat were taken from other locations. Mostly upper limits of concentrations of ^{239,240}Pu were obtained for biological samples. In samples of wild food, i.e. berries, mushrooms and moose meat Pu was not found, when detection limit varied 0.7–3 mBq/kg f.w. Based on analysis of soil sections, a total activity density of about 40 Bq/m^2 was estimated for the forest soil. The ingestion dose from Pu through consumption of wild foods was estimated for adults to be less than 4 nSv/a. (Rantavaara and Kostiainen 2002a).

Dietary ^{137}Cs and ^{90}Sr received in Finland in 1960–2000

A study was performed for estimation of dietary intake of ^{137}Cs and ^{90}Sr and time-integrated ingestion doses through agricultural produce and freshwater fish during 1960–2000. Accuracy of dose estimation was improved with simple calculation models to provide data series relevant for the assessment.

The study suggests that average adult Finns have received through the long-lived nuclides ^{90}Sr and ^{137}Cs in foodstuffs an internal dose slightly exceeding 2 mSv in 1960–2000. Domestic animal products dominated dietary intake of ^{137}Cs in 1960–2000. Freshwater fish and vegetable products of agricultural origin were almost equal contributors of ^{137}Cs to the diet. Wild foods received from forests assessed using a simple approach turned out to be non-negligible source of ^{137}Cs. Marine and brackish-water fishes added to the ingestion dose through a higher consumption rate (Rantavaara et al. 2002b).

Strontium 90 has not been a significant dietary nuclide through the diet of Finns. However, during the years of maximum deposition rates in the early 1960s the doses exceeded as much as tenfold the doses in the following decades and the doses received after the Chernobyl accident. The wild foods from forests are not likely to contribute to ingestion of ^{90}Sr essentially (Rantavaara 2003).

24-h diets tested for monitoring of ^{137}Cs and ^{90}Sr intakes

Usefulness of a 24-h diet for monitoring of ingestion dose was studied by analysing contents of ^{137}Cs and ^{90}Sr in diet samples collected daily during six weeks at a hospital. The continuously collected data for long-lived radionuclides in foodstuffs nationwide allowed comparison of estimated intakes of ^{90}Sr and ^{137}Cs with the measured 24-h diets.

The results of the study supported the view that daily diet samples are a reliable tool in assessing the ingestion doses received through food. The benefits of the method vary by radiation situation, but often some parts of foodstuff surveillance can be replaced or complemented by analysis of daily meals. Significant differences in daily intakes of ^{137}Cs were caused by wild foods, which need separate surveys by food type. (Rantavaara and Kostiainen 2002b).

Dietary ^{137}Cs through wild mushrooms, by regions in Finland in the late 1990s

For a Nordic comparison the consumption pattern quantified after mid-1990s was applied to ^{137}Cs concentrations of different types of wild mushrooms, analyzed since 1986. Distinct differences in ingested ^{137}Cs were found between the four regions, the Metropolitan area, Western, Eastern and Northern Finland. The annual intake in the late 1990s was highest in Western Finland where the number of inhabitants, contamination from the Chernobyl accident, and the type of species and their processing all contributed to the ingested activity more than elsewhere (Rantavaara and Markkula 2000).

Regional assessments for transfer of radionuclides to foodstuffs

The transfer of ^{137}Cs and ^{90}Sr from soil to cereal grains in various regions in Finland was studied. The transfer ratios of ^{137}Cs from soil to oats, rye and barley were highest in organic soils, and lowest in clay soils. The uptake of ^{137}Cs decreased in the samples from the same sampling areas in the order: oats > rye > barley, wheat. The concentrations of ^{90}Sr were higher in the cereal grains from sand and silt soils than from clay and organic soils, and decreased by cereal type in the order: oats > barley > rye > wheat, in all the soils from the same sampling regions. The study resulted in distributions of transfer parameters for ^{137}Cs, which represent real production conditions. The regional surveillance data was found to indicate reasonably well the ^{137}Cs concentration levels when site-specific information is not available (Kostiainen and Rantavaara 2002).

The decrease rates of ^{137}Cs and ^{90}Sr in milk were studied in the years following the atmospheric nuclear weapon tests and after the Chernobyl accident in 1986. The highest ^{137}Cs and ^{90}Sr concentrations in the 1960s in Finnish dairy milk were recorded in Lapland even though the deposition of ^{137}Cs and ^{90}Sr in Lapland did not significantly differ from other localities in Finland. The ecological half-times for ^{137}Cs and ^{90}Sr in dairy milk were estimated. For ^{90}Sr they were about twice as long as those for ^{137}Cs, and nearly the same in all the studied areas. The half-times of ^{137}Cs were distinctively higher in northern and eastern areas than in the intensively-cultivated clayish western areas. (Kostiainen and Rissanen 2003, Kostiainen 2005)

<u>ECODOSES, Improving regional impact assessments and improving radiological assessments of doses to man from terrestrial ecosystems (NKS)</u>
The aim of the Nordic ECODOSES project is to improve the accuracy in radiological modelling through gathering of available Nordic regional data. The focus has been on finding the appropriate parameters for different regions to be incorporated in the food chain and dose models. The Laboratory has produced regional data on ^{137}Cs and ^{90}Sr in deposition and milk since the 1960s.

<u>Long-term behaviour of ^{137}Cs in Finnish lakes</u>
Following the Chernobyl accident ^{137}Cs was unevenly distributed in Finland. This caused large variation in the ^{137}Cs contents of freshwater fish in Finnish lakes. Over time environmental processes such as sedimentation, runoff, water flow and hydrological cycling, and factors such as chemical characteristics of the lake water, soil type and topography of the catchment have affected the behaviour and transfer of ^{137}Cs in watersheds. High activity concentrations of ^{137}Cs still occur in fish in certain lakes in the areas of the highest deposition. ^{137}Cs in perch varied from 20 to 7 800 Bq/kg f.w. and those in lake water from 4 to 330 Bq/m^3 in 1998–2000. Activity concentrations of ^{137}Cs in predatory fish varied by a factor of 300 when 18 years had elapsed since the deposition. Activity concenrations per unit deposition are clearly lower in eutrophic than in oligotrophic lakes. Average aggregated transfer factors of ^{137}Cs to pike were 0.03 and 0.004 m^2/kg in oligotrophic and eutrophic lakes, respectively, with large variation range for both, during 1998–2002. Concentration ratios (CF) for perch in different lakes varied by a factor of 25. Ecological halftimes of ^{137}Cs in perch from various lakes varied between three to nine years in 1988–2002 (Saxén and Koskelainen 2005, Saxén 2004).

<u>Transuranic elements in fishes compared to ^{137}Cs</u>
Besides for ^{137}Cs, transfer factors for Am, Cm and Pu from lake water to fish were determined and compared with each other in a joint study with the NPP Environmental Laboratory of STUK. Transfer factors for ^{137}Cs were the highest and those for Am and Cm about twice as those for Pu (Ikäheimonen and Saxén 2002).

<u>Distribution of ^{137}Cs and ^{90}Sr in various organs and tissues of fish</u>

The degree of radiocontamination in fish is usually analysed to estimate doses to fish consumers, for which radionuclide contents in edible parts of fish are needed. Due to the recently increasing attention focused on radiation protection of plants and animals the distribution of ^{137}Cs and ^{90}Sr in various organs of fish (muscle, bones, skin and fins, liver, spawn, sperm) was analysed. Muscle tissue accounted for 74–82% of the total amount of ^{137}Cs in fishes. The importance of skin and fins was evident as a source of ^{90}Sr to fish. Skin and fins contributed 70–85% to the total amount of ^{90}Sr in fish. (Saxén and Koskelainen 2002a; Saxén et al. 2002).

<u>Environmental mobility of radiostrontium from weapons testing and Chernobyl fallout in river catchments</u>

The analyses of the mobility of ^{137}Cs presented in Smith et al. (2000) was continued with a similar study on mobility of ^{90}Sr in t he same five major Finnish rivers. Water samples of these rivers have been analysed regularly at STUK for four times a year since 1964. No significant differences were found between the mobility of ^{90}Sr from nuclear weapons tests and from the Chernobyl accident. Model parameters obtained by fitting to the measurements of the deposition and runoff rates of the nuclear weapons test fallout gave predictions which were consistent with the mid and long-term contamination by the Chernobyl fallout. A comparison of the relative mobility of ^{90}Sr with respect to ^{137}Cs revealed that the fast flush processes of ^{90}Sr and ^{137}Cs have similar orders of magnitude. But as time passed the relative mobility of ^{90}Sr increased with respect to ^{137}Cs over a period of 5-8 years. Once the relative mobility reached equilibrium, it was found that the mobility of ^{90}Sr was around an order of magnitude greater than that of ^{137}Cs (Cross et al. 2002).

Radiation protection of the environment

<u>FASSET, Framework for assessment of environmental impact</u>

In the EU project FASSET a framework for the radiation protection of the environment was developed. The system includes transfer of radionuclides from several types of ecosystems to various reference organisms, dosimetry of organisms and dose-effect relations. Data on transfer of radionuclides in the freshwater and brackish water environment was collected by STUK and look-up tables for the framework were produced. The results of the project are reported in the final report and in five deliverables, which are available in the internet address: www.fasset.org.

Dose rates from naturally occurring radionuclides for European aquatic environments were assessed. It was made through a process of data collation with respect to levels of radioactivity in water, sediments and aquatic flora and fauna, the use of suitable distribution coefficients, concentration factors and utilization of a reference organisms approach and suitable geometries to allow dose per unit concentration factors to be derived for the subsequent absorbed dose calculations. The majority of the calculated absorbed dose arises from internally incorporated alpha emitters, with ^{210}Po and ^{226}Ra being the major contributors. Calculated doses and the range were somewhat higher for freshwater compared to marine organisms. Many data gaps were identified concerning data on radionuclide transfer in various environments (Brown et al. 2004).

A model for the evaluation of radiation doses to organisms was developed at STUK. The model was used to estimate radiation doses caused by ^{137}Cs from the Chernobyl deposition for a pelagic species of fish, perch, from Lake Päijänne. The internal radiation doses to perch from ^{137}Cs have been up to a few mGy/a. The external doses from ^{137}Cs were small compared to the internal, only a few microGy/a. Most of the internal dose, up to 95%, was caused by the beta radiation of ^{137}Cs (Oksanen et al. 2003).

2.5.6 Research plans for the next five years

The research of the Ecology and Foodchains Laboratory during the next five years will be focused on nuclear emergency management and decision support systems, on radioecology and dose assessments and on radiation protection of the environment. The research projects for the period 2003–2005 are described in detail in the report STUK-A202 (Salomaa 2004) and listed below. In addition, those projects that are not presented in the report are briefly described below.

Nuclear emergency management and decision support systems

The following research projects are carried out:

- Extension of countermeasure compendia for food production systems in agricultural and semi-natural areas (EURANOS, CAT1RTD01)
- Production of a generic handbook for the management of contaminated food production systems in Europe (EURANOS, CAT1RTD03)
- Production of a generic European handbook for the management of contaminated inhabited areas, including stakeholder opinion (EURANOS, CAT1RTD04)
- Restructuring of the foodchain and agricultural countermeasures module and incorporation of handbook information (EURANOS, CAT2RTD03)
- Extension of the portability and operability of the RODOS system (EURANOS, CAT2RTD06)
- Further enhancement of evaluation tools in decision support systems for operational applicability (EURANOS, CAT2RTD11)

- EURANOS demonstrations (EURANOS, CAT2DEMxx) which intend to determine which of the tools, method and approaches for emergency preparedness developed in the previous Framework Programmes and/or within the EURANOS project are ready for actual operational applications and where additional research and development is needed to enable operational use
- Preparation of a training course for decision makers and relevant stakeholders to use advanced evaluation tools and methods in the different phases of a nuclear or radiological emergency situation (EURANOS, TREVA1)
- RODOS Users Group (EURANOS, RUG) which aims at assuring RODOS users that their experience and demands are adequately considered and that the RODOS developers have a long-lasting commitment to ensure proper operation and maintenance of the system in the future
- Decision Support Handbook for remediation of contaminated inhabited areas (NKS, URBHAND) which aims at supporting Nordic decision-makers in the event of a severe nuclear accident
- Clean-up actions in food industry in a radioactive contamination situation. Clean-up methods that can be used to decontaminate food industry facilities and their surroundings in a radioactive contamination situation are described.

Radioecology and dose assessments

- FOREST, Radioecology network and sampling procedures for forests (NKS). The aims of the project are to compile a sampling guide for radionuclide analysis of northern forests and to activate a network of Nordic forest radioecology. The sampling procedures for soil, trees and understorey vegetation will be prepared. Participants come from the Swedish Defence Research Agency (FOI), Institute for Energy Technology (IFE, Norway), Finnish Forest Research Institute (Metla) and STUK.
- Radioecology of forest management. The research programme for radioecology of forest management will continue in collaboration with the Finnish Forest Research Institute. Testing of management effect on forests will be focused on complementing the knowledge base on factors influencing the remedial effect of various forest management methods and the related time dependencies. The project is described in the report STUK-A202 (Salomaa 2004), p. 43.
- Long-term effects of ^{137}Cs fallout in various forest types. Variation in the radioactivity of trees due to differences in the age and site type of forests will be assessed based on samples from commercial forests. ^{137}Cs

distribution in dominant trees (pine and spruce) and in the soil will be examined. The study areas represent the most common site types and development classes of growing forests in Finland.

- ECODOSES, Improving regional impact assessments and improving radiological assessments of doses to man from terrestrial ecosystems (NKS). The project is described in the report STUK-A202 (Salomaa 2004), pp. 78–79.
- The IAEA Programme on Environmental Modelling for Radiation Safety (IAEA, EMRAS) is joined in two working groups: (1) Revision of IAEA Technical Report Series No. 364 "Handbook of parameter values for the prediction of radionuclide transfer in temperate environments" and (2) The Chernobyl ^{131}I release: model validation and assessment of the countermeasure effectiveness working group.
- ^{137}Cs in mushrooms. The internal radiation dose received via mushrooms can be reduced by processing mushrooms before consumption. Household methods are studied to find out their efficiency to reduce ^{137}Cs contents of mushrooms. The methods tested are the ones which are normally used in cooking, among others soaking in cold or boiling water, starting with fresh, salted and dried mushrooms with different amounts of water and periods of time. The tests are made for various species of mushrooms.
- Radioactivity of wild food. The project is described in the report STUK-A202 (Salomaa 2004), p. 41.
- Variation of ^{137}Cs in wild mushrooms and freshwater fish in a locally restricted area. The aim is to study variation of ^{137}Cs in freshwater fish and edible wild mushrooms locally inside one municipality. Fishes are sampled in all the lakes and mushrooms in habitats of different types found in the area. The samples are analyzed both in local laboratories and at STUK to test the applicability of the measuring equipment of local laboratories for monitoring radionuclides in foodstuffs in emergency and normal situations.
- Natural radionuclides in foodstuffs. Naturally occuring radionuclides in Finnish foodstuffs will be determined. The project will be carried out in collaboration with the Natural Radiation Laboratory of STUK.
- Regional and lake specific variations of ^{137}Cs and ^{90}Sr in lake water and fish. The project is described in the report STUK-A202 (Salomaa 2004), p. 42.
- Behaviour of long-lived radionuclides in lake ecosystems and their storage in the bottom sediments of the lakes. The first results have shown that the lakes in which contents of ^{137}Cs in fish stay high for a long time after the deposition have a very low sedimentation rate (Ilus and Saxén, 2005).

The next step in the study is to form a total picture of the distribution of radionuclides in the catchment, lake water, aquatic plants, bottom animals, bottom sediments and in fish. The project is carried out in collaboration with the NPP Environmental Laboratory of STUK. The project is described in the report STUK-A202 (Salomaa 2004), p. 45–46.

- The relation of ^{137}Cs contents to the age of the fish. The activity concentrations of ^{137}Cs in fish vary depending on the size and habitat of the fish. The relation between the activity concentration of ^{137}Cs and the age of fish is studied in a few selected areas. The age of the individual fishes (pikes and perches) will be determined and compared with the ^{137}Cs contents. The project is carried out in collaboration with the NPP Environmental Laboratory.

Radiation protection of the environment

- ERICA, Environmental Risks from Ionising Contaminants: Assessment and Management (EC 6th Framework Programme). The project continues to develop further the system developed in the FASSET project for the radiation protection of the environment. The final outcome of the project will be the ERICA integrated approach to assessment and management of environmental risks. Important aspects are how to characterize the environmental risks, giving basis for managerial decisions and bringing stakeholder views into decision-making. The data gaps revealed in the FASSET project will also be addressed. The project is described more detailed in the report STUK-A202 (Salomaa 2004), pp. 95–96.

2.5.7 List of publications

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2.6 Airborne Radioactivity

2.6.1 Key words and specific technologies

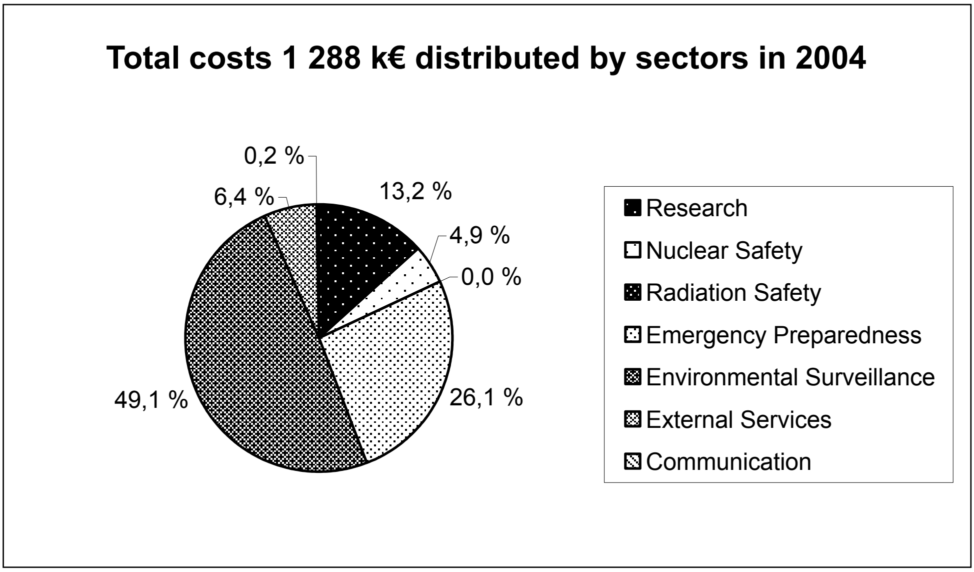
Key words

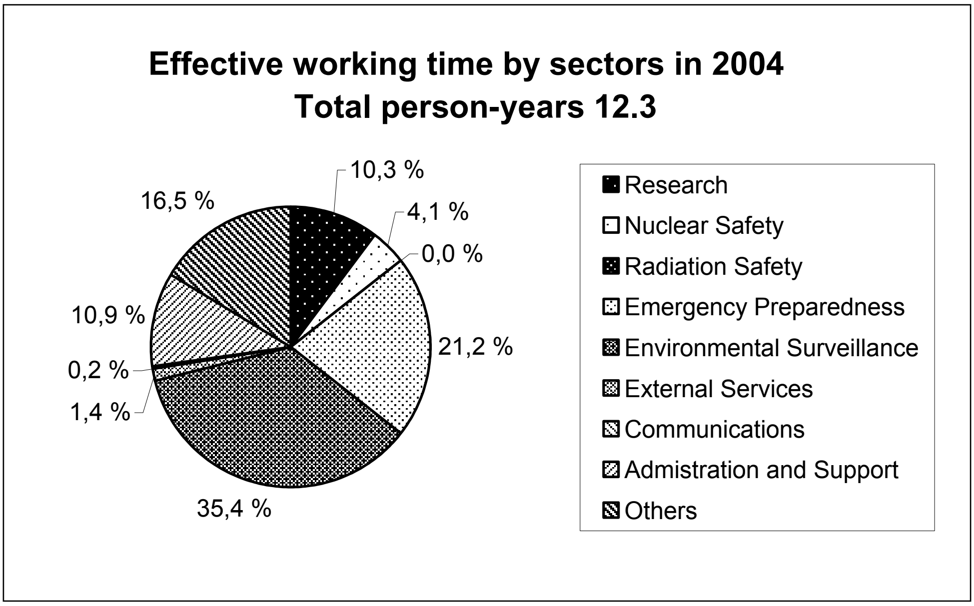
Airborne radioactive material, radiation monitoring, external dose rate, atmospheric transport, mobile radiation measurement, radioactive particles, particle analysis, fallout mapping, dose estimation, emergency preparedness.

Specific technologies

Computer codes for atmospheric transport, dispersion and doses of radioactive substances, nation-wide external dose rate monitoring and information system, nation-wide surveillance of airborne radioactive material, mobile laboratory for environmental monitoring, gamma spectrometry, direct alpha spectrometry, autoradiography, analyses of individual radioactive particles.

2.6.2 Description of activities





The responsibilities of the Laboratory are:

- Nation-wide monitoring of external radiation and airborne radioactive material;
- Development and maintenance of tools for emergency preparedness (short-term dose assessment, radiation measurements in the field, etc.);
- Research on airborne radioactive particles (analysis methods), gamma spectrometry (sampling and analysis of the spectra), direct alpha spectrometry (rapid identification of transuranium nuclides in air), mobile radiation detection methods and
- Expert services especially in the area of CTBT (Comprehensive Nuclear-Test-Ban Treaty).

Environmental radiation monitoring

The Laboratory is responsible for monitoring external dose rate and airborne radioactive substances. The nation-wide dose rate monitoring network consists of 290 stations. A real-time radiation monitoring and information system, known as USVA, was developed and is continuously maintained. USVA utilizes web technology in disseminating radiation data and other related information.

Airborne radioactivity is monitored by eight sampling stations. Most of the samplers are manually operated; however, on the roof of STUK building in Helsinki there a is fully automated station. The device filters radioactive substances from the air, monitors radionuclides collected on the filter in real-time, changes the filter, prepares the sample for on-site counting with a high-resolution gamma spectrometer, analyses the spectrum and reports the data via STUK www-pages.

Emergency preparedness

Analysis of potential release scenarios of radioactive material is the basis for planning of emergency preparedness. In threat situations the personnel of the Laboratory serves in field measurements, performs laboratory analyses and collects information on the event to comprehend better the prevailing radiation situation.

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

Research

The research carried out at the Laboratory supports emergency preparedness. Methods of gamma spectrometry and direct alpha spectrometry of air filters are currently the major topics. Results are typically published in international scientific journals.

The Laboratory develops tools for monitoring of external dose rate and airborne radioactive substances. Environmental radiation monitoring in general is one of the Laboratory's major tasks. Results are typically published in the STUK report series and in scientific conferences.

The Laboratory co-operates with several Finnish universities and research institutions. Publications have also been prepared jointly with the other laboratories of STUK.

Services

STUK is one of the IMS (International Monitoring System) radionuclide laboratories for the verification of the CTBT. The laboratory was certified in 2003 by the CTBT Organisation for the gamma spectrometric analyses of IMS air filter samples.

The Laboratory provides routine services for the CTBTO on service-for-fee basis. In addition, the contracts are concluded in order to develop the gamma spectrometric analyses. Besides CTBT services, other services are provided (IAEA, domestic enterprises).

Communication and training

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 are displayed on STUK's www-pages.

The personnel of the Laboratory gives lectures on radiation monitoring and on radiation risks related to accidents. Local rescue authorities are the main target group. Training is also given on international level through courses of CTBTO, IAEA and projects concerning the Baltic Sea countries.

2.6.3 Personnel

The Laboratory was established in 1992; the staff consisted of five persons. In 1996, the national external dose rate monitoring was added to the Laboratory's responsibilities, and in 1999, CTBT laboratory functions were initiated. In January 2005, the Laboratory had altogether 12 permanent and fixed-term posts, distributed as follows:

Harri Toivonen, D. Tech (nuclear physics), head of laboratory
Radiation measurements, CTBT monitoring, emergency preparedness, radiation and nuclear threats

Juhani Lahtinen, MSc (eng.), senior scientist
Atmospheric dispersion and dose calculations, radiation monitoring, analyses of radiation threats, emergency preparedness

Roy Pöllänen, PhD (physics), senior scientist
Airborne radioactive particles, particle analysis techniques, aerosol physics, dose calculations, direct alpha spectrometry.

Mikael Moring, MSc (eng.), scientist
CTBT laboratory services, complex gamma spectrum analyses, mobile radiation measurements.

Teemu Siiskonen, PhD (physics), scientist
Monitoring of airborne radioactive substances, routine gamma spectrometry, alpha spectrometry, nuclear physics.

Kaj Vesterbacka, MSc, (physics), inspector
Nation-wide external radiation monitoring and information system, software development.

Santtu Salmelin, eng., inspector
Maintenance of the nation-wide external dose rate monitoring network.

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

Tarja Ilander, system analyst
Development of tools for environmental monitoring and preparedness, system design, programming, emergency preparedness.

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

Satu Kuukankorpi, MSc (physics), scientist
Mobile radiation measurements.

Petri Smolander, MSc (physics), scientist
Mobile radiation measurements.

2.6.4 Aims of research and technical development

The priority areas for research and technical development are:

1. Development of tools for monitoring of external dose rate and airborne radioactive substances. In an emergency, automatic monitoring networks (accompanied by manual measurements) combined with state-of-the-art data management systems give a rapid and reliable overview of the radiation situation and thus facilitate implementation of countermeasures.
2. Development and maintenance of tools for the early phases of a nuclear or radiological incident involving releases to the atmosphere (calculation of atmospheric transport, dispersion, deposition and doses). In an emergency, these tools enable STUK to estimate short-term consequences of radioactive releases and also help to disseminate the calculation results to different parties.
3. Analyses of accidents and threat scenarios. Results of various threat studies provide background information and support material that can be used in emergency planning and in real situations.
4. Development of mobile radiation monitoring techniques and instrumentation (mobile laboratory, aerial vehicles, etc.). 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.

5. Development of assay methods for characterizing radioactive particles in a nuclear incident. Particle characteristics are not only needed for radiological hazard analysis but they are also a fingerprint in tracing illegal nuclear activities, and thus support safeguard activities.
6. Development of spectrometric methods for air sample analysis. These methods support emergency preparedness and environmental radiation monitoring. The laboratory has special expertise to deconvolute complex gamma and alpha spectra.

2.6.5 Progress report on research and technical development over the last five years

The following discussion considers scientific and technical priority areas of research and development.

Monitoring external dose rate and airborne radioactive substances

In 2004, the Laboratory carried out preliminary studies aiming at renewal of the nation-wide dose rate monitoring network. The goal was to develop a prototype station which can provide real-time monitoring data through a secure communication link for the central database at STUK and for the command centres of the local rescue authorities. The technical development led to recognition and documentation of the basic principles of the new generation monitoring station. The prototype concept was a technical success and consequently, government funding was attained for renewal of the complete network.

The Laboratory operates eight aerosol sampling stations. The filters provided by these stations are analyzed in high-resolution gamma spectrometry. An analysis pipeline was developed; the system controls sample measurement and analysis, saves the results in STUK intranet and provides a convenient interface to the results in html format. In this process a database, known as Linssi, plays a major role. The database and related software save the analysis results transparently providing full confidence on the quality of the analysis. Linssi is built on open-source platform (Linux) and has been adopted by other institutions (CTBTO, BfS (Germany), Health Canada).

Tools for operational emergency preparedness

The dispersion model system SILAM, developed by the Finnish Meteorological Institute (FMI), is in operative use at STUK. For the software development

STUK has provided functionality definitions and end-user views on the usability. If needed, STUK experts are able to launch runs of the model through a web-based user interface.

Based on the initiative of the Laboratory, STUK and FMI drafted in 2004 a plan for a centralized system for managing results of dispersion and dose calculations. The design makes use of a database which serves not only as a data storage but also as an interface between various mathematical models.

Advance analyses and emergency planning

A comprehensive internal report on radiation threats was prepared in early 1990s. In 2002–2004, this report was partially revised and updated. The report is of crucial importance for emergency planning and for designing operational tools. In addition, an internal study addressing the factors affecting radiation measurements in emergencies has been prepared. The report helps STUK to define the practical radiation monitoring strategies for different threat scenarios (Lahtinen, 2004). The work forms the basis for STUK's contribution in the EURANOS project on radiation measurement strategy (starting 2006).

In 2002, a Nordic NKS project Emergency management and radiation monitoring in nuclear and radiological accidents (EMARAD) was started under the leadership of the Laboratory. The deliverables of the project, ending in 2005, will be a www-server with stored pre-calculated accident (primarily NPP accident) consequence data and a selection of other support material, as well as some computer programs that can be utilized to process the downloaded data locally in the user's own computer environment. The aim is that the system as a whole could be used in exercise planning and in monitoring strategy planning.

Mobile radiation detection and field measurement techniques

A sophisticated measurement vehicle, known as SONNI, was developed for environmental radiation measurements in different nuclear or radiological incidents (Smolander and Toivonen, 2004). Three NaI(Tl) scintillation detectors and one electrically cooled HPGe detector are installed for in-situ measurements. In addition, another HPGe is mounted in a lead shield for sample analysis. Equipment for direct alpha spectrometry consists of a commercial spectrometer with a vacuum chamber and a pump, a multichannel analyser and a power supply. The vehicle is also equipped with several air samplers; two of them are in fixed position and they can be operated while the vehicle is moving. Dose rate and rain information are stored once a minute. The vehicle contains a satellite navigation system for route planning and linking the measurement data with coordinates. Satellite and GSM based telecommunication systems accompanied by Tetra based radio network allow radiation measurement data and positioning data to be sent to a remote control centre. All measurement data and analysis results are stored in a local Linssi database.

The Laboratory has designed a prototype radiation detection and sampling system for Ranger unmanned aerial vehicle (Kurvinen et al., 2000; Kurvinen et al., 2001; Smolander et al., 2003). The instrument consists of a GM-tube and two gamma spectrometers (NaI(Tl) and CZT) and an air sampling unit. In addition to the standard electronics for data acquisition, the system contains an onboard computer, a GPS receiver and environmental sensors, all enclosed in a single housing manufactured of fibreglass-reinforced composite material. The radiation surveillance unit is an independent module and can be used as such, for example, in an aeroplane, a helicopter or a car.

Radioactive particles from nuclear incidents and development of assay techniques

Radioactive 'hot' particles may be released in a nuclear accident. The hazard related to these particles was estimated (Pöllänen, 2002). The programme focused on the release and characteristics of radioactive particles, their transport in air, particle detection and possible radiation threats. Main outcome of the programme, published in a PhD thesis, was that the health hazards of nuclear fuel particles must be taken into account in estimating the consequences of a severe nuclear accident and in planning countermeasures to protect the rescue workers and the general public. Several assay methods are needed for the complete characterization of radioactive particles (Moring et al., 2001, Pöllänen, 2002).

During the Balkans war the use of munitions containing depleted uranium raised concerns about the health and environmental risks. STUK performed analyses for three depleted uranium penetrators from Kosovo (Pöllänen et al., 2003). The presence of ^{236}U in the penetrators referred to reprocessed ura-nium. However, no Pu nor other transuranium elements were detected. A penetrator in contact with skin may cause a notable equivalent dose to skin as demonstrated by measurements and Monte Carlo calculations.

Development of gamma spectrometry

Gamma spectrometry starts from sample treatment and counting. The subsequent analysis is traditionally an interactive process using dedicated software. To improve efficiency and speed, which are important in emergency, the Laboratory has adopted another strategy. The gamma spectrum is interpreted automatically by a state-of-the-art software package (UniSAMPO/Shaman) and the results are saved in the Linssi database. At this stage the status of the results is "preliminary". Later on the analysts review the results again, save a new analysis in the database, and give it a status of "final". All data, including calibrations, are saved for later retrieval. The Linssi database was developed in co-operation with the Helsinki University of Technology (HUT) and Health Canada.

Besides improving operational usage, the Laboratory has made considerable scientific work on algorithms for gamma spectrum analysis. The major interest was given to the development of methods to analyze complex spectra containing peaks with interference from other peaks (multiplets). These methods are most useful for Xenon analysis (Siiskonen and Toivonen 2004, Stocki et al. 2004) reducing minimum detectable activity by an order of magnitude. Another application is the quantification of the fast neutron response in a germanium crystal (published in NIM A 2005). In fact, the very same algorithms can be used for multiplet deconvolution in various spectrometric applications, including alpha spectrometry.

Development of direct alpha spectrometry

Direct alpha spectrometry is a useful method for rapid identification of the presence of Pu and other alpha-emitters in air. A Monte Carlo code for simulating alpha-particle behaviour in the filter matrix was developed (Siiskonen and Pöllänen, 2003; Siiskonen and Pöllänen 2004). The code is designed to simulate alpha-particle energy spectrum and is intended to be a comprehensive package in which all major processes influencing the spectrum are included. The direct spectrometry is suitable for field measurements and is therefore used in SONNI.

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

Emergency preparedness and environmental monitoring remain as the major application field of the Laboratory's research and technical development. Studies are carried out on the behaviour of airborne radioactive material and on assay techniques, gamma spectrometry and direct alpha spectrometry in particular. The Laboratory makes full use of the modern communication technology to develop real-time radiation monitoring systems and other tools to support emergency preparedness. The areas of research and technical development during the next five years are:

- The nation-wide network for external dose rate monitoring will be completely renewed during 2005–2007. The stations and their detectors are purchased whereas software for communication and data management are developed. The new station design has already been adopted by the industry, i.e., new products are, or will be, available according to the requirements and design of the Laboratory.

- Monitoring of airborne particulates continues. Further effort is placed in automatization of data analysis and in quality control. In 2007, xenon monitoring is planned to be started. Data analysis expertise is already available.
- Real-time atmospheric transport, dispersion and dose calculations will be integrated to STUK's decision-making process for facilitating rapid and timely countermeasures in a nuclear incident. Results of the calculations will be stored in a database which enables flexible data management, including integration with geographical post-processing (maps). The work will be done together with the Finnish Meteorological Institute (FMI).
- Mobile radiation detection techniques will be developed. SONNI vehicle plays the key role but also hand-held applications are studied and linked to secure communication (Tetra/Virve). In addition, unmanned aerial radiation detection techniques will be studied and developed should a suitable framework emerge. Mobile measuring techniques are needed for emergency preparedness and for support to other security authorities.
- Methods for spectrum analysis will be studied for fast determination of alpha-emitters. This leads to software development and implementation of deconvolution algorithms.
- Research is continued on assay techniques for analysing radioactive particles present in environmental samples.
- Commitments of the EU project (EURANOS) Radiation monitoring strategies and their optimisation are fulfilled. Its results are used in domestic projects running in parallel.

STUK research projects for the period 2003–2005 are described in detail in the STUK-A202 report (Salomaa 2004). The projects of the Laboratory are:

- Radiation monitoring strategies and their optimisation;
- Emergency management and radiation monitoring in nuclear and radiological accidents (EMARAD);
- Testing of radiation surveillance equipment in aerial vehicles;
- Fast method for detecting airborne artificial alpha-active substances;
- Improvement of the analysis chain for aerosol samples and
- Neutron-induced background in gamma spectrometry.

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2.7 Regional Laboratory in Northern Finland

2.7.1 Key words and specific technologies

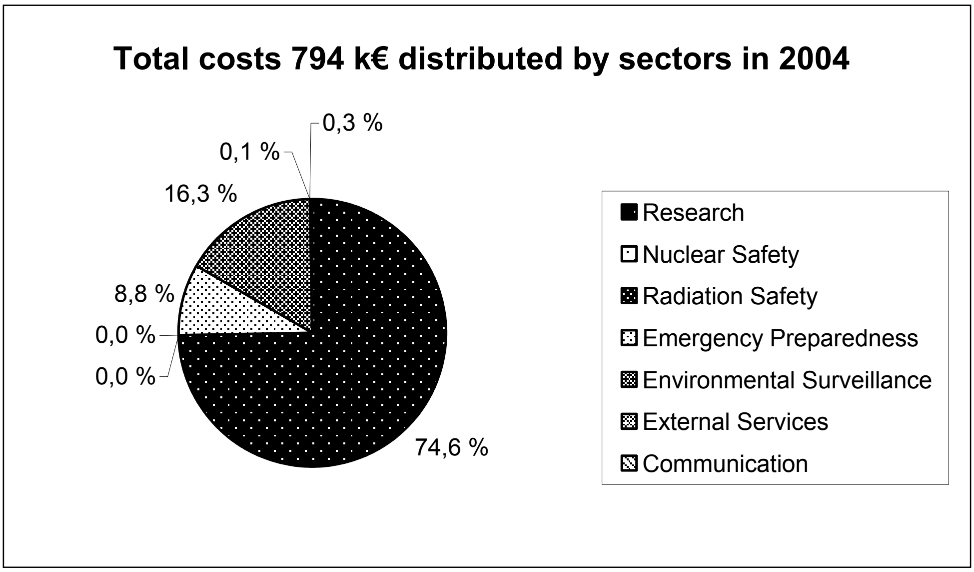
Key words

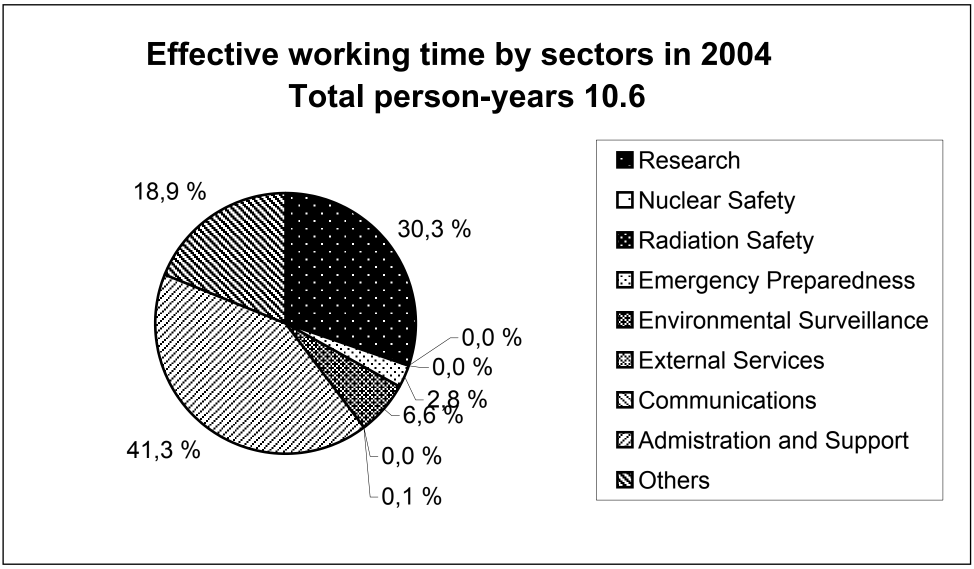
Environmental radioactivity in northern Finland, terrestrial radioecology, arctic and subarctic food chains, lichen, reindeer, monitoring of foodstuffs produced in northern Finland, radioactivity in Russian arctic sea areas, arctic monitoring, emergency preparedness, quality assurance

Specific technologies

Gamma spectrometry, alpha spectrometry, beta spectrometry, radiochemical methods, environmental sampling methods, surveillance of airborne radioactivity and fallout in Finnish Lapland, nation-wide external dose rate monitoring USVA, mobile laboratory for environmental monitoring.

2.7.2 Description of laboratory activities





The operational area of STUK's Regional Laboratory in Northern Finland is the northern half of Finland, comprising 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 cooperate 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 an EMP shield, filters, aggregates, etc.

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

In 90s the radioecological research was expanded to the arctic sea areas and shores of NW Russia. The laboratory's sample bank contains today 1 700 samples from NW Russia.

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

Nordic countries, Europe, Russia and North America, and presented research results at several international meetings and published results in national and international scientific journals and reports.

2.7.3 Personnel

Kristina Rissanen, retired on April 1, 2005, MSc (radiochemistry), head of laboratory, senior scientist
Management, terrestrial radioecology in northern Finland, transport and accumulation of radionuclides in arctic and subarctic food chains, especially the food chain 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

Dina Solatie, PhD (radiochemistry), head of laboratory (acting, since September 15, 2004), senior scientist, head of laboratory since April 1, 2005
Management, terrestrial radioecology in northern Finland, transport and accumulation of radionuclides in arctic and subarctic food chains, especially the food chain lichen – reindeer – man, radioactivity concentrations in locally produced foodstuffs, radiochemical analyses, alpha, beta and gamma spectrometry, quality assurance at the laboratory

Jarkko Ylipieti, B.Sc (land surveyor and computer science and information engineer) laboratory engineer
Collecting, processing, presenting and using spatial and geographical data in digital form (Geomatics), development and maintenance of Laboratory Information Management System and Geographical Information System, data analyses from results of radiological measurements, modelling radiological data collected from the environment (Information Processing Science)

Pertti Niskala, assistant researcher
Gamma spectrometry, airborne radioactivity, nation-wide external dose-rate monitoring system, mobile radiation measurement, quality assurance of gamma measurement in Rovaniemi

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

Tuula Virtanen, laboratory operator
Pre-treatment of samples, radiochemical ^{90}Sr analyses

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

Eeva Hakamaa, laboratory operator
Pre-treatment of samples, radiochemical plutonium and polonium analyses

Aila Iivari, research secretary

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 food chains 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 food chains, 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.

2.7.5 Main results over the last five years

The arctic food chain: lichen – reindeer – man

The arctic food chain 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 reindeer herding areas. However, ^{137}Cs and ^{134}Cs concentrations in lichen and reindeer have been monitored regularly in the Finnish reindeer herding area since the 60s, 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 that before the Chernobyl accident, when it was 300 Bq/kg. The

^{137}Cs concentration in reindeer meat varies throughout the year due to changes in food selection. During summer, the reindeer eat herbaceous vegetation, and in the autumn large amounts of mushrooms – if available. In winter they prefer to eat ground and arboreal lichen.

The increase in the reindeer stock in Finland has led to overgrazing and degradation of the lichen ranges. The range of winter fodder available for reindeer today is not the same as that in the 60s and 70s following the nuclear weapons fallout period, and therefore, the previously used ecological half-life values may no longer be applicable to the present situation (Rissanen at al., 2003).

Arctic monitoring and assessment programme (AMAP)

The Arctic Monitoring and Assessment Programme (AMAP) is a group working under the Arctic Council (AC). The arctic countries include the USA, Canada, Russia, Norway, Sweden, Finland, Iceland, Denmark. The Arctic Council Ministers have requested AMAP to produce assessment reports on the status and trends of the conditions of the Arctic ecosystems; identify possible causes for the changing conditions; detect emergency problems and potential risk to Arctic ecosystems including indigenous peoples and other Arctic residents; and to recommend actions to reduce risks to Arctic ecosystems. One of the key pollutants examined in the AMAP programme is radioactivity. One of the big issues is the effect of global warming on the arctic ecosystems.

The 2nd AMAP Radioactivity Report of the Radioactivity Expert Group (published in 2004) deals with issues relating to the presence and effects of radioactive contaminants in the Arctic. This report is a successor to the 1st AMAP assessment published in 1997. The purpose of this second assessment was to provide an update where new information had become available, and which either warrants revised assessment or relates to activities and sources that were not previously considered. Such new information has come to light through the provision of information and data by arctic countries as a result of further research or as a consequence of the AMAP monitoring activities. The report deals with sources, contamination levels and trends, human exposures, protection of the environment, vulnerability, potential accidents and risk management (AMAP, 2002).

Radiocaesium concentrations in humus layers in Finland and NW Russia

The monitoring of anthropogenic radionuclides concentrations in the humus layer in Finland and Northwest Russia was carried out as a part of the Barents Ecogeochemistry Project, the aim of which was to provide the authorities and other involved parties with a basis for assessing the existing state of the environment.

The NW part of Russia will be the focus of increased human activities in the near future, e.g. as a result of the further exploitation of natural resources.

The project area encompasses the whole of Finland, as well as that part of Russia stretching from St. Petersburg to the coast of the Barents and Pechora Seas, and from the Russian/Finnish/Norwegian border to the Ural Mountains. The uppermost 3 cm of the O horizon (humus layer) were collected at ca. 1 550 sampling sites in 2000–2001 by Russian field teams.

The most contaminated region was South Finland, followed by Leningrad Region. The humus layer in the Arctic areas had low ^{137}Cs concentrations. Because of the long physical half-life (30 years) of ^{137}Cs, the humus layer still contained about 72 per cent of the original ^{137}Cs isotope levels in 1986, but only about 0.7 percent of the 1986 level of the short half-life (2 years) ^{134}Cs isotope. Part of the ^{137}Cs concentrations originate from the global fallout period, but the ^{134}Cs isotope is Chernobyl-specific. After passing over Finland, along a corridor running from the Finnish cities of Kokkola to Kajaani, the first Chernobyl plume (on 28th and 29th of April, 1986) seems to have proceeded to the northeast into Russia and eastwards as far as the Ural Mountains (Salminen at al., 2004).

Inventory of ^{137}Cs levels in reindeer summer fodder in the Finnish reindeer management area

The aim of this inventory was to determine which reindeer summer fodder plant species accumulate the highest ^{137}Cs concentrations, and to estimate which reindeer herding co-operatives would be the most vulnerable to heavy radioactive fallout owing to the type of soil and vegetation. The Chernobyl fallout was sufficiently homogenous in most parts of the Finnish reindeer management area to allow this kind of assessment. Because of the decreasing availability of lichen pasture, the importance of summer fodder is also having an increasing effect on the concentrations measured in reindeer meat during slaughtering season in autumn and early winter.

About 980 measurements of the more than 1 000 samples have been performed and ten thematic maps showing the ^{137}Cs concentration in different reindeer co-operatives produced. The ^{137}Cs concentration appears to vary from a few Bg/kg to over 900 Bq/kg dry weight. The highest concentrations occurred in plant species growing on nutrient-poor (especially potassium deficient) mires, as was also seen before the Chernobyl accident. The Chernobyl fallout affected only the south easternmost corner of the Halla co-operative while all the other co-operatives further north were not much contaminated by the Chernobyl fallout (Rissanen and Ylipieti, 2003).

Radioecological research in NW Russian Arctic Seas and in Kola Peninsula

From 1993 to 1996 radioecological research was performed also on the Arctic Sea areas and shores of NW Russia. After the end of the ARCTICMAR Project in 2001, STUK has continued to exploit the extensive sample material collected during scientific expeditions with the Murmansk Marine Biological Institute and stored in STUK's sample bank in Rovaniemi. The aim was to gain more information on levels and origin of caesium and plutonium in Russian Arctic areas.

Radiochemical plutonium analyses were performed on benthic fauna samples collected in the Barents, Pechora, Kara Sea and White seas and in the Kola Bay. For concentration factor (CF) calculations, the ^{137}Cs and ^{239,240}Pu concentrations in biota samples (fresh weight) were compared to seawater concentrations. For concentration ratio (CR) calculations, the concentrations in biota (dry weight) were compared to concentrations in dry surface sediment. Quantitatively collected terrestrial surface vegetation and soil plots collected on the shores and islands of NW Russia were analysed for plutonium isotopes and ^{239,240}Pu concentrations per square metre as well as Pu-isotope ratios were calculated. Soil plots from Northern Finland were also analysed as reference material (Rissanen et al., 2002b; Rissanen et al. 2001).

Benthic fauna plays an important role in the transport of radionuclides into arctic food chains. The results provided data on the state of Russian Arctic Sea areas. STUK's results on CF values have been used in the FASSET Project. The Bq/m^2 results form a background data on the occurrence of plutonium in Arctic terrestrial environment.

Ecological half-life of ^{137}Cs in mushrooms collected at different forest stands in Kivalo experimental area after the Chernobyl accident

Although the Chernobyl ^{137}Cs fallout in 1986 was low in Finnish Lapland, averaging only 1 000 Bq/m^2, measurable concentrations are still found in nature. The sharp, additional radiocaesium labelling with a ^{137}Cs/^{134}Cs isotope ratio of 1.6:1, due to the accident has made it possible to determine ecological half-lives and to estimate how much of the ^{137}Cs in the Arctic environment still originates from the global fallout period. The aim of this project was to determine ecological half-life of ^{137}Cs in the fruiting bodies of different mycorrhizal mushrooms in Finnish Lapland after the Chernobyl accident. Concentrations before and after the accident were compared and accumulation rate of caesium from soil to mushroom calculated.

The accumulation rate for different mushroom species varies but there does not seem to be any clear correlation between the ^{137}Cs concentrations (Bq/kg dry weight) in the mushrooms and the length of the biological half-life. This is despite the fact that highest concentrations have been measured in Cortinarius armillatus, the biological half-life of which appears to be of the order of the physical half-life of ^{137}Cs, 30 y. The type of forest stand does not seem to have any effect on the caesium concentrations, except possibly for Rozites. After a nuclear accident people are able to avoid mushroom consumption, but reindeer will continue to collect as many mushrooms as available, because the mushrooms are their most important autumn fodder. Since radiocaesium is effectively accumulating in mushrooms and the rate of decrease is slow, mushrooms will contribute significantly, for a long period of time, to the intake of reindeer following a severe nuclear accident (Rissanen et al., 2002a).

^{210}Po and ^{210}Pb in terrestrial subarctic food chain in Finland

At the Regional Laboratory in Northern Finland, measurements of ^{210}Po and ^{210}Pb activity concentrations in terrestrial environmental samples from Finnish Lapland have been performed. Especially the arctic lichen-reindeer-man food chain has been studied due to the fact that Sami reindeer herders have substantial intakes of reindeer meat in Finland. The highest ^{210}Po and ^{210}Pb concentrations were found in lichen samples. Lichen has a high adsorption capacity for trace elements direct from the air, and because of its slow growth it accumulates them over a long period of time. High ^{210}Po and ^{210}Pb concentrations were also found in reindeer soft tissues, reindeer meat having an especially high $^{210}Po/^{210}Pb$ ratio. The polonium concentration in reindeer meat varies seasonally, since reindeer are eating mostly lichen from September to May and vascular plants during the summer. Most of the ^{210}Pb in reindeer is stored in the bones. Bone from reindeers is not a direct source of ^{210}Pb for human beings, but it is of interest by integrating the intake, it may indicate the average ^{210}Pb content of the meat. While activities of ^{210}Pb in reindeer meat are low relative to those in bone, it still constitutes the major source of this nuclide in indigenous Sami reindeer herders. ^{210}Pb in bone is also a source of ^{210}Po, which increases the whole body ^{210}Po concentration. According to these measurements, the mean ^{210}Po concentration in reindeer meat was 6 Bq/kg fresh wt. (dry wt. % of wet wt. is 24%), which would lead to a daily intake of 1.2 Bq for Sami people consuming in average 200 g/day of reindeer meat. This corresponds to 0.5 mSv annual dose and it is about 14% of the Finnish annual average dose from all sources. If inner organs are also consumed, the ^{210}Po intake increases slightly (Solatie and Rissanen, 2004).

2.7.6 Research plans for the next five years

The research during the next five years will be focused on

- AMAP, Arctic Monitoring and Assessment Programme, preparedness for a potential for future contamination of the Arctic as a result of accidents involving nuclear and or radioactive materials is an issue of particular concern. The development of assessment approaches that will support risk reduction, prevention strategies and enhance emergency preparedness are therefore identified as issues of high priority for the next phase of AMAP work on radioactivity in the Arctic. The potential impact of climate change on the transport of radionuclides to the Arctic from sources outside the region, and the way in which the distribution of radionuclides already present in the Arctic may be influenced by a change in climate, are of particular interest.
- ^{210}Po and ^{210}Pb in terrestrial subarctic food chain in Finland and in seal samples from Lake Saimaa and Baltic Sea
- ^{90}Sr in food chain: soil – plant – milk in Finnish Lapland
- Countermeasures for reindeer in a fallout situation, jointly with the Reindeer Research Station of the Finnish Game and Fisheries Research Institute.
- Regional differences in reindeer radiocesium contamination
- Producing local map information in digital form from the Finnish arctic region to RODOS system and use data in countermeasures in a fallout situation
- Mapping radiocesium concentrations from the Baltic countries and attach the results with Barents Ecogeochemistry radiocesium concentrations to find out the state of the environment 20 years after the Chernobyl accident.
- Evaluating the vulnerability of Finnish reindeer herding area in local scale analysing collected summer fodder data statistical and comparing the data with the present soil and vegetation situation in the reindeer herding area
- Wild reindeer in Perho and Kuhmo municipalities in Finland, a joint project with the local game management area
- Seals from the Svalbard and Greenland area, a joint project with the AkvaPlan Niva, Tromsø
- Studies on radioactive particles in contaminated environmental samples from Gomel Russia

2.7.7 List of publications

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2.8 Radiation Biology

2.8.1 Key words and specific technologies

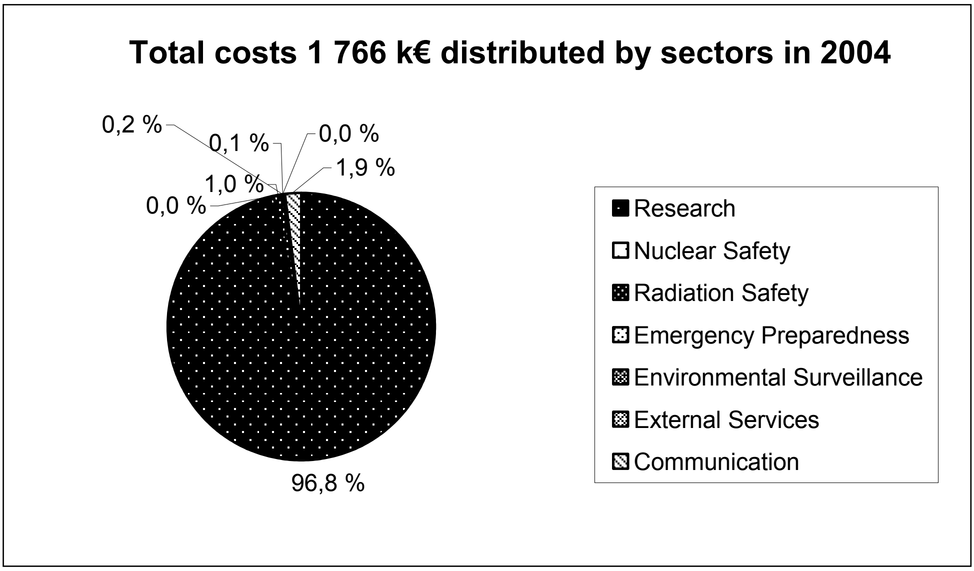
Key words

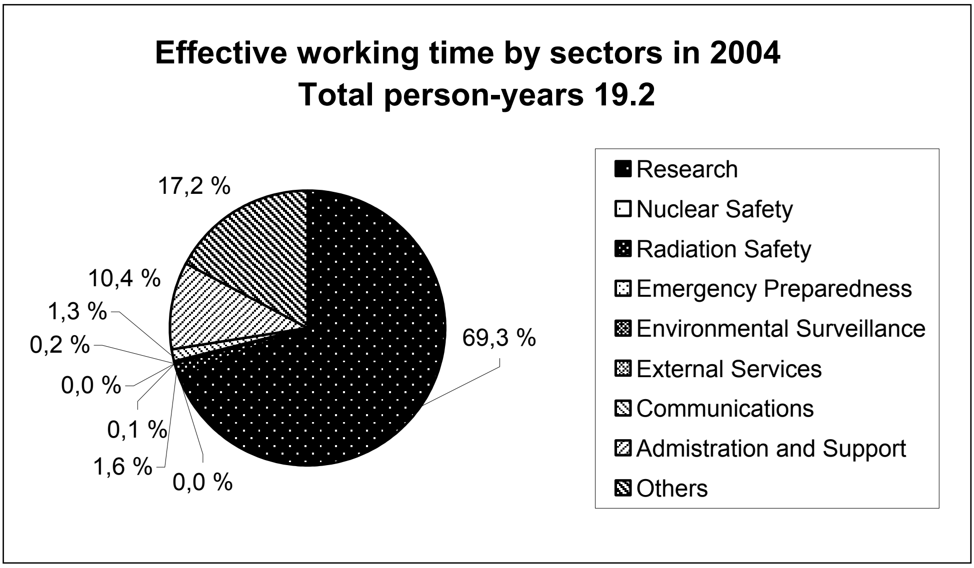
Radiation biology, molecular biology, molecular cytogenetics, biodosimetry, transcriptomics, proteomics, epidemiology, biological monitoring, health effects, health risk assessment, ionising radiation, radon, uranium, cosmic radiation,α-particle irradiation, x-ray and γ-ray irradiation, microbeam irradiation, narrow/ broad beam α-particle irradiation, non-ionizing radiation, UV-A/UV-B, solaria, sunbathing, RF-EMF, mobile phones, radiation-induced cancer, hereditary effects, non-targeted radiation effects, chromosomal aberrations, radiation induced bystander effect, radiation-induced genomic instability, individual radiosensitivity, thyroid cancer, brain cancer, secondary sarcomas, minisatellites, mutations, single nucleotide polymorphisms (SNPs), genome-wide gene expression changes, proteome-wide protein expression changes, endothelial biology, apoptosis, blood-brain-barrier, kidney function, bone turnover

Specific technologies

SSCP, DNA sequencing, cDNA expression array, gene differential display, two-dimensional gel electrophoresis, PDQuest protein expression pattern analysis, differential display proteomics, mass spectrometry protein identification (Maldi-ToF), protein activation (phosphorylation) assay, immunohistochemistry, Western blotting, Southern blotting, Northern hybridization, FISH chromosome painting, comet assay – single cell gel electrophoresis, PCC (premature chromosome condensation), PCR-RFLP, apoptosis assays, gap-junction function, non-invasive 3D deep tissue imaging, artificial human tissue systems, primary human skin explants.

2.8.2 Description of laboratory activities





The responsibilities of the Radiation Biology Laboratory were:

- research of the biological and health effects induced by ionizing and non-ionizing radiation,
- biological dose assessment by chromosomal analysis,
- biological expertise for the assessment of medical consequences of radiation exposure.

Research

Research projects conducted at the Radiation Biology Laboratory examine biological and health effects that are induced by exposing of living matter (cells, tissues animals, humans) to ionizing and to non-ionizing radiation.

During 2000–2004, topics in biological studies of ionizing radiation were: (1) gene expression in radiation-induced cancer, (2) hereditary radiation effects, (3) radiation-induced genomic instability, (4) radiation-induced bystander effect, (5) individual radiosensitivity and (6) biodosimetry for reconstruction of radiation dose.

Topics in biological studies of non-ionizing radiation were: (1) genomewide and proteome-wide analysis of cell response to mobile phone radiation (RF-EMF) and to long-wave ultraviolet radiation (UV-A), (2) proteome-wide analysis of protein phosphorylation changes induced by RF-EMF, (3) cellular stress response induced by RF-EMF, (4) anti-apoptotic effects of RF-EMF, (5) effect of RF-EMF on blood-brain barrier function, (6) effect of UV-A on the adhesive properties of melanoma cells *in vitro*, and (7) effect of UV-A on melanoma cell metastasis *in vivo*.

Topics in epidemiological studies were: (1) lung cancer induced by radon, (2) carcinogenicity of natural radionuclides in drilled wells, (3) kidney effects of uranium in drinking water, (4) health consequences of Chernobyl accident, (5) cancer among nuclear workers, (6) cancer risk attributable to cosmic radiation, and (7) cellular phone use and brain cancer.

Laboratory actively participates in national and international reseach programmes and is collaborating with research institutes in Europe, USA and Asia. Funding for research projects come from both national funding agencies (Academy of Finland, National Technology Agency, Finnish Cancer Society, Ministry of Social Affairs and Health, Emil Aaltonen Foundation, Finnish Work Environment Fund) and international funding agencies (EU 5th and 6th Framework Programmes, EU Inco Copernicus, International Union against Cancer, Nordic Cancer Union, National Cancer Institute, and Japanese Society for Promotion of Science).

Expert services
Biological dose assessment by analysis of dicentric chromosomes is performed in cases of suspected over-exposure to radiation. The dose assessment method is accredited.

2.8.3 Personnel

Dariusz Leszczynski, Ph.D., D.Sc., Docent (molecular biology & biochemistry), research professor (2000–) and head of laboratory (2003–2008)
Laboratory management, leader of Functional Proteomics group, genome-wide and proteome-wide screening of cell response to non-ionizing radiation (in 2005 also ionizing radiation), cellular stress response, cytoskeleton, signalling pathways

Riitta Mustonen, Ph.D., Docent (genetics), head of laboratory 1997–2003 (03/2003–02/2008 on leave of absence)
Biological effects of radiation, including radiation-induced cancer; hereditary effects and radiation-induced genomic instability; individual radiosensitivity and risk assessment

In March 2003, the staff of the Laboratory was re-organized into four research groups with their specific research areas:

- BioDos – biological dosimetry and individual sensitivity to ionizing radiation,
- NTIRE – non-targeted ionizing radiation effects, and
- BioNIR – biological effects of non ionizing radiation (presently FunProt)
- EPI – epidemiology, (in 01/2005 EPI group has been reorganized into separate Epidemiology and Biostatistics Laboratory)

Biological Dosimetry Group (BioDos)
Carita Lindholm, Ph.D. (genetics), senior scientist; leader of the BioDos group
Molecular cytogenetics, biological effects of ionising radiation, biodosimetry (including retrospective dosimetry), genetic susceptibility, individual radiation sensitivity, emergency preparedness

Wendla Paile, M.D. (medicine), senior scientist (moved to the newly formed Epidemiology and Biostatistics Laboratory in 01/2005)
Health effects of radiation, emergency preparedness, iodine prophylaxis, deterministic effects

Anne Kiuru, Ph.Lic. (genetics), scientist, doctoral student
Molecular biology, molecular cytogenetics, hereditary effects of radiation, mutation analysis, individual radiation sensitivity, genetic susceptibility, emergency preparedness

Armi Koivistoinen, M.Sc. (genetics), assistant researcher
Molecular cytogenetics, chromosome aberrations, FISH chromosome painting, comet assay

Päivi Jokinen, M.Sc. (genetics), researcher (05/2004 – 04/2005)
Molecular biology, genetic susceptibility

Sirpa Luomahaara, M.Sc. (genetics), researcher (11/2000 – 02/2001)
Individual radiation sensitivity

Marja Huuskonen, technician (serves equally all research groups in the Laboratory)
DNA extraction, protein extraction, SDS-PAGE gel electrophoresis, cell culture, RF-EMF cell exposures

Non-Targeted Ionising Radiation Effects Group (NTIRE)
Oleg Belyakov, Ph.D. (radiation biology), senior scientist, leader of the NTIRE group
Low-dose cellular radiobiology methods, radiation induced genomic instability and bystander effect assays, microbeam-related techniques, theoretical biology (mathematical modelling), construction of isotope-based irradiation facilities

Heli Mononen, M.Sc. student (biochemistry), scientist (05/2004 –)
Cell culture, cellular radiobiology methods, in situ apoptotic assays, total cellular damage assay, morphometry

Marjo Perälä, B.Sc. Engineer (food processing), research assistant
Cell culture, cellular radiobiology methods, in situ apoptotic assays, total cellular damage assay, morphometry, cDNA expression array, Northern hybridization, cloning, SSCP

Eeva Romppanen, M.Sc. (biochemistry), scientist (left in 2003)
Molecular biology, thyroid cancer, cDNA expression array, differential display, DNA sequencing, Northern hybridization

Aki Salo, M.Sc. (biology), scientist, doctoral student (left in 2003)
Molecular biology, radiation-induced genomic instability, cDNA expression array, differential display, single cell gel electrophoresis, Northern hybridization

Functional Proteomics Group (FunProt) (until November 2004 the BioNIR Group)
Dariusz Leszczynski, Ph.D., D.Sc., Docent (molecular biology/biochemistry), research professor, head of laboratory and leader of FunProt group
Proteomics, transcriptomics, genome-wide and proteome-wide screening of cell response to non-ionizing radiation (in 2005 also ionizing radiation), cellular stress response, cytoskeleton, signalling pathways

Riikka Pastila, M.Sc. (biochemistry), scientist, doctoral student, (left in 2005)
Molecular biology, UV-A/UV-B, melanoma, metastasis, adhesion molecules

Reetta Nylund, M.Sc. (Eng.) (biochemistry), scientist, doctoral student
Molecular biology, protein expression, protein phosphorylation, proteome-wide screening of cell response to non-ionizing radiation (RF-EMF and UV-A)

Sakari Joenväärä, M.Sc. (biochemistry), scientist (left in 2001)
Molecular biology, protein expression, protein phosphorylation, apoptosis, protein kinase C, proteome-wide screening of cell response to RF-EMF

Jukka Reivinen, Ph.D. (biochemistry), senior scientist, post-doctoral fellow (2001–2003)
Molecular biology, gene expression, protein phosphorylation, genome-wide screening of cell response to non-ionizing radiation (RF-EMF)

Mikko Luokkamäki, Ph.Lic. (genetics), scientist (on leave of absence)
Molecular biology, DNA sequencing, cloning, single cell gel electrophoresis

Pia Kontturi, laboratory operator
Cell culture, SDS-PAGE gel electrophoresis, immunohistochemistry, flow cytometry, histology

Hanna Tammio, laboratory operator
Cell culture, two-dimensional gel electrophoresis, immunohistochemistry, flow cytometry

Epidemiology Group (EPI)
Päivi Kurttio, Ph.D. (environmental health), senior scientist (since 01/05 the head of the newly formed Laboratory of Epidemiology and Biostatistics)
Drinking water, uranium, biological monitoring, cancer, epidemiology

Anssi Auvinen, M.D., Ph.D. (medicine, epidemiology), research professor (part-time affiliation), professor of epidemiology at University of Tampere
Radiation epidemiology, neoplasms, mobile phones, radiation-induced hereditary effects

Taina Ilus, Ph.Lic. (organic chemistry), scientist (01/05 moved to the newly formed Laboratory of Epidemiology and Biostatistics from Department Management Unit)
Data management and analysis, statistics

Tiina Salminen, Ph.D. (public health), scientist (2000–2002)
Epidemiology, mobile phones, brain neoplasms

Jani Raitanen, M.Sc. (statistics), scientist (2003–2004)
Data management and analysis, statistics, mobile phones

Anna Lahkola, M.Sc. (environmental health), scientist, doctoral student (2001–2005)
Epidemiology, mobile phones, brain neoplasms

Katja Kojo, M.Sc. (public health), scientist, doctoral student (2000–2005)
Epidemiology, airline personnel, cosmic radiation, breast neoplasms, UV

Kari Tokola, M.Sc. (statistics), scientist, doctoral student (2003–2006)
Data management and analysis, statistics, mobile phones

Mika Helminen, M.Sc. (statistics), research assistant (2004–2006)
Data management and analysis, statistics, cosmic radiation

Anu Outinen, research nurse (2003–2005)
Interviews, sampling, data cleaning

2.8.4 Aims of research

The broad aims of the research are to determine the spectrum of biological effects that are induced in cells by the exposures to low-doses of ionizing and non-ionizing radiation and to increase knowledge on health risks related to radiation in human populations.

The aim of the biological dosimetry research is to study the effects of ionizing radiation on different endpoints at DNA, gene and chromosomal level, particularly those endpoints that can be used for biological dose estimation (dicentrics, translocations), those clarifying the mechanisms (DNA breakage and rejoining) and causes (genetic susceptibility) of individual radiosensitivity, or those describing possible hereditary effects (minisatellite mutations) of ionizing radiation.

The aim of the non-targeted ionizing radiation effects research is to study mechanisms of bystander effects and genomic instability induced by ionizing radiation in cell cultures and three-dimensional (3D) tissue systems. The final goal is to develop a unifying hypothesis for the role of non-targeted effects in radiation-induced tissue responses and, ultimately, carcinogenesis. Research results will be applicable in the development of radiation protection.

The aim of the functional proteomics research is to identify the full spectrum of the genes and proteins that are affected by the exposures to low doses of non-ionizing radiation (RF-EMF and UV-A) as well as ionizing radiation. Identification of the exposure-affected genes and proteins will allow, in long run, to predict and to identify the full spectrum of physiological functions that might be affected by the radiation and that might be relevant to the issue of potential health hazard in humans. Currently the focus of the research is on the identification of genes and proteins that are affected by RF-EMF and by UV-A exposures and in 2005 the ionizing radiation effects will be added to the research scope.

The aim of the epidemiology research is to increase knowledge on health risks related to radiation in human populations. Research topics are selected based on scientific and public health importance as well as based on public risk perception. Radiation risks, particularly those that are not well-known (scientific relevance) or are of major concern in Finland (public health relevance), are assessed.

2.8.5 Progress report on research over the last five years

BioDos Group

An Inco Copernicus funded project was conducted to determine minisatellite mutation rates in families in three generations and to perform retrospective biodosimetry (FISH chromosome painting and glycophorine A somatic mutation assay) of individuals in these families living close to the Semipalatinsk nuclear test site in Kazakhstan (Bersimbaev et al. 2002). The oldest generation (P0) lived in the area at the time of the first Soviet nuclear test in 1949 whereas the younger generations (F1, F2) were exposed to smaller doses from the residual fallout and later tests. The minisatellite mutation rate in the cohort of P0 parents was 1.8-fold higher than in the control non-exposed population (Dubrova et al. 2002). Moreover, the minisatellite mutation rate in the cohort of F1 parents from the exposed area showed a significant negative correlation with the year of birth, fully consistent with the decay of radioisotopes after the cessation of surface and atmospheric nuclear tests. The results from the FISH painting analysis showed similar translocation frequencies in the Semipalatinsk cohort and the control group (Salomaa et al. 2002). Based on the FISH results it was concluded that the P0 generation has received a cumulative mean dose of less than 0.5 Gy. The GPA assay did not reveal any significant differences in the variant cell frequencies for all subjects from the Semipalatinsk area compared with the matched controls (Lindholm et al. 2004). However, a significant increase ($P < 0.05$) of the mean allele-loss ØN variant frequency was observed among the exposed P0 generation in comparison to controls. Considering the sensitivity of the GPA assay, the results suggest that the mean dose to the P0 generation of the affected villages was relatively low and in accordance to the results obtained using FISH. As a result of an expert group workshop held at STUK in 2001 (Lindholm et al. 2002), a summary of evidence from various physical measurements and biological analyses was not supporting external dose greater than 0.5 Gy (Simon et al. 2003).

The co-operation between the European laboratories concerning the FISH technique continued as a concerted action (COD) and resulted in general guidelines for the use of translocations in retrospective dosimetry (Edwards et al. 2005). Further studies on the control level of translocations have provided comprehensive data on the age-dependent increase of translocations (Whitehouse et al. 2005). A new approach considering the cell status has shown that translocations in stable cells are persistent with time (Lindholm and Edwards 2004). An intercomparison of samples obtained from the follow-up of the Estonian radiation accident victims in Kiisa showed that relatively consistent FISH scoring was performed between laboratories (Lindholm et al. 2002).

High frequency of structural chromosome aberrations (CAs) in peripheral lymphocytes has previously been demonstrated to be predictive of an increased cancer risk. The factors, especially genetic susceptibility factors, underlying this finding were investigated in the CancerRiskBiomarkers project. The effect of genetic polymorphisms on the level of CAs appears to be complex, with several polymorphisms of DNA repair proteins, xenobiotic metabolizing enzymes and enzymes of folate metabolism showing an influence. This probably reflects the multiple external and internal exposures inducing a multitude of DNA lesions eventually resulting in CAs. Polymorphisms affecting the level of cytogenetic biomarkers can be viewed as potential factors influencing the cancer risk predictivity of CAs. The magnitude of this tentative effect on cancer risk could not, however, be estimated since genotype data were not available for the polymorphisms of interest in cancer cases and controls of whom cytogenetic analyses were performed. It was demonstrated that both chromosome and chromatid-type aberrations show equally strong cancer predictivity (Hagmar et al. 2004).

The hereditary effects of low paternal radiation doses were studied by comparing the minisatellite mutation rates of children born to Estonian Chernobyl cleanup workers after the accident with those of their siblings born prior to it. A 1.33-fold non-significant (95% CI 0.80–2.20) increase was detected in the minisatellite mutation rate among children born after the accident. However, the radiation doses of the cleanup workers were so low that the results were consistent with either no effect of radiation on minisatellite mutations or a slight increase at dose levels exceeding 200 mSv (OR 3.00, 95% CI 0.97–9.30) (Kiuru et al. 2003; Kiuru 2004).

We have evaluated the influence of DNA repair gene polymorphisms on the frequency of chromosomal aberrations (CAs) analyzed in peripheral lymphocytes using the fluorescence in situ hybridization (FISH) technique. The CA data were obtained from an earlier study of 84 healthy non-smokers carefully characterized for indoor radon exposure. The role of DNA repair polymorphisms in OGG1 (codon 326), XPD (codon 751), XRCC1 (codons 194, 280, and 399), and XRCC3 (codon 241) were determined. Carriers of the XRCC1 codon 280His variant allele showed a two-fold increase ($P=0.046$) in unstable exchanges (dicentrics and ring chromosomes). In addition, an age-associated increase of two-way translocations was observed in subjects with the XRCC3 codon 241 homozygous variant genotype (Met/Met). Our data suggest that the XRCC1 280His and XRCC3 241Met alleles affect individual CA levels, most probably via influencing the DNA repair phenotype.

NTIRE Group

During the period of 2000–2003 a research group, then under the supervision of Dr. Riitta Mustonen, was involved in the execution of the EU FP5 funded project "Genomic Instability and Radiation-Induced Cancer" (RADINSTAB). The role of radiation-induced genomic instability in radiation carcinogenesis was studied in cell cultures, mechanistic investigations of its induction and perpetuation were carried out. Genes and specific gene products were studied and the basis of individual susceptibility investigated. The relationship of genomic instability endpoints to radiation dose, dose rate and quality was determined.

From May 2003 onwards the research into non-targeted effects of ionizing radiation has been led by Dr. Oleg Belyakov.

Mechanisms of radiation induced genomic instability and bystander effect were studied within the framework of EU funded Marie Curie project in several human normal cell strains including hTERT immortalized systems. Conventional broad field x-ray irradiation was partial field exposure and medium transfer techniques were used. In addition to the existing collaboration, we performed experiments with charge particle microbeam irradiation systems. A variety of endpoints were used to study bystander effect and genomic instability: cytogenetic damage was estimated with micronucleus analysis, apoptosis was assessed with morphological and biochemical (3OH' DNA end labelling and Annexin V staining) and Gap Junction Intercellular Communication (GJIC) was studied with immunohistochemical detection of expression of Connexins 26, 32 and 43. Intercellular communication was also measured with the Lucifer Yellow loading technique. Bystander effects were demonstrated as increase in the micronucleation and apoptosis after partial field exposure to x-rays. Extensive sell survival assays were performed, dose responses for micronuclei production and apoptosis induction were obtained. The relative contribution of GJIC and soluble extra cellular factors on bystander effect was estimated after exposure to low doses of x-ray radiation.

The next step was to study mechanisms of non-targeted effects of ionizing radiation in 3D artificial human skin tissue systems after broad field and microbeam irradiation. These activities were part of the EU funded ongoing Integrated Project "DNA damage repair, Genomic instability and Radiation-Induced Cancer: The problem of risk at low and protracted doses" (RISC-RAD).

In 2004, the group started work with the EPI-200 MatTek EpiDerm human artificial skin model. During this stage of the project we used a histological approach for the reconstruction of the 3D microarchitecture. The Gray Cancer Institute (GCI) microbeam charged particle facility (UK) was used for delivering counted protons and 3He2+ions. Tissues were irradiated within a single or multiple spot ith various numbers of particles to study LET and dose dependency of the bystander effect under the 3D tissue conditions. Currently, we concentrate on the morphological analysis using haemotoxylineosin staining and in situ apoptosis assay with a 3'-OH DNA end-labelling based technique. In addition, non-invasive deep-fixed and unfixed tissue imaging was performed using an unique ApoTome system, available in GCI. 3D tissue morphmetric measurements of artificial human skin microarchitecture were performed. The main aim of these studies is to improve microdosimetic calculation for more precise characterisation of the bystander effect.

Additionally, construction of STUK narrow/broad beam α-particle irradiation facility started in collaboration with the Radiation Metrology Laboratory of STUK. The constructed α-particle irradiator is specially designed for experiments using either cell cultures or 3D tissue systems (artificial skin, skin explants).

Based on the data obtained a theory was postulated that the main function of the non-targeted effects is to decrease the risk of transformation in a multicellular organism exposed to radiation.

FunProt Group (formerly BioNIR Group)

During the period of 2000–2004 the group has examined effects of mobile phone radiation (radio-frequency modulated electromagnetic fields; RF-EMF) on endothelial cells and effects of solaria long-wave ultraviolet radiation (UV-A) on melanoma cells.

The rapid increase in the use of mobile phones has brought up an urgent need to determine whether mobile-phone-emitted microwave radiation (radio-frequency-modulated electromagnetic fields; RF-EMF) could cause any biological effects and whether these biological responses could potentially lead to human health hazard. The possibility of such hazardous effects of RF-EMF remains controversial.

Preparations for the studies examining cellular responses to mobile phone radiation have started in 1997 and the experimentation has begun in the end of 1999. Research funding was secured from the Finnish Technology Development Agency – TEKES (there were two consecutive consortia – ETX and LaVita), the Academy of Finland (post-doctoral fellowship), from the EU 5th Framework Programme (REFLEX consortium) and from the Verum Foundation, Munich, Germany. In addition, STUK has provided budget support and the Finnish Ministry of Social Affairs has provided ear-marked funding for the purchase of a mass spectrometer Maldi-ToF. Research data obtained since 1999 were published in three articles and presented in numerous invited lectures and seminars throughout the world. In addition, research has got broad world-wide news media coverage since the publication of the first article in 2002.

In the first published study (Leszczynski et al. 2002) we have examined whether non-thermal exposures of the cultures of human endothelial cell line EA.hy926 to 900MHz GSM mobile phone microwave radiation00 could activate stress response. Obtained results have shown that the 1-hour non-thermal exposure of EA.hy926 cells causes changes in the phosphorylation status of several hundreds of proteins. One of the affected proteins was identified as the small stress response protein: heat-shock protein-27 (Hsp27). Mobile phone exposure has caused a transient increase in the phosphorylation of Hsp27, which effect was prevented by SB203580, a specific inhibitor of p38 mitogen-activated protein kinase (p38 MAP kinase). This kinase is located up-stream of the Hsp27 and its activity indirectly (via MAPKAPK-2/3 or PRAK kinase) affects the phosphorylation of Hsp27. Also, mobile phone exposure has caused transient changes in the protein expression levels of Hsp27 and p38 MAP kinase. All these changes appeared to be non-thermal effects because, as determined using temperature probes, irradiation did not alter the temperature of cell cultures, which remained throughout the irradiation period at 37 ± 0.3oC. The observed changes in the overall pattern of protein phosphorylation suggest that the mobile phone radiation exposure causes activation of a variety of cellular signal transduction pathways, among them the Hsp27/p38 MAP kinase stress response pathway. Based on the known functions of Hsp27, we have put forward a hypothesis that the mobile phone radiation-induced activation of Hsp27 may (1) facilitate the development of brain cancer by inhibiting the cytochrome c/caspase-3 apoptotic pathway and (2) cause increase in the blood-brain barrier permeability through stabilization of the endothelial cell stress fibers. We have postulated that these events, when occurring repeatedly over a long period of time, might become a health hazard because of the possible accumulation of brain tissue damage. Furthermore, our hypothesis has suggested that other brain-damaging factors may co-participate in the mobile phone radiation-induced effects. In conclusion, this first study has demonstrated that in spite of its very low energy, RF-EMF is recognized by cells as an external stress factor and it triggers counteracting stress response. However, these results can not be used for evaluating whether or whether not, the RF-EMF exposure might be hazardous to human health.

Elucidation of the biological and health effects of mobile phone radiation has been done for decades but the reliable answers concerning potential health hazard are still missing. Extensive epidemiological studies are commonly expected to provide the answer whether the RF-EMF might be hazardous to people. However, finding and scientific validation of any potential health hazard, whether it would be cancer or non-cancer effect, might not be possible using epidemiological approach alone. This, because the “low sensitivity” of the epidemiological methodology might be insufficient to reliably detect health impact of the weak biological effects caused by RF-EMF. Therefore, although epidemiological studies will be needed to ultimately validate the extent of any potential health hazard of RF-EMF to human population, they also need to be supplemented and supported by the data from animal and in vitro studies. The so far used research approach to search for biological effects of RF-EMF does not provide sufficiently fast and sufficiently broadly the variety of biological end-points that could be used for health hazard studies. Therefore, we have proposed that the use of modern high-throughput screening techniques (HTST) of transcriptomics and proteomics, although expensive and laborious, is scientifically justified and necessary in studies that examine biological effects of mobile phone radiation. We argued that HTST will allow rapid identification of molecular targets of this low-energy radiation that will help in defining potential end-points for further investigations. Although such screenings will not provide information about health risks, however, they will indicate what physiological processes might be potentially affected. Further studies will be necessary to determine whether these alterations might cause any human health-related risk.

To demonstrate the usefulness of HTST in search for the biological effects induced by RF-EMF, we have performed a 5-step feasibility study using the Hsp27 protein as an example (Leszczynski et al. 2004). In this study we have shown that HTST are applicable to the research on mobile phones' effects and that they may be of great value in determining the new end-points for the further research. Furthermore, using high-throughput screening we were able to determine that even proteins that were only modestly altered, by exposure to mobile phone radiation, expression and/or activity might exert a significant impact on cell physiology. This study has shown that the use of high-throughput screening techniques might help in rapid identification of potentially all genes and proteins that respond to the exposure. This, in turn, can help in speeding up of the process of determining whether these changes on cellular level might induce any physiological changes on the whole-body level and eventually lead to some impact on human health.

In the third published study (Nylund & Leszczynski 2004), we have applied the HTST approach to look at the protein expression changes in human endothelial cell line EA.hy926 that was exposed to the mobile phone radiation. Protein expression changes were examined using a 2-dimensional electrophoresis and PDQest software. In this study, we have identified 38 various proteins which have statistically significantly altered their expression levels following the irradiation. Four of these proteins were identified with Maldi-ToF. Two of the affected proteins were determined to be isoforms of cytoskeletal vimentin. This finding has provided further support for our earlier presented working hypothesis (Leszczynski et al. 2002) which suggests that the mobile phone radiation might affect cytoskeleton and might have an effect on such cell physiological functions that are regulated by the integrity and localization of cytoskeleton.

The other area of research of the FunProt group is the effects of the long-wave ultraviolet radiation (UV-A) on the process of metastasis of melanoma cells. This research direction stems from the hypothesis put forward by the research performed by us in 1995–1996 (Leszczynski et al 1995, Leszczynski et al 1996).

Ultraviolet (UV) radiation is known to play a significant role in the development of skin cancer. Depending on the latitude and the season of the year, the terrestrial spectrum of solar UV radiation consists of 1–5% of UV-B radiation (280–320 nm) and 95–99% of UV-A radiation (320–400 nm). UV-B radiation is fully absorbed by the stratum corneum and the top layers of the epidermis, whereas up to 50% of incident UV-A radiation penetrates Caucasian skin deep into the dermis, and irradiates the full thickness of skin, including capillary blood vessels. UV-B radiation is commonly considered as the more harmful part of the UV spectrum due to its DNA damaging potential. UV-A radiation is still regarded as a relatively low health hazard.

The major sources of human exposure to UV-A radiation are extensive sunbathing and tanning in solaria. The use of sunscreens does not diminish, but even increases, the UV-A radiation exposure because: (1) the presently available sunscreens poorly absorb UV-A wavelengths and (2) people using sunscreens tend to sunbath longer because of the diminished pain-causing erythema.

Thus far, the majority of the biomedical studies have focused on the mutation-inducing and immunosuppressive effects of the UV-B radiation. The biological effects of UV-A radiation exposure are far less known about. Recently, it has been shown that UV-A exposure induces characteristic DNA mutations present in various human skin hyperplasia. Most worrisome was the increase of UV-A-characteristic mutations in epidermal basal cells. We have previously suggested that UV-A radiation might affect tumor metastasis. Also, a growing number of published studies have demonstrated that the UV-A radiation regulates a variety of cellular processes. The UV-A radiation-affected cellular functions, with the potential of impact on the metastatic process, are e.g. (1) activation of protein kinase C (PKC), (2) induction of secretion of collagenase and metalloproteinases, (3) induction of changes of the expression pattern of the various adhesion molecules and the major histocompatibility (MHC) antigens, and (4) modulation of cell attachment to fibronectin via integrins. In the skin *in vivo*, the responses induced by the UV-A radiation might be potentiated by the effects induced in epidermis by the UV-B radiation (e.g. generation of cytokines and eicosanoids).

Our present research on the effects of the UV-A radiation examines the hypothesis, put forward by Leszczynski et al (1995 and 1996), which suggests that the UV-A radiation exposure (UV-A alone or in concert with UV-B) might alter the profile of adhesion molecules expressed on the surface of the exposed cells. Such effect might be possible not only via indirect UV-A effect on epidermal cells (cytokine or eicosanoid-mediated) but also via a direct effect of the UV-A on tumor cells. We suggest that the UV-A-induced alteration of the adhesive properties of cells, when induced in tumor cells that either reside in the skin or are passing with blood circulation through the dermal capillaries, could lead to the increase of the metastatic capability of these tumor cells.

In the *in vivo* pilot study (Pastila & Leszczynski in press) we have examined the plausibility of the hypothesis by looking at the effect of UV-A exposure on metastasis of tumor in mice. The study was executed using C57BL/6 mice and syngeneic B16 melanoma cell lines. Mice were *i.v.* injected with either B16-F1 or B16-F10 melanoma cells into the tail vein and then immediately exposed to UV-A. Fourteen days after melanoma injection, lungs were collected and the quantity and quality of metastases were determined under dissecting microscope. As an outcome of the pilot study we have observed that intravenously injected melanoma cells formed 10-fold more lung metastases in the UV-A exposed mice in comparison to the control mice. This result suggests that the UV-A exposure of mice, with melanoma cells present in blood circulation, increases the formation of melanoma metastases in lungs. Further studies should determine whether similar pro-metastatic effect, as this observed in mice, could occur in humans and whether other than melanoma tumors might be susceptible. This pilot *in vivo* study has been since reproduced in the second study executed by us and the same result was obtained (Pastila et al, submitted). This new study has also indicated that one of the mechanisms responsible for the increased melanoma metastasis in UV-A exposed mice might be the weakened immunity of the exposed animals. However, this mechanism did not account for the full extent of metastasis increase. Therefore it is possible that also other mechanisms are involved, such as generation of cytokines by skin cells and alteration of the adhesive properties of melanoma cells.

The effect of the UV-A exposure on the adhesive properties of melanoma cells was examined *in vitro* (Pastila & Leszczynski; in press). As an experimental *in vitro* model we have used the C57BL/6 mouse-derived B16 F1 and B16-F10 melanoma cell lines and the syngeneic MS-1 endothelial cell line. The melanoma cells were exposed to different doses of UV-A irradiation. We have determined that the single dose of UV-A at 8 and 12 J/cm^2 causes 88% ($p<0.001$) and 32% ($p<0.05$) increase in B16-F1 melanoma cell adhesiveness to the non-irradiated endothelial monolayer, respectively. The peak of the response was 24h after the irradiation. The UV-A dose of 8 J/cm^2 delivered in four doses separated by 1h intervals (4 × 2 J/cm^2) has caused 149% ($p < 0.001$) increase of B16-F1 melanoma adhesiveness already at 1h after the last dose of UV-A. Besides the induction of increase in the melanoma-endothelial cell adhesion, UV-A exposure has induced a rapid decline (1h after exposure) in homotypic melanoma-melanoma cell adhesion (clustering). The clustering decline of B16-F1 cells was by 61% ($p < 0.05$) with the single dose of UV-A at 8 J/cm^2 and by 35% ($p < 0.05$) with 4 × 2 Jcm^2. Pilot experiments have shown that the changes of the adhesive properties of melanoma cells were accompanied with an increase in the N-cadherin expression and a decline in the E-cadherin expression. Such change in cadherin expression profile has been shown to be an indicator of the increased metastatic potential. In conclusion, our results suggest that the UV-A radiation appears to alter the adhesive properties of melanoma cells *in vitro*, by diminishing the melanoma-melanoma adhesion and by increasing melanoma adhesion to endothelium. This suggests that the UV-A exposure might increase the metastatic capability of the melanoma cells.

In another set of experiments we have examined effects of the UV-A exposure on the gene expression of the B16-F1 cells using a transcriptomics approach (cDNA Expression Array). We have investigated the changes in the expression profile of genes in the mouse melanoma B16-F1 cells 4 hours after a UV-A dose of 8 J/cm^2. Atlas™ cDNA Expression Arrays were used to identify the genes involved in the regulation of carcinogenesis, tumor progression and metastasis. Our study has revealed (Pastila & Leszczynski; submitted) that the physiologically relevant UV-A dose induces changes in the expression of 10 genes. Eight out of them were up-regulated (HSC70, HSP90 α/HSP86, α-B-crystallin, GST mu2, Oxidative stress induced protein OSI, VEGF, TDAG51, cyclin G) and two of them were down-regulated (G-actin, non-muscle cofilin) by the UV-A exposure. This suggests that the UV-A radiation, by inducing changes in the expression of various genes, might have a greater impact on cell physiology than the previously thought.

EPI Group

<u>Indoor air radon</u>

In collaboration with Natural Radiation Laboratory we have participated in an international study on lung cancer risk of indoor air radon in which 13 epidemiological studies were pooled. After detailed stratification of smoking there was strong evidence of an association between the radon concentration at home and lung cancer. The dose-response relationship seems to be linear with no evidence of a threshold dose, and there was a significant dose-response relation even below currently recommended action levels. The absolute risk to smokers and recent ex-smokers was much greater than to lifelong non-smokers. Radon at home accounts for about 9% of deaths for lung cancer and 2% of all deaths from cancer in Europe (Darby et al. 2005).

Natural radionuclides in drilled wells

High levels of natural radionuclides, uranium and radon, can be found in drilled wells in the southern Finland. Therefore, health effects from ingested radionuclides can be studied among the users of drilled wells. Uranium concentrations in drinking water and urine were measured among 325 persons who had used drilled wells for drinking water. Uranium exposure was weakly associated with altered proximal tubulus function (fractional excretion of calcium and phosphate) without a clear threshold. Despite chronic intake of water with high uranium concentration, no effect on glomerular function was bserved (Kurttio et al. 2002). Indicators of bone turnover were also studied among these study persons. There was some suggestion that elevation of indicators of bone turnover (serum type I collagen carboxy-terminal telopeptide) could be associated with increased uranium exposure in men, but no similar relationship was found among women (Kurttio et al. 2005). The analysis methods for uranium in drinking water, urine, hair and nails that were developed in this study can also be used for monitoring of uranium exposure as well as in studies on uranium metabolism (Karpas et al. 2005).

The effect of natural uranium and other radionuclides in drinking water on risk of leukemia and stomach cancer has been assessed among the cohort that lived outside the municipal tap water system. A case-cohort design was used comparing exposure among cases with leukemia (N = 35) and stomach cancer (N = 88) with a stratified random sample (N = 274) from the subcohort. The results do not indicate an increased risk of leukemia (Auvinen et al. 2002) or stomach cancer (Auvinen et al. 2005) from ingestion of natural uranium or other radionuclides through drinking water at these exposure levels.

The above mentioned studies were carried out in co-operation with the NRL.

Chernobyl accident

Together with the Radiation Hygiene Laboratory the Laboratory has studied the health consequences from the radioactive fallout from the Chernobyl accident because they have been a major public concern. Possible effects of Chernobyl fallout on pregnancy outcomes in Finland were evaluated in a nationwide follow-up study. No marked changes in induced abortions or stillbirths were observed. A statistically significant increase in spontaneous abortions with dose of radiation was observed. However, it is probably not a biological effect of radiation, but more likely related to public concerns of the fallout (Auvinen et al. 2001).

Nuclear workers

Because of their well-documented exposures to repeated low doses of ionizing radiation, nuclear reactor workers offer an opportunity to assess cancer risk from low-dose radiation. A cohort of all 15 619 Finnish nuclear reactor workers was established through dose-monitoring records of STUK. In the follow-up for cancer incidence, no clear excess in cancer incidence was observed overall, nor was any observed in any of the specific cancer types studied (Auvinen et al. 2002). This cohort is a part of the international nuclear worker study coordinated by the International Agency for Research on Cancer (Cardis et al. BMJ, 2005).

Cosmic radiation

During flight, pilots and cabin crew are exposed to increased levels of cosmic radiation which consists primarily of neutrons and gamma rays. Because there are so few populations exposed to neutrons, studies of airline personnel are of particular interest (Boice et al. 2000). Our studies do not indicate a marked increase in cancer risk attributable to cosmic radiation, although some influence of cosmic radiation on skin cancer cannot be entirely excluded.

Retrospective cohort studies, with follow-up of cancer incidence through the national cancer registries in Denmark, Finland, Iceland, Norway, and Sweden, included about 10 000 male and 200 female airline pilots. The only significantly increased SIRs were for skin cancers (melanoma, non-melanoma, basal cell carcinoma) in male (Pukkala et al. 2002, 2003). The relative risk of skin cancers increased with the time since first employment, the number of flight hours, and the estimated radiation dose. There was an increase in the relative risk of prostate cancer with increasing number of flight hours in long-distance aircraft.

In a cohort study in nine European countries the mortality of airline pilots and flight engineers was studied. Cockpit crew cohorts were identified and followed up in Denmark, Finland, Germany, Great Britain, Greece, Iceland, Italy, Norway and Sweden, including a total of 28 000 persons. The study shows that cockpit crew members have a low overall mortality. Furthermore, overall cancer mortality and mortality from lung cancer were decreased. An increased mortality from malignant melanoma was observed but no consistent association between the employment period or duration and cancer mortality was observed. A low cardiovascular mortality and an increased mortality caused by aviation accidents were noted (Blettner et al. 2003).

In another European study, mortality among more than 44 000 airline cabin crew members was investigated. Among female cabin crew, overall mortality and all-cancer mortality were slightly reduced, while breast cancer mortality was slightly but nonsignificantly increased. Overall mortality and mortality from skin cancer among male cabin crew were somewhat increased. Males had excess mortality from aircraft accidents and from acquired immunodeficiency syndrome (Zeeb et al. 2003).

In a European cohort study (ESCAPE) cancer mortality was investigated on the basis of individual effective dose estimates for 19 184 male pilots. Mean annual doses were in the range of 2–5 mSv and cumulative lifetime doses did not exceed 80 mSv. All-cause and all-cancer mortality was low for all exposure categories. A significant negative risk trend for all-cause mortality was seen with increasing dose. Neither external and internal comparisons nor nested casecontrol analyses showed any substantially increased risks for cancer mortality due to ionizing radiation (Langner et al. 2004).

A method for assessing dose radiation on the basis of individual flight history has been developed. Finnair timetables and an expert panel of pilots consulted in this method which provides a procedure for assessing cosmic radiation exposure among attendants when survey data are missing. With this method the radiation dose was estimated for 544 flight attendants with the active work of 0–30 years. The mean cosmic radiation dose was 3 (range 0–10) mSv per active work year and the mean cumulative career dose was 34 (range 0–157) mSv (Kojo et al. 2004).

Cellular phone use

Brain tumours are some of the most lethal adult cancers and there is a concern that the incidence is increasing. It has been suggested that the reported increased incidence can be explained e.g. by improvements in diagnostic procedures or use of mobile phones. The incidence trends of adult primary intracerebral tumours in four Nordic countries during 1969–98, a period with introduction of new diagnostic procedures and increasing prevalence of mobile phone users, was studied. An average annual increase of all intracerebral tumors was 0.6% for men and 0.9% for women. The increase in the incidence was confined to the late 1970s and early 1980s and coinciding with introduction of improved diagnostic methods. This increase was largely confined to the oldest age group. After 1983 and during the period with increasing prevalence of mobile phone users, the incidence has remained relatively stable for both men and women (Lönn et al. 2004).

We have conducted a register-based case-control study on cellular phone use and cancer. The study subjects were all cases of brain tumour (N = 398) and salivary gland cancer (N = 34) diagnosed in Finland in 1996, with five controls per case. Cellular phone use was not associated with brain tumours or salivary gland cancers overall, but there was a weak association between gliomas and analog cellular phones. However, a register-based approach has limited value in risk assessment of cellular phone use owing to lack of information on exposure (Auvinen et al. 2002b).

The Laboratory has carried out the field works for INTERPHONE, an international collaborative case-control study of tumours of the brain and salivary glands related to mobile telephone use, coordinated by the IARC. We have evaluated the participation of mobile phone users and non-users in the Finnish part of INTERPHONE. The results suggest that selection bias is unlikely to affect the risk estimates related to mobile phone use (Lahkola et al. 2005).

2.8.6 Research plans for the next five years

BioDos

The major research area in the biological dosimetry group during the next five years is individual sensitivity to radiation. The relationship between gene variants (single nucleotide polymorphisms, SNPs) and effect end-points, such as chromosomal aberrations (CAs) and cancer, will be investigated. In addition to genotypes, also phenotype studies of the gene variants are planned.

In an INTAS-funded project, biosample banks established from three NIS populations exposed to ionizing radiation will be exploited to study together with EPI the relationship of common DNA repair and cell cycle control gene variants and cancer risk, the rate of minisatellite mutations in germ line, CAs in lymphocytes and loss of heterozygosity in erythrocyte precursor cells in bone marrow (GPA mutations). The project will also yield a large amount of new FISH CA data that can be used in the exposure assessment of the populations involved.

As a part of the INTERPHONE project, dealing with brain tumours and the use of mobile phones, an individual susceptibility study will be completed in 2005. As a collaboration between laboratories in the Nordic countries and the UK, the association of gene variants in a number of DNA repair, XME and cancer genes with brain tumours will be revealed. Future plans include an expansion of the list of gene variants to be studied.

Interindividual response to ionizing radiation-induced DNA damage and its repair will continue to be studied. The association between damage on chromosome level (FISH CA analysis) and DNA level (Comet assay analysis) will be exploited. In addition to individual sensitivity, biological (including retrospective) dosimetry will continue to be developed.

NTIRE

The main rationale for our research is that the bystander effect and genomic instability are likely to be natural phenomena which should be studied in vivo, such as the multicellular system with preserved 3D tissue microarchitecture and microenvironment. This necessitates moving from in vitro cell culture systems to tissue-based systems (RISC-RAD) to investigate:

- the link between non-targeted effects and radiation-induced health effects; determine the dose-effect relationships of non-targeted effects in space and time. Establish a conceptual framework for the generation of a new radiobiological paradigm that covers both targeted (direct) and non-targeted effects of ionizing radiation (NOTE).
- direct and non-targeted effects of exposure to alpha-particles in telomerase-immortalized (hTERT) human epithelial cell line (ALPHA).
- nature of bystander effect messengers, in particular, contribution of 26S proteasome complexes to induction and perpetuation of bystander effect in epidermal A-431 cells after exposure to the medium from x-rays irradiated cells (PSBE).
- whether the non-targeted effects relate to protective or harmful functions in response to radiation (NOTE).
- potential significance of the bystander effect for the radiation regulation issues and applicability of the Linear-No-Threshold (LNT) model in extrapolating radiation risk data into the low-dose region (All projects).

Based on these projects NTIRE will attempt to develop a unifying hypothesis for the role of non-targeted effects in radiation-induced tissue responses and, ultimately, carcinogenesis (Generic).

STUK α-particle irradiation facility will be upgraded to narrow beam mode of operation. The facility will be equipped with a removable collimator system and an X-Y motorized stage allowing precise micron range patterned irradiation, positioning and repositioning of biological samples (tissues or confluent cells cultures) (STUK funded project).

FunProt

<u>Effects of the RF-EMF on human primary endothelial cells isolated from umbilical cord vein – HUVEC</u>

The project will determine whether the changes observed in RF-EMF exposed human endothelial cell line EA.hy 926 occur also in primary human endothelium. Cells will be exposed to GSM radiation of 1800 MHz. Following exposure cells will be examined for the:

- cellular stress response: Hsp27 expression and phosphorylation, expression and phosphorylation of the up-stream kinases of the p38 MAP kinase pathway
- effect of the exposure on cytoskeleton
- effect of the exposure on the pinocytosis of cells and on the permeability of monolayer for various sizes of molecules (in vitro blood-brain barrier)
- using differential display proteomics will be examined global changes in protein expression and phosphorylation by using 2-D electrophoresis and Maldi-ToF or HPLC and tandem mass spectrometry (ongoing collaboration with Prof. Griffin, Univ. Minnesota, USA).

<u>Effects of RF-EMF on the skin of human volunteers (Tekes-funded HERMO-SKIN project)</u>
The project will determine whether the RF-EMF exposure induces any significant changes in protein expression in cells exposed in their native location. Skin will be exposed to GSM radiation of 900 MHz. Following the exposure punchbiopsies will be harvested from an exposed and non-exposed skin area of the same person, proteins will be extracted and analyzed using differential display proteomics approach (2-D electrophoresis + Maldi-ToF).

<u>Effects of solaria UV-A exposure on the skin of human volunteers</u>
The project will determine what kind of global change in protein expression pattern is induced by the UV-A exposure. Volunteers will be exposed in a commercially available solarium. Following the exposure punch-biopsies will be harvested prior to the exposure (control sample) and after the exposure from an exposed and non-exposed skin area of the same person. Proteins will be extracted and analyzed using differential display proteomics approach (2-D electrophoresis + Maldi-ToF). The study will be a part of the ongoing research concerning the safety of use of solaria and other tanning equipment that deliver very high doses of UV-A radiation (up to 10-folds higher than the solar UV-A levels).

EPI
One of the research strategies is based on utilizing the opportunities for large-scale population-based studies provided by the highly developed Finnish registries such as population registry, cancer registry, hospital discharge registry and others. Comprehensive national networks among scientists and the positive attitude of Finnish people for participating scientific studies are advantages for epidemiological studies. International collaboration is of primary importance for strengthening the breadth of expertise, adopting new approaches and increasing statistical power.

In future, the focus will be moved to non-cancer effects of ionizing radiation. Furthermore, methods of radiation exposure assessment will be developed and the knowledge in statistics will be improved.

The role of radiological examinations and mobile phones in the aetiology of brain tumours will be assessed in a collaborative study coordinated by the IARC. The same material and national registries will be used to evaluate other risk factors and the brain cancer trends in Nordic collaborative studies. As a part of a new international co-operation study, a large cohort of mobile phone users, whose health status will be followed for 25 years, is planned.

A pooled analysis of European studies of indoor radon and lung cancer coordinated by the NRPB will be completed.

A pooled analysis of cancer mortality among nuclear workers is under way with the IARC coordination.

Cancer risk from ingested radionuclides among reindeer-herding Saami is studied in collaboration with Swedish and Norwegian researchers.

A study on cancer risk among the Chernobyl cleanup workers from Estonia and Latvia will be continued. The effects of the Chernobyl fallout on thyroid cancer in Finland will be explored.

The biological monitoring and toxicity of ingested uranium are being investigated. The effects of radionuclides in drinking water on the risk of bladder and kidney cancer are being studied.

The occupational versus life-style and other factors to breast cancer risk among cabin attendants will be studied. A Nordic combined analysis of cabin crew will be completed with more detailed exposure estimation by GSF.

The relation between UV exposure and incidence of cutaneous malignant melanoma will be studied.

The risk of developing a bone or soft tissue sarcoma after radiotherapy for a primary cancer will be studied.

A nation-wide cohort of children who have been examined with CT is planned. Once established, e.g., cancers and school performance will be studied in this cohort.

The STUK research projects for the period 2003–2005 are described in detail in the STUK-A202 report (Salomaa 2004). A list of the projects to be carried out by the Radiation Biology Laboratory and by the Epidemiology and Bioststistics Laboratory are given below.

Radiation Biology Laboratory

IONIZING RADIATION (laboratory's *in vitro / in vivo* studies)

- The use of FISH techniques for retrospective biodosimetry (COD)
- Cytogenetic follow-up of the radiological accident in Estonia

- Cytogenetic biomarkers and human cancer risk (CancerRiskBiomarkers)
- Susceptibility factors and biomarkers of effect in humans exposed to low-dose radiation
- Inter-individual differences in the yield of radiation-induced chromosomal aberrations and DNA-damage
- Individual sensitivity in the aetiology of brain tumours
- The effect of genotypes on stable chromosome aberrations in radon-exposed persons
- Mechanisms of radiation-induced genomic instability and bystander effect
- Non-Targeted Ionizing Radiation Effects

NON-IONIZING RADIATION (laboratory's *in vitro*/*in vivo* studies)
- Development of In Vitro Dosimetry and Bio-Markers (LaVita)
- Mechanism of mobile phone radiation-induced bioeffects (LaVita-2 Mechanisms)
- Potential health hazards of mobile telephones (REFLEX)
- Transcriptomics and proteomics approach to study cellular responses to mobile phone radiation and UV-A radiation
- UV-A effects on melanoma metastasis (SYTTY and SYTYKE)
- UV-A effects on melanoma cells

Epidemiology and Biostatistics Laboratory
IONIZING RADIATION (epidemiological studies)
- An international pooled analysis on indoor radon and lung cancer studies
- An international pooled analysis on cancer risk among nuclear workers
- Cancer among Baltic Chernobyl clean-up workers
- Chernobyl and thyroid cancer in Finland
- Exposure to cosmic radiation and cancer risk among airline crew
- Cancer risks from radioisotopes in drinking water
- Kidney and bone effects of uranium in drinking water
- Risk factors for brain tumours
- Cancer risk among reindeer-herders and saami people
- Cancer risk among x-ray workers
- Sarcomas after radiotherapy
- Health effects of CT-images in childhood

NON-IONIZING RADIATION (epidemiological studies)

- Case-control study on mobile phone use and brain tumours
- Mobile phone use and brain tumor risk: assessment of uncertainty and sources of errors
- Cohort of mobile phone users
- Ultraviolet radiation and skin cancer

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2.9 Radiation Practices Regulation

2.9.1 Key words and specific technologies

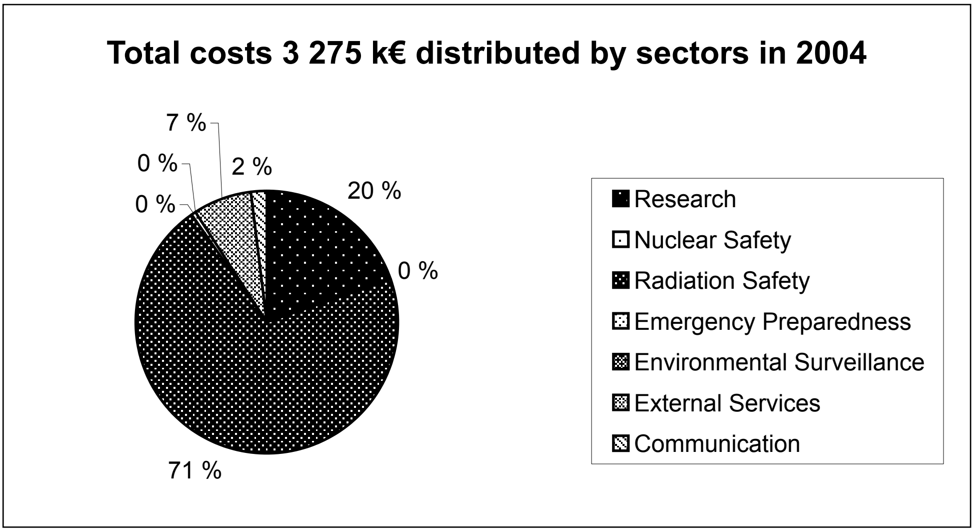
Key words

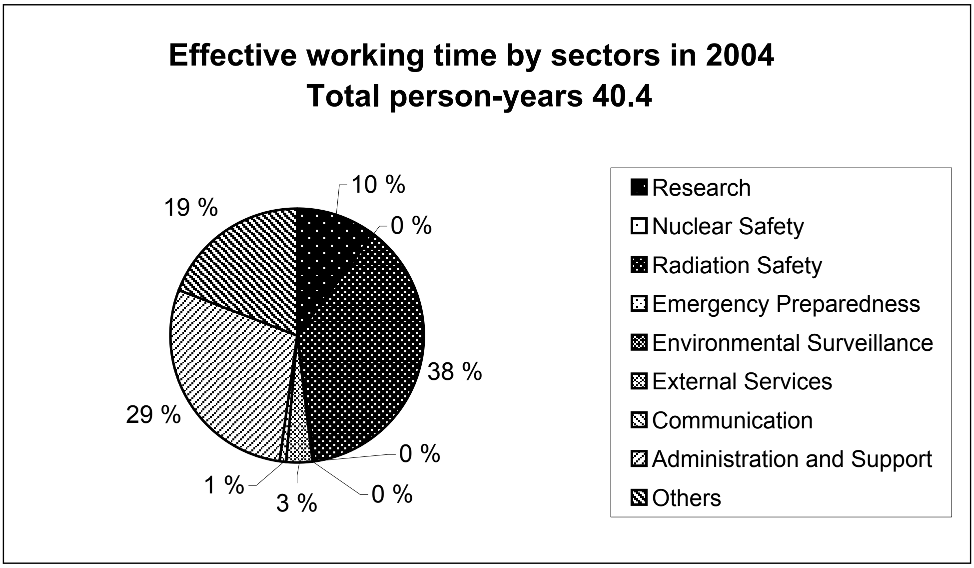
Medical use of radiation, ionising radiation, radiation dosimetry, diagnostic x-ray imaging, radiation protection, patient dose, image quality, radiation risk, radiation metrology, standard dosimetry, calibration techniques, personal dosimetry, individual dose monitoring.

Specific technologies

Dosimetric techniques, calibration techniques, x-ray spectrometry, Monte Carlo calculation methods, image quality evaluation tools, surveys on medical use of radiation, surveys on individual dose monitoring.

2.9.2 Description of laboratory activities





Radiation Practices Regulation is the department of STUK which is responsible for the supervision and regulation of radiation use. The main objective of the department is to protect the people, the society, the environment, and future generations against the harmful effects of radiation. The regulation and supervision concerns the use of radiation in health care, veterinary medicine, industry, education, research, and work where natural radiation is of special concern. The department keeps the occupational dose registers in Finland and approves individual dose monitoring services. The Radiation Metrology Laboratory of the department is responsible for the maintenance of the national standards for dose quantities of ionising radiation. To support the regulatory activities, the department also carries out research on medical use of radiation, radiation metrology and, to some extent, also on individual monitoring of occupational radiation doses.

Research

The research on the medical use of radiation and in individual dose monitoring is aimed to improve the knowledge and expertise in general, and to support the regulatory activities. The research on radiation metrology is related to the maintenance and development of the national standards for dose quantities of ionising radiation. In this work special attention is paid to disseminating reliable dosimetry methods for the users of radiation. To ensure the best knowledge available and to optimise the available resources, the research on medical use of radiation is organised in projects and carried out mainly by persons from two units: the Office for Radiation in Health Care and the Radiation Metrology Laboratory. The Office for Radiation in Health Care is a regulatory unit which, among other activities, makes site visits to hospitals and carries out research, usually in collaboration with Finnish hospitals. Research on radiation metrology is carried out by the staff of Radiation Metrology Laboratory. The research on individual dose monitoring is centred in the Office for Regulatory Control Development and Support, and is related to the harmonisation of individual dose monitoring in Europe and verification of the quality of dosimetric services.

In addition to the internal research projects, research work is also done in national and EU-funded research projects and in collaboration with other research organizations. In 2001–2004 we participated in the EU shared-cost research project Measures for optimising radiological information and dose in digital imaging and interventional radiology (DIMOND III). Research-related co-operation is also done with organizations such as ICRU and IAEA, in their various working groups and report committees. In metrology, co-operation is carried out with other Nordic dosimetry laboratories and the EUROMET organization (European Collaboration in Measurement Standards). In the field of individual dose monitoring European projects are mainly performed under the umbrella of the EURADOS (the European Radiation Dosimetry Group).

Education and training

The following education and training activities are organised:

- annual courses for the radiological personnel of hospitals, institutes and companies in Finland
- regular meetings with the radiotherapy physicists in Finland
- regular meetings with the nuclear medicine personnel of hospitals in Finland
- regular meetings with technical x-ray personnel of hospitals and x-ray companies in Finland.

The courses on radiation protection and quality assurance for radiological personnel have been organised annually for fifteen years and meetings for radiotherapy physicists for more than twenty years. In these meetings, reviews on current scientific topics are presented in addition to regulatory subjects. The lectures in the radiological meetings have been published as STUK-A and STUK-C reports and distributed to the participants.

The personnel of the department has also participated in the following education and training activities:

- giving invited lectures in international (IAEA, EU) and national courses
- supervising doctoral theses and MSc theses. (These theses a listed among other publications in the list of publications.)
- acting as an opponent in the public defence of a doctoral thesis.

The experts in the department have also written the volume "Use of Radiation" in the seven-volume book series on radiation and nuclear safety (In Finnish), which is being published by STUK. The department has also participated in the writing of another volume in the series.

The department has participated in the EU development projects for Baltic countries: the Twinning project and the Latvian Phare project.

Expert services

The Radiation Metrology Laboratory has provided expert services that are related to its responsibilities as a national standard dosimetry laboratory or to the expertise gained in research work on the medical use of radiation. The services provided are:

- calibration and testing services for dosemeters used in radiation protection, diagnostic radiology and radiotherapy
- testing of diagnostic x-ray units in the laboratory and on-site
- selling and user support for the PCXMC and ESD programs

2.9.3 Personnel

The permanent personnel participating in research work:

Antti Kosunen, PhD (physics), Radiation Metrology Laboratory, head of laboratory.
Management, quality management, radiation metrology, dosimetry, radiotherapy dosimetry.

Markku Tapiovaara, MSc (physics) Radiation Metrology Laboratory, senior scientist.
Research and development of x-ray dosimetry, theory of imaging physics, optimisation of imaging techniques, patient dose assessment, performance of x-ray units, expert services, standardisation.

Tuomo Komppa, LicPhil (physics), Radiation Metrology Laboratory, senior scientist.
Research and development of x-ray dosimetry, applied and standard dosimetry, quality management, quality assurance, patient dose assessment, radiation risk assessment, standardisation.

Ilkka Jokelainen, MSc (physics), Radiation Metrology Laboratory, physicist.
Research and development of dosimetry for radiotherapy, standard dosimetry, measurement and calibration techniques, quality assurance, calibration services, standardisation.

Arvi Hakanen, PhD (physics), medical physicist, Radiation Metrology Laboratory, scientist.
Research and development of dosimetry for radiation protection, standard and applied dosimetry, measurement and calibration techniques, quality assurance, calibration services.

Paula Pöyry, MSc (physics), Radiation Metrology Laboratory, scientist.
Research and development of x-ray dosimetry, applied and standard dosimetry, measurement and calibration techniques, standard dosimetry, quality assurance, calibration services.

Teuvo Parviainen, senior radiographer, Radiation Metrology Laboratory, inspector.
Research and development of x-ray dosimetry and quality assurance, applied and standard dosimetry, education and training in radiation protection, expert services, quality assurance.

Matti Toivonen, PhD (physics), Radiation Metrology Laboratory, senior scientist, (retired in 2003).
Metrology, dosimetric methods: TLD, BNCT dosimetry, patient dose assessment, optimisation studies on x-ray examinations, research and development of x-ray dosimetry and quality assurance.

Ritva Parkkinen, Lic.Phil. (physics) medical physicist, Radiation in Health Care, head of section.
Regulatory activities, management, quality management, research and development in medical use of radiation, radiotherapy dosimetry.

Juhani Karppinen, MSc (physics), Radiation in Health Care, senior inspector.
Regulatory activities in diagnostics, inspections of radiological units in hospitals, patient dose measurements, research and development in x-ray dosimetry and radiation safety in diagnostics.

Petri Sipilä, MSc (physics), Radiation in Health Care, senior inspector.
Regulatory activities in radiotherapy, inspections of radiotherapy units at hospitals, research and development in radiotherapy dosimetry and radiation safety, standardisation.

Helinä Korpela Lic.Phil. (chemistry), Radiation in Health Care, senior inspector.
Regulatory activities in nuclear medicine, quality assurance, inspections of nuclear medicine units at hospitals, research and development in dosimetry and in radiation safety, patient dose evaluation.

Markku Pirinen MSc (physics), Radiation in Health Care, senior inspector.
Regulatory activities in x-ray diagnostics, quality assurance, inspections of diagnostic units at hospitals, research and development in x-ray dosimetry and radiation safety in diagnostics

Asko Miettinen Engineer, Radiation in Health Care, inspector.
Regulatory activities in x-ray diagnostics, quality assurance, inspections of diagnostic units at hospitals, research and development in x-ray dosimetry and radiation safety in diagnostics.

Timo Kiljunen MSc (physics), Radiation in Health Care, inspector.
Regulatory activities in radiotherapy and x-ray diagnostics, quality assurance, inspections of radiotherapy units and x-ray diagnostic units at hospitals, research and development in x-ray dosimetry and in radiation safety in diagnostics.

Hannu Järvinen, MSc (eng.), Management Support, principal adviser.
International co-operation, regulatory activities, research and development in medical use of radiation and in metrology.

Eija Vartiainen, MSc (physics), Regulatory Control Development and Support, development manager, head of the unit.
Personal dosimetry, quality management, quality assurance, radiation protection education.

Antti Servomaa, Docent, PhD (physics), Regulatory Control Development and Support, research professor, retired in 2004.
Patient dose and radiation risk in radiology, quality assurance, optimisation, education and training.

2.9.4 Aims of research

The aim of research in medical use of radiation is to enable and ensure the justified and optimized use of radiation in Finland. In addition to the more general goal of improvement of knowledge and expertise, research is focused on tasks to support regulatory activities. Specific aims are:

- optimal x-ray examination techniques, taking account of image quality and patient dose
- reliable calibration and measurement methods for radiation dosimetry,
- reliable assessment of patient doses and radiation risk
- reliable evaluation of performance and quality assurance required for technologies and examination/treatment methods that are used in diagnostic radiology, nuclear medicine and radiotherapy
- reliable follow-up of radiation exposures of patients in diagnostic radiology, nuclear medicine and radiotherapy and
- reliable verification of dose planning and dose delivery in radiotherapy.

The aim of research in radiation metrology is to confirm internationally comparable maintenance of national standards for dosimetry. The research on metrology is focused on development of optimum calibration techniques for dosemeters and reliable methods for applied dosimetry.

The aim of research and development in individual dose monitoring is to get reliable and precise information on the doses of highly exposed personnel or from exposure in complicated radiation conditions. The actions are focused in the harmonisation of individual dose monitoring in Europe and verification of the quality of the dosimetric services.

2.9.5 Main results over the last five years

Medical use of radiation

<u>Measurement of image quality in fluoroscopy</u>

Image quality is the fundamental factor of limiting patient dose reduction in diagnostic radiology. Therefore, in order to be able to work at as low doses as possible, it is desirable to have suitable and reliable methods for assessing image quality. The present consensus of objective methods for the measurement of image quality relies on the statistical decision theory (SDT, see for example ICRU Report 54) – visual assessment methods have been shown to be inaccurate and subjective. The SDT approach has been extensively studied and used for static radiography.

We have earlier (Phys.Med.Biol. 38, 71–92 and 1761–1788 (1993), Med. Phys. 24, 655–664, (1997)) developed SDT concepts that can be used for assessing dynamic imaging. In the reporting period, we have published a computer program (FluoroQuality) that measures and analyses the image quality of dynamic medical image sequences using the SDT framework. The present version of the program is written for measuring the image quality in medical fluoroscopic x-ray systems, but the method is easily extendable for digital cine imaging as well. The method should be useful for several purposes, such as specifying the image quality in fluoroscopic images, for optimising the image quality and dose rate in fluoroscopy, and for quality control of fluoroscopic equipment.

The measurement method of FluoroQuality is based on phantom imaging. The measurement considers the detectability of an arbitrary detail object, which can be added to and removed from a phantom. The object to be detected can be for example a disk detail or a piece of a catheter – or whatever object that is considered of being relevant in the imaging task of interest – and the phantom can be either uniform or structured. The imaging task needs not be restricted just to the detectability of the detail, but the task can as well be, for example, to decide which of two details is actually in the image or to decide in which of two possible positions the detail is located. By choosing the task, one will then automatically weigh the importance of the different image quality parameters according to what is important in the clinical task that is being simulated. The measurement is accurate and can be made for both weak and strong details. This is in contrast to visual assessment methods, which suffer from high variability of results and are limited to details that are at the visual threshold.

The measurement system analyses the quality of fluoroscopic images by the accumulation rate of the square of the ideal observer's signal-to-noise ratio (SNR2rate), the SDT-concept applicable to dynamic imaging. The system produces also other quality-related measures of the images: e.g., the SNRideal of single image frames, the spatio-temporal noise power spectrum, NPS(fx, fy, ft), and a measure for the temporal lag.

The program has been published along with a report, which reviews the theory behind the measurement method and explains the measurement of the various quantities in detail (Tapiovaara 2003). An example of using the method for optimising a specified fluoroscopic procedure is also given.

The relationship between measured and visual image quality in fluoroscopy

Acceptance and constancy testing – and image quality evaluation in general – frequently include the assessment of the threshold contrast (or contrast-detail performance). Although these measurements may seem simple, they suffer from several difficulties, e.g. the large inter- and intra-observer variability which prevents reliable detection of moderate faults or slow deteriorating of the imaging system. The physical measurement of SNR2rate is precise and able to reveal even small differences in image quality.

Establishing links between physics-based and subjective measurements of image quality was one of the objectives of the DIMOND III project. The relevance of SNRideal for static radiography has already been documented in the literature. In the project we focused on clarifying the relationship between SNR2rate and human visual performance. Knowing this relationship is necessary for using SNR2rate-measurement as a tool for optimising the dose rate and image quality of fluoroscopic examinations, but useful also if the physical measurement system is to be used as a quality control tool. The results of this study have been reported by Tapiovaara and Sandborg (2004).

A threshold contrast test phantom (resembling the Leeds N3 phantom) was constructed by using 1 cm diameter PMMA disks of various thicknesses as test details. The average response of the observers, the inter- and intra-observer variability and the sensitivity of detecting imaging technique changes in the threshold contrast test was evaluated for 24 observers and 7 observing sessions. The results showed a total (inter- and intra-observer) variability of 23% and a reduced sensitivity to notice changes when the imaging parameters were varied. From these results it was concluded that imag-ing system changes corresponding to a dose rate change (or another imaging parameter, expressed in terms of an equivalent dose rate) by a factor smaller than 3 cannot be reliably detected by the visual contrast threshold test performed by one observer. If the observer is different in subsequent tests, per-formance is notably worse. The performance can be improved by employing a large number of observers, but then the practicality of the test is compro-mised.

In addition to the purely subjective contrast threshold tests, some of the ob-servers participated also 16-AFC tests and 2-AFC tests, where the correctness of the observers' response is controlled. These results suggest that the observers in the threshold test make very conservative estimates of detail detectability: actually, the observers detect much lower-contrast objects than they tend to report in the threshold test.

The relationship between the various observer tests and the physical SNR2rate measurements was studied. It was found that human performance can be related to SNR2rate by introducing the concept of the effective image information integration time (teff). When measured for an unlimited observation time, it depicts the saturation of human performance in detecting a static low-contrast detail in dynamic noise. Depending on the detectability test, teff values ranging from 0.3 – 0.6 s were found. The human observer's detectability index can then be obtained as $d' \approx \sqrt{(teff \cdot SNR2rate)}$. In our tests, the average subjective impression of visibility corresponded to SNR2rate values between 60 and 140, or to d' values of the order 4 – 9, as estimated by the relationship above. This is in good agreement with the common rule of thumb in static imaging saying that an SNR of the order of 5 (or 3 – 10) is required to judge the detail to be visible.

<u>Surveys for frequency of x-ray examinations and for patient doses</u>
The Medical Exposure Directive (MED 97/43/Euratom) and its implementation in national legislation (the Decree of the Ministry of Health and Social Affairs on the Medical Use of Radiation, 423/2000) calls for users of radiation to monitor the doses to patients in x-ray diagnostic and nuclear medicine examinations. Further, a summary of the total number of different examinations and the doses to patients shall be reported to STUK according to a special guidance given by STUK. The aim of this study is to develop a national patient dose register and appropriate methods for a systematic collection of data in this register. The data will be used for setting or updating diagnostic reference levels, for estimating examination-specific effective doses and collective doses, and for issuing statistical data to international databases (e.g. UNSCEAR).

The first step of the project, a survey of the number of x-ray examinations was carried out in 2000 (Hakanen et al. 2003). Surveys of the administered activity of a radiopharmaceutical in nuclear medicine examinations in 2000 and 2003 have also been carried out (Kairemo and Korpela 2001, Korpela 2002 and 2005). The second step of the project was the preparation and publication of guidance to the medical users of radiation on the methods of patient dose determination. This guidance was published as a STUK information series report 1/2004. The third step, a pilot study on patient dose collection from x-ray diagnostic facilities, is in progress.

Specific studies on patient doses in radiology have been carried out by Grøn et al. (2000) and Servomaa (2001). Reviews and proposals for patient dose measurement protocols in interventional radiology have been made by Toivonen (2001).

<u>Reference dose levels for radiological examinations</u>
The Medical Exposure Directive and its implementation in national legislation require national diagnostic reference dose levels to be established for medical exposures. Within the DIMOND III project the establishment of the reference

dose levels was one of the main objectives (Vano et al. 2001). An extensive survey of patient doses in cardiology was carried out in 2003 (Neofotistou et al. 2003). Based on this study and some other studies diagnostic reference dose levels for most the frequent cardiology examinations have been proposed and forwarded to Finnish cardiologists for consideration. The diagnostic reference levels for these examinations will be set shortly, and will be based on a consensus obtained with cardiologists.

For paediatric examinations specific studies on patient doses have been carried out (Servomaa et al. 2000 and 2003, Parviainen et al. 2003 and Kiljunen 2004).

Optimisation of the use of CT equipment

The number of CT examinations has been increasing with the rapid development of the technology. While the relative number of CT examinations is still only about 5% of all x-ray examinations, the collective patient dose from CT examinations represents about 40% from the collective dose from all x-ray examinations. It is highly important, therefore, that the CT examinations are well justified and the scanning programme and parameters are optimised for a given task and patient. We aim to survey the application of the optimisation principle in the use of CT equipment in Finland and to develop a plan to improve the optimisation of the current practices.

As a first step towards the optimisation of the use of CT equipment the proper use and definitions of dosimetric quantities for computed tomography (CT) was studied (Karppinen et al. 2003). There is some confusion on the use and definitions of dosimetric quantities for CT, which is mainly caused by the technical development in CT scanners. We have proposed the weighted dose length product (DLPw) and the multiple scan average dose (MSADw) to be used as basic dosimetric quantities and the national guidance for CT dosimetry is based on the use these quantities.

Investigation of mammography imaging techniques

Patient doses, image quality and some technical parameters of mammography x-ray equipment in Finland were studied in 2000–2002 (Miettinen and Pirinen 2003). The study was conducted to review the overall condition of mammography equipment and image quality in actual mammography practice in Finland. The purpose was to find out the weak points in the mammography practices in order to suggest improvements in the practices and their quality control procedures. The entrance surface dose distribution obtained was fairly consistent with the current diagnostic reference level and suggests that the current level is reasonable. The results for the testing of image quality indicated that the major reasons for a sub-optimal image quality are related to shortcomings in the film processing (53% of all cases) and in the adjustments of the automatic exposure control systems. Relatively simple improvements in the techniques and maintenance procedures together with further training of the users are needed to overcome these problems. A system of regularly monitoring patient dose and image quality is proposed, in order to ensure continuous achieving of high quality mammography examinations.

<u>Dosimetry of boron neutron capture therapy</u>
Techniques for the dosimetry of epithermal neutron beams used in boron neutron capture therapy (BNCT) were developed in the EU shared cost research project. This project was started in the fourth framework programme; it was completed in 2003 and lead to published European recommendations for BNCT dosimetry (Voorbraak and Järvinen 2003). Several studies on the dosimetry of epithermal neutron beams of BNCT, linked to the European recommendations and to the national project for BNCT treatments, were published in 2000–2004.

<u>Computer programs for radiation protection in radiology</u>
STUK has produced a number of computer programs for helping in radiation protection problems; some of these programs are intended solely for STUK's own use, while others are also being offered for other users. These programs include:

1. PCXMC (which calculates the organ doses and effective dose in x-ray examinations)
2. ESD calculation (for calculating and analysing entrance surface doses in x-ray examinations)
3. FluoroQuality (for measuring the image quality in fluoroscopy. For a more specific description, see earlier text).

Other programs, related to calculating the required shielding in x-ray rooms, for estimating the radiation risk based on the organ doses, age and gender, and software for measuring, correcting and analysing measured x-ray spectra and generating computational spectra are being currently updated from their older versions.

PCXMC
In medical radiology, the air kerma at the patient entrance surface (ESD) and the kerma-area product (DAP) 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.

In 1997 we published a PC program (PCXMC) that is capable of providing such data, calculated by the Monte Carlo method and utilizing the mathematical phantoms of Cristy (1980). Since then the program has been developed further: the calculation speed has been increased, the user interface has been modified and the few errors that have been found in the program have been corrected. The program has been further modified so, that doses can be estimated also solely by the information of the x-ray examination technique factors, without the necessity of measuring the ESD or DAP.

The program is used in STUK for our own research work, for estimating the effective doses related to actual patient dose measurements and for estimating foetal doses of pregnant patients. Program licences are also sold to other interested parties. So far, more than 150 programs have been sold, more than 90% of them abroad. The program has been widely used in scientific work: there are more than 40 citations to the program in the scientific literature. The Internet pages describing the program are available at the address www.stuk.fi/sateilyn_kayttajille/ohjelmat/PCXMC/fi_FI/pcxmc/. These pages are being continuously maintained and improved.

ESD calculation

ESD calculation is a program that STUK published in 2003 to help Finnish x-ray departments to determine their patient doses in terms of the ESD. The program requires the user to input patient exposure factors (x-ray tube voltage, filtration, tube current-time product, FSD) and calculates the ESD, based on measured x-ray tube radiation yield values. Such a calculation is easily done by using a simple spread sheet program, but our program can be also used to extrapolate and interpolate to x-ray tube voltage values where measured data may not be available, and it helps the user analyse the results. The Internet pages describing the program are available at the address www.stuk.fi/sateilyn_kayttajille/ohjelmat/ESD/fi_FI/esd/. So far, 10–20 programs have been supplied for Finnish hospitals.

Dosimetric techniques and radiation metrology

<u>Dosimetry of radiotherapy in external high-energy photon and electron beams</u>

National guidance for dosimetry of external high-energy photon and electron beam radiotherapy was published (Kosunen et al. 2005, Kosunen et al. 2003, Parkkinen et al. 2003). This guidance was aimed to maintain the achieved good level of consistency of dosimetry in external beam radiotherapy when the ‘absorbed dose to water’-based approach of IAEA TRS 398 was taken into use in Finland. The report (Kosunen et al. 2005) considers also the technical data for the dosemeters used in Finland as well as a step-by-step description of the actual dose measurement procedure. To confirm the reliability of the calibration/measurement chain from the calibration laboratory to the user, the dosimetric methods and the calibration procedures used by the Radiation Metrology Laboratory were harmonized.

Calibration and measurement techniques for dose-area product meters

The dose-area product (DAP) is generally measured to evaluate radiation exposure to patient in diagnostic x-ray examinations. To meet reasonable accuracy requirements on patient dose assessment, appropriate calibration methods for DAP meters are needed. For this purpose, technical and dosimetric properties of DAP meters were studied, and a practical method of calibrating field DAP meters with a reference DAP meter was developed. In this method the reference DAP meter is calibrated comprehensively, using several radiation qualities in a calibration laboratory. The field DAP meters are calibrated in their normal clinical environment, using one or more radiation qualities which are typical in the clinical practice. Because the response of a typical DAP meter depends significantly on the energy distribution of the x-ray beam, a single-valued calibration factor may not be adequate for the accuracy expectations in most cases. Guidance for users on calibration of the field instruments is under preparation, and Nordic recommendations have been planned in the Nordic group for dosimetry. A comparison of the calibration of (reference) DAP meters was organized in 2004 between the Nordic national calibra-tion laboratories.

Dose evaluation in interventional radiology

Related to the DIMOND III project a review and study on dosimetric techniques in interventional radiology were made (Toivonen 2001a and 2001b, Quai et al. 2002).

Beta-ray dosimetry for brachytherapy

We have participated in a study of calculation methods for radiotherapy ophthalmic beta ray applicators (Cross et al. 2003), where the experimental dosimetry methods were studied at STUK (Soares et al. 2001). Also the calibration methods of scintillation detectors for ophthalmic 90Sr beta-ray radiotherapy applicators were studied (Hakanen et al. 2004).

Effect of radiation qualities for accuracy in dosimetry of mammography
The effect of different x-ray qualities on the calibration of mammographic dosemeters was investigated within the framework of a EUROMET project (Witzani et al. 2004). The calibration coefficients of two ionisation chambers and two semiconductor detectors were established in 13 dosimetry calibration laboratories for radiation qualities that are used in mammography. They were compared with calibration coefficients for other radiation qualities, including those defined in ISO 4037-1 with first half value layers in the mammographic range. The results show that the choice of the radiation quality used in the calibration is not crucial for instruments with a small energy dependence of the response (ionisation chambers). However, the radiation quality has to be chosen carefully, if instruments with a notable energy-dependence are calibrated (e.g., semiconductor-based instruments).

Individual dose monitoring
Radiation doses to the staff in interventional radiology
The radiation doses to the radiological staff, and the characteristics of thermoluminescent dosemeters and diodes for occupational dose measurements were studied in the DIMOND III project (Parviainen et. al 2003b, Toivonen et al. 2003). The results show a clear correlation between the patient dose and the personal dose of the cardiologist performing the examination or interventional procedure. For the hands of the cardiologists, the measured doses of varied considerably. Staff doses measured with TL and diode dosemeters were compared in eight different procedures. The results agreed within 35% in six cases while differing by about 50% in two cases. A more comprehensive study on the characteristics of dosemeters and examination specific staff doses is in progress. A summary of the results in several European countries was prepared within the DIMOND III project (Tsapaki et al. 2004). Staff doses in interventional radiology have also been studied by Servomaa and Karppinen (2001).

Harmonisation and quality assurance in individual dose monitoring
EURADOS started in 1997 a working group called "Harmonisation and dosimetric quality assurance in individual monitoring for external radiation". The project consisted of reviewing national regulations standards and recommendations and aimed to promote harmonisation in the field by making the information and the results available in the open literature and at a workshop. Our work was summarised by Hyvönen and Vartiainen (2001), Kiuru et al. (2001) and Servomaa and Karppinen (2001).

Another EURADOS working group "Harmonisation of individual monitoring in Europe and information on new techniques in this field" was a continuation of the previous working group. The network was extended to the new Member States of the European Union.

The working group was divided into four subgroups dealing with: (1) implementation of standards by dosimetric services; (2) harmonisation policies for the integration of dosimetry for internal and external occupational exposure; (3) electronic dosemeters for individual monitoring and other new developments; and (4) quality assurance, quality control and reliability of dosimetric systems. STUK contributed mainly to the work on the implementation of standards by dosimetric services. The first subgroup's main task was to make a comprehensive report on the international and national standards and other documents relevant for individual monitoring, especially in monitoring external radiation. (Fantuzzi et al. 2004, Lopez et al. 2004).

2.9.6 Research plans for the next five years

Medical use of radiation

In 2005–2007 the department is participating in the EU Coordination Actions project Safety and efficacy for new techniques and imaging using new equipment to support European legislation (SENTINEL). This project is aimed to establish safety and efficacy for new radiological imaging techniques, with particular emphasis on frequent examinations, high-dose procedures and sensitive groups.

The follow-up methods of x-ray examination frequencies and patient doses will be developed to a reliable and well repeatable procedure. A pilot study has been started in 2004 and a detailed plan will be made, based on findings in this study.

The project surveying the use of CT equipment will be completed. The detailed objectives of the project are to update and/or set diagnostic reference levels for CT examinations (in particular for children), to give recommendations on how to optimise CT examinations, to update STUK's CT inspection methods and to update STUK's recommendations for the quality control of CT equipment. The project comprises hospital visits, with measurements for the most common CT examinations (head, chest: general, mediastinal vessels and HRCT, liver and spleen, abdomen: general, osseous pelvis and lumbar spine). The project intends to evaluate patient doses (DLPw and MSADw), technical image quality (uniformity, noise, high and low contrast resolution) and clinical image quality, for a few units of each type of equipment that is used in Finland. The clinical image quality will be assessed from patient images by a group of radiologists using the published EC quality criteria. The local scan protocols and quality control programmes will also be analysed and compared.

Reference dose levels for paediatric examinations will be set. The survey and study of patient doses in paediatric examinations has been made in 2004–2005. The results of this study will be analysed and published. For paediatric examinations in computed tomography a Nordic cooperative project will be performed.

Occupational staff doses in interventional radiology will be studied further aiming for examination-specific results on staff doses and improved accuracy in dosimetry by usage of electronic dosemeters. A survey of the staff doses will be made within the SENTINEL project.

The pilot study on the technical quality control requirements for digital imaging will be completed. This study was started as a Master's thesis work in 2004 and a detailed work plan will be made based on the findings in this study. Investigations of mammographic imaging techniques will be continued to cover the technical performance requirements for digital systems.

The project considering measurement methods and surveying of patient doses in dual-energy x-ray bone mineral density measurements will be completed. A Master's thesis on the subject is to be published in 2005.

Presently, the ICRP is planning to modify the definition and the organ weighting factors of the effective dose. When published, these changes will be taken into account in the PCXMC program, and a new version of the program will be released.

Development of methods for routine verification of the accuracy of dose planning for brachytherapy has been carried out. Results are to be published in 2005

A study on the optimization of frequency of radiotherapy linac beam output measurements relative to the acceptable radiobiological risk of the patient has been started in 2004 and the results are to be published in 2005. The study is carried out in co-operation with the Helsinki university hospital.

Dosimetry techniques and radiation metrology

The ability to use Monte Carlo based dosimetric methods will be improved. The aim is to complement dose measurements by Monte Carlo techniques in studies of applied and standard dosimetry.

Calibration procedures for dose-area product meters and dose-length product meters will be developed and set in practice. Nordic Recommendations for calibrating DAP meters have been planned to be prepared in the Nordic group for dosimetry.

Individual dose monitoring
STUK will participate the research work on individual dose monitoring within the EURADOS collaboration. The suggested topics of work are: revision of EUR 14852 (Technical recommendations for monitoring individuals occupationally exposed to external radiation), procedures and criteria for approval of individual monitoring service aiming at a desirable mutual recognition of results, database of dosimetric services, harmonisation in extremity dosimetry, organization of intercomparison exercises and performance characteristics testing.

STUK will also participate in the ESOREX 2005 project. The main goals of this project will be to finalise the updating of the country reports by describing the current situation on the field of occupational exposure control, evaluation and registration of personal doses of radiation workers, and to collect dosimetric data for the period of the years 2001–2005.

2.9.7 List of publications

Annala H. Level of quality assurance quidance for image workstations in radiological imaging units. Master thesis, University of Oulu, Faculty of Medicine, Nursing Sciences and Health Administration, 2004. Supervised at STUK by Servomaa A.

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2.10 Non-Ionizing Radiation

2.10.1 Key words and specific technologies

Key words

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

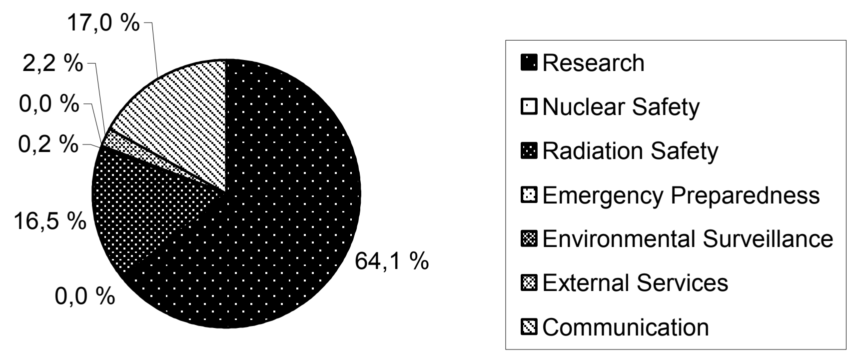
Power lines, magnetic resonance imaging (MRI) devices, electronic article surveillance devices (EAS), metal detectors, radio-frequency identification devices (RFID), high-frequency heaters, broadcasting stations, mobile phones, base stations, microwave dryers, radars, lasers, sunlamps and sunbeds, UV-phototherapy,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

Specific technologies

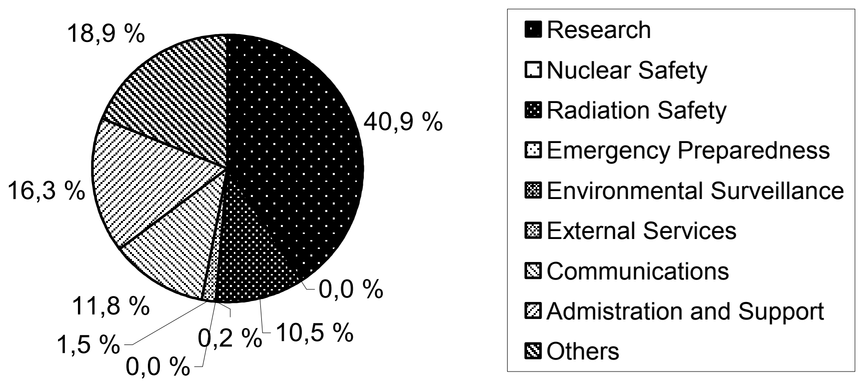
EM field measurement techniques, exposure measurements, metrology, calibration, primary and secondary standards, traceability, Helmholtz-coil, TEM transmission cell, waveguide chamber, anechoic chamber, calibrated antenna, automated SAR meaurement system, calorimetry, in Vitro exposure chamber, *in Vivo* exposure chamber, quartz-halogen lamp, detector-based calibration, filter radiometer, portable calibrator, radiometry, UVR dosimetry, broadband UV-radiometers, spectroradiometers, solar UVR measurements, weighted magnetic field measurement, numerical EM field dosimetry, experimental RF-dosimetry.

2.10.2 Description of laboratory activities

Total costs 833 k€ distributed by sectors in 2004



Effective working time by sectors in 2004
Total person-years 10.0



Mission and general functions

- carries out regulatory functions on the basis of the radiation protection legislation
- carries out research and technical development work to serve the needs of the 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 and communications),
3. field surveillance (solaria, laser shows, base stations, indoor distribution trans-formers, etc.)
4. market surveillance (mobile phones, EAS devices etc.).

Typical expert services include

1. calibration of EM field meters and SAR probes
2. calibration of solar UVR monitors
3. calibration of UV-irradiance meters for UV phototherapy
4. assessment of EM field safety in occupational environment (high frequency heaters, broadcasting stations, radar stations, arc-furnaces, induction heaters, etc.)
5. UV dose assessment of phototherapy devices

The reculatory functions and expert services are not considered in more details in this report, where the main focus is on the research and related activities. The staff of the laboratory has also been engaged in the preparation of the series of radiation protection books published by STUK. The book for electromagnetic fields will be published in 2005 and the book for UV and laser radiation in 2006 or 2007. This work has been a considerable load for the relatively small laboratory.

Summary of research activities

The laboratory started the NIR research in the beginning of 80s. The research was initially financed fully by STUK, but around the beginning of 80s and 90s external funding and strict project working became increasingly important. The other laboratories of STUK have since followed the same course. During the period 2000–2005 the main funding organizations were the EU, ESA/ESTEC, National Technology Agency (two parallel research programs) and National Agency of Medicines. In 2000–2005, the support received by the laboratory from external funding organizations continued to increase. A short summary of main research projects in the period of 2000–2005 will be presented next. A more detailed description on the main results can be found in the chapter section 5.

The development of reliable calibration to assure good quality of NIR measurements in exposure assessment and biological research is one of the most important research areas of the laboratory. In the EM field ranges, the cali-bration of electric fields was extended to frequencies of 900 MHz and 1800 MHz, the most important frequency ranges for mobile communications. A portable calibrator was developed to transfer the calibration of SAR probes from the primary standard of STUK to another SAR laboratory.

NIR laboratory carries out regular market surveillance SAR tests of mobile phones marketed in Finland. As far as we know, STUK is the only regulatory authority carrying out such a test. Each year ca. 20 commonly used models will be tested. The high quality of the tests is assured by comparing results obtained for a test specimen circulating then through other high quality test laboratories. Calibration comparison of SAR probes showed that the calibration scale of the market leader of the probes is within specified uncertainties.

The NIR laboratory has participated in all four national research programmes for mobile phone safety (the first started in 1994). Exposure facilities operating at 900 MHz frequency and associated dosimetry were developed for the Radiation Biology laboratory of STUK, University of Kuopio and Tampere University of Technology. During the last five years the new advances were the design and construction of radial waveguide system for the exposure of free moving rats and the development of exposing anesthesized pigs to high level local (10–50 W/kg) SAR in the head. Experimental dosimetry of two in Vitro chambers designed before 2000 was validated and extended with Finite Difference Time Domain model calculations.

Radiation hazard assessment methods for satellite communications terminals was studied by carrying out SAR and power density measurements around the frequncy of 10 GHz. The results showed that the maximum frequency for SAR tests is 6 GHz instead of 10 GHz that was recommended by ICNIRP in 1998 guidelines.

Improvements of exposure measurement technology is needed particularly in the low-frequency range where a new broadband magnetic field meter based on the weighted peak exposure scheme was designed. This study is a technical extension of the laboratory’s earlier study which resulted in the formulation of the weighted peak exposure restriction principle adopted by ICNIRP (International Commission on Non-Ionizing Radiation) for the limitation of pulsed and broadband magnetic field exposures. The head of the laboratory, Dr. Kari Jokela, participated in the preparation of this guidance statement as a member of ICNIRP standing committee 3.

Numerical dosimetry is needed for the realistic assessment of distribution of EM fields in tissue and cell cultures. A new numerical method was developed for the application of FIT (Finite Integration Technique) to the quasistatic frequency range below 100 kHz. This technique was used for the calculation of broadband current density induced by the pulsed battery current of GSM mobile phones. The exposure analysis was based on the comparison of the current density with the present exposure limits by applying the new weighted peak method and the more traditional spectral method (multi-frequency rule of ICNIRP).

In the optical range the objective of metrological research is to reduce the un-certainty in solar UV measurements and provide convenient methods for the measurement of UV appliances in the field.

A high precision portable field calibrator was developed for the calibration of solar UV-spectroradiometers. The instrument is based on the detector moni-toring and enables a very short calibration chain to a detector-based primary standard. A new unexpected error source was observed in solar spectral measurements. The transmittance of the most commonly used input element (Teflon diffuser) changes abruptly the amount of 3% at the temperature of 19°C, which significantly increases theuncertainty of the most precise solar UV measurements (ca. ± 5%).

In the field measurements of UV appliances small diode array (CCD) spectro-radiometers are more convenient than bulky and sensitive scanning spectro-radiometers. A complicated error correction procedure was developed for a commercial CCD spectroradiometer. The accuracy level achieved was sufficiently low to enable spectral measurements of solaria on-site. Additionally, the emission characteristics of lamps used in the UV phototherapy and solarium appliances were measured in the same project. The main objective of the measurements was to provide good information for the replacement of lamps and ensure that the lamps used for cosmetic purposes are not too powerful.

Training and communication

- An annual undergraduate course held by Kari Jokela in Helsinki University of Technology, on biological effects and measurements of electromagnetic fields and optical radiation.
- Numerous other lectures by the staff of NIR-laboratory in various training courses and seminars.
- Articles in magazines including medical and scientific societies and ALARA, the magazine of STUK. Numerous interviews in massmedia on radiation from wireless communication systems and other sources of NIR.

2.10.3 Personnel

Kari Jokela, Dr. Tech., research professor (head of the laboratory)

Lauri Puranen, Lic.Tech., project manager (assistant head of laboratory)
EM studies

Tim Toivo, M.Sc. (Tech.), research engineer, rost graduate student
EM studies

Ari-Pekka Sihvonen, B.Sc., assistant researcher
EM studies, numerical dosimetry

Tommi Toivonen, M.Sc. (Tech.), research engineer, post graduate student
EM studies

Heidi Nyberg, Lic.Tech. research engineer
General NIR safety, editor

Reijo Visuri, M.Sc., physicist
Optical radiation safety

Lasse Ylianttila, M.Sc. (Tech.), scientist
Optical radiometry

Riikka Pastila, M.Sc. (Biochemistry), post graduate student,
UV Biologist, optical radiation safety, public information

Sami Kännälä, B.Sc., graduate student

Hilkka Karvinen, publications editor
Public information, administration

2.10.4 Aims of research

- To study exposure to NIR and compare them with exposure standards and current knowledge on thresholds of biological effects
- To examine 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-characterized exposure systems for biological research
- To study biophysical interaction mechanisms of NIR
- To obtain quantitative and reliable data for the dissemination of public information

2.10.5 Progress report on research over the last five years

Numerical EM-field dosimetry

Battery currents of GSM mobile phones were measured and extremely low-frequency (ELF) current densities induced in the head of the phone user were calculated in a national project funded by the National Technological Agency of Finland (TEKES). Calculations with simplified models of the head and battery circuit of the phone gave an exposure index which was not far from the exposure limit. The main results were reported in a paper published in Health Physics (Jokela et al. 2004). The study was continued with development of a realistic numerical model of a head and a calculation method based on the finite integration technique (FIT). Induced current densities were calculated by using the measured ELF magnetic field of the phone as a source data. Calculated results were in excellent agreement of the results calculated by the Electromagnetics Laboratory of the Helsinki University of Technology that used a different method (finite element method FEM). Both calculation methods and calculation results were reported in two papers which were submitted for publication in Bioelectromagnetics (Sihvonen 2005; Ilvonen et al. 2005). The numerical models and calculations were extended for the whole body and current densities induced by several different GSM phone models will be calculated in different parts of the human body. The study will end during 2005. The main results concerning the whole body will be reported in a paper to be submitted for publication in Bioelectromagnetics.

<u>Safety assessment of multimedia satellite terminals</u>

Radiation safety aspects of multimedia communications terminals operating via a satellite link were studied in a project funded by the research centre of the European Space Agency (ESA/ESTEC). The study consisted of a critical literature survey, SAR and power density measurements around the frequency of 10 GHz. The literature survey dealt with the international exposure standards and biological effects of radio-frequency radiation in the frequency range of 300

MHz – 300 GHz. The SAR and power density measurements were carried out for the validation of the numerical methods to be used for the exposure assessment of multimedia terminals. In addition, these measure-ments were performed in order to evaluate the relevant transition frequency from the SAR to power density as an basic exposure quantity. The measurement results revealed that the relevant transition frequency may be 6 GHz instead of 10 GHz determined by the International Commission of Non-Ionizing Radiation Protection (ICNIRP). The essential results obtained from the literature survey and the measurements were presented in the technical reports delivered to ESTEC.

Exposure systems and dosimetry for biological studies of radiation from mobile phones

An exposure system was developed for rats to be used by the University of Kuopio in a cocarcinogenesis study belonging to the fifth framework program of the European Union. Female Wistar rats were exposed to GSM phone radiation (pulse duration 0.577 ms and pulse period 4.615 ms, resulting in pulse frequency of 217 Hz) at 900 MHz for two hours a day, five days per week for a life time or a period of two years. The total number of RF-exposed rats was 216 which was divided in three groups of 72 rats. The first group was sham-exposed (Specific Absorption Rate, SAR, averaged over the whole body and the pulse period of GSM signal, was 0 W/kg), the second group was exposed to 0.3 W/kg (low exposure) and the third group to 0.9 W/kg (high exposure), respectively. The system enabled to place 216 rats in separate cages in nine different exposure chambers on three racks requiring only 9 m^2 of floor area. Exposure chambers were radial transmission lines which consisted of two parallel circular aluminium plates short-circuited at the edges. The diameter of the plates was about 150 cm and the separation distance 15 cm. Absorbing material was attached to the edges inside the chambers to remove the reflections from the edges. A plane-wave-kind electromagnetic field (vertical electric (E) field perpendicular to the plates and azimuth magnetic field parallel to the plates) was generated in the chambers by a monopole antenna mounted in the centre of the chambers. Rats could freely move in their cages where food and drinking water was provided ad libitum except during the RF exposure periods. This exposure arrangement eliminated the stress of the rats caused by the rest-raining and reduced the daily handling work with the rats.

SAR determination was based on analytical calculations with homogeneous prolate spheroidal models of rats, calorimetrical measurements and FDTD calculations with homogeneous cylindrical rat phantoms. The development and RF dosimetry of the exposure system will be reported in a scientific paper which is under preparation.

RF dosimetry

Battery currents of GSM mobile phones were measured and extremely low-frequency (ELF) current densities induced in the head of the phone user were calculated in the national projects (NAMS and AMEST) funded by the National Technology Agency. The calculations with the simplified models of the head and battery circuit of the phone gave an exposure index which was not far from the exposure limit. The main results were reported in a paper published in Health Physics (Jokela et al. 2004). The study was continued with development of a realistic numerical model of a head and a calculation method based on the Finite Integration Technique. Induced current densities were calculated by using the measured ELF magnetic field of the phone as a source data. Calculated results were in excellent agreement with the results calcu-lated by the Electromagnetics Laboratory of the Helsinki University of Technology (TKK) that used a different method (finite element method FEM). Both calculation methods and calculation results were reported in two papers which were submitted for publication in Bioelectromagnetics. The numerical models and calculations were extended for the whole body and current densities induced by several different GSM phone models will be calculated in different parts of the human body. The study will end during 2005. The main results concerning the whole body will be reported in a paper to be submitted for publication in Bioelectromagnetics.

A portable calibrator was developed to transfer the calibration of SAR probes at the frequencies of 900 MHz and 1800 MHz in a national project (AMEST) funded by the National Technology Agency. The calibrator enables the transfer of the SAR probe calibration from the primary standard of STUK to another SAR laboratory. The calibrator consists of an air-filled double-ridge lower section and a liquid-filled rectangular upper section with a liquid-tight thin PVC slab separating the sections. The portable calibrator increased the uncertainty of the SAR probe calibration by only one percentage unit with respect to the primary standard. The development of the portable calibrator was reported in the technical reports and in a manuscript to be submitted for publication in the IEEE Transactions on Electromagnetic Compatibility.

The feasibility of SAR measurements in the frequency range of 3 GHz–6 GHz was studied in a national project (AMEST) funded by the National Technology Agency. Exposure assessment is necessary for new emerging low-power devices mounted near the body in order to test their compliance with the exposure standards. The feasibility study was based on the literature survey and on calculations and simulations with simplified models of body parts. The literature survey, calculations and simulations indicated that peak SARs depend very strongly on the thicknesses of different tissue layers. The feasibility study will end in 2005 and the main results will be included in a technical report.

RF metrology
The NIR laboratory participated the EUROMET project No. 446 where laboratories from eight European countries measured the magnetic flux density at frequencies up to 20 kHz in a field coil acting as a transfer standard. STUK's frequency range was 16.7–400 Hz. The comparison indicated good agreement in spite of a number of different measurement techniques and the variations were well within the measurement uncertainties given by each laboratory. The main results were reported in a scientific paper published in Metrologia (Weyand et al. 2001).

NIR laboratory participated the EUROMET project No.520 where laboratories from 13 countries calibrated a circulated electric field strength meter in the frequency range of 10 MHz–1 GHz by using their own standardized methods. STUK's frequency range was 10–300 MHz and 900 MHz. The comparison indicated good agreement in spite of a number of different measurement techniques and the variations were well within the measurement uncertainties given by each laboratory. The main results were reported in the final report of the project "GT-RF key comparison CCEM.RF-K20" which will be published as a scientific paper in Metrologia.

Calibration standards were developed for calibrating small electric field probes (such as SAR probes) in air in the frequency band of 750–1120 MHz and 1.7–2.6 GHz. The setups enable the calibration in an electric field parallel or perpendicular to the probe axis, thus all kinds of isotropic and non-isotropic probes can be calibrated. For the latter band, also a setup for transferring the calibration to free space for calibrating larger probes was developed.

Formerly developed setups for calibrating SAR probes in tissue simulating liquids at 900 and 1800 MHz were maintained. Improvements were made to increase the positioning accuracy of the probes and the reliability of the data acquisition system.

Good agreement was found in a calibration comparison organised by METAS (Metrologie und Akkreditierung Schweiz). Two SAR probes were calibrated by STUK and SPEAG (Schmid &Partner AG, Switzerland). The calibrations were performed for electric field in air at 30 MHz and 1800 MHz and for SAR in brain simulating liquid at 900 MHz and 1800 MHz.

Weighted peak magnetic field meter
On the basis of the studies, a study carried out by the NIR laboratory (Jokela 2000) and the International Commission on Non-Ionizing Radiation (ICNIRP) published in 2002 a guidance statement on determining compliance of exposure to pulsed and complex non-sinusoidal waveforms below the frequency of 100 kHz with the ICNIRP guidelines (Health Physics 2003; 84:383–387). The new

exposure assessment method, which is particularly useful for magnetic fields, is based on the weighting of the magnetic flux density with a simple high-pass filter simulating the frequency dependence of the reference limit for the magnetic field. The instantaneous peak value of the weighted exposure is limited below a peak value obtained directly from the ICNIRP guidelines. This method is biologically more realistic and technically more feasible than the spectral addition rule recommended previously. A new broadband and isotropic (30 to 100 kHz) magnetic field meter was developed for the measurement of the weighted peak magnetic field. In addition to this, the meter gives the relative increase of the exposure due to harmonic components. It should be noted that the magnetic fields from electrical appliances and distribution networks are contaminated by high-frequency harmonics, which commonly increase the effective exposure increases more than 50 per cent.

UV radiometry

A portable field calibrator for solar UV monitoring spectroradiometer was developed in co-operation with the Metrology Research Institute at Helsinki University of Technology (TKK) as a part of the EC project SMT4-CT98-2242 (Ylianttila et al. 2003, Kärhä et al 2003) The calibrator is based on a 1-kW DXW lamp mounted in an aluminum housing. The stability of the lamp's irradiance is monitored by two temperature-stabilized filter radiometers at wavelengths of 313 nm and 368 nm. The various field tests showed that the calibrator works satisfactorily under a wide variety of environmental conditions. The calibrator can be calibrated directly with the TKK's trap-based filter radiometers thus making the calibration as short as possible.

An unexpected change in the transmittance of PTFE diffusers at 19°C was found (Ylianttila and Schreder 2005). The measured changes have been between 1–3%, whereas the change is different for different diffusers. The transmittance change affects mostly outdoor solar UV radiation measurements.

The use of small diode array spectroradiometer in sunbed UV radiation measurements was evaluated. (Ylianttila et al. 2005). To make accurate measurements, a complicated error correction procedure is needed. The main points for accurate measurements are calibration, stray-light correction, radiation geometry correction (cosine-correction), wavelength accuracy and the temperature of the instrument. The achieved accuracy is sufficient, but for the proper use of the single monochromator diode array spectroradiometer a competent user is needed.

UV radiation exposure and risk studies
UV lamps marketed in Finland for cosmetic or medical purposes were measured and classified by the spectral irradiance. This facilitates comparison between original and replacement lamps used in sunbeds and phototherapy devices. A study was carried out where the use and quality assurance practices of UV phototherapy appliances were surveyed. In the final report, practical recommendations for the quality assurance of phototherapy units and UV irradiance measurements were given (Ylianttila et al., in press)

2.10.6 Research plans for the next five years

General research areas
Due to the advancement of radio communication technology and increased public concern, research on the RF safety testing and measurement methods as well as on the RF exposure of the general population must be continued.

Implementation of the new directive for EM fields increases needs to examine exposure conditions in the workplaces. Particularly problematic are high intensity low-frequency magnetic fields and intense near-fields generated by industrial high-frequency heaters. In these and other critical cases, where the action levels expressed in terms of external electric and magnetic fields are exceeded, there is a definite need to compute reliably the induced current and SAR, which needs a lot of study.

The national mobile phone program (HERMO) needs further dosimetrical support. It would be interesting to explore biophysical mechanisms which might elucidate RF effects observed in cells below a clear hyperthermic level.

Because the health effects of UV are one of the major radiation problems, the research of biological effects should be continued at STUK. The NIR laboratory can participate this by providing expertise on UVdosimetry and biology.

Specific projects

- Compliance assessment of mobile phones and base stations[1)] (the ongoing AMEST project which ends in the end of 2005).
- Determination of SAR in anesthesized pigs and human volunteers (the ongoing HERMO project).

[1)] SAR testing of an UMTS mobile phone, measurement of near field of a base station for dosimetric modelling, measurement of pulsed magnetic fields of five mobile phones.

- RF exposure from new wireless systems (not yet decided).
- Relation of induced current and SAR in the near field of high-frequency heaters (the ongoing project of STUK).
- Computation of current density induced by metal detectors in human body (planned).

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