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

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

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

2.9.5 Progress report on research over the last five years

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

The hereditary effects of paternal radiation exposure were studied by determining the frequency of radiation-induced heritable minisatellite mutations among the children of Estonian clean-up workers (liquidators). The cases and controls were children born to the same families after and before the father’s exposure at Chernobyl. Minisatellite mutations were studied using eight minisatellite probes in a method based on Southern blot. Paternal minisatellite mutations were detected in approximately the same number of case children as control children. In this study we did not observe any statistically significant increase in minisatellite mutation frequency among the children of radiation-exposed fathers (Kiuru et al. manuscript in preparation).
Our studies on gene expression in radiation-induced thyroid carcinogenesis using DD-RT PCR and cDNA expression array, demonstrate that the gene expression profiles are heterogeneous and no common gene pathway defect could be demonstrated. In general, the relative amount of all expression changes (up and down) is not dependent on the radiation type or dose. However, downregulation of p21 in many of these in vitro irradiation-induced tumour cell lines prevents p53 from inducing any G1 arrest, revealing that the p53 apoptosis pathway might be dysregulated irrespective of the p53 mutation status. (Romppanen et al. 3 manuscripts in preparation).

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

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

Molecular epidemiological approaches have been used to study the significance of p53 mutations for individual radiation sensitivity. p53 mutations in human head and neck cancer cell lines were shown to be associated with increased radiosensitivity and capacity to repair sublethal damage (Pekkola-Heino et al. 1996, Servomaa et al. 1996, Pekkola-Heino et al. 1998). In addition, mutations or overexpression of p53 were not shown to predict survival among secondary rectal cancer patients who received radiation therapy for uterine cancer (Hirvikoski et al. 1999, Servomaa et al. in press).
Studies on genomic instability have indicated that the incidence of cytogenetically abnormal rogue cells show a large variability between studies and individuals and that no correlation between long-term radiation exposure and the occurrence of rogue cells was demonstrated (Mustonen et al. 1998). Irradiation of CHO cell lines previously used in bystander effect studies, showed that radiation induces less micronuclei but more single strand breaks in G6PD deficient cell line compared to wild type cells. G6PD enzyme is important in defence against radiation-induced oxygen radical attack and cells lacking the enzyme seem to be lethally damaged immediately after irradiation (Salo et al. manuscript in preparation).

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

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

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

RF-EMF studies have preliminarily shown that short-term (1h) exposure of cells to a low-level (2 SAR) 900GSM signal causes changes in protein expression and protein phosphorylation; this indicates that cells respond to the RF-EMF signal in spite of its very low energy. (Joenväärä & Leszczynski, manuscript in preparation). A report on the possible health effects of mobile phones was prepared at the request of the Finnish Ministry of Social Affairs and Health (Jokela et al. 1999).
Microcavitation studies carried out at Harvard Medical School, Boston, MA, USA, have shown that irradiating cells that contain light-absorbing particles with nano-second length laser pulses is a very efficient and selective method of killing cells, and one that might have applications in tumor therapy. (Leszczynski 1999).

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

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

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

**2.9.6 Research plans for the next five years**

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

Four main topics are foreseen in radiobiological research at STUK during next few years: mechanisms of radiation-induced carcinogenesis, mechanisms of radiation-induced genomic instability, interindividual variation in response to ionising radiation and biodosimetry.
Gene expression studies will continue in our research on radiation-induced carcinogenesis. Two genome-wide expression methods (cDNA Expression Array and differential display) will be applied in studies of radiation-induced primary human tumour cell lines derived from thyroid carcinomas from Belarussian children. The results will be compared with previous data obtained using cell lines from *in vitro* radiation-induced human thyroid tumours. Our project on radiation-induced genomic instability will aim to identify genes playing a pivotal role in the induction of genomic instability. The project will also study how genomic instability can be transmitted to cells that are not directly hit by irradiation (‘bystander effect’).

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

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

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

Studies of the possible health effects of mobile communication devices will focus on proteomic approach to determine the mechanism of action of RF-EMF. Using two-dimensional gel electrophoresis, the proteins and phosphoproteins generated in cells exposed to RF-EMF and control cells at different points of time will be identified. Furthermore, the persistence of any protein expression changes will also be determined. Changes in gene expression will be determined using cDNA arrays.
Studies on the effects of UV radiation on melanoma metastasis will continue in animal studies and in human volunteers’ to confirm the pro-metastatic effects of UVA observed in vitro.

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

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

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

- Genomic instability and radiation-induced cancer (RADINSTAB)
- The use of FISH techniques for retrospective biological dosimetry (COD)
- The significance of individual radiation sensitivity for secondary cancer
- Inter-individual differences in the yield of radiation-induced chromosome aberrations
- Radiation-induced changes in gene expression
- Minisatellite mutations and biodosimetry of the population around the Semipalatinsk nuclear test site (SEMIPALATINSK)
- Radiation-induced heritable mutations in humans
- Mobile phones and the risk of brain tumours (INTERPHONE)
• Pooled analysis of European case-control studies of radon and lung cancer (RADON EPIDEMIOLOGY)
• Cancer risk among nuclear workers (LOWDOSERISK)
• Cancer risk among airline personnel (ESCAPE, NoESCAPE)
• Cancer among Sami people (Lapps)
• Kidney toxicity of uranium in drinking water (JURMU)
• Radioisotopes in drinking water and cancer risk (JUORAAS)
• Chernobyl fallout and adult leukemia
• Brain tumors and X-ray examinations
• Leukemia incidence in the vicinity of nuclear facilities
• Radon and lung cancer: an analysis using additive generalised linear models (RALMA)
• Health risk assessment of wireless communications (LaVita)
• Risk evaluation of potential environmental hazards from low energy electromagnetic fields (EMFs) exposure using sensitive in vitro methods (REFLEX)
• Biological effects of microwave radiation emitted by mobile phones
• Effects of UV on melanoma metastasis (SYTTY)
• Follow-up chromosomal aberration frequencies among accidentally exposed subjects
• Cytogenetic biomarkers and human cancer risk (CancerRiskBiomarkers)
• Cancer incidence among Baltic Chernobyl clean-up workers
2.10 Radiation Metrology Laboratory

2.10.1 Key words and specific technologies

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

2.10.2 Description of laboratory activities

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

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

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

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

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

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

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

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

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

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

2.10.4 Aims of the research

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

2.10.5 Progress report on research over the last five years

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

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

• Development of standardised methods to specify of dose delivery in radiotherapy. Through a number of scientific enquiries and discussions, consensus was reached between the Nordic countries, which has since largely been adopted also by the International Commission on Radiation Units and Measurements. This work was done in Nordic co-operation through a working group of the Nordic Association of Clinical Physics, which was chaired by a representative from the Radiation Metrology Laboratory.

• Development of a Quality System (QS) for a Secondary Standard Dosimetry Laboratory (SSDL). A number of Quality Control (QC) techniques have been investigated to establish an optimum QC program for an SSDL. The work was carried out as a part of a Co-ordinated Research Project of the International Atomic Energy Agency (IAEA). The results provide detailed guidance not only on the QC program but also on development of the overall QS to conform to an appropriate international standard (ISO 17025).

2.10.6 Research plans for the next five years

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

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

2.11 Non-Ionising Radiation Laboratory

2.11.1 Key words and specific technologies

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

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

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

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

2.11.2 Description of laboratory activities

NIR Laboratory, costs by sector in 1999, k€
The Non-Ionising Radiation Laboratory

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

The regulatory functions include

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

Typical expert services include:

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

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

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

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

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

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

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

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

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

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

2.11.3 Personnel

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

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

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

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

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

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

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

Valpuri Jalarvo, BSc, assistant researcher

Kari Keskinen, technician

2.11.4 Aims of research

• To study exposures to NIR and compare them with exposure standards and current knowledge on thresholds of biological effects
• To examine the biological and biophysical basis of exposure limits
• To develop experimental and theoretical methods for exposure assessment
• To develop precise standards for the calibration of instruments used for exposure measurements
• To provide well characterised exposure systems for biological research
• To study the biophysical interaction mechanisms of NIR
• To obtain quantitative and reliable data for the dissemination of public information

2.11.5 Progress report on research over the last five years

Development of EM field exposure measurement instruments

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

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

RF-dosimetry

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

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

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

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

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

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

MRI study

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

Broadband electric and magnetic fields

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

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

**UV radiometry**

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

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

**UVR exposure and risk studies**

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

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

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

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

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

**Optional new research plans**

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

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

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

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

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

A calibration standard will be developed for the low-frequency electric field strength (50 Hz–10 kHz).
The effects of harmonic frequencies on exposure to intense electric and magnetic fields in the vicinity of power lines will be investigated. Other low frequency and broadband exposures to be surveyed arise from digital mobile phones, welding, induction heating, switched power sources, electrolysis etc. Due to the new recommendations of the ICNIRP and the EU Council, there is a much greater need for assessment of exposure to low frequency and broadband electric and magnetic fields.

A broadband magnetic field meter that shows the weighted peak magnetic flux density will be developed.

The long-term stability of solar UVR measurements and calibrations will be monitored.

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

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

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

Exposure models and dose assessments will be developed and provided for epidemiological studies of the health effects of solar and artificial UVR.
3 LIST OF PUBLICATIONS (last five years)

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

3.1 Research and Environmental Surveillance, Management Unit


3.2 Natural radiation


Salonen L, Huikuri P. Utilisation of Low Background Liquid Scintillation Spectrometry and Pulse Shape Analysis in Testing Various Methods for Removing Natural Radionuclides from Drinking Water. Poster presentation
at the 45th Conference on Bioassay, Analytical & Environmental Radiochemistry, Gaithersburg, MD, USA, 18-22 October, 1999.


3.3 Radiation Hygiene


Bunzl K, Albers BP, Schimmack W, Rissanen K, Suomela M, Puhakainen M, Rahola T, Steinnes E. Soil to plan uptake of fallout $^{137}$Cs by plants from

Bunzl K, Schimmack W, Schramel P, Suomela M. Effect of sample drying and storage time on the extraction of fallout $^{239,240}$Pu, $^{137}$Cs and natural $^{210}$Pb as well as of stable Cs, Pb and Mn from soils. Analyst, 1999;124:1383-1387.


Puhakainen M, Riekkinen I, Heikkinen T, Jaakkola T, Rissanen K, Steinnes E, Suomela M, Thørring H. Effect of chemical pollution on forms of $^{137}$Cs, $^{90}$Sr and $^{239,240}$Pu in the arctic soil studied by sequential extraction. J. of Environmental Radioactivity (in press).


Rahola T, Suomela M, Illukka E, Pusa S. Assessment of the internal contamination of nuclear power plant workers in Finland. IRPA 9, 1996


3.4 NPP Environment


Ilus E. Evaluation of sediment sampling devices and methods used in the NKS/EKO-1 project. NKS/EKO-1 (96) TR-1. Risø, Denmark, 1996. 1-54.


Rissanen K, Ikäheimonen T K, Matishev D, Matishev G G. Radioactivity levels in fish, benthic fauna, seals and sea birds collected in the Northwest Arctic of Russia. Radioprotection - Colloquies, 32, C2, 1997:323-331,


3.5 Ecology and Foodchains


Rantavaara A, Kostiainen E, Sihvonen H. The transfer of $^{137}$Cs from nuclear fallout to milk in Finland. In: (Ylätalo S, Pöllänen R, eds.) Properties of


### 3.6 Airborne Radioactivity


Summary report of the exercise “RESUME95: Rapid Environmental Surveying Using Mobile Equipment”. Copenhagen, NKS, 1997:
- Markkanen M, Honkamaa T, Niskala P. In-Situ Measurements in Vesivehmaa Air Field-STUK team. 119-126.
- Toivonen H. Detection of Hidden Sources - Prompt Reports by Airborne Teams in RESUME95, 325-339.


techniques to the verification of the comprehensive nuclear test ban treaty. Analyses of samples from Kuwait and from AFTAC. STUK-A149, 1997.


- Pöllänen R. Reactor inventory data management using computer codes ORIGEN2 and OTUS: an application for calculating properties of nuclear fuel particles, 41 - 46.
- Pöllänen R. Dose estimation of nuclear fuel particles deposited on the skin, 47 - 56.
- Pöllänen R. Transport of large particles in air, 57 - 66.


## 3.7 Regional Laboratory in Northern Finland


Rissanen K, Ikäheimonen TK, Nielsen SP, Matishov DG, Matishov GG. Gammanuclide and plutonium concentrations in the White Sea. The Third International Conference on Environmental Radioactivity in the Arctic 1997; Extended abstracts volume 2: 222-224.


Rissanen K, Pempkoviak J, Ikaheimonen TK, Matishov DG, Matishov GG. $^{137}$Cs, $^{239,240}$Pu, $^{90}$Sr and selected metal concentrations in organs of Greenland seal pups in the White Sea area. In Strand P, Jolle T. (Eds.) Environmental Radioactivity in the Arctic. Proceedings of the 4th International Conference on Environmental Radioactivity in the Arctic. Norwegian Radiation Protection Authority, Norway, 1999: 186-188.


### 3.8 Medical Radiation


3.9 Radiation Biology


Auvinen A, Karjalainen S. Possible explanation for social class differences in cancer patient survival. In: Kogevinas M, Pearce N, Susser M, Boffetta P.


Joenväärä S. Protein kinase C-alpha regulates proliferation but not apoptosis in rat vascular smooth muscle cells. M.Sc thesis in biochemistry, University of Helsinki, 1998. (in Finnish)


Leszczyński D, Leszczyński K, Servomaa K. Long-wave ultraviolet radiation causes increase of membrane-bound fraction of protein kinase C in rat


Leszczynski D, Pitsillides CM, Anderson RR, Lin CP. Induction of apoptosis and necrosis following pulsed laser irradiation of intracellular pigment microparticles. Optical Society of America Technical Digest, 1999, 139-141.


Salo A. Radiation-induced genomic instability and the induction mechanisms in Chinese hamster ovary cell lines. M.Sc thesis in radiation biology, University of London, 1999
