MIKES

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FINNISH NATIONAL
STANDARDS LABORATORIES

BIENNIAL REPORT 2007-2008

Contents

Centre for Metrology and Accreditation

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Editorial board: Martti Heinonen, Jaana Järvinen,
Antti Lassila and Antti Manninen
Layout: Jenni Kuva

Espoo 2009

MIKES - COMING OF AGE

At the age of majority, 18 years in Finland, a lot of things happen overnight. Suddenly you can drive a car, your vote is valid at election, you can sign your own absent hours from school, you can go to a restaurant for a legal drink, you can by a bottle of beer or cigarettes at a local store, you can sign your tax announcement, you can play online poker, you can go to military service, you leave your family and rent a flat and start to earn your pension. What were the influences to MIKES when coming to age? Not many. We have pretended like an adult for years with unquestionable acceptance. To drive our car - the new building - we have already learnt by the hard way. Army service or tax announcement is like EURAMET ToRs; more discipline, more work, more reports - we are getting used to that. Looking for a new flat might mean that both Metrology and Accreditation have new fiancée and bride in sight. Good candidates chased down for both. Metrology will inherit the building. It is nice to be adult.

Highlights from the last two years. Development towards more customer and research oriented MIKES Metrology has successfully continued. Increase of 30 % of external funding from 2007 to 2008 was recorded. Traceability service has been stable during the last 10 years: the number of calibration certificates has been about 1000 per year including our own internal calibrations like thermometers, barometers etc. I expect to see a small increase in the traceability service because of new measurement setups and because of new customers from Finland and abroad. At MIKES Metrology the rapidly growing field is research. Now we take part in addition to local activity to nine ERA-NET Plus projects. The total number of projects in Finland is thirteen out of twenty one. Researcher exchange has also started. Visits to NRC (Canada), NMIJ (Japan), CMI (Czech Republic) will be followed by couple of agreed ERA-NET Plus visits to PTB (Germany) and NPL (United Kingdom). Research exchange the other way round, i.e. researchers coming to MIKES, would be most desirable. This has happened this far only in a small scale.

Concerning our slightly distributed metrology infrastructure there has been a change to more centralised system: high voltage metrology from TKK (Helsinki University of Technology) has been moved to MIKES. This reduced redundancy and increased our staff by two senior research scientists. During the over ten years period TKK started and developed high voltage metrology to world class. The devices developed or bought were moved to MIKES. Other new equipments at MIKES are e.g. PTU-chamber (measurement chamber with independent regulation of humidity, temperature and pressure for small laptop size objects), small scale wind tunnel traceable to mass via humid air. New device, Dry Millikelvin Cryostat, has been designed and ordered from a nearby enterprise. The first big challenge with the cryostat is to make measurements in the Closing-the-Metrological-Triangle project.

In the future agreements like Strategic companionship with Oulu University - some 500 km north from MIKES - plays an important role getting metrology efficiently distributed and having a talented partner in development projects. Another strategic like program started with CMI (Czech Republic). Here we decided to have annual peer review visits mutually.

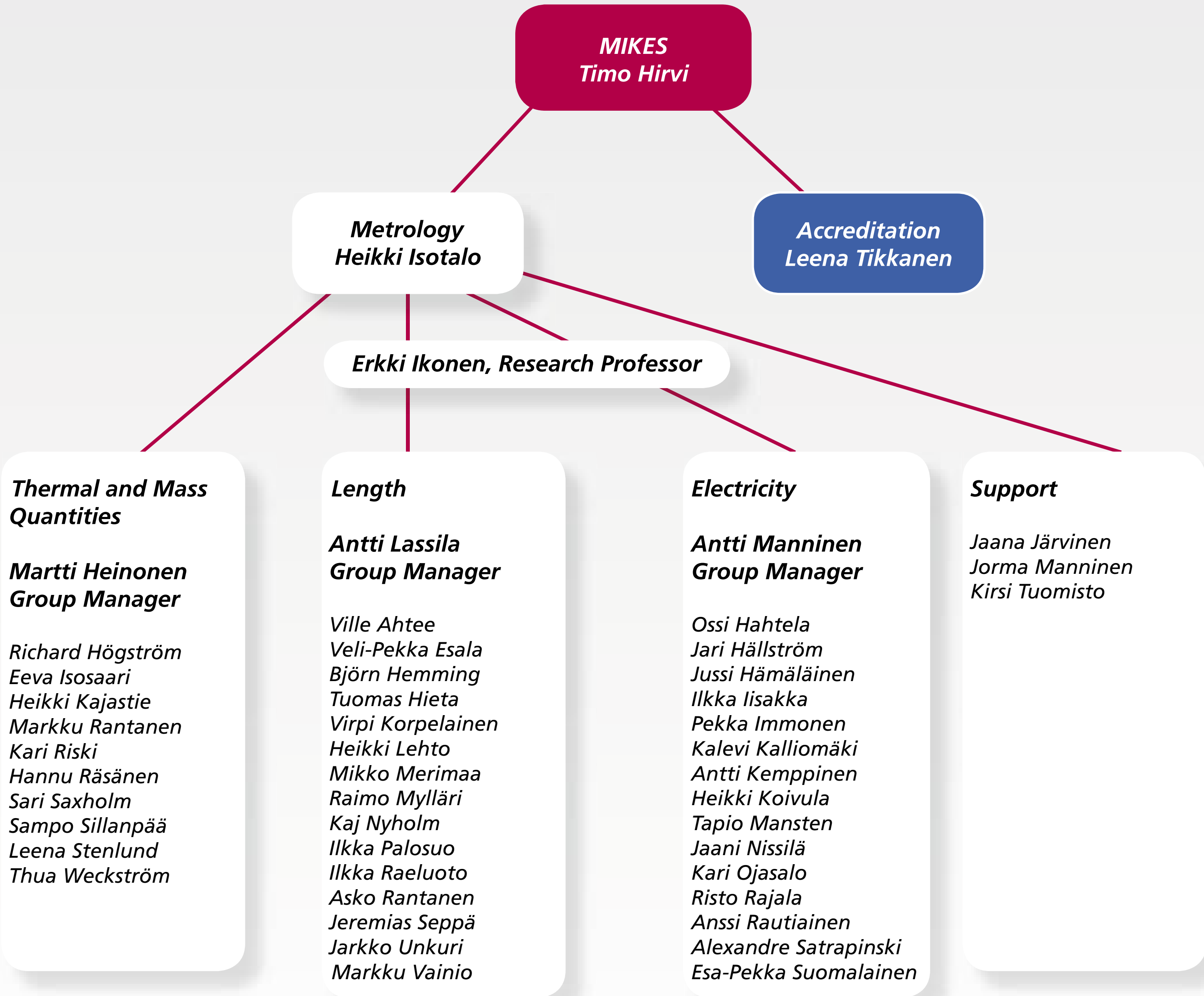
Otaniemi 20 May 2009

Heikki Isotalo
Director
MIKES Metrology

Mission of MIKES Metrology

In Finland the Centre for Metrology and Accreditation (MIKES) is responsible for the implementation and development of the national measurement standards systems. MIKES also participates actively in international co-operation and ensures that Finnish metrology is up to international requirements.

Today Finland has a slightly decentralised organisation of its National Standards Laboratories (NSLs). MIKES itself acts as the National Metrology Institute (NMI) of Finland, designating the National Standards Laboratories and financing the maintenance, research and development of the national measurement standards. Some of the activities are delegated to Contract Laboratories. International co-operation is also channelled through MIKES. The personnel of the department of metrology is divided into three metrology groups: thermal and mass quantities, length, and electricity, supported by assisting activities.



International Co-operation

MIKES participates in European and international research programmes and in scientific and technical activities promoted by European and international bodies in metrology, such as EURAMET, CGPM/CIPM/BIPM, NICe etc.

Training

MIKES organises various training courses and seminars in several sub-fields of metrology. In addition, experts from MIKES give lectures in courses and seminars.

Research

Research on the realisation methods of SI units, measurement standards and methods is carried out in various research projects, often in co-operation with other research institutes and universities. In these projects, several young scientists are carrying out their practical training.

Consultancy

MIKES Metrology works together with industry and various institutes. This type of national co-operation in the field of metrology is increasing in Finland.

Realisation of SI Unit

The national standards for mass, temperature, pressure, electrical quantities, time, frequency, humidity, flow, acoustics, length and dimensional quantities are maintained and developed at MIKES to fulfil the needs of consumers and the society in Finland. The duties of the National Standards Laboratories for photometry and radiometry, length in geodesy, acceleration of free fall, and ionising radiation have been delegated to other institutes outside MIKES. In addition, the traceability, international relations and expert services in the field of force, torque, and air quality measurements have been organised through Contract Laboratories.

Calibrations

The laboratories of MIKES Metrology offer a calibration service to establish the traceability of reference standards at the accredited laboratories. The calibration service is also offered directly to end users, mostly when the scope or accuracy level of accredited laboratories is not sufficient for the customer.

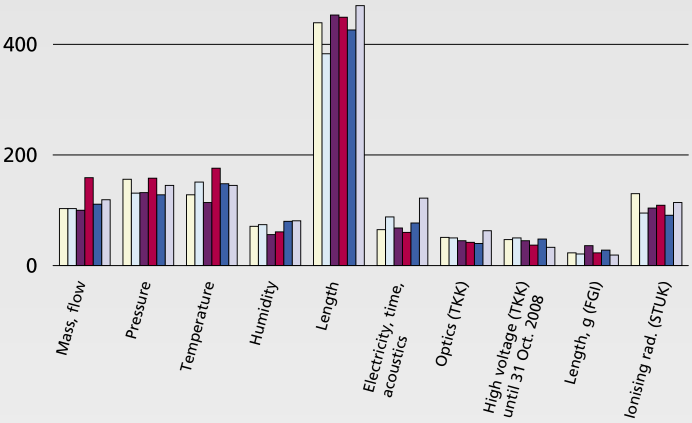
Within MIKES, the Metrology Department is responsible for tasks relating to the maintenance and supervision of the national measurement standards system. Below is the organisation of the National Standards Laboratories in Finland on 31 December 2008.

MIKES = Centre for Metrology and Accreditation, TKK = Helsinki University of Technology, FMI = Finnish Meteorological Institute, FGI = Finnish Geodetic Institute, STUK = Radiation and Nuclear Safety Authority.

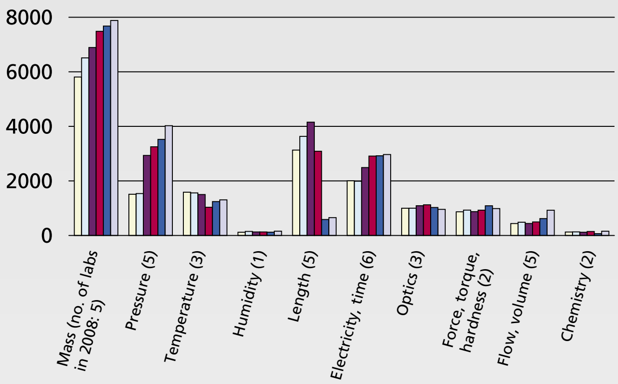
2007-2008 in numbers

Number of calibration certificates 2003-2008

NATIONAL STANDARDS LABORATORIES



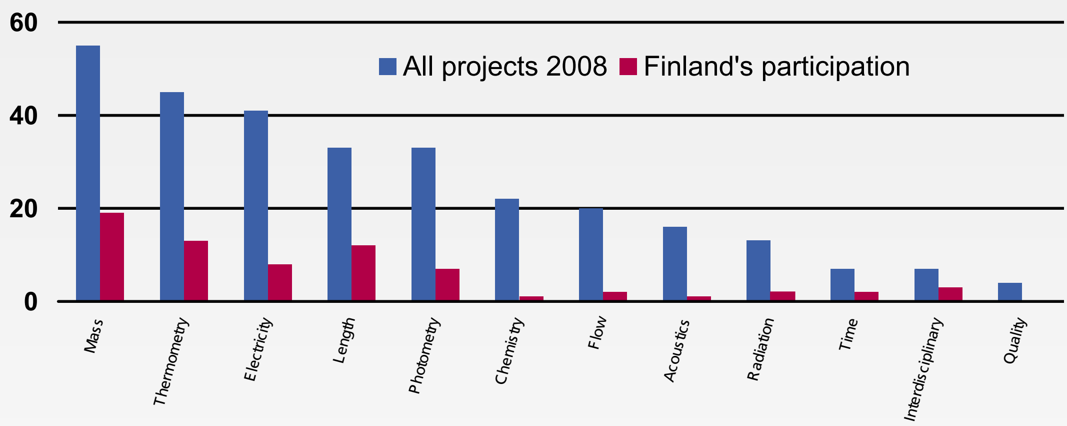
ACCREDITED CALIBRATION LABORATORIES



The total number of certificates given by National Standards Laboratories (NSL) has been about 1000 certificates per year over six years. The accredited calibration laboratories give altogether about 20000 certificates annually. The number of accredited calibration laboratories in length field decreased from 9 to 5 in 2007 which can be seen in the number of calibration certificates.

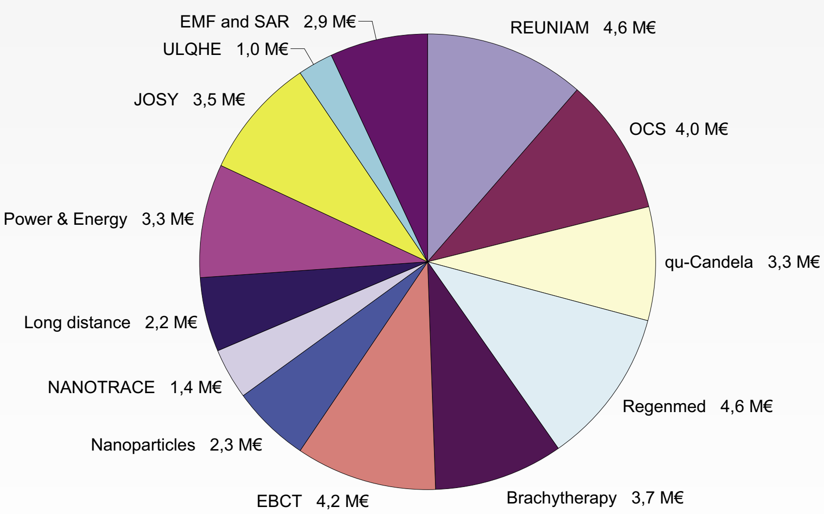
EURAMET projects

AGREED AND PROPOSED PROJECTS



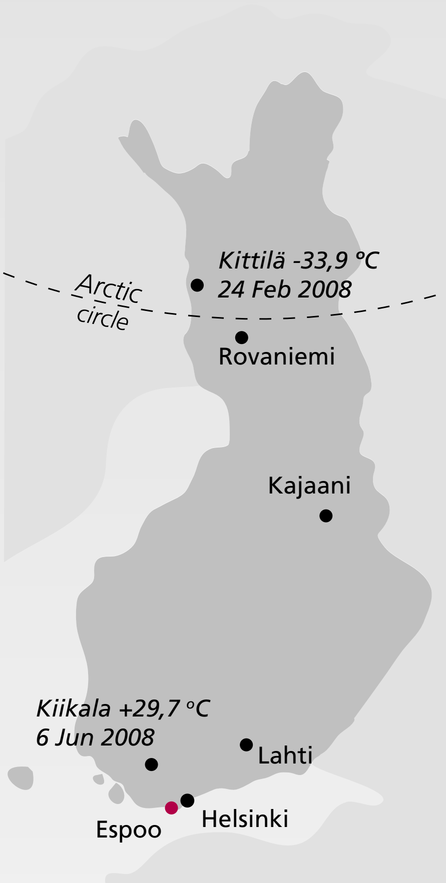
Projects of EURAMET Technical Committees are divided to traceability, consultation, comparison, and research projects. Here is shown the total number of projects and Finland's participation in various subject fields.

FINNISH PARTICIPATION IN EMRP



Finland participates in total of 13 out of 21 ongoing iMERA Plus projects. Projects will run for three years and the total volume of the 21 projects is 64 M€ out of which one third is financed by EU.

REUNIAM = Foundations for a redefinition of the SI base unit ampere
OCS = Optical clocks for a new definition of the second
quCandela = Towards quantum-based photon standards
Regenmed = Metrology on a cellular scale for regenerative medicine
Brachytherapy = Increasing cancer treatment efficacy using 3D brachytherapy
EBCT = External Beam Cancer Therapy
Nanoparticles = Traceable characterization of nanoparticles
NANOTRACE = New Traceability Routes for Nanometrology
Long distance = Absolute long distance measurement in air
Power & Energy = Next generation of power and energy measuring techniques
JOSY = Next generation of quantum voltage systems for wide range applications
ULQHE = Enabling ultimate metrological Quantum Hall Effect (QHE) device
EMF and SAR = Traceable measurement of field strength and SAR for Physical Agents Directive

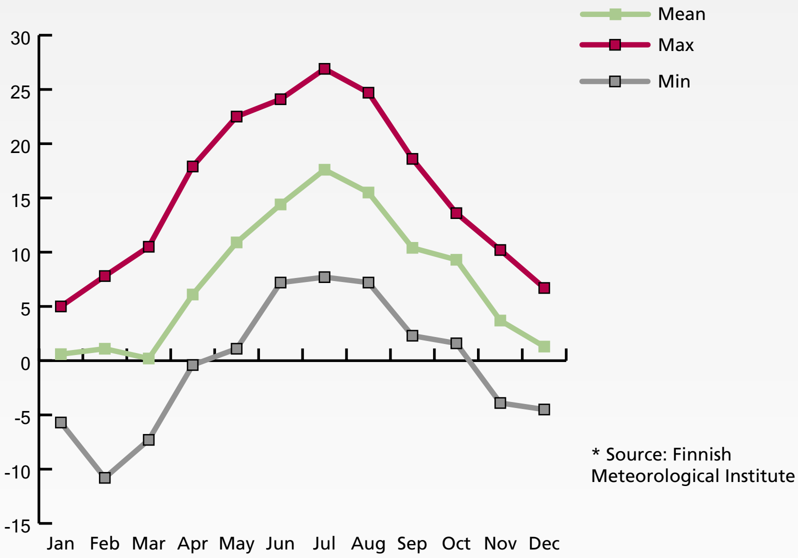


FACTS ABOUT FINLAND

5 326 314 (12/2008) inhabitants
338 425 km²
188 000 lakes
Capital: Helsinki
Land border with: Norway, Sweden, Russia
Official languages: Finnish and Swedish
200 000 reindeer
Currency: euro
Gross domestic product: 186 · 10^9 €
5 biggest trade partners (export, 2008): RU, SE, DE, USA, GB
R&D investments: 3.4 % of the GDP
Recent Nobel prizes: Martti Ahtisaari (peace)
Biggest Company: Nokia
Fastest Finn: Kimi Räikkönen

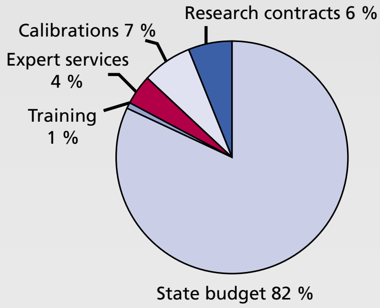
Source: Statistics Finland

TEMPERATURES IN HELSINKI (°C)

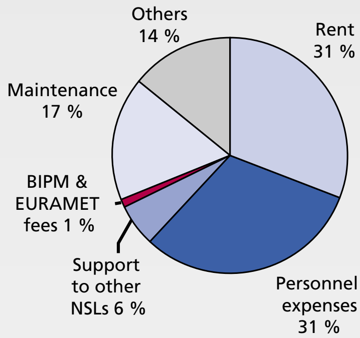


MIKES METROLOGY

PROCEEDS 6.7 M€

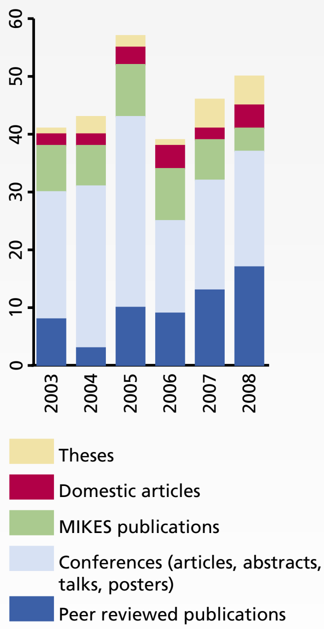


COSTS 6.7 M€



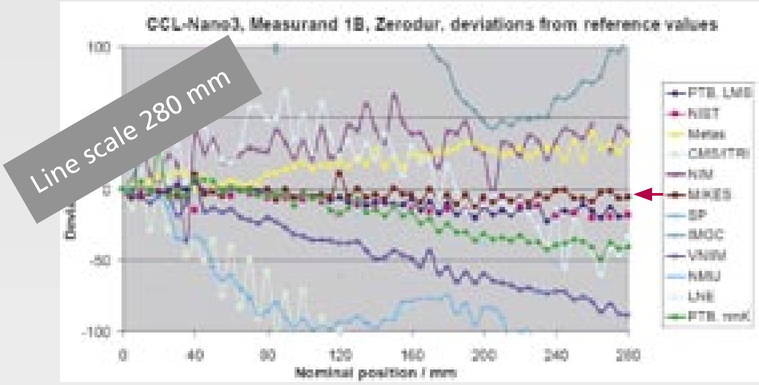
Total budget of MIKES is 9.1 M€ including MIKES Metrology, FINAS and administration. FINAS is essentially self supporting and expenses of administration are divided to Metrology and to FINAS as a ratio of personnel. As a result budget of MIKES Metrology was 6.7 M€ in 2008.

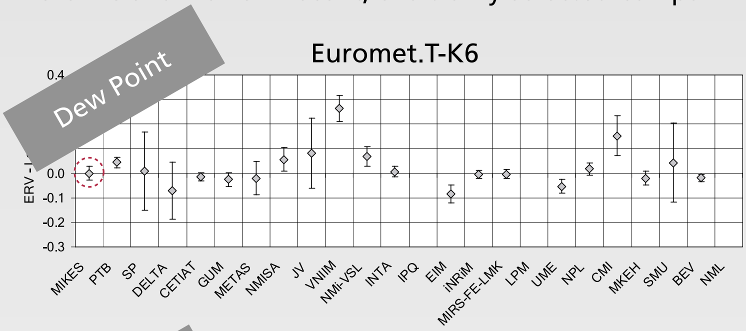
PUBLICATIONS (MIKES ONLY)

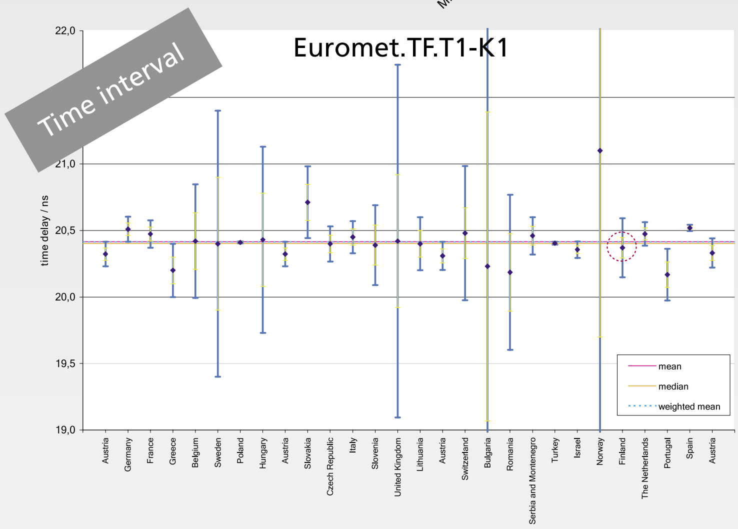


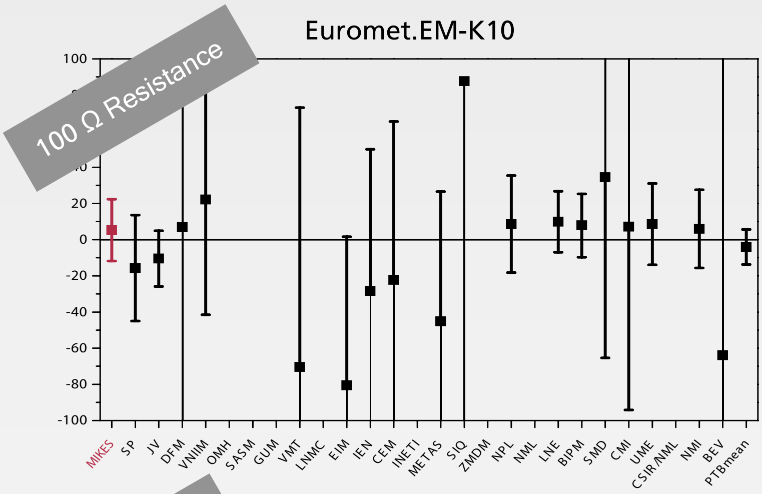
MIKES participation in comparisons

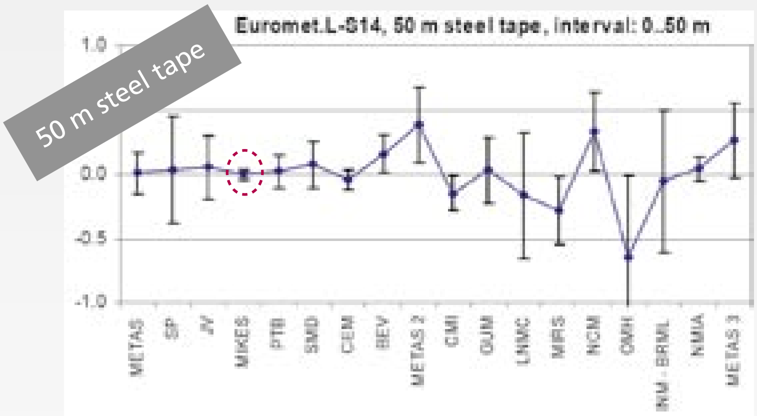
In metrology there is no unit for scientific excellence. Here our measure is comparison to other laboratories. Comparisons can be bilateral comparisons between two laboratories, EURAMET comparisons between European NMIs or CIPM comparisons between NMI laboratories around the world. Here we show a few recent, arbitrarily selected comparisons which MIKES has taken part in.

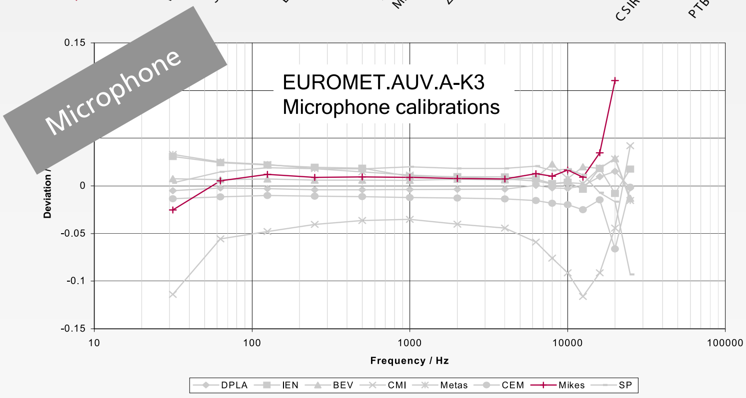


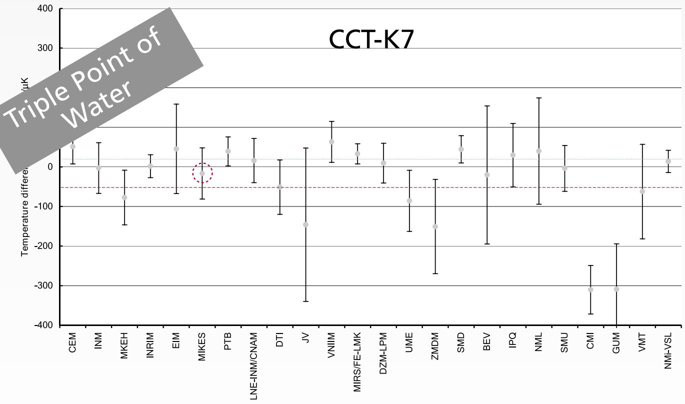


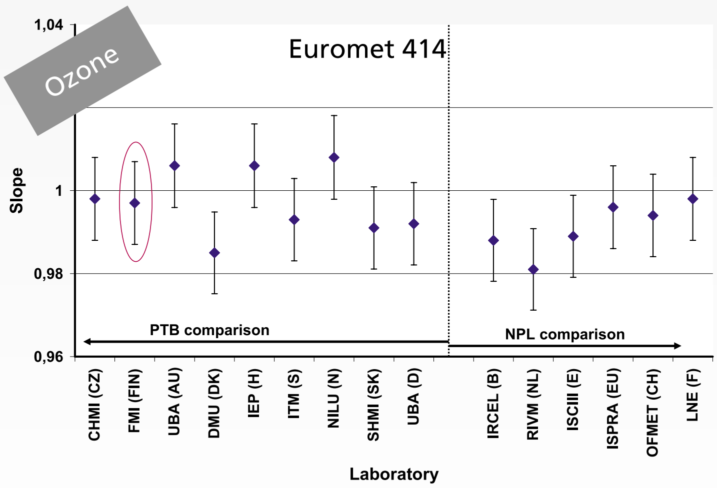












Thermometry and Mass

Personnel
MIKES

Dr. Martti Heinonen	*Principal Metrologist, Group Manager*
M.Sc. Markku Rantanen	*Senior Research Scientist*
Dr. Kari Riski	*Senior Research Scientist*
Dr. Thua Weckström	*Senior Research Scientist*
Lic.Sc. Heikki Kajastie	*Research Scientist*
M.Sc. Richard Högström	*Research Scientist*
M.Sc. Eeva Isosaari	*Research Scientist*
M.Sc. Sari (Semenoja) Saxholm	*Research Scientist*
M.Sc. Sampo Sillanpää	*Research Scientist*
M.Sc. Leena Stenlund	*Research Scientist*
Mr. Jorma Manninen	*Laboratory Engineer*
Mr. Hannu Räsänen	*Assistant Research Scientist*
Mr. Lippo Järviö	*Trainee (1.6. – 31.8.2007)*
Mr. Teemu Hynönen	*Trainee (1.6. – 31.8.2008)*

MIKES-Lahti Precision

M.Sc. Michael Sachs	*Head of the Laboratory since May 2008*
B.Sc. Aimo Pusa	*Head of the Laboratory*
Mr. Mikko Mäntylä	*Laboratory Supervisor*
Mr. Urpo Viinikangas	*Quality Manager*

FGI

Prof. Markku Poutanen	*Head of Department of Geodesy and Geodynamics, Quality Manager*
Dr. Jaakko Mäkinen	*Chief Research Scientist, Head of Laboratory*
M.Sc. Hannu Ruotsalainen	*Senior Research Scientist, Deputy Head of Laboratory*
M.Sc. Mirjam Bilker-Koivula	*Senior Research Scientist*
Dr. Heikki Virtanen	*Specialist Research Scientist*

The MIKES Thermal and Mass Quantities carries out research and provides measurement service in the field of mass and temperature related metrology. The laboratories realise units for mass, temperature, pressure, small mass and volume gas flow, density, dew-point temperature and relative humidity. Research activities are focused in measurement standards and calibration methods. The expert service for customers provided by the Group covers training, co-operative development projects and consultation. The Group issued about 980 calibration certificates for customers at accredited laboratories, research institutes, industry and MIKES during years 2007 to 2008.

MIKES has a contract with Lahti Precision Oy nominating its Force and Mass Laboratory to take care of needs of force and torque metrology. On the basis of its own legislation, the Finnish Geodetic Institute (FGI) is the National Standards Laboratory for the measurement of the acceleration of the free fall.

Highlights in 2007-2008

MEASUREMENT STANDARD FOR NANOMETRE SCALE PARTICLES IN AEROSOLS

A research project to develop a measurement standard for nanometre scale particles in aerosols was launched in 2008. The project forms one work package in the iMERA-Plus JRP T3.J1.1 project: Traceable characterization of nanoparticles. Other partners in the European project are: NPL (UK), PTB (DE), CMI (CZ), CEM (ES), METAS (CH), INM (RO), INRIM (IT). In the work package, a new Single Charge Aerosol Reference Instrument (SCAR) is developed and validated with AFM measurements. The core idea of SCAR is the electric charging of nanoparticles. With this equipment, it will be possible to realize a validated traceable measurement standard for the number concentration of nanoparticles (Fig. T1). It can be used, for example, for characterization of commercial nanometre scale particle detection instruments. The SCAR will be compared against the standardised gravimetric method and used for studying the so-called filter artefact in the after-treatment devices. It will also be used for producing samples for evaluating biological hazards of nanoparticles. The project is carried out in collaboration with the Aerosol Physics Research Group in Tampere University of Technology and four Finnish companies: Dekati Ltd, Ecocat Ltd, Gasmet Ltd and Histola Ltd.

Figure T1. The testing of the mixing system for the carrier gas and particles.

A NEW TYPE OF COULOMB BLOCKADE THERMOMETER

MIKES has been developing with LTL (the Low Temperature Laboratory at the Helsinki University of Technology) a new primary standard for a cryogenic temperature range. The standard is based on the principle of Coulomb Blockade Thermometer invented in 1994 by prof. J. Pekola. The method is in line with a new definition of Kelvin that has been proposed to be adapted in 2011 [1, 2]. Since 2007, fabrication methods and aging of CBT tunnel junctions have been investigated [3]. Preliminary studies on modelling error sources contributing the final measurement uncertainty with a CBT have been carried out. In 2008, a significant step forward was taken when introducing a novel single junction thermometry (SJT) method (Fig. T2) [4, 5].

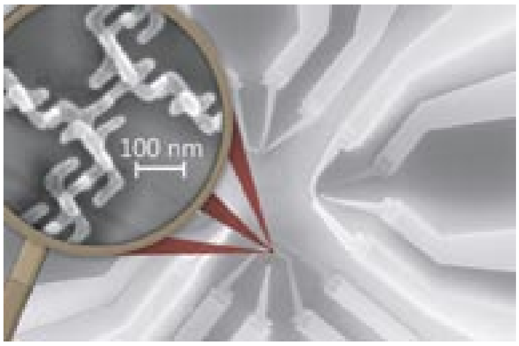


Figure T2. Lay-out of a single junction thermometer set-up.

RESEARCH IN RADIATION THERMOMETRY

MIKES research in radiation thermometry was focused in applications of filter radiometers and temperature measurement of micro components. The research has been carried out in close co-operation with Helsinki University of Technology. Filter radiometers were studied at MIKES to be used in the quality assurance of linear pyrometer measurements [6]. Our radiation temperature standards were successfully compared in the temperature range from 1570 K to 2770 K with PTB (DE) in the framework of the iMERA Special Facility co-operation program (Fig. T3) [7, 8]. A radiation temperature measurement method was developed for studying the temperature of microglows, i.e. miniature suspended silicon bridge structures designed for emitting light. In particular, the emissivity of microglows was investigated experimentally and by modelling (Fig. T4) [9].

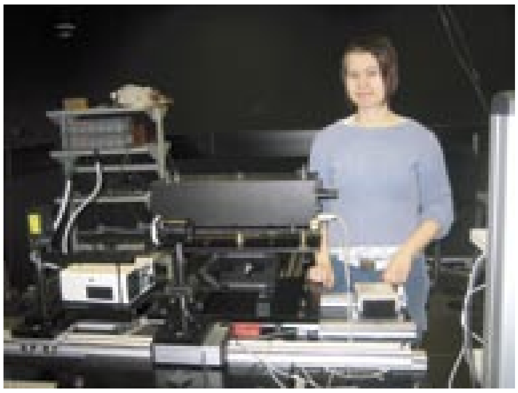


Figure T3. Maija Ojanen comparing a filter radiometer to a linear pyrometer.

EXPERT SERVICE ON DEW-POINT TEMPERATURE STANDARDS FOR EUROPEAN NMIS

In the framework of EURAMET project no. 782, MIKES arranged in September 2008 a training 3-day course on the use of a humidity generator as a primary standard. The course was repeated in December 2008. In total 8 persons from Croatia, Denmark, Greece, Egypt, Serbia, Netherlands, Norway and Poland attended in the courses. The topics of the courses covered theory, design and use of primary humidity generators. Uncertainty estimation and creating corresponding CMC entries were studied thoroughly. Hands-on training had a major role in the courses.

MIKES also designed, manufactured and characterized two saturator systems to FSB-LPM in Croatia to be used in the Croatian National Humidity Standards (Fig. T5). The saturators cover the range from -70 °C to +60 °C. MIKES staff also assisted in setting up the standards. The co-operation will continue in 2009 as a bilateral comparison.

Figure T4. A silicon wafer ready for an emissivity test in a high-temperature furnace.

Figure T5. The High-Range Saturator designed and manufactured for FSB-LPM by MIKES.

A TORQUE REFERENCE MACHINE TO SWEDEN

In 2007 the Lahti Precision Force and Mass Laboratory delivered a 5 kN·m torque reference machine to SP in Borås, Sweden. The device was mechanically completely designed by the laboratory and built by Lahti Precision. It is suitable for stepwise and continuous torque calibration procedures. The cooperation with SP still continues for the development of suitable machine control systems (software and HMI) and calibration procedures.

Figure T6. The absolute gravity site Haumýrar in Iceland.

THE GRAVITY REFERENCE NETWORK OF ICELAND

In July to October 2007 the National Land Survey of Iceland (LMI) and FGI measured 8 absolute-gravity stations in Iceland with the FG5-221 of the FGI. They form the gravity reference network of Iceland. The network was established in 1997 when LMI and the Federal Agency of Geodesy and Cartography (BKG, Frankfurt am Main) measured 7 of these stations with the FG5-101 of the BKG. At that time FGI participated at 2 stations. The boundary between the Eurasian and North American tectonic plates runs right through Iceland. Volcanism, earthquakes, and changes in glacier mass balance cause rapid gravity change and thus frequent re-measurements of the network are needed. On the other hand, they give information of the underlying geodynamics. The largest gravity change from 1997 to 2007 was –0.5 µm s^{-2} at the station Haumýrar (Fig. T6).

Research projects

CONTAMINATION OF CLEAN METAL SURFACES IN METROLOGICAL APPLICATIONS (MIKES)

At MIKES a research project on clean metal surfaces (weights) has been continued. The influence of different environmental conditions on the stability of metal surfaces is investigated. The effects of vacuum exposure, humidity changes and cleaning methods are studied. The test samples have been made from high quality polished stainless steel. The surface changes have been determined by weighing and by measurements with an atomic force microscope (Fig. T7).

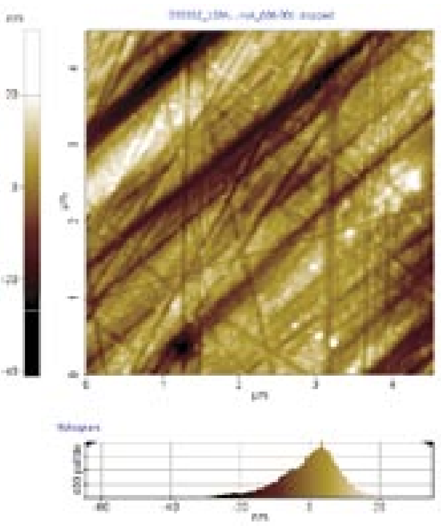


Figure T7. Topography of a test metal surface measured with an AFM.

TRACEABILITY TO NANOFORCE AND SUBMILLIGRAM MASS MEASUREMENTS (MIKES)

Small forces and masses are present in various applications and the need to measure them in accurate and traceable ways is arising. To satisfy the needs, MIKES is developing methods establish traceability to these measurements. We have successfully measured vertical forces in the range of 10 nN – 50 mN. This has been achieved with a setup consisting of an optically driven bending cantilever, a microbalance and a linear positioning sensor. The set-up can generate nanometer scale movements. Different materials for cantilevers have been tested by measuring reproducibility, linearity and hysteresis.

We have also been exploring the measurement methods for small masses with a QCM (Quartz Crystal Microbalance) in the range of 5 ng – 10 ug. The main task is to find a traceable calibration procedure for the QCM. Applications of the QCM in surface and environment research are also under study.

REALISATION OF THE KILOGRAM (MIKES)

In co-operation with VNIIM (Russia) and VTT Information Technology, MIKES studied a levitation method for the realization of the kilogram [10, 11]. We developed a new design in which the magnitude of the force is determined with a mass comparator. The weight of the superconducting plate can be compensated by the comparator and no additional magnetic field is required to lift the plate. In the new design either the traditional levitation method with direct energy transfer or the so-called watt balance method with separate force and induction measurements can be applied. The design will be published in Metrologia [12].

EFFECTS OF DIFFERENT HEAT TRANSFER MECHANISMS IN CONTACT THERMOMETRY (MIKES)

Thermal radiation and heat conduction along thermometers are typical sources of error in contact thermometry. These effects are of major interest when measuring the temperature of air/gas, a surface or a target with insufficient immersion depth. Experimental and theoretical methods are developed to analyse and improve the quality of temperature measurements. In 2007, the heat conduction effect was studied in an application where thin PRTs are calibrated using small triple point of water cells (mini-TPW) [13]. In 2008, MIKES started piloting a research and comparison project in the framework of EURAMET (project no. 1061) in which errors in air temperature measurements are studied. There are participants from 18 countries (BG, CH, CZ, DE, DK, EE, ES, FI, GR, HU, IT, MT, NO, PL, RO, SI, TR, UK) in the project.

THE EFFECT OF BACK-DIFFUSING WATER VAPOUR IN LEAKS ON DEW-POINT TEMPERATURE MEASUREMENTS (MIKES)

When measuring low dew-point temperatures a leak from the sampling tubing to ambient may cause a significant error due to back-diffusion of water vapour. The significance of this effect was studied experimentally and theoretically. The work was focused in the dew-point temperature range between -80 °C and -60 °C. The results show that penetration of water vapour into a sampling line can effectively be prevented by maintaining gauge pressure in the line. It was shown that in many cases a tiny leak may be more harmful than a larger one [14]. The project was carried out in co-operation with University of Tartu.

CONTINUOUS HUMIDITY COMPARISON SERVICE (MIKES)

MIKES is developing a method to provide continuous comparison data for quality insurance in humidity calibration laboratories not only in Finland but throughout the world. In contrast to traditional comparisons, there are neither pre-defined participants nor completion date in this new comparison scheme. Furthermore, only the range of measurements is fixed but not the measurement points. The relative humidity and temperature ranges cover 10 % to 95 % and +10 °C to +60 °C, respectively. Any laboratory can join the comparison when appropriate for its needs and get results within about one month after the measurements. In this development project, appropriate calculation and reporting methods are developed at MIKES to ensure the reliability of the results at the stated uncertainty level as well as the impartiality and confidentiality of the results. The comparison service will be opened in 2010.

RESEARCH ON MOISTURE MEASUREMENTS (MIKES)

A research project on the reliability of moisture measurements in laboratories and on-line applications was initiated in 2008. The project is being carried out on the basis of the needs of the partners. The first task was to analyse water activity measurements of food samples. For this purpose, a measurement set-up was developed to compare directly the equilibrium humidity of a sample to a reference gas from a dew-point generator using capacitive sensors (Fig. T8). The research was carried out in co-operation with Helsinki University.

Figure T8. A honey sample located in the measurement chamber of the apparatus developed at MIKES.

USE OF FPG-TYPE DIGITAL PISTON MANOMETERS (MIKES)

MIKES is coordinating a EUROMET project on FPG-type digital piston manometers (EUROMET Project no.803). The pressure laboratories of BNM-LNE in France, CMI in Czech Republic, SP in Sweden and MIKES use this novel type of pressure standard for absolute and gauge pressures in the range 1 Pa to 15 kPa. In this project, information is exchanged between the participating laboratories on characterisation of the instrument, estimation of uncertainty and maintenance and stability.

DETERMINATION OF EFFECTIVE AREA (MIKES)

MIKES is developing a method to determine effective area of a piston-cylinder assembly by dimensional measurements. In the project the geometry of a large diameter piston-cylinder assembly is studied using the coordinate measuring machine of MIKES. An analysis method is developed for determining the effective area from the dimensional data. The dimensions of large diameter (50 mm and 35 mm) piston-cylinders were measured. The effective area of the 50 mm diameter piston-cylinder unit of MIKES was also determined by LNE in France on the basis of dimensional measurements and using the cross-floating method. The measurements were carried out as a part of the iMERA Special Facilities co-operation program.

PTU-CALIBRATION SYSTEM (MIKES)

Devices measuring pressure, temperature and humidity simultaneously are used in e.g. weather observation systems and wrist computers. MIKES is developing a calibration system for these devices for the ranges 500 hPa to 1200 hPa in absolute pressure, -50 °C to +80 °C in temperature and 10 % to 95 % in relative humidity. All combinations over the pressure, temperature and humidity ranges will be possible. The inner diameter of the measurement chamber will be 150 mm. The first version of the system was constructed and tested [15]. Since then, a new humidity control system has been designed and more practical handling system for the cover of the measurement chamber was made. According to the project plan, the system will be ready for routine work in the end of 2009.

CONTRIBUTION OF VARYING SHEAR STRESS TO THE UNCERTAINTY IN GRAVIMETRIC GAS MASS FLOW RATE MEASUREMENTS (MIKES)

The gas cylinder of the dynamic gravimetric gas mass flow standard is never in thermal equilibrium between the ambient. This causes the time dependent natural convection heat transfer inducing air flow up- or downwards in the boundary layer of the gas cylinder. The air flow produces a time depended shear stress to the wall of the gas cylinder which disturbs the weighing process. In this study, the magnitude of the shear stress was determined in different conditions. Also, a theoretical model to predict the effect of shear stress on cylindrical surfaces was developed. The model was validated against experimental tests. With the model, it is now possible to take into account more accurately the effect of varying shear stress [16, 17]. This improves the uncertainty estimation and measurement process of the dynamic gravimetric gas mass flow rate measurement standard.

NOVEL METHOD TO ESTABLISH THE TRACEABILITY OF AIR VELOCITY MEASUREMENTS TO MASS FLOW STANDARDS (MIKES)

Traditionally, different primary standards for air flow have been needed for air velocity and mass/volume flow rate measurements. Typically laser-Doppler anemometers have been used in air velocity calibrations whereas gravimetric or volumetric standards are in use in other cases. With the novel mixing method developed at MIKES, also the air velocity measurements can be linked directly to the mass flow standards. The method can be applied to the metrological wind tunnels. It is based on the controllable humidification of incoming air with a known mass flow rate of water. From the mass balance and absolute humidity differences in the tunnel, it is possible to calculate the air velocity as a function of the humidification water mass flow rate. The method was implemented in a small open circuit wind tunnel and was found to be feasible, for example, in Pitot tube calibrations [18].

MULTI-GAS CALIBRATIONS OF FLOW METERS AND HYGROMETERS (MIKES)

In industrial applications, flow meters are used with various gases but the calibration of flow meters has usually been performed with one gas, such as nitrogen. The difference, however, between the flow meter reading and the actual flow rate through the meter may depend more or less on the properties of the gas. In this project, this effect is studied both theoretically and experimentally. The goal of this research project is to develop a calibration method, where the calibration corrections of the flow meter used for various gases can be deduced from the base gas calibration results. At the first phase, the method will be applied to the secondary standards of MIKES flow laboratory.

EXPERIENCE IN TORQUE MEASUREMENT, TRANSFER TO BOLT JOINT FASTENING (LAHTI PRECISION)

The aim of this project is to investigate the influence factors to the quality of bolt joints, especially the influences of the users. For the purpose, it has been built a device for simultaneous measurement of the screw tightening torque and the resulting axial force. This device can be used for screw testing as well as for the teaching of users to get a better understanding of the screw tightening process.

GRAVITY EFFECTS OF THE FENNOSCANDIAN POSTGLACIAL REBOUND (FGI)

The *Nordic Absolute Gravity Project* started in 2003. It aims at maintaining a time series of absolute gravity measurements at more than 20 sites in the Fennoscandian postglacial rebound (PGR) area. The time series of gravity are compared with vertical motion estimated from continuous GPS, repeated precise levelling and tide gauges, with regional gravity change determined using the satellite gravity mission GRACE, and with gravity change predicted from geophysical models of the PGR [19, 20, 21, 22, 23]. The measurements are coordinated by the Working Group for Geodynamics of the Nordic Geodetic Commission (NKG). They are performed by institutes in Germany, Norway, Sweden, Denmark and Finland. FGI made measurements in Finland at 4 stations in 2007 and at 8 stations in 2008. The gravity trends agree with the observed vertical motion and with GRACE gravity rates within their uncertainties. Discrepancies appear in comparison with some geophysical models. Also, an inter-annual variation in gravity is visible at many stations, probably due to hydrology.

The relative measurements made on the Fennoscandian land uplift gravity lines 1966–2003 were re-analyzed [24]. The ratio of gravity change to vertical velocity was found to be –1.5 to -1.8 nm s^{-2} per 1 mm of uplift, depending on the uplift model used. Newer uplift models tend to produce a ratio in the lower end (by absolute value) of this range.

THE GRAVITY REFERENCE NETWORK OF ESTONIA (FGI)

In cooperation with the Estonian Land Board the FGI measured seven absolute gravity stations in Estonia in July–August 2008. The purpose of the measurements was to support the establishment of the national gravity reference network of Estonia, and to perform research on the Fennoscandian PGR. Four stations were new, while three stations had been measured for the first time in 1995 by the FGI, using the JILAg-5 gravimeter. Gravity change 1995–2008 agrees with PGR estimates.

GRAVITY MEASUREMENTS IN THE MARGIN OF THE FENNOSCANDIAN PGR (FGI)

In December 2007 the FGI made absolute gravity measurements at the ECGN (European Combined Geodetic Network) stations Borowa Góra (Poland), Vilnius (Lithuania), and Riga (Latvia). All stations have been previously occupied by the FGI in various bilateral and European projects. These measurements are used to monitor the stability of the national gravity reference of the countries, to provide information on PGR in its marginal area, and to maintain the European Reference Frame in gravity, height, and 3-D position. In Poland measurements were also made in Wladysławowo and in Ksiaz. Wladysławowo is an ESEAS tide gauge site previously measured by FGI in 2004 and 2005, and Ksiaz an underground laboratory with long water-tube tiltmeters. The cooperation partners are Institute of Geodesy and Cartography (Warsaw), Space Research Centre (Warsaw), Vilnius Gediminas Technical University, University of Latvia, and the Latvian Geospatial Information Agency.

GRAVITY MEASUREMENTS IN NORTHWEST RUSSIA (FGI)

In 2007, the FGI measured with TsNIIGAiK (Moscow) absolute gravity in Pulkovo close to St. Petersburg and in Lovozero in the Kola Peninsula. These stations are fundamental points of Russian geodetic control, with continuous GNSS measurements. A future repeat of the absolute gravity would allow conclusions about the PGR at these sites.

ENVIRONMENTAL EFFECTS IN GRAVITY (FGI)

In this project, the main subjects are hydrology and the Baltic Sea. For terrestrial water storage, it is useful to distinguish between (i) the local effect and (ii) the regional and global effects. The local effect is caused by the Newtonian attraction of very close water. In flat topography on shallow aquifers it is sufficient to consider only the area within 100 m from the gravity sensor. The regional and global effects are mainly due to vertical deformation caused by large-scale variation in the water load. In them the Newtonian attraction only enters through Earth curvature.

The main tools in the hydrological studies are the superconducting gravimeter TT020 at the Metsähovi Geodetic Observatory [25, 26, 27, 28, 29, 30], and the gravity satellite GRACE [31, 32, 33, 34]. In Metsähovi the typical seasonal variation in gravity as observed by the TT020 is 60 to 80 nm s^{-2} peak-to-peak. Depending on the hydrological model used, at least 1/3 of the variation is explained by regional and global loading. As the local effect and the regional/global effect are nearly in phase, it is not possible to separate them in the gravity record using statistical methods, e.g. regression on a local indicator like groundwater level. Physical modelling of the local effect is required. Metsähovi has three borehole wells in fractured bedrock. In 2006 the Finnish Environment Institute installed two arrays of TDR sensors for soil moisture at about 30 m distance from the gravimeter. In 2008 the Laboratory of Geoenvironmental Engineering of the Helsinki University of Technology installed 10 more TDR arrays at 30…100 m from the gravimeter. A 20x20 m^2 grid for soil resistivity measurements with 441 electrodes was constructed. Plans for the installation of groundwater tubes in soil, and for extensive soil sampling were drawn up.

FGI continues to use GRACE data for the study of gravity effects of regional hydrology [35] in cooperation with the Finnish Environment Institute. The water level in the Baltic Sea [36, 37, 38, 39, 40, 41] is studied in cooperation with the Finnish Institute of Marine Research (now the Finnish Meteorological Institute).

Methods to correct absolute gravity measurements at field sites for environmental effects were investigated [42]. Baltic sea and regional hydrology are straightforward to deal with. Local hydrology is problematic since collecting sufficient data for modelling is so laborious that it only is practicable on a limited number of stations.

The work was partly funded by the Academy of Finland.

GRAVITY MEASUREMENTS IN THE ANTARTIC (FGI)

Results of absolute gravity results made in the Antarctic by the FGI and other teams were compiled and compared with observed vertical rates, and with rates predicted from PGR models [43, 44, 45, 46, 47].

Figure T9. Irina Sadkovskaya and A. Eichwaldista from VNIIM visiting the MIKES pressure laboratory.

MAINTENANCE OF THE CALIBRATION LINE (FGI)

The FGI maintains the Masala-Vihti calibration line for relative gravimeters. In 2008 the endpoints of the line were remeasured with the absolute gravimeter FG5-221. The vertical gradient of gravity was determined as a function height at all 6 stations of the line. Thus the FGI can now provide the users with the gravity differences between the stations at any height between 0.05 and 1.3 m above the station markers. This is apparently unique.

A remove-restore procedure was developed for dealing with the influence of piers and other very close density anomalies on the vertical gradient.

Comparisons

INTERNATIONAL COMPARISONS

MIKES

EUROMET-T.K6 Key comparison in humidity (dew-point temperature): MIKES coordinated the key comparison which has participants from 23 countries (AT, CH, CZ, DE, DK, ES, FI, FR, GB ,GR, HR, HU, IE, IT, NL, NO, PL, PT, RU, SE, SI, SK, TR, ZA). The comparison was realised in three parallel loops piloted by MIKES, VSL and METAS. MBW Calibration Ltd delivered the first of six chilled mirror hygrometers used as the transfer standards. All measurements were completed in January 2008. The draft B report was delivered to CCT in January 2009. The expanded uncertainties of the comparison reference values are between 5 mK and 18 mK, which indicates that the exercise was very successful. Also the results of MIKES are very good.

EURAMET.M.M-K2: EURAMET key comparison of multiples and sub-multiples of the kilogram. Participants: most EURAMET members. The final report is waiting for the link to CCM.M-K2 comparison. The results of MIKES were in agreement with other participants. The stability of some of the transfer standards was not sufficient.

EURAMET.M.M-K4: EURAMET key comparison of 1 kg standards in stainless steel. Participants: BE, CH, CZ, DE, DK, ES, FI, FR, GB, HU, IE, IS, IT, NL, NO, PT, SI, TR. The final report has been published. Results of MIKES were in good agreement with other participants.

EURAMET 832: Comparison of 50 kg weights between MIKES, Metrosert, LNMC, JV and EIM. A link to CCM key comparison CCM.M-K3 from PTB. MIKES was the pilot laboratory. The final report has been published: The Results of MIKES were in agreement with other laboratories. [48].

EUROMET.T-S2: Comparison of Realizations of the Indium Freezing Point, participants: JV, LNE, BEV, SMD, METAS, CMI, PTB, DTI, CEM, EIM, MIKES, NPL, INRIM, VSL, IPQ, SP, SMU, MIRS/FE-LMK, UME, GUM. [49].

EUROMET 412: Intercomparison of local realizations of the ITS-90 above the silver point, participants: PTB, CEM ,BNM-LNE, MIKES, NPL, OMH, IMGC, NMi, IPQ, SP, SMU, UME and CSIR.

EUROMET 552, Key comparison EUROMET T-K3: Comparison of the realisations of the ITS-90 from 83.8058 K to 692.677 K, MIKES results are good. [50].

EUROMET 820: Comparison of realisations of the ITS-90 at the freezing points of Al and Ag, participants PTB, BEV, FSB, TekIn, MIKES, BNM/INM, EIM, OMH, IMGC, NMI/VSL, JV, IPQ, INM, CEM, SP, SMU, MIRS, METAS, UME, NPL. MIKES results are good. [51].

EUROMET 844: Intercomparison of copper fixed-point cells by using Pt/Pd thermocouples, participants PTB, BEV, CEM, CMI, EIM, GUM, INM, LMQ, LPM, MIKES, NMI, NMS, SP, UME. The MIKES results differ from the mean by less than 50 mK, which is very good. [52].

A trilateral comparison between MIKES, Metrosert in Estonia and FORCE Technology in Denmark was arranged in 2006 in gauge pressure range from -2000 Pa to +2000 Pa. The transfer standard was not as stable as expected, and the uncertainties of some reference values were high. However, a good agreement was found [53].

EUROMET 881: A comparison in the gauge pressure range from 50 MPa to 500 MPa between MIKES, CMI of the Czech Republic, Metas of Switzerland, NMi of the Netherlands and Later PTB of Germany, SMD of Belgium and SP of Sweden was carried out in 2005 – 2007. The project, coordinated by MIKES, was registered as EUROMET No. 881. The final report was published [54] and presented as a poster in the IMEKO conference in Merida, Mexico [55]. The preliminary results show a good agreement of the results from all the participants.

A barometric pressure comparison between MIKES, Vaisala and LNE was carried out in 2007. Vaisala Oyj is a well known manufacturer of barometers and other weather monitoring instruments. The results of the comparison give a strong support on the planned lower uncertainties for MIKES and the measurement standards laboratory of Vaisala [56].

The pressure laboratory of VNIIM in St. Petersburg, Russia is developing a new laser interferometric oil manometer for low absolute and gauge pressures. In February 2008 a comparison between MIKES and VNIIM was arranged in the range from 10 Pa to 1300 Pa absolute and gauge pressure (Fig. T9). The results were published in a Russian technical journal [57].

EURAMET 1047: The EURAMET key comparison in the range 0.5 Pa – 15 kPa, gauge and absolute, was started in 2008. The project is coordinated by CMI of the Czech Republic. In the first phase the non-rotating digital piston gauge DHI FPG 8601of CMI is serving as the transfer standard. MIKES carried out the measurements with its similar FPG piston gauge during September – October 2008 at CMI.

CCT-K6 Key comparison of humidity standards: MIKES carried out its measurements of the comparison and reported the results in 2004. The other partners are in the order of the comparison scheme: MIKES (FI), IMGC (IT), INTA (ES), NIST (USA), SPRING (Singapore), NRCCRM (China), VNIIM (RU). The measurements are expected to be completed in 2009.

EUROMET 715: Investigation on frost-point temperature scales and comparison of standards: To study the performance of the low frost-point generators, a comparison between IMGC (IT), CETIAT (FR), VNIIM (RU) and MIKES was initiated in 2002. IMGC provided the transfer standard hygrometer and is the pilot laboratory. Due to problems with the hygrometer, all laboratories will repeat their measurements. The measurements were re-started in summer 2006. MIKES carried out measurements in January and February 2007. No results have been published yet.

EUROMET 717: Comparison in dew-point temperature (high range): A dew-point comparison in the range +20 °C to +90 °C has been agreed by 16 laboratories from the following countries: AT, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, NL, PL, SI, SK, TR. The project is coordinated and piloted by PTB. MIKES will carry out measurements in 2009.

EUROMET 906: In this project a bilateral comparison between UME (Turkey) and MIKES in Finland was carried out in 2006 using two chilled mirror hygrometers as the transfer standards. The mean difference between the laboratories is within ±0.15 °C in the whole dew-point temperature range –20 °C to +60 °C. The estimated expanded uncertainty (k=2) of the difference is 0.20 °C at 20 °C and 40 °C, and 0.30 °C elsewhere. The results were published in [58].

The EURAMET 806 comparison of low pressure gas flow facilities using a molbox1/molbloc transfer package was completed and final results were published. Partners in the order of the comparison scheme were: NEL (UK), EIM (GR), NMi (NL), CMI (CZ), INRIM (IT), MIKES (FI), METAS (CH), PTB (DE), LNE (FR), FI (DE) and UME (TR). The results of the comparison showed that the normalized difference (D_n) between calibration results at MIKES compared to the reference value of the comparison were 0.5 at the maximum. That shows an excellent performance of the MIKES primary standard for small gas flow rates and uncertainty calculation methods.

EURAMET 1024: This project was initiated to be a continuation of the EURAMET 806 project. The project is piloted by LNE and MIKES. It covers the gas flow rates from 25 l/min to 100 l/min.

LAHTI PRECISION

The annual bilateral comparisons in force and torque with PTB and SP were again realized in 2007 and 2008. The results of these comparisons proofed the laboratories uncertainty level. Furthermore the comparisons showed the very good long term stability of the laboratories 1 MN hydraulically amplified force standard machine.

The CCM.F-K1a and b Force key comparison dealt with the 5 kN and 10 kN step. The Lahti Precision Force and Mass Laboratory worked as the pilot laboratory. The report was finalized in end of 2008, but it is still listed as Draft B on the BIPM web page. The comparison proofed the laboratory's own uncertainty level.

EURAMET.M.F-K1: The Lahti Precision Force and Mass Laboratory piloted also the EURAMET key comparison equivalent to the CCM.F-K1. Also this EURAMET 535 project was reported in the end of 2008, and is listed as Draft A. This regional key comparison within EURAMET should be repeated in the near future, as the number of participants in the first run was very small.

CCM.F-K2: The Lahti Precision Force and Mass Laboratory participated also in the CCM.F-K2 a and b key comparison at the 50 kN and 100 kN point, where NPL acts as the pilot. The measurements for that comparison have been done in 2007. The report was in draft A status by the end of 2008. The results of Lahti Precision were very good as they had a very low deviation to the mean values of the comparison.

CCM.T-K2 : In 2008 started the measurements for the torque key comparison at the 10 kN·m and 20 kN·m load points with PTB as the pilot laboratory. The measurements at the Lahti Precision Force and Mass Laboratory will be done in spring 2009.

Within the CFI the Lahti Precision Force and Mass Laboratory organised a comparison for torque tool calibrations. The comparison was intended for laboratories (accredited and non-accredited) that calibrate torque wrenches and other torque tools. The measurements took place between autumn 2007 and spring 2008. The report was still under work in the end of 2008.

FGI

European comparison of absolute gravimeters (November 2007): This was a EURAMET pilot study in anticipation of the MRA key comparison at BIPM in September–October 2009. Twenty gravimeters from 16 countries participated. The laboratory has 16 piers. Each gravimeter occupied 3 of them in a designed configuration. The result of the FG5-221 was close to the reference value of the comparison (Fig. T10).

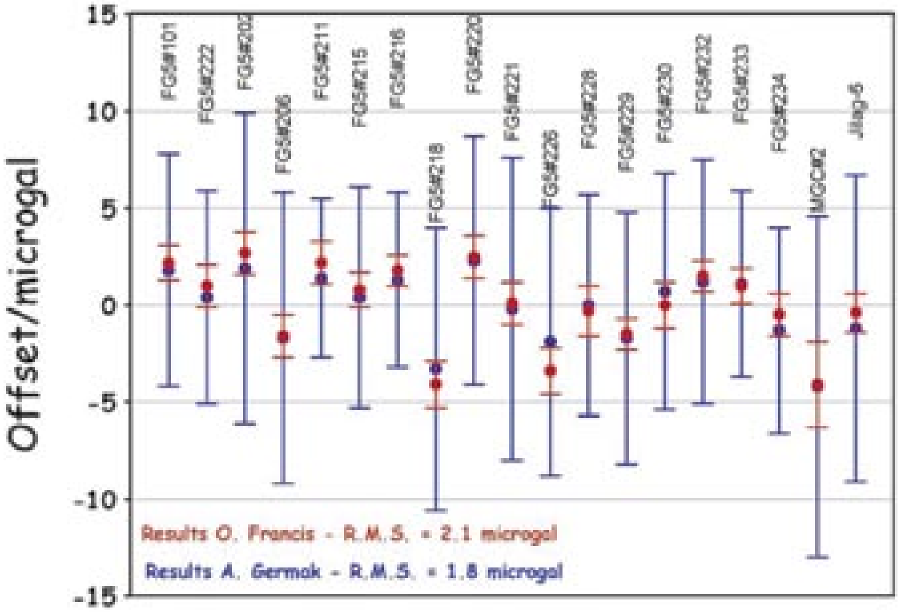


Figure T10. Results of the European comparison of absolute gravimeters, Walferdange, Luxembourg, November 2007. The unit is microgal (μgal); 1 μgal = 10 nm s^{-2}. The FGI gravimeter is FG5#221. Two different methods of evaluation were applied. Error bars by O. Francis are one-sigma and only include the standard deviation of the results between the three sites occupied. Error bars by A. Germak combine the standard deviation with the uncertainties provided by the participating team at each site and give the expanded uncertainty at the 95 % confidence level [59].

7th International Comparison of Absolute Gravimeters (ICAG-2005). The report was submitted to publication. The result of the FG5-221 of FGI was very close to the reference value of the comparison [60].

Within the Nordic Absolute Gravity Project, gravimeter FG5-221: Bilateral comparisons with the IfE (gravimeter FG5-220) were made at Metsähovi in July 2007 and in May 2008. Bilateral comparisons with Lantmäteriet (gravimeter FG5-233) were made in Metsähovi in March 2007 and in September 2008.

Within the absolute-gravity campaign in Northwestern Russia, gravimeter FG5-221: Bilateral comparisons were made in June 2007 with the TsNIIGAiK (gravimeter FG5-110) at both Pulkovo and at Lovozero.

NATIONAL INTERCOMPARISONS

A comparison between MIKES and the measurement standards laboratory of Vaisala was carried out in 2007. The range in the comparison was absolute pressure from 10 Pa to 5000 Pa absolute [61].

An intercomparison in the barometric pressure range from 50 kPa to 110 kPa for the Finnish pressure laboratories was arranged in 2008. Four laboratories participated and the results will be published in 2009.

In 2007, MIKES arranged a national interlaboratory comparison on thermocouple calibrations in the range from 0 °C to 1000 °C [62].

A comparison on calibration of Pt-100 thermometers was arranged by MIKES in 2008. Measurements were done in the range between -80 °C and 200 °C [63].

Microbalance comparison for accredited laboratories. Five participants from three accredited laboratories [64].

Length

Personnel
MIKES

Dr. Antti Lassila	*Principal Metrologist, Group Manager*
M.Sc. Veli-Pekka Esala	*Senior Research Scientist*
Dr. Björn Hemming	*Senior Research Scientist*
Lic.Sc. Heikki Lehto	*Senior Research Scientist*
Dr. Mikko Merimaa	*Senior Research Scientist*
Dr. Kaj Nyholm	*Senior Research Scientist*
Dr. Markku Vainio	*Guest Research Scientist at NRC 2008*
M.Sc. Virpi Korpelainen	*Research Scientist*
M.Sc. Ilkka Palosuo	*Research Scientist*
M.Sc. Jarkko Unkuri	*Research Scientist*
M.Sc. Ville Ahtee	*Research Scientist*
M.Sc. Tuomas Hieta	*Research Scientist*
M.Sc. Jeremias Seppä	*Research Scientist*
Mr. Raimo Mylläri	*Research Assistant*
Mr. Ilkka Raeluoto	*Research Assistant*
Mr. Asko Rantanen	*Research Assistant*
M.Sc. Aarni Iho	*Student (2007)*

FGI

Prof. Markku Poutanen	*Head of Department of Geodesy and Geodynamics, Quality Manager*
Lic.Sc. Jorma Jokela	*Specialist Research Scientist, Head of Laboratory*
Dr. Mikko Takalo	*Specialist Research Scientist (retired in April 2007)*
M.Sc. Paavo Rouhiainen	*Senior Research Scientist, Deputy Head of Laboratory*
M.Sc. Joel Ahola	*Senior Research Scientist*
M.Sc. Pasi Häkli	*Senior Research Scientist*
M.Sc. Ulla Kallio	*Research Scientist (since May 2008)*
M.Sc. Jyrki Puupponen	*Research Scientist (until December 2008)*

According to the Finnish National Standards Laboratory scheme, realisation and maintenance of the units of length and development of length metrology are responsibilities of MIKES and the Finnish Geodetic Institute (FGI).

The MIKES length group realises units for length, flatness, straightness, roundness, cylindricity, surface roughness, and angle and carries out research, development projects, and training within its field. The length group also develops and offers services on co-ordinate measuring machine metrology. The operation of the FGI is based on its own legislation. FGI operates as a National Standards Laboratory for geodetic length measurements. Measurement standards of FGI in geodetic measurements include quartz meters, Väisälä interferometer geodetic baselines, precision tacheometers and other high precision electronic distance measurement instruments, laser interferometers, and comparators for levelling rods. FGI maintains traceability for geodetic measurements and performs high precision measurements and calibrations for various geodetic applications.

The MIKES length group and FGI made altogether 454+489 (2007+2008) calibration certificates for over 250 different customers in accredited laboratories, research institutes, and industry during 2007-2008. The total number of calibrated measurement standards and devices was approximately 4000.

Highlights in 2007-2008

Figure L1. Delegates of EURAMET TC-L meeting 2008 at MIKES.

EURAMET LENGTH TECHNICAL COMMITTEE 2008 MEETING AT MIKES

From 6th to 8th of November EURAMET Technical Committee of Length had its annual meeting at MIKES. 31 delegates from 28 European Metrology Institutes, Egypt and BIPM were represented (Fig. L1). During the last day, a workshop presenting recent developments in laboratories was hold.

MIKES INTERFEROMETRICALLY TRACEABLE METROLOGY AFM OPERATIONAL

MIKES interferometrically traceable metrology atomic force microscope (IT-MAFM) is now operational [65]. A lot of work was done in mechanical design and construction, electronics and in software development. 3D interferometers, piezo stage, AFM head, optical microscope and stepper motors were integrated by self-designed metrology frame and controlled by our own measurement software. An accurate method for the detection and correction of periodic nonlinearity of the laser interferometer was developed and integrated in the measurement software. The IT-MAFM was used in international comparison of step height and pitch standards for scanning probe microscopes (SPM, Fig. L2).

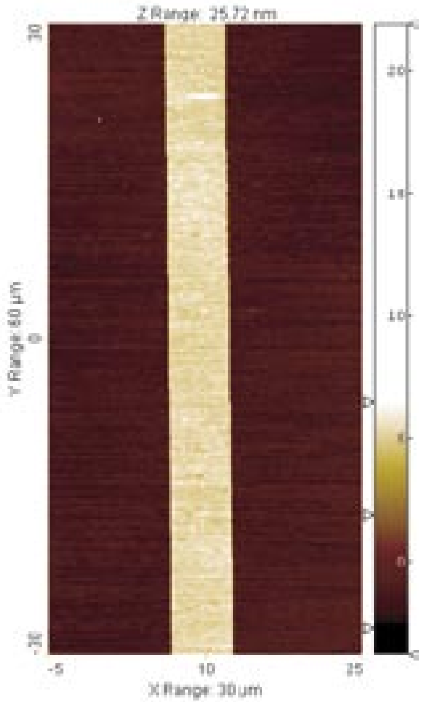


Figure L2. Measurement of a 7 nm step height standard by IT-MAFM.

NEW INTERFERENCE MEASUREMENTS AT THE NUMMELA STANDARD BASELINE (FGI)

For more than 60 years now, the Nummela Standard Baseline has been one of the most accurate geodetic measurement standards in the world. During the first decades it was used for calibration of invar wires and thereby to determine the scale of triangulation network and maps. Nowadays the most precise distance meters are calibrated there, enabling traceable scale transfer to geodetic baselines and test fields around the world. In 2007–2008 such measurements were performed e.g. in Austria, Estonia and Lithuania and at the Olkiluoto nuclear power plant test field. The Nummela Standard Baseline is also utilized in the European Metrology Research Project (EMRP) in validation of new absolute distance measurement methods.

The Nummela Standard Baseline is unique because of its length, accuracy and stability. The length, 864 122.8 mm, can be determined with 0.1 mm standard uncertainty with the Väisälä (white light) interference comparator (Fig. L3). The rare measurement method needs extremely stable weather conditions and is rather laborious.

In autumn 2007 the Nummela Standard Baseline was measured for the 15th time with the Väisälä comparator, 11 years after the previous measurements of the entire baseline. The weather conditions were "exceptionally normal", and the distance of 864 metres was measured an unprecedented eight different times during the cloudy October and November nights. Before this, the first half, 432 metres, had already been measured three times. New results are very well compatible with the results of year 1996 for the entire baseline and with the results of seven measurements of the first half in 2005. Throughout the 60 years time series, the maximum variation of the 864 metres has been 0.6 mm. The measurements at Nummela are traceable to the definition of the metre via the quartz gauge system of Tuorla Observatory of University of Turku, reference quartz metres of which have been calibrated by MIKES long gauge block interferometer. The latest comparisons of quartz gauges were performed at Tuorla in March and December, 2007. The length of the quartz gauge no. VIII, that brings the scale to the Väisälä comparator at Nummela, is (depending on the temperature) about 1.000 151 metres and known with about 40 nanometres standard uncertainty.

Figure L3. Pasi Häkli and Martin Rub are installing the Väisälä comparator for interference measurements at the Nummela Standard Baseline.

Figure L4. The main benchmark of the new Finnish height system N2000 is buried under a granite monument. The radome of the VLBI telescope is in the background.

N2000 HEIGHT SYSTEM (FGI)

The new Finnish height system N2000 [66] is a great application of geodetic length metrology. It is based on the third national precise levelling in 1978–2006 [67] and tied to modern European height systems. The N2000 system, introduced in 2007, replaces the previous N60 system, and is now the basis for all surveying and mapping in Finland in vertical direction. The main benchmark of the new system is buried under the granite monument at the Metsähovi Research Station (Fig. L4).

Development in reference frames and other advances, including related geodetic metrology, is reported in the annual EUREF Symposia. The latest published report is from Riga 2006 [68]; reports from London 2007 and Brussels 2008 are in preparation. A report was written also for the IUGG General Assembly in Perugia 2007 [69].

WORKING PREMISES (FGI)

A new metrology laboratory room was built on the first floor of the main building of FGI in Masala in 2008. The room is equipped with pillars and benches for gravity and length measurements. It replaces the old gravity laboratory room in the basement floor, which was turned over to a remote sensing laboratory room.

Reconditioning of the Nummela Standard Baseline was continued by renewing the observation pillars in 2007.

MIKES LENGTH NODE LABORATORY IN CCL-K11

The key comparison CCL-K11 is designed to provide a basis for demonstrating equivalence of national realizations of wavelength standards used for the practical realization of the definition of the SI-metre. Hence, it provides a technical basis for the review of CMC (Calibration and Measurement Capabilities) in the field of standard based optical frequency/wavelength calibrations especially for those that are given under the following entries in the list of "Classifications of services in length": *1.1.1 Stabilized laser of the "mise en pratique"; 1.1.2 Other stabilized lasers*. The CCL-K11 is the successor of the BIPM.L-K11 (K10) key comparison. The pilot laboratory of the comparison is BEV from Austria. In addition to the pilot laboratory, measurements are carried out in four node laboratories in the different regional metrological organizations. MIKES is one such node laboratory.

The introduction of optical frequency combs enabled standards of different wavelengths to be measured with direct traceability to the SI-second in a straightforward manner [70]. Therefore, the CCL-K11 was broadened to include also other wavelengths important in dimensional metrology than the 633-nm iodine-stabilized standards [71]. In addition to absolute frequency measurements using an optical frequency comb, CCL-K11 allows two alternative methods: matrix measurement and direct frequency heterodyne measurements in which only the difference in frequency between two standards is measured. At MIKES all of the three methods are available but absolute frequency measurement using the MIKES frequency comb generator is the primary one.

MITTAUKSET KONEPAJASSA –SEMINARS 2007, 2008 (MIKES)

A seminar on Measurements in workshop was arranged on 7-8 June 2007 by MIKES in Espoo. The amount of participants was more than 80. This time the theme was dimensional measurements in general. Lectures came from industry, calibration laboratories, universities and MIKES. On the second day the following nearby institutes were visited: VTT, Inspecta and MIKES.

On 5-6 June 2008 the seminar was arranged for 116 participants in Imatra by Etelä Karjalan mittauskeskus Oy. The theme was measurements of large objects.

MIKES RESEARCHERS ABROAD

Two researchers from the length group have been working abroad in other NMIs: Virpi Korpelainen as a guest researcher in NMIJ/AIST Japan and Markku Vainio as a postdoc researcher in NRC Canada.

Virpi Korpelainen was working four weeks in Japan in October 2007. As a start of a nanoparticle project at MIKES, she was learning nanoparticle measurements at NMIJ/AIST.

Markku Vainio started as a guest researcher at NRC in August 2008 (Fig. L5). During his one-year visit he participates in research of two optical atomic clocks: a clock based on a single Sr-ion and a clock based on multiple neutral Sr atoms trapped in an optical lattice.

DISSERTATION IN MACHINE VISION (MIKES)

M.Sc. Björn Hemming successfully defended his doctoral thesis "Measurement Traceability and Uncertainty in Machine Vision Applications" [72, 73, 74] on 17 December 2007. Prof. Leonardo De Chiffre from Department of Mechanical Engineering of Technical University of Denmark and Prof. Heikki Tikka from Department of Production Engineering at Tampere University of Technology were acting as opponents (Fig. L6). Prof. Erkki Ikonen was the custos.

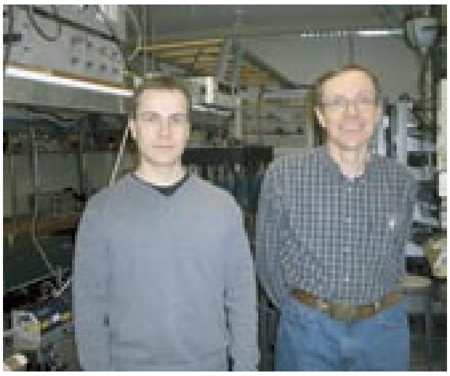


Figure L5. Markku Vainio (left) and John Bernard, Group Leader, Frequency and Time Standards of National research council Canada.

Figure L6. Björn Hemming (right) and opponents H. Tikka (left) and L. De Chiffre (middle).

Research Projects

JRP NEW TRACEABILITY ROUTES FOR NANOMETROLOGY, NANOTRACE (MIKES)

The joint research project (JRP) aims to 10 pm accuracy of displacement metrology namely by refined optical interferometry [75]. The challenge is an uncertainty reduction of one order of magnitude with respect to the present state of the art. The project started in April 2008 as a joint research project between seven European NMIs and it is piloted by INRIM (Italy). MIKES is developing phase measurement of interference signals by utilising time difference measurement and by combining an interferometer with a capacitive sensor in order to do cross linearization. During 2008 first version of an averaging phase meter setup for a heterodyne interferometer was designed and constructed. The setup includes electronics and a programmable frequency counter. The electronics consists of two channels with mixers, band pass filters, a mixer frequency generator, a reference frequency generator and a phase shifter. Preliminary tests show that the phase resolving power target is achievable. The project is a consortium of seven national metrology institutes (INRIM, MIKES, BEV, CMI, NPL, PTB and UME).

JRP ABSOLUTE LONG DISTANCE MEASUREMENT IN AIR (MIKES, FGI)

Within the EMRP targeted program for length, MIKES and FGI participate in the joint research program "Absolute long distance measurement in air" [76]. New methods and instruments for long-range, 10 m to 1 km, distance measurements at 10^{-7} relative uncertainty are needed in engineering industry, nuclear industry, and geodetic surveying. For example, in aviation industry it is important to know very precisely the geometry of the airframe to optimize fuel efficiency of an aircraft. Nuclear industry, on the other hand, has to know the integrity and stability of the bedrock at nuclear waste disposal sites, which can be assessed through careful measurements of small movements of the earth's crust. In geodetic surveying, lower uncertainty in long-distance measurements would allow improved predictions of earthquakes and volcanic activity as well as improved investigations on the uncertainty of satellite positioning systems. However, practical devices capable of measuring 1 km distances at an uncertainty of 1 mm do not exist today. To reach the goal of the project many approaches, including optical frequency combs, synthetic wavelengths, and two-colour interferometry, are investigated. However, accurate measurement of the refractive index of air is essential in all cases. In the project, two methods to measure the refractive index are investigated: two-colour interferometry and spectroscopy. MIKES is developing the spectroscopic method to measure the average air temperature and humidity over long distance (Fig. L7).

Figure L7. Test setup for spectroscopic air temperature measurement on MIKES 30 m interferometric bench.

The recently re-measured Nummela baseline of the FGI is practically the only place in the world where smaller than 0.1 mm standard uncertainty over 1 km distance can be realized with the Väisälä interference comparator and the baseline will be used to validate the methods developed in this project [77]. In September 2008 one more baseline was prepared, when the FGI and BEV calibrated the BEV baseline in Innsbruck, Austria, using a high-precision EDM instrument as a transfer standard. The 1 080 m baseline is a slightly curving break-line of seven observation pillars. Projections and calibrations were successfully performed in favourable weather conditions before and after the scale transfer. Eight calibrations "double-in-all-combinations" were performed at Nummela, which means 240 measurements, each of them consisting of at least two single observations. In Innsbruck the environment and weather were more challenging, but also there preliminary results seem to be reasonable. Four calibrations including 168 measurements were performed there. After weather corrections, before any adjustments, daily variations in observed distances are smaller than 1.6 mm, being largest for the longest distances, especially to/from pillar no. 7 in divergent surroundings. Location of the baseline between a busy motorway and a fast-flowing river next to a mountain wall form a challenging environment for further research.

The project is a consortium of nine national metrology institutes (LNE, MIKES, FGI, BEV, CEM, CMI, INRIM, NMi VSL, and PTB).

JRP OPTICAL CLOCKS (MIKES)

Primary frequency standards are in the midst of the greatest period of change since the introduction of the caesium atomic clock in 1950's. This is due to the optical frequency comb generator, which has opened a way for the optical atomic clocks. Use of an optical clock transition at hundreds of THz has the potential for a performance improvement by several orders of magnitude. Several groups already claim uncertainty budgets well below the 10^{-16} level, clearly exceeding the uncertainty of the best radio frequency clocks. It is also reasonable to expect that the definition of the second will eventually reflect this progress. This project is established to study reproducibility of optical clocks developed at various institutes, to study systematic effects affecting the clock transition, and to design an advanced optical clock. The MIKES contribution in the project will be in the form of researcher exchange.

The project is a consortium of five national metrology institutes (LNE, MIKES, PTB, NPL, and INRIM).

NANOMETROLOGY (MIKES)

As a part of MIKES nanometrology project, a laser diffactometer was developed for accurate characterization of grating pitch. The basic principle of the measurement is simple: the sample, which is mounted on a rotary table, is rotated so that diffracted beam traces back to the direction of incident beam (i.e. fulfils the Littrow condition). The grating pitch is calculated from the diffraction angle, diffraction order and wavelength of the laser light. The requirements for accurate measurement are accurate detection of the diffracted angle and of the Littrow condition. In the MIKES setup we use a CCD camera to detect the diffracted beam position. A self-calibration method based on error separation and on the use of an uncalibrated grating was developed for the angle scale calibration. [78, 79, 80].

Surface metrology activities included also material research in two separate projects. In co-operation with Nokia Research centre Dynamical Nonlinearities in Piezoelectric Materials were studied [81, 82]. Together with VTT tribologists surfaces of steel and silicon nitride rolls were investigated [83].

SINGLE-FREQUENCY SYNTHESIS AT TELECOMMUNICATION WAVELENGTHS (MIKES)

This project, funded by the Academy of Finland, was completed in 2008. The project yielded a frequency synthesiser capable of generating a single user-specified frequency within the 192–196 THz bandwidth of an erbium-doped fibre amplifier from an atomic time base [84, 85, 86]. Further, a fibre-based acetylene-stabilized laser was developed in the project to allow performance characterization of the synthesizer [87, 88].

Unlike conventional frequency comb generators that produce a multitude of frequency components, the developed device provides a single frequency, directly suitable for e.g. high precision component characterisation and spectroscopy. Advanced frequency measurement technologies are required for the development of modern optical networks, as their characteristic features are high component count, high spectral efficiency, narrow tolerances, and need for interoperability. Examples of today's optical network components, which characterisation requires high frequency accuracy, are lasers, fibre gratings, and dense wavelength division multiplexers. The frequency synthesizer makes directly traceable frequency measurements at the telecommunications range possible.

We have also used the synthesizer to do absolute spectroscopy of Doppler-free acetylene lines at 1.55 μm and rubidium lines at 780 nm. In measurements of the acetylene lines we have investigated mechanisms affecting the symmetry of the line and, consequently, the frequency of a stabilized laser. We have used the directly measured spectroscopic data to calculate the line centres and the results agree with the CIPM values.

STEP GAUGE INTERFEROMETER (MIKES)

From the beginning of 2008, a project for implementing a new interferometer for step gauges has been running. The target is a measurement capability of gauges up to 2 m with expanded uncertainty of less than 200 nm/m. The operating principle of the instrument has been designed. It will be a four-pass homodyne interferometer with two plane mirrors symmetrically on both sides of the tactile probe. Used geometry will eliminate the Abbe error. The mirror probe combination will have a piezo driven angular position control. The feedback comes from a detector measuring the position of the back reflected laser beam. In addition to interferometrically measured movement, the tactile probe will also have vertical and horizontal movements to allow it to move to the next gap between the gauges and to be able to measure parallelism of the gauge faces. A stone table having a rail for air carriage with air bearing and a table for gauge and optomechanics was specified, ordered and received from manufacture (see Fig. L8). The components for short linear movements of the probes were designed and acquired. The hardware implementation will continue in 2009 and the making of the measurement software will be started.

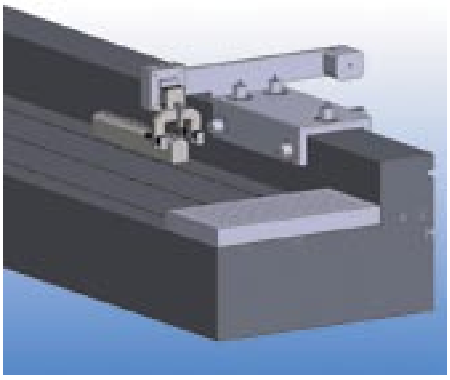


Figure L8. Preliminary CAD drawing of the designed step gauge interferometer.

ANGLE METROLOGY (MIKES)

In angle metrology project, the angle setup was redeveloped to be suitable for calibration of vertical angle scale of total stations. Also a method for studying back lash of rotational movements of laser trackers was developed (Fig. L9).

CORRECTION OF CMM MEASUREMENTS BY CALIBRATION DATA (MIKES)

Procedures and operation manuals for ball plate measurements and CMM calibration with a ball plate have been finalised. Three different methods for the characterisation of errors of a CMM were compared in calibration of MIKES CMM. Substitution method for measurement and uncertainty evolution is taken

Figure L9. Characterisation of a laser tracker with angle setup.

into use as one alternative. Studies to use Monte Carlo analysis for uncertainty estimation was performed. A calibration tool, which utilises a sphere, a gauge block, a linear rail and a laser interferometer, was developed and tested for calibration of large coordinate measurement machines.

MID-INFRARED SPECTROSCOPY (MIKES)

In this project, Gasmet Technologies Oy and MIKES are developing a quantum cascade laser based mid-infrared spectrometer. Rapid progress in the development of quantum cascade lasers has made the mid-infrared spectroscopy increasingly interesting e.g. for life sciences, environmental monitoring, emissions monitoring, and atmospheric research. The importance of the mid-infrared region, the so-called molecular fingerprint region, stems from the strength and richness of the molecular lines at this wavelength region. Sensitivity and selectivity of trace gas detection can be improved by several orders of magnitude simply by using mid-IR spectroscopy instead of the conventional techniques at shorter wavelengths. The wavelength region between 2.5 µm and 5 µm is important from the practical point of view due to gaps in the absorption spectra of water and CO_2, as an excessively strong water and CO_2 absorption easily obscures weaker absorption lines of other trace gases. The main objective of the project is to demonstrate feasibility of a simple quantum-cascade laser based mid-infrared spectrometer for the detection of trace gases that are difficult to detect with conventional means.

MEASUREMENT DEVICE FOR TREE DIAMETER (MIKES)

Tree diameter is perhaps the most important measured variable in forest industry. Diameters are used in forest planning, in generation of forest resource inventory, and in timber measurements. In models describing the growing stock, the tree diameter at breast height is the most common independent variable. Decisions concerning forest management procedures, such as silviculture treatments, thinnings and final cuttings are often made either directly or indirectly from the gathered tree diameter measurements. Tree diameter has been traditionally measured using mechanical measurement devices that require the measurer to visit each tree. In this project a device for remote image-based measurement of tree diameter was designed and constructed. The developed device is based on a combination of a digital single-lens reflex camera, a laser line generator and a custom-made computer for the image processing. Structured light, a laser line on the surface of the target, is applied to aid the recognition of the target from the background and to provide scale to the measurement.

The goal of the project was to reach 5 mm uncertainty for diameter measurement within measurement distance range from 2 m to 15 m. The developed device was proven functional in laboratory experiments and in a field study conducted by the University of Helsinki, where a total of 728 diameter measurements were made from 265 trees. The standard error of diameter observations using semiautomatic interpretation was 6 mm.

CALIBRATIONS AND BASELINE MEASUREMENTS (FGI)

The Nummela Standard Baseline was used in calibration of high precision EDM instruments before the interference measurements in 2007, and again in 2008 all field work season from May to November. Tacheometry-based projection measurements between the observation pillars and more permanent underground benchmarks are needed for this. Results from 2008 indicate good repeatability in them and stability of the both pillar lines: the differences of average values of projection corrections in May–June (six projections two times) and August–November (six projections four times) are from –0.05 mm to +0.13 mm.

In addition to the measurements for EMRP JRP, international scale transfer measurements were performed to the national calibration baselines in Kyviskes, Lithuania, in August 2007 and October 2008 [89], and in Vääna, Estonia, in October 2008 (Fig. L10). Again, the Kern ME5000 precise distance meter of the Laboratory of Geoinformation and Positioning Technology at the Helsinki University of Technology was used as a transfer standard, calibrated at the Nummela Standard Baseline before and after. All instrument corrections were almost insignificant, which is not the case for most EDM instruments. Now all differences be-

Figure L10. Vääna calibration baseline in Estonia.

tween the measured values and the true differences from interference measurements were within a few tenths of millimetres.

System calibration of digital levelling was a service in demand as usual. Customers were from Nordic and Baltic countries [90].

MEASUREMENTS AT OLKILUOTO (FGI)

Measurements at the control network around the Olkiluoto nuclear power plant and disposal site of spent nuclear fuel have continued semi-annually since 1996 [91, 92]. Together with new extensions the network now covers a large area around towns Rauma and Pori. One of the sides of the original network at Olkiluoto is a 511-m-long baseline, which is measured with both GPS and EDM. The small but significant systematic scale difference between them has activated further investigations.

LOCAL TIES AT GEODETIC STATIONS (FGI)

High precision geodetic coordinate measurements for large structures are a topical task in dimensional metrology. At the Metsähovi research station of the FGI, local tie measurements between the co-located global geodetic fundamental stations were continued. At the moment the work focuses on (up to real-time) millimetre accuracy determination of the vector between the reference points of a permanent GPS station and a VLBI telescope.

In 2007, a network of seven concrete pillars was constructed around the fundamental stations to empower the high-precision tie measurements. It was first measured as tacheometer network with horizontal and vertical angle and distance measurements in June 2008. A local static GPS measurement campaign was carried out in September 2008. The combined network adjustment of GPS vectors and angle and distance measurements was calculated in autumn 2008.

In February 2008, GPS measurements were tested inside the VLBI radome. The results encouraged to install two GPS antennas to the opposite sites of the VLBI antenna plate board in order to be tracked from the pillar points and the IGS reference point (Fig. L11). A schedule of antenna positions was made and two hours static measurements at every antenna position were carried out during normal telescope use in December 2008 and January 2009.

Figure L11. Installing a GPS antenna for tie measurements in the 14 m high VLBI telescope at Metsähovi.

Traditional terrestrial surveying methods combined with engineering techniques have also been tested. After precision simulations the method seemed promising. Since the VLBI telescope is covered by a radome, a small network was measured under it. The network was tied to the pillar network outside of the radome. Some tests with space intersection technique were then performed by measuring reflecting targets fixed on antenna constructions with two tacheometers on different antenna positions. This method proved to be too time consuming and limited by the intensive use of the telescope.

Simultaneous measurements during three geo-VLBI sessions were also performed to track the moving GPS antennas relative to the GPS pillar network. Kinematic solutions of the GPS antenna positions are then used in calculations of the reference point.

Desired millimetre accuracy is difficult to obtain in the varying telescope positions, and the analyses and measurements will continue in 2009.

HISTORY OF GEODETIC METROLOGY (FGI)

A historical DVD-documentary about triangulation was completed [93]. It was partly filmed at the Nummela Standard Baseline, where calibration of invar wires was performed for scale determination. The world premiere was at the FIG Working Week in Stockholm in June 2008 [94].

History is also abundantly presented in the hundreds of photographs in the 90th anniversary publication of the FGI [95].

Comparisons

INTERNATIONAL COMPARISONS

EUROMET.L-K5.2004: Calibration of a step gauge (MIKES)
The pilot laboratory of the comparison is Centro Español de Metrología (CEM) and there are 20 participants in the comparison. The measurement artefact is a step gauge with a steel frame and 11 tungsten carbide gauges. Nominal maximum length of the artefact is 420 mm. Comparison measurements at MIKES were done in November 2006. The pilot laboratory published draft A report of the comparison in October 2008. Results for MIKES were good.

CCL-Nano5: Comparison of 2D gratings (MIKES)
The pilot laboratory of the comparison is DFM from Denmark. The other participants are METAS, PTB, BIPM, NPL, IMGC, NMi, CMI, NIST, VNIIM, NIM, NRLM, CMS, KRISS and MIKES. The pitches of the measured gratings were ~300 nm and ~1000 nm. Orthogonality of the gratings was also measured. The comparison measurements at MIKES were done in December 2005 and March 2006. Report was finished in 2008 [96]. E_n values for MIKES were from 0.06 to 0.41.

APMP.L-K6: 2D CMM artefacts (MIKES)
The pilot laboratory of the comparison is NMIJ from Japan (National Metrology Institute of Japan). There are 14 participants all over the world in the comparison. The measurement artefacts are two-dimensional (2-D) artefacts (Ball Plate & Hole Plate). The first one is a 620-mm steel ball plate, with 5x5 ceramic 22 mm in diameter balls and 133 mm pitch between the ball centres. The other is a 600-mm hole plate made of a low thermal expansion glass, with 44 holes, 20 mm in diameter, and 50 mm pitch between hole centres. The comparison started in May 2006 and ended in October 2007. Comparison measurements at MIKES were done in September and October 2007. The pilot laboratory has not yet published the preliminary results.

EUROMET.L-K7.2006: Line scales (MIKES)
In this key comparison distances between centres of lines will be calibrated on one 100 mm glass line scale. The measurements will be performed in a predefined section. MIKES made measurements early 2007. The comparison is not yet in report phase.

EUROMET #866: Interferometric calibration of microdisplacement actuators (MIKES)
The goal in this co-operation in research project was to exchange experience between NMIs to establish the necessary metrological confidence in the field of interferometric calibration of microdisplacement actuators, possible down to the sub-wavelength range [97]. The pilot laboratory was INRIM (Italy). Other participants were BEV, CEM CMI, CSIR-NML, DFM, LNE, METAS, MIKES, SMD, SMU and SP. The measurements at MIKES were done in February 2007. Report is in preparation.

CCL-K11: Key comparison of optical frequency/wavelength standards (MIKES)
Measurements as part of the new key comparison CCL-K11 were held at MIKES in the period 10–14 December, 2007 for iodine-stabilised He-Ne lasers at 633 nm. The participating institutes (standards) were GUM (GUM1) from Poland and MIKES (MRI3) from Finland. As this was the first measurement campaign within the CCL-K11, Lennart Robertsson from the BIPM acted as an observer during the campaign. Absolute frequency determinations of the 633-nm iodine-stabilized standards were made using the MIKES optical frequency comb generator.

EURAMET #925: Step height and 1D gratings by SPM (MIKES)
The comparison was a subsequent comparison for finished comparisons CCL-NANO2 and EUROMET #707. Two different types of standards were measured by scanning probe microscopes: step height (nominal heights 7 nm, 40 nm, 1000 nm and 2000 nm) and 1D gratings (300 nm and 700 nm). The pilot laboratory in the comparison was PTB. Other participants were INRIM, NMi-VSL and A*STAR. MIKES measured the samples in June 2008. Report is in preparation.

APMP Pilot study: Calibration of EDM (FGI)
Reporting of the results of Asia-Pacific Metrology Programme (APMP) Comparison for pilot study on Calibration of EDM is still in preparation. Final results are now available, and they are consistent. The FGI participated in the comparison between four institutes arranged at the Korea Research Institute of Standards and Science (KRISS) in Daejeon, Korea, in October 2006.

Electricity, Time and Acoustics

Personnel
MIKES

Dr. Antti Manninen	*Principal Metrologist, Group Manager*
Prof. Kalevi Kalliomäki	*Senior Research Scientist, Head of Time and Frequency Laboratory*
Dr. Jari Hällström	*Senior Research Scientist (1.11.2008 -)*
M.Sc. Tapio Mansten	*Senior Research Scientist*
Dr. Jaani Nissilä	*Senior Research Scientist*
Dr. Alexandre Satrapinski	*Senior Research Scientist*
Lic.Tech. Esa-Pekka Suomalainen	*Senior Research Scientist (1.11.2008 -)*
Dr. Ossi Hahtela	*Research Scientist (15.5.2007 -)*
M. Sc. Jussi Hämäläinen	*Research Scientist*
M.Sc. Ilkka Iisakka	*Research Scientist*
M.Sc. Pekka Immonen	*Research Scientist*
M.Sc. Antti Kemppinen	*Research Scientist*
M.Sc. Heikki Koivula	*Research Scientist*
M.Sc. Kari Ojasalo	*Research Scientist*
B.Sc. Risto Rajala	*Research Scientist*
B.Sc. Anssi Rautiainen	*Research Engineer (Permanent position: VTT)*
Mr. Jussi Kaasalainen	*Trainee (2007, 2008)*
Mr. Ville Maisi	*Trainee*
Mr. Johan Nysten	*Trainee (June - August, 2007)*
Mr. Jussi Seppälä	*Trainee (2007, 2008)*

***MIKES-TKK** until 31 October 2008*

Dr. Jari Hällström	*Senior Research Scientist, Group Manager*
Lic.Tech. Esa-Pekka Suomalainen	*Senior Research Scientist, Quality Manager*
M.Sc. Juri Chekurov	*Research Scientist*
Mr. Olli Kara	*Research Assistant*
Mr. Matti Löytty	*Research Assistant*
Mr. Joni Klüss	*Research Assistant*

The Electricity Group of MIKES includes the National Standards Laboratories of electrical quantities, time and frequency, and acoustics (sound pressure). Until the end of October, 2008, MIKES's NSL of electricity included DC voltage, DC current, AC voltage, AC current, resistance, capacitance, electric power, and high frequency quantities, all only at low voltages (< 1 kV) and low currents. Metrology of high voltage quantities (DC and AC voltage and current, capacitance, inductance, impulse voltage, impulse current, apparent charge, ESD discharge) was in the responsibility of Helsinki University of Technology (TKK), Department of Electrical Engineering. However, the National Standards Laboratory of high voltage quantities (MIKES-TKK) was transferred from TKK to MIKES on 1 November, 2008, and the scope of MIKES's NSL of electricity was complemented by maintenance and development of the national standards of high voltage quantities.

National Standards Laboratories are responsible for realisation and maintenance of the units, and they perform active research and development in metrology. The units are disseminated by calibrating standards and devices for accredited calibration laboratories and other customers who need traceable calibrations at the highest level of accuracy. In 2007 and 2008, respectively, the number of calibration certificates written for customers was 68 and 90 at the Electricity Group of MIKES, and 57 and 32 at MIKES-TKK. Several calibrations were performed to customers abroad: MIKES to Estonia and MIKES-TKK to Brazil, Germany, the Netherlands, and Sweden. Co-operation with industry and with other research institutes is continuously expanding towards new forms in addition to calibrations and fundamental metrology (see, e.g., [81, 98, 99, 100, 101]).

Highlights in 2007-2008

HIGH VOLTAGE METROLOGY MOVED FROM TKK TO MIKES

The high voltage National Standards Laboratory started at Helsinki University of Technology (TKK) in 1994, and since then the number of services and the level of metrology research on the area has been recognized worldwide. Successful era of Department of Electrical Engineering of TKK as the NSL of high voltage quantities ended on 31 October, 2008, when the high voltage metrology was incorporated into the Electricity Group at MIKES. Both equipment and researchers moved from TKK to MIKES. One laboratory room at the MIKES building has been furnished as a high voltage laboratory, enabling calibrations to be performed up to 200 kV at MIKES premises (Fig. E1). In February 2009, most of the high voltage metrology activities and services at MIKES have reached a similar status as they used to have at TKK before the move. An advantage of this change is the synergy of having a larger group working on electrical metrology instead of dividing the effort between two organizations. Collaboration with TKK continues. For example, the highest voltage levels (above 200 kV) cannot be reached in MIKES premises, but such calibrations can be performed in the TKK high voltage halls.

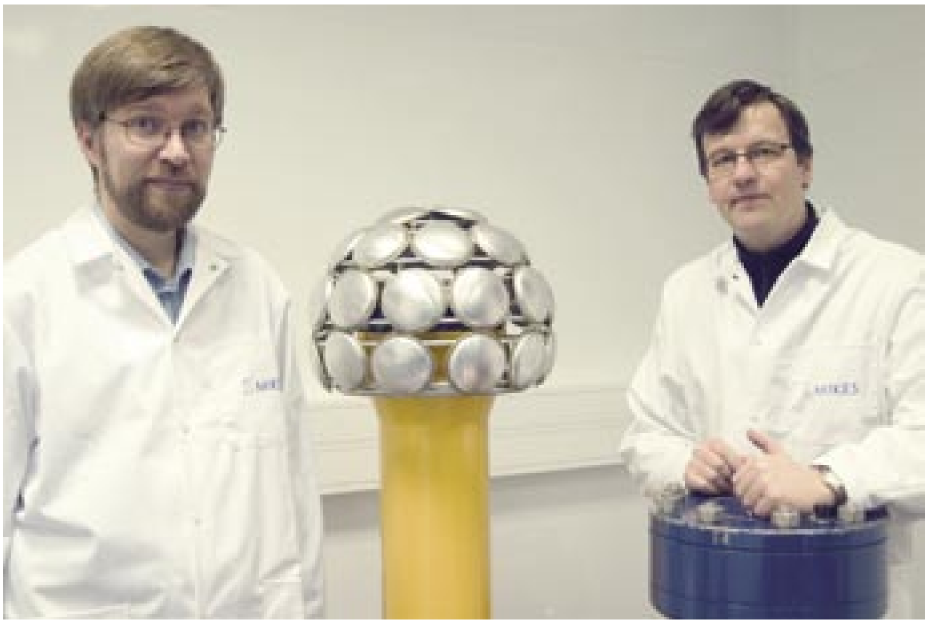


Figure E1. Jari Hällström and Esa-Pekka Suomalainen in the new high voltage laboratory in the MIKES building.

EMRP PROJECTS IN ELECTRICAL METROLOGY

Joint research projects of the iMERA-Plus programme, which is the first phase of the European Metrology Research Programme (EMRP), have been especially important for electrical metrology. Research in electromagnetic metrology was selected as one of the four targeted programmes of iMERA-Plus (others are grand challenges of fundamental metrology, health, and length metrology), and altogether six joint research projects in the field of electrical metrology were started in spring 2008, including one project in the targeted programme of fundamental metrology. MIKES participates in four of those three-year projects: Next generation of power and energy measuring techniques (Power & Energy), Next generation of quantum voltage systems for wide range applications (JOSY), Enabling ultimate metrological Quantum Hall Effect devices (ULQHE), and Redefinition of the SI base unit ampere (REUNIAM). Total funding from the European Community for MIKES's work in those projects is about 260 000 €. Moreover, Radiation and Nuclear Safety Authority (STUK) is a partner in the fifth project of electrical metrology, Traceable measurement of field strength and SAR for the Physical Agents Directive (EMF and SAR).

EUROMET EXPERT MEETINGS

MIKES was the host of the EUROMET DC and Quantum Electrical Metrology Expert Meeting (DCQM) and the EUROMET LF Electricity Expert Meeting, which were for the first time arranged during one week, 25 - 29 June, 2007. The DCQM and LF meetings were held during the first and second halves of the week, respectively. Wednesday was a common day for both meetings and included, for example, presentations on AC applications of Josephson voltage arrays and a lab tour to the new MIKES building. There were altogether 93 participants in the two meetings, 74 of them from outside Finland and 13 from NMIs outside EURAMET/EUROMET, and 28 of the foreign guests participated both meetings. Talks and posters were very interesting, and both of the meetings, including the common day, were very successful (Fig. E2). The meetings were the last ones arranged under EUROMET: on 1 July, 2007, EURAMET e.V. took over the responsibilities of EUROMET as the European Regional Metrology Organisation.

MIKES-TKK was the coordinator of the EURAMET project No. 1044, under which EURAMET's first meeting for high voltage experts was held on 1 September, 2008, on Palma de Mallorca, Spain, following the initiative of MIKES-TKK and SP, Sweden. There were altogether 14 participants from 9 NMIs. Five of the participants were from NMIs outside EURAMET.

IEC 1906 AWARD TO JARI HÄLLSTRÖM

Jari Hällström was awarded the IEC 1906 Award in 2007 for his convenorship of the revision of IEC 61083-2 and for his contributions to TC 42 working groups and maintenance teams. He has taken part on TC 42 work since 1998 (Fig. E3).

SEMINARS

In 2008, MIKES arranged its first seminar in the field of measurement of mechanical vibrations. Topics included theory, equipment, traceability and legal requirements of vibration measurements, and health effects of vibrations. A seminar on time and frequency was arranged, too, in 2008. In addition to basics of time and frequency measurements, the seminar included talks on atomic clocks, available radio signals, calibrations, time stamps, and VLBI interferometry. Feedback from the participants of both seminars was very good.

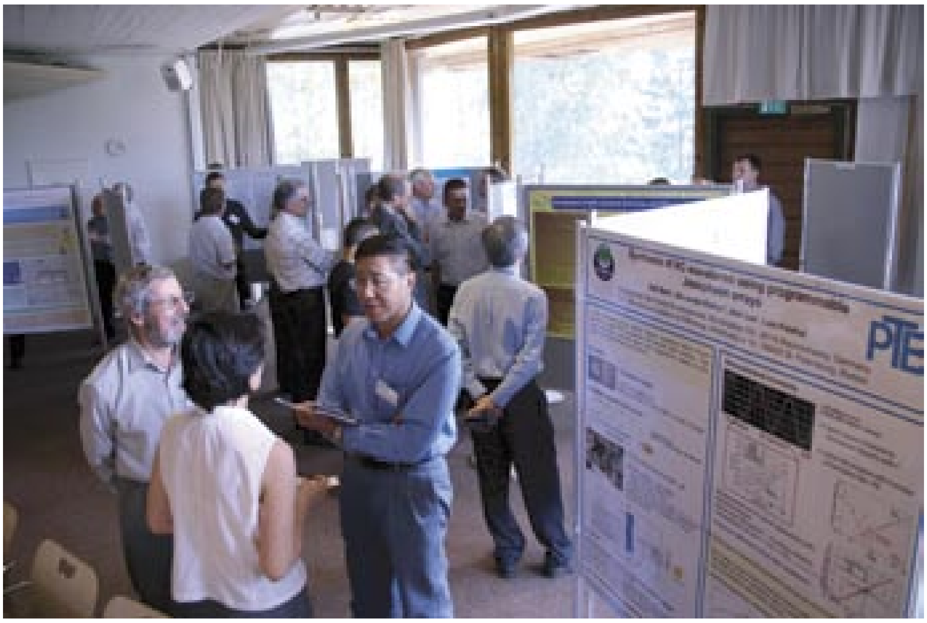


Figure E2. Posters, which were on view continuously for the whole week of the EUROMET DCQM and LF Expert Meetings, initiated lively discussions both during the poster sessions and during coffee breaks.

Figure E3. Director Sinikka Hieta-Wilkman from the SESKO Electrotechnical Standardization in Finland delivered the IEC 1906 Award to Dr. Jari Hällström on 21 September, 2007. Photo: Mikael Pettersson.

Research Projects

QUANTUM METROLOGY TRIANGLE

A major challenge of fundamental electrical metrology is the quantum metrological triangle (QMT), i.e., testing with relative accuracy of 10^{-7} or better that the values of fundamental constants *e* (elementary charge) and *h* (Planck's constant) have identical values in three physical phenomena which link electrical units with constants of nature: Josephson effect, quantum Hall effect, and single charge transport (SCT). MIKES has continued research towards direct closure of QMT in collaboration with VTT Technical Research Centre of Finland and Low Temperature Laboratory of the Helsinki University of Technology (TKK) [102] and, since spring 2008, also with several other European NMIs as a part of the REUNIAM project of EMRP. The work of MIKES has mainly concentrated on developing SCT devices and cryoresistors, and on designing cryogenic infrastructure for the experiment.

The first SCT device that MIKES investigated in collaboration with TKK was the so-called sluice [103], by which Cooper pair pumping at 1 nA level has been demonstrated [104] but only with rather limited accuracy. The main reason for the inaccuracy is the uncontrolled leakage current through the two mesoscopic SQUIDs of the sluice. We have shown experimentally that the leakage can be decreased considerably by replacing the two-junction SQUIDs by a "balanced SQUID" which consists of three Josephson junctions [105].

An even more promising SCT device was invented recently by the TKK group: a turnstile which is based on a normal metal - superconductor hybrid structure with the same simple geometry as the single electron transistor [J.P. Pekola et al., Nature Physics 4 (2008) 120-124]. Later MIKES and TKK have demonstrated flat 0.3 pA current steps within 1 fA noise level [106, 107]. More recently we have shown that the generated current at 10 pA level has the expected value within relative uncertainty of about 10^{-3}, and we have also observed reasonably flat current plateaus at I = 160 pA. Work is in progress for improved accuracy and magnitude of the generated current (Fig. E4).

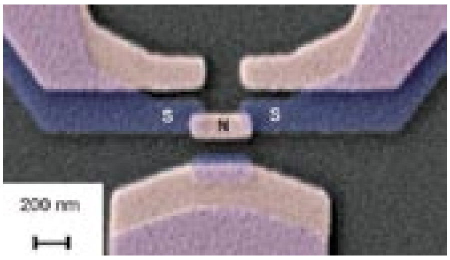


Figure E4. Scanning electron micrograph of a SINIS hybrid turnstile. Electrons can be transported through the device one by one, from one superconducting electrode (S) to the other one via the normal metal island (N), by applying a control voltage to the gate electrode (bottom).

Another major activity of MIKES in the QMT research has been the development of stable cryogenic high-value thin-film resistors to be used as a transfer standard in the experiment. The work has been done in collaboration with the Low Temperature Laboratory and the Department of Micro and Nanosciences of TKK. Investigations of Ni-Cr based thin film resistors have indicated that by optimising the composition of Ni-Cr alloy with added Ge and Mn it is possible to reduce temperature coefficient (TC) down to about $-50 \cdot 10^{-6}$ / K at 4.2 K [108, 109, 110]. In the temperature range from 50 mK to 150 mK, TC of Ni-Cr alloy containing 2.5 % of Ge reaches the value $-4.15 \cdot 10^{-3}$ / K. We have also demonstrated the usefulness of coating the thin film resistor with a thin alumina layer using ALD techniques (Atomic Layer Deposition): by coating, the drift rate of resistance at room temperature could be decreased from -2.45 ppm/hour down to about 0.03 ppm/hour [111, 112]. Preliminary experiments with cryoresistors fabricated from pure Pd have been performed, too.

In the quantum metrological triangle experiment, the key components must be cooled down to less than 0.1 degrees above absolute zero temperature. For that purpose we have ordered a dry, pulse tube driven dilution refrigerator from BlueFors Cryogenics Ltd, Espoo, Finland. Construction of the device and necessary modifications of the laboratory are almost finished, and the cryostat is expected to be operational at MIKES in spring 2009 (Fig. E5).

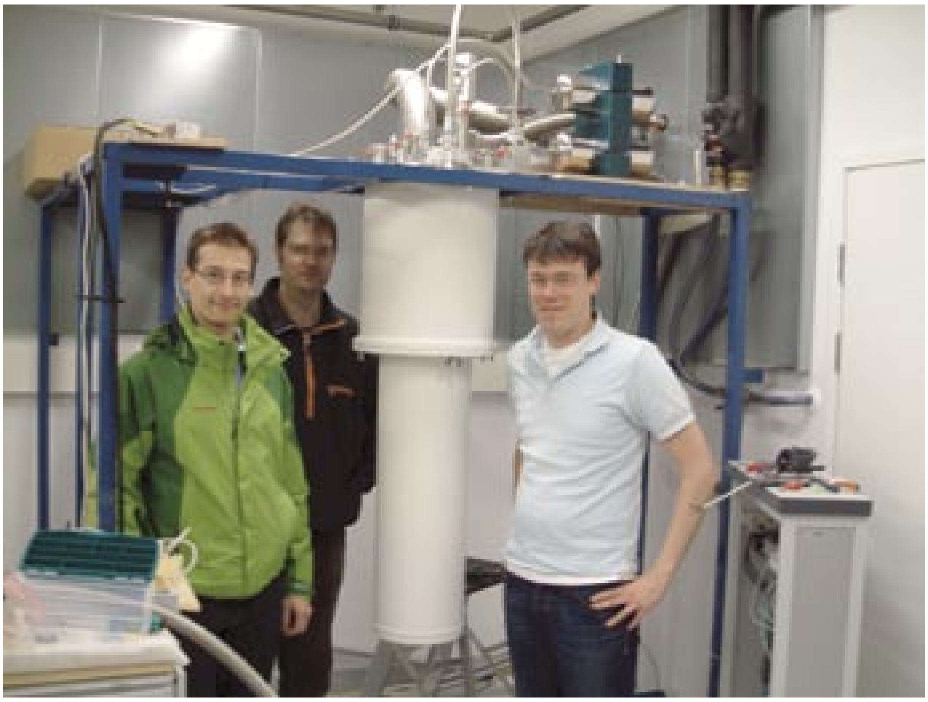


Figure E5. Ossi Hahtela checking the status of MIKES's new dilution refrigerator with Pieter Vorselman and Rob Blaauwgeers of BlueFors Cryogenics Ltd.

AC JOSEPHSON VOLTAGE STANDARD

Development of AC voltage standard based on a programmable Josephson array has been continued [113]. Chips with two independently biasable 1.7 V nonhysteretic arrays designed and manufactured by VTT are used [114]. In our AC standard, the Josephson array is driven by a square wave current bias, and the fundamental frequency component of the square-wave voltage output is compared with the sinusoidal voltage of a stable AC source using a lock-in amplifier. Since March 2008, most of the work of MIKES has been done in the JOSY project of EMRP.

The square-wave bias and the sine wave generator of the system must be very well phase locked together. For this purpose, a new home-made sine wave source based on direct digital synthesis (DDS) has been designed and constructed as the output generator of the standard. The output voltage of the first version is 1 V but can evidently be increased up to 10 V. The amplitude adjustment resolution is 30 nV and phase resolution 30 ps at 1 kHz. The stability of the source has been measured to be excellent, RMS measurements with 1 s integration time show a standard deviation of less than 1 ppm at 1 kHz at 1 V level. The contribution of harmonics is less than 0.1 ppm in thermal converter measurements. A new square wave bias source for driving the Josephson array has been finished and tested as well. Together with the above mentioned sine wave source we should be able to reach the 0.1 ppm accuracy goal in the frequency range from 10 Hz to 10 kHz.

Unity-gain buffer amplifiers are needed for the applications of AC-JVS. We have designed and tested amplifiers based on the circuit ideas by Ilya Budovsky (NMIA). Circuit simulations suggest a very high accuracy for the gain: for example at 1 kHz with load impedance 10 MΩ and 10 pF, the amplifier gain is expected to deviate from unity only by a few ppb. The simulations also predict a rather fast risetime of less than 10 ns from 0 V to 1 V. At the moment, the experimental error in gain is about 2 ppm at 1 kHz. The problem has been located and further investigations are to be done soon.

Problems related to very rapid aging of the chips due to freezing moisture have been solved by a new cryoprobe in which the surroundings of the array is evacuated and then filled with He heat exchange gas.

QUANTUM HALL RESISTANCE

MIKES participates the ULQHE project of EMRP in tasks related with characterisation of graphene and double 2DEG quantum Hall devices and quantum Hall array resistance standards (QHARS). Our first measurements with GaAs-based 1.29 MΩ QHARS from LNE were performed in January 2008 using the CCC Resistance Bridge, and new measurements with a new sample are in progress. Double 2DEG devices of PTB will be tested early in spring 2009, too. We have also started investigating characteristics of graphene layers, which have been fabricated in the Helsinki University of Technology (TKK) by annealing of SiC substrates at high temperatures. Electrical properties at low temperatures and at magnetic fields up to 10 T are under investigation.

IMPEDANCE METROLOGY DEVELOPMENT

In the field of development of impedance standards, the frequency dependence of acdc resistors of different types has been investigated in collaboration with LNE [115]. 1 kΩ and 10 kΩ bifilar resistors were transported from MIKES to LNE at the end of September 2007 and returned back after two weeks. The results showed that the bifilar resistors have exactly the same frequency behaviour: the resistance ratio change between 0.4 kHz and 1.6 kHz is much lower than $1\cdot10^{-8}$. Comparison of 1 kΩ and 10 kΩ bifilar resistors against 1 kΩ coaxial thin wire (Haddad) resistor shows frequency-dependent changes of $7\cdot10^{-8}$ and $8\cdot10^{-8}$, respectively, while the ratio between coaxial thin film and Haddad resistors does not change with frequency at a level of $1\cdot10^{-8}$. The latter result indicates that the frequency behaviour of the coaxial thin film and Haddad resistors is the same within the measurement uncertainties although the resistors are of completely different designs.

Study of the 100 mH transportable inductance standard has been continued partly in collaboration with VNIIM, Russia. The resonance method is used for estimatig the value of this standard. Also, characterisation of a commercial LCR meter (QuadTech7600) has been performed in collaboration with Metrosert, Estonia.

POWER AND ENERGY

Electricity network operators are faced with significant challenges by the increase of electronic based products that present a non-linear load to the power grid, and by the planned increase in renewable generation. Both factors have the potential to induce poor power quality, which in turn could cause widespread power failures if left unchecked. As a result, an evolving regulatory system enforces the requirement that all new electrical products must be type tested to ensure that their detrimental effect on power quality is minimized. These measurements are complex and involve the measurement of a number of different power quality parameters on distorted and fluctuating waveforms. These problems are tackled by the EMRP project "Next generation of power and energy measuring techniques" (Power & Energy), in which MIKES participates with 15 other partners.

For practical, on-site measurements of power and power quality parameters on the high voltage grid, a portable multiphase digitiser will be developed by MIKES and NPL. The main technological challenges are achieving good isolation and noise immunity, whilst maintaining sufficient accuracy for metrology use. It is envisaged that this system will become the standard system for NMIs engaged in on-site power quality measurements.

MIKES and SMU are working towards a current measurement system for on-site use, encompassing sufficient EMI resistance and suitability for non-invasive use. Power frequencies and harmonics at a measurement bandwidth of 2 kHz suitable for continuous currents up to 10 kA are considered. Rogowski coils suffer from sensitivity to current carrying wire position, orientation and external fields. When used for on-site applications the reproducibility of these parameters cannot be guaranteed and part of the work will be to optimise the design to minimise these effects.

DEVELOPMENT OF CALIBRATION SERVICE FOR LOW CURRENTS

A new current source for generating traceable DC currents from 1 fA to 100 pA has been developed [116]. The method is based on charging a capacitor with a voltage ramp generated by a single 16-bit digital-to-analog converter (DAC). The work was started in spring/summer 2007, and in February/March, 2008, we used the new current generator for our measurements in EUROMET. EM-S24 comparison of ultra-low DC current sources. Relative variations of the slope dU/dt during a single ramp are on the order of 10^{-4} due to nonidealities of the DAC, but the ramps are very reproducible: relative standard deviation between the average dU/dt values of 70 ramps was not more than 10^{-6}. Development of an improved current generator using two DACs, based on a very similar idea that PTB has developed independently [G.-D. Willenberg and H.N. Tauscher, IEEE Trans. Instrum. Meas. 58 (2009) 756 - 760], was started in autumn 2007. However, that work has not been continued because it turned out that the uncertainty of calibration of state-of-the-art commercial current meters and electrometers is not limited by the uncertainty of the more simple generator based on a single DAC.

APPLICATIONS OF MEMS

Our earlier work in collaboration with VTT has shown that the pull-in voltage of a DC biased moving-plate MEMS component is not stable enough to be used as a DC voltage reference, mainly due to slow charging phenomena in the component. That problem is eliminated when AC actuation is used, and we have earlier demonstrated a MEMS-based 9 V / 100 kHz AC voltage reference, whose drift was less than 2 ppm during a 3-week measurement period [117, 118]. In 2007 and 2008, MIKES has investigated the possibility of a MEMS-based DC reference using AC actuation of the component. The MEMS component is kept close to the pull-in by a feedback loop with a square-wave voltage, in which the polarity is reversed with a frequency of about 1 Hz. Jussi Kaasalainen showed in his M.Sc. Thesis that such a DC voltage reference has similar performance as the MEMS-based AC voltage reference: during a 3-week measurement period, no drift is observed within scatter of about ±2 ppm after pressure and temperature dependencies are corrected for [119].

DEVELOPMENT OF ACCELERATION CALIBRATION FACILITIES

The calibration facilities for secondary calibrations of vibration transducers were finalised in 2008. A software lock-in amplifier using commercial National Instruments data acquisition PCI-card has been completed and is applied in vibration measurements. The reference accelerometer was calibrated at PTB and another accelerometer at METAS for internal validation purposes. Results from METAS were compared to the results obtained using the MIKES measurement setup. Acceleration charge sensitivity values agree within 0.7 % in magnitude and within 0.4° in phase. Uncertainty evaluation of the system is in progress, including effects caused by transverse motion of the vibration exciter and mass loading effects (Fig. E6). The first prototype of a new self-designed DC coupled power amplifier has been tested in 2008. The aim is to replace the presently used AC-coupled model with two new ones driven in bridge mode, in order to provide the AC excitation and stable DC current bias for varying mass load compensation.

CALIBRATION OF FLICKER METERS (MIKES-TKK)

One of the quantities measured by power quality meters is the flicker index, which is related to the irritation effect of flickering of lighting due to changes in the mains voltage. In this project, a system for calibration of flicker meters was developed. The characteristics of flicker meter, and the relation between the voltage fluctuations on the mains voltage and flicker index, are standardized on an international standard IEC 61000-4-15. The developed method follows the standard, and it is based on sampling of the ac signal. The sampled signal is then processed by software to provide the flicker index. Mr. Olli Kara prepared his M.Sc. thesis on the subject [120]. A comparison of the flicker measurement algorithm was launched with NPL in autumn 2007. This work was continuation of MIKES-TKK research on ac sampling techniques [121].

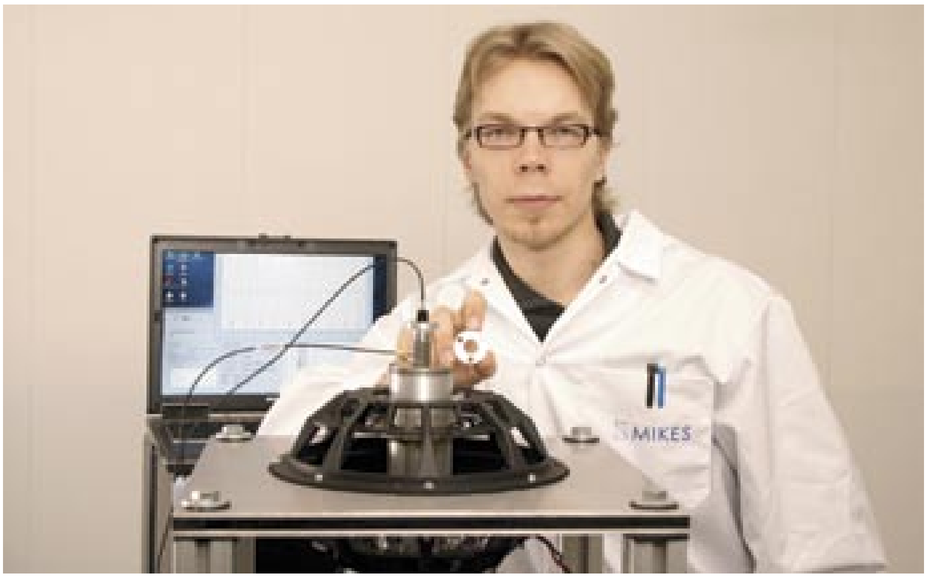


Figure E6. Jussi Hämäläinen preparing for tests of mass loading effects on the sensitivity of the reference accelerometer.

OTHER PROGRESS

In January 2008, MIKES received its fifth atomic clock, an active hydrogen maser CH1-75A fabricated by IEM KVARZ, Russia (Fig. E7). The new device has turned out to be very stable: during the first year of operation, its aging rate has been less than $0.3 \cdot 10^{-15}$/day. Thus it is better than our older active maser by a factor of 5 and better than our passive maser by a factor of more than 2. The short time stability is naturally much better in active masers than in the passive maser [122].

Figure E7. Dr. Nikolai Demidov from IEM KVARZ visited MIKES and made the final adjustments of the new active hydrogen maser CH1-75A in January 2008.

Capability for on-site calibration of a current transformer on transmission grid substation has been developed by MIKES-TKK. The first open-air calibration was performed on high voltage substation (400/110 kV) in December 2007 (Fig. E8). Ratio error and phase displacement of three current transformers were calibrated. One section of the high voltage busbar, including the current transformers to be calibrated, was disconnected from the transmission grid. External voltage source and transformer were used to generate a current up to 750 A. Regardless of the low temperature (c. 3 °C) on the location, no significant problems were experienced during the calibration. Calibration uncertainties were comparable to those achieved in laboratory conditions [123, 124].

Figure E8. On-site calibration of a current transformer on the 400 kV grid. The current transformer under calibration is in the center of the picture. The orange cable hanging down from the high voltage line was used to feed the current, and the current generator together with the reference instrumentation were in the van.

Measurement of impulse phenomena has been one of the main research areas in MIKES-TKK. Key projects have been going on related to international comparisons [125, 126, 127] and development of impulse parameter evaluation methods [128, 129, 130, 131].Other topics on impulse measurements have been physics of gas discharges [132, 133] and calibration of ESD testers [134], which have been the topics of Joni Klüss's and Matti Löytty's M.Sc. Theses.

A new busbar has been taken into use for high alternating current calibrations. The new busbar both increases the highest achievable calibration current (designed up to 10 kA) and makes changing of the setup easier. The setup was immediately used for determination of the effect of changing of the return current path for Rogowski coil measurement errors [135].

Comparisons

INTERNATIONAL COMPARISONS

CCEM.RF-K19.CL: Attenuation at 60 MHz and 5 GHz using a 50 ohm Type-N step attenuator. Key comparison. Participants: CMI (CZ), INRIM (IT), KRISS (KR), LNE (FR), METAS (CH), MIKES (FI), MIRS/SIQ (SI), NIM (CN), NIST (US), NMIJ (JP), NMISA (ZA), NPL (UK, pilot), NPLI (IN), NRC (CA), PTB (DE), SP (SE), SPRING (SG), UME (TR), VNIIFTRI (RU), VSL (NL). The measurements at MIKES were made in October 2004. The final report was approved by CCEM in March 2009. All results of MIKES are consistent with the key comparison reference value within the claimed uncertainties, which range from 0.026 dB (60 MHz, 20 dB attenuation level) to 0.083 dB (5 GHz, 60 dB attenuation level), k = 2. The uncertainties of MIKES are very similar to those of other laboratories using vector network analysers.

EUROMET.EM-K2 (EUROMET project no. 851): Resistance standards at 10 MΩ and 1 GΩ. Key comparison to be linked with CCEM-K2. Participants: BEV (AT), CEM (ES), CMI (CZ), EIM (GR), GUM (PL), INM (RO), IPQ (PT), JV (NO), LNE (FR), LNMC (LV), METAS (CH, pilot), MIKES (FI), MIRS/SIQ (SI), MKEH (HU), NML (IE), NPL (UK), PTB (DE), SMD (BE), SMU (SK), UME (TR), VMT/PFI (LT), VNIIM (RU), VSL (NL). The measurements at MIKES were made in March 2006. Three different measurement methods were used, giving consistent results: DCC bridge, substitution method with Hamon standards, and a modified Wheatstone bridge with two calibrators (in case of 1 GΩ) [136]. A corrected Draft A of the final report was distributed for the participants in December 2008. The results of MIKES are consistent with the comparison reference value within the relative uncertainties 1.75 μΩ/Ω at 10 MΩ and 9.77 μΩ/Ω at 1 GΩ (k = 2).

EUROMET.EM-K10 (EUROMET project no. 636): 100 Ω standard resistor. Key comparison to be linked with CCEM-K10. Participants: BEV (AT), BIPM, CEM (ES), CMI (CZ), DFM (DK), DMDM (RS), EIM (GR), GUM (PL), INETI (PT), INRIM (IT), JV (NO), LNE (FR), LNMC (LV), METAS (CH), MIKES (FI), MINECO (BE), MIRS/SIQ (SI), MKEH (HU), NMISA (ZA), NML (IE), NPL (UK), PTB (DE, pilot), SASM (BG), SP (SE), UME (TR), VMT (LT), VNIIM (RU), VSL (NL). The measurements at MIKES were made in April and July/August, 2003. MIKES belonged to the organisation group of the comparison and acted as a "subpilot" of the Nordic loop of the comparison: two temperature and pressure stabilised standard resistors of MIKES were circulated by car and measured at MIKES, SP, JV, DFM, PTB, and VNIIM. Draft B of the final report was received in August 2008. The results of the Nordic loop organised by MIKES agree within reported uncertainties, but in one of the other loops the transfer standards apparently showed some jumps, and this had to be taken into account by an additional transport uncertainty term. The relative deviation of MIKES's result from the comparison reference value was (5,3 ± 17,1) nΩ/Ω, k = 2.

EUROMET.EM.RF-K8.1.CL (EUROMET project no. 818): Calibration factor of thermistor mounts up to 18 GHz. Bilateral comparison subsequent to key comparison EUROMET.EM.RF-K8.CL and linked with CCEM.RF-K8.CL. Participants: MIKES (FI), NMi-VSL (NL, pilot). MIKES made the measurements in December 2004 and February 2005. The results were published in BIPM KCDB in March 2007. Deviation of MIKES results from the reference value of CCEM.RF-K8.CL was smaller than 0.4 % at all frequencies except 18 GHz, where deviation was -1.28 % ± 2.25 % (k = 2). The overall uncertainty of the comparison, which varied from 0.85 % at 50 MHz to 2.25 % at 18 GHz (k = 2), was largely dominated by the measurement uncertainty of the pilot laboratory, as was discussed in Heikki Koivula's M.Sc. Thesis [137].

COOMET.EM-S6: Ratio error and phase displacement. Supplementary comparison of ratio error and phase displacement of voltage transformers, from 20 kV to 100 kV. Participants: VNIIMS (RU, pilot), MIKES-TKK (FI), SP (SE). MIKES- TKK made the measurements in September 2007. A current comparator bridge was provided by VNIIMS as the transfer reference, and the high voltage transformers available in MIKES-TKK or SP were used for comparison.

EUROMET.EM-S24: Ultra-low DC current sources (100 fA - 100 pA). Supplementary comparison. Participants: CEM (ES), INRIM (IT), IPQ (PT), LNE (FR), METAS (CH), MIKES (FI), NIS (EG), NPL (UK), PTB (DE, pilot), UME (TR), VNIIM (RU), VSL (NL). The measurements at MIKES were made in March 2008 using the new current source based on charging a capacitor with a voltage ramp generated by a DAC [116]. According to the preliminary results, which were sent for participants in January 2009, almost all results of MIKES agree with the mean value of the participants within relative uncertainty ranging between $2 \cdot 10^{-4}$ and $2 \cdot 10^{-3}$ (k = 2).

EUROMET.EM-S29: Traceability of DC high voltage reference systems. Supplementary comparison of high direct voltage from 1 kV to 200 kV. Participants: BIM (BG), LCOE (ES, pilot), MIKES-TKK (FI), SP (SE), UME (TR), VSL (NL). The measurements at MIKES-TKK were made in January 2008. Draft A is under preparation.

EUROMET.TF.TI-K1 (EUROMET project no. 828): Comparison of time interval (cable delay) measurement. Participants: BEV (AT, pilot), EIM (GR), GUM (PL), INM (RO), INPL (IL), INRIM (IT), IPQ (PT), IREE/CMI (CZ), JV (NO), METAS (CH), MIKES (FI), MKEH (HU), NCM (BG), NMi-VSL (NL), NPL UK), OP/SYRTE (FR), PTB (DE), ROA (ES), SIQ (SI), SMD (BE), SMU (SK), SP (SE), UME (TR), VMT/PFI (LT), ZMDM (RS). The measurements at MIKES were made in February 2006. Final report appeared in June 2007. All results of MIKES are consistent with the mean and median values of all participants within the uncertainties, which range from 154 ps at 20 ns to 428 ps at 175 ns (k = 2). However, that was not the case with many other participants. At the end of the activity it became clear that the measurement task had not been sufficiently well defined, and the project is considered neither as a key comparison nor as a supplementary comparison.

EUROMET 860: Time comparison using a transportable atomic clock. Participating NMIs: LNMC (LV), Metrosert (EE), MIKES (FI, pilot), SP (SE), VMT/PFI (LT). MIKES organised the comparison in four parts. In November 2005, one of the Cs clocks of MIKES was transported by car to SP and back. In May 2006, a Rb clock was transported from MIKES to Metrosert, LNMC and VMT/PFI, and back. Finally, in October and November, 2008, a Cs clocks of MIKES was transported to SP and back and then to Metrosert, LNMC and VMT/PFI, and back. Comparison uncertainties between different laboratories ranged from about 0.5 ns to 10 ns. Results were reported in the EURAMET TC-TF meeting in March, 2009.

EUROMET.AUV.A-K3 (EUROMET project no. 674): Laboratory standard microphone calibrations. Key comparison linked with CCAUV.A-K3. Participants: BEV (AT), CEM (ES), CMI (CZ), DPLA (DK), INRIM (IT, pilot), METAS (CH), MIKES (FI), SP (SE). The measurements at MIKES were performed in March - April, 2004. The results were published in BIPM KCDB in September 2007. Deviations of MIKES results from the CCAUV.A-K3 reference value are 0.035 dB or less for all frequencies between 31.5 Hz and 16 kHz, but at the highest frequency of MIKES, 20 kHz, the deviation is (0.110 ± 0.095) dB, k = 2. Deviations MIKES results are smaller than CMC uncertainties at all frequencies, even at 20 kHz, where MIKES's CMC claim is 0.14 dB.

Photometry and radiometry

Personnel
MIKES-TKK

Prof. Erkki Ikonen	*Head of the National Standards Laboratory*
Dr. Petri Kärhä	*Senior Research Scientist, Quality Manager*
Dr. Farshid Manoocheri	*Senior Research Scientist, Head of Calibration Services*
Dr. Jouni Envall	*Senior Research Scientist (till Oct 2007)*
Dr. Pasi Manninen	*Senior Research Scientist*
M.Sc. Silja Holopainen	*Research Scientist*
Lic.Sc. Maija Ojanen	*Research Scientist*
M.Sc. Tuomas Poikonen	*Research Scientist*
Lic.Sc. Mikko Puranen	*Research Scientist (till May 2008)*
M.Sc. Maksim Shpak	*Research Scientist*
M.Sc. Meelis-Mait Sildoja	*Research Scientist*
Mr. Petteri Ahonen	*Research Assistant*
Mr. Teemu Jaakkola	*Research Assistant*
Mr. Jani Kivilähde	*Research Assistant (till Sep 2007)*
Mr. Antti Kunnas	*Research Assistant*
Ms. Liisa Ollikka	*Research Assistant (till Mar 2007)*
Ms. Jonna Paatelma	*Research Assistant (till Dec 2008)*
Mr. Juha Peltonen	*Research Assistant (till Dec 2007)*
Ms. Kaija Rantoja	*Research Assistant (till Dec 2008)*
Ms. Satu Ristiluoma	*Research Assistant (till Dec 2007)*
Mr. Aleksi Sormanen	*Research Assistant*
Mr. Markku Valkonen	*Research Assistant (till Jun 2007)*
Mrs. Jaana Hänninen	*Coordinator (till Mar 2008)*
Mrs. Ulla Sikander	*Secretary*
Mr. Tarmo Simonen	*Network and PC Administration*

Metrology Research Institute (MRI) is a joint laboratory of the Helsinki University of Technology (TKK) and MIKES.

Metrology Research Institute is designated by MIKES to act as the National Standards Laboratory for optical quantities. The quantities are: luminous intensity, illuminance, luminance, luminous flux, spectral irradiance, spectral radiance, colour co-ordinates, colour temperature, optical power, fibre optic power, transmittance, reflectance, spectral responsivity, spectral diffuse reflectance, optical wavelength (transferred to MIKES/Length 2008), chromatic dispersion (transferred to MIKES/Length 2008).

Metrology Research Institute (represented by Erkki Ikonen) is a member laboratory of the Consultative Committee for Photometry and Radiometry (CCPR).

Highlights in 2007–2008

The laboratory participated strongly in the NEWRAD 2008 conference arranged in Daejeon, Korea, in October 2008. Petri Kärhä gave an invited talk [138] on the effects of distance dependence in radiometric measurements. Silja Holopainen gave an oral contribution [139] on non-Lambertian behaviour of fluorescence. Posters were presented by Pasi Manninen [140], Silja Holopainen [141], Farshid Manoocheri [142], Meelis Sildoja [143], and Maija Ojanen [7]. Pasi Manninen's poster was on the effect of pulse width modulation on the LED colour, a topic also reported earlier in *Applied Physics Letters* [144]. Erkki Ikonen and Maija Ojanen were involved in the oral presentation given by Xu Gan of Singapore [145].

Erkki Ikonen acts as the Chairman of the Scientific Program Committee of the NEWRAD Conference. In this role, he was in charge for the preparation of the scientific program of the NEWRAD 2008.

Realisation, maintenance

SIMPLE ACTIVE METHOD FOR REDUCING MAGNETIC INTERFERENCE IN A THERMOELECTRICALLY COOLED PHOTOMULTIPLIER TUBE

The visible detector of the spectroradiometer system of the laboratory was improved [146]. The thermoelectrically cooled photomultiplier tube (PMT) assembly was modified to eliminate the magnetic interference between the Peltier element and the PMT (Fig. P1). An active compensation was accomplished by forming current loops of the wires of the Peltier element and placing them in such a way that they eliminate the interfering magnetic field. It was demonstrated that the improved system reduced measurement errors of the order of 1 % to the level of noise at 0.07 %.

Figure P1. Modification of the current leads of the Peltier element. The positive current lead forms two loops that are placed in such an orientation that the magnetic field produced compensates for the magnetic field produced by the Peltier element.

UNCERTAINTY ANALYSIS OF SPECTRAL INTEGRALS

New research has begun related to the uncertainty analysis of spectral integrals used for certain parameters and quality factors in photometry and colorimetry. In this research, statistical Monte Carlo simulation is used as the basis of the analysis. However, the error models used in the simulations must be carefully evaluated that they actually represent the real uncertainties of the measurements. The first parameter, for which the new error models are tested, is the spectral quality factor f_1' of photometers [147]. The parameter f_1' defines the average quality of the spectral matching with the $V(\lambda)$ function and gives an order of magnitude indication of how large errors are obtained, when measuring ordinary broadband light sources with different spectral power distributions. The uncertainty simulations continue and the error models will be later extended to other spectral integrals.

A METHOD FOR UNCERTAINTY ANALYSIS FOR LINKING A BILATERAL KEY COMPARISON TO THE CIPM KEY COMPARISON

A method for analyzing the uncertainty in linking a bilateral key comparison to another key comparison with several participants was developed for the analysis of bilateral key comparison EURAMET.PR-K1.a.1. Equations were derived for the uncertainties of the unilateral and mutual degrees of equivalence for the linked participant in the bilateral comparison. It was shown that the uncorrelated uncertainty components of the linking participant play a critical role in determining the additional uncertainties due to the linking process. The uncorrelated uncertainty of the link NMI was found to account for more than 80 % of the additional uncertainty due to the linking process in the degrees of equivalence of the linked NMI. In this case, the uncertainty of the linked NMI typically contributed 90 % of the uncertainty of the unilateral degrees of equivalence. If an NMI with uncertainty below the cut-off uncertainty in CCPR-K1.a would be the linked NMI, the uncertainties of their degrees of equivalence would be largely affected by the uncorrelated uncertainty of the linking NMI.

SIGNIFICANT PUBLICATIONS AND PRESENTATIONS

As the result of other maintenance work, following articles and presentations were published in 2007-2008 [148, 72].

Research Projects

PREDICTABLE QUANTUM EFFICIENT DETECTOR

Development of a new primary standard, the PQED (Predictable Quantum Efficient Detector), for optical power and photon flux measurements has been launched within several national metrology institutes [143]. The new standard is based on low doped silicon photodiodes operated at liquid nitrogen temperatures and under reverse bias. In matters of achieving low level of optical losses, two candidate structures for the device have been proposed and calculations of the specular reflectance have been carried out. It is shown that a simple two-photodiode arrangement (Fig. P2) is capable of reducing the specular reflectance to values lower than 1 ppm and is suitable for the PQED needs, if the diffuse reflectance from the photodiodes is of the same order of magnitude as the specular reflectance. A second detector with a single diode and a hemispherical mirror is considered, if the diffuse reflectance from the custom-made photodiodes turns out to be too high, more than 1 ppm.

REDUCING REFLECTANCE IN CUSTOM MADE PHOTODIODES

A method is proposed to reduce the reflectance from a custom-made silicon photodiode with thick oxide layer [149]. Increasing the oxide coating thickness to a value much larger than typical thickness (25-30 nm) will lead to a situation where destructive interference for p-polarized reflected beam occurs simultaneously at multiple wavelengths. It is due to the periodic behaviour of the reflectance as a function of the oxide thickness (Fig. P3). Wavelengths 453.5 nm, 488.1 nm (Ar^+), 528.5 nm, 576.0 nm, 633.0 nm (HeNe), 703.0 nm and 790 nm (Ti:Sapphire) reach low reflectance with the photodiode oxide layer thickness of 2907 nm. The incident angles for all the wavelengths are rather similar and correspond to the Brewster angles for the vacuum-silicon interface. This mechanism allows developing a single photodiode detector where losses due to reflection are minimized at several commonly used laser lines.

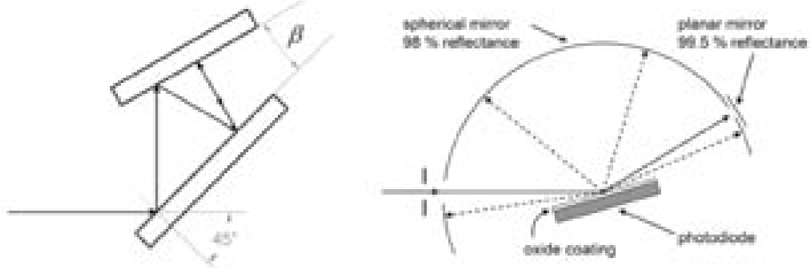


Figure P2. Two-photodiode structure and the hemispherical structure of the detectors.

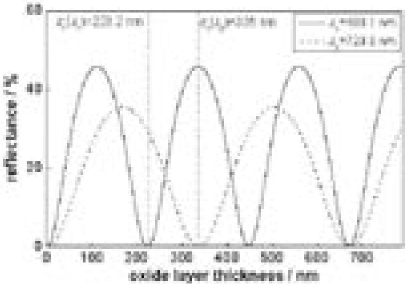


Figure P3. Reflectance from a silicon photodiode as a function of oxide layer thickness. Incident p polarized beams are arriving to the photodiode at Brewster angles.

METROLOGY OF LED LIGHT SOURCES [150, 151, 152, 153]

During 2008, the MRI participated in the APMP supplementary comparison of light-emitting diodes (LEDs). The measurement quantities of the comparison were the averaged LED intensity, total luminous flux of LEDs and emitted colour of LEDs. The comparison included 14 LEDs with four colours. As a part of the LED project, describing the colour rendering properties of white LED light sources were studied. For that purpose, a literature review of a new colour rendering metrics was done and a LabVIEW program for calculating the colour rendering index defined by the Commission Internationale de l'Eclairage was constructed. The project also involved a study on the measurement of low light (mesopic) levels. The conventional $V(\lambda)$ function of photometry cannot be used in mesopic light levels because the spectral sensitivity curve of the human eye is shifted toward shorter wavelengths. A dual-channel mesopic photometer for measuring light levels between the scotopic and photopic photometry was designed. Using that photometer, mesopic illuminance levels in highway and street lighting at night can be measured.

BEHAVIOUR OF LEDS UNDER PULSE-WIDTH MODULATION DIMMING

During 2007, as a part of light emitting diode (LED) project, spectral and thermal behaviours of three AlGaInP LEDs were studied when controlling their brightness with pulse-width modulation (PWM) [144]. In the work, variations in the peak wavelength and band width of the emission spectrum of the studied LEDs with different colours under PWM dimming were investigated as well as changes in their junction and charge carrier temperatures. The measurement results indicated the blue-shift of the peak wavelength and the bandwidth narrowing for the studied LEDs as the width of the pulse was decreased. Also, the junction temperature and carrier temperature of the studied LEDs linearly rose with increasing duty cycle. Perceivable changes in colour of AlGaInP LEDs under the PWM scheme were observed.

LUMINOUS FLUX MEASUREMENT OF LIGHT EMITTING DIODES

A setup was designed, built and characterized for luminous flux measurements of Light Emitting Diodes (LEDs). The measurement setup is based on the CIE 127 standard and uses an integrating sphere method. Both the total luminous flux and the partial LED flux of low or high power LEDs can be measured using the same 30-cm integrating sphere. In addition to a detector port and an auxiliary LED port, the integrating sphere has only one entrance port, in contrast to other designs which have an additional port for the total luminous flux measurement. The measurement setup was calibrated and test measurements were conducted using two white LEDs. The expanded uncertainties (k=2) for the measurement setup vary between 0.5 % and 2.2 % depending on the measurement mode and the properties of the tested LED. The measurement uncertainty is comparable to those of the measurement setups developed in other metrology institutes. The measurement setup is fully functional and can be used for calibrating standard LEDs for customers and for further research of LEDs.

In 2008, the measurement setup was improved regarding the total luminous flux measurement mode of low power LEDs. In this measurement mode, a lamp holder is used for placing the LED in the center of the sphere. A new, much smaller lamp holder was designed to reduce screening (Fig. P4). Special attention was paid to minimize the near-field absorption of the backward emission of the LED to improve the reliability of the measurement. The conical head piece was machined from aluminum and was painted with barium sulfate ($BaSO_4$). The holder was equipped with two parallel terminals for the LED, of which either one can be used.

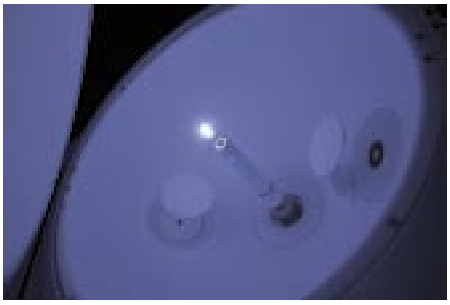


Figure P4. A photograph of a LED comparison measurement showing the new improved LED holder in operation. The screening due to the new holder is barely visible. Only the two baffles form shades inside the sphere, preventing the detector and auxiliary port from seeing the light source directly.

The spectral throughput of the integrating sphere was measured using the auxiliary LED port and a white LED. The results show that the use of the new lamp holder results in almost identical spectral throughput as in the other two measurement modes. This makes the analysis easier, because the same colour correction factor can be used for the same LED, regardless of the measurement mode. The new lamp holder, being much smaller than the earlier one, also results in larger signal levels and better integration inside the sphere. The most important improvement is the reduced screening due to the lamp holder. The screening of the new lamp holder is only about 6 % of the original. In Fig. P4 can be seen that the screening is barely visible around the base of the lamp holder, whereas the original lamp holder caused visible screening, reaching the shades produced by the two baffles.

IMPROVING THE ACCURACY OF LINEAR PYROMETER MEASUREMENTS [154, 6] AND COMPARISON OF THE RADIATION TEMPERATURE SCALES BETWEEN PTB AND MIKES

Methods for improving the extrapolated radiation temperature measurements above the metallic fixed points using linear pyrometers were compared. Four different methods for obtaining the effective wavelength were studied. These include direct measurement of the spectral responsivity of the pyrometer, comparison of two measured pyrometer signals at known temperatures, comparison against a narrow-band filter radiometer operating as an irradiance mode transfer pyrometer, and calculating the effective wavelength using reliable intercomparison data. The improvements obtained using the methods are estimated by comparing the results with extrapolation using the Sakuma-Hattori method and analysis using Planck's law with the nominal wavelength (651 nm) of the pyrometer tested. Experimental results of the study are based on a large set of intercomparison data resulting from a recent temperature intercomparison between the PTB (Germany) and the MIKES (Finland) in the range of 1570 K to 2770 K. The measurement artifacts include a high temperature black body, a strip lamp used as an ITS-90 reference, two linear pyrometers and various irradiance-mode filter radiometers. It was shown that improper understanding of the pyrometer properties may lead to systematic measurement errors up to several Kelvins. With careful analysis, uncertainties of the order of 1 K are obtainable.

The results of the comparison of the radiation temperature scales with PTB were reported at NEWRAD conference in 2008 (Fig. P5) [7]. The agreement was partial: two filter radiometers and the linear radiation thermometer of MIKES agreed well with the equipment of PTB, while two filter radiometers deviated from the other equipment. To get a deeper understanding of the reasons of the deviation, the results were studied in terms of both temperature and radiance. The deviation was found constant in terms of radiance.

The radiation temperature measurements were studied also at lower temperatures. Two one-diode silicon filter radiometers with nominal wavelengths of 800 and 900 nm, and an InGaAs filter radiometer with nominal wavelength of 1550 nm were tested at temperatures from 770 K to 1020 K. The silicon filter radiometers were found to have low noise. They could thus be used in accurate measurements of the above mentioned temperatures with a current meter calibrated for low currents.

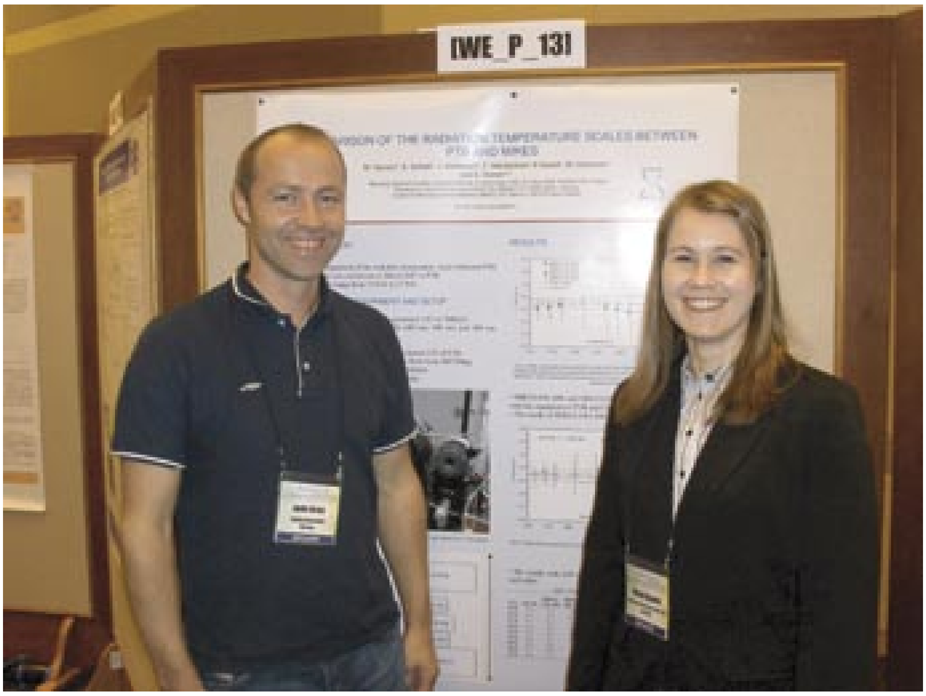


Figure P5. Jarle Gran from Justervesenet (Norway) visiting Maija Ojanen's poster at the NEWRAD 2008 conference.

OPTICAL TEMPERATURE MEASUREMENT OF MINIATURE SILICON EMITTERS

Microbridges, also known as microglows or micro-filaments, are miniature silicon filaments that are used e.g. in analysers as light sources. A microbridge is brought up to incandescence by passing an electrical current through it. Temperature determination of an operating microbridge with a contact measurement is complicated due to the small size of the bridge and the heat loss via the contact probe.

In this work, we have developed and tested a method to determine the temperature of a microbridge by measuring its emission spectrum. The measurement setup consists of a monochromator, detectors for the visible and near-infrared spectral regions and focusing optics based on a microscope objective. The setup was used to measure temperatures of microbridges that have dimensions of 400 × 20 × 4 μm^3. They are made from a highly doped single-crystal silicon. The bridges have thin protecting layers of silicon dioxide on all sides.

Determination of the temperature is possible using Planck's radiation law if the emissivity of the object is known. Emissivity of silicon at high temperatures is often assumed to be constant in the visible and near-infrared regions. However, a microbridge is thin and thus semi-transparent. The thin layers of silicon dioxide also introduce interference effects. As a consequence, microbridges do not behave like grey bodies (Fig. P6). To solve this problem, a semi-empirical model was constructed to describe the emissivity of the multi-layer structure. To determine the optical constants of silicon needed, radiation spectra of a piece of SOI wafer were measured at known temperatures. In particular, the extinction coefficient of the highly doped silicon at high temperatures in the near-infrared region was determined from the measurements and compared with literature values. The results were fitted to the emissivity model. At present, we can measure the temperature with an uncertainty of ±50 K.

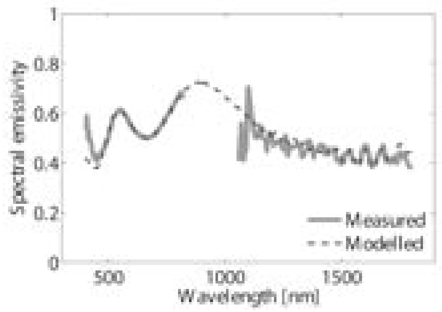


Figure P6. Modelled and measured emissivities of the microbridge at 1100 °C. Measurements between 820 nm and 1050 nm were very noisy and the results were thus removed from the graph.

COMPARISON OF DETECTOR-BASED SPECTRAL IRRADIANCE SCALES USING NIR LASERS [155]

Spectral irradiance measurements using filter radiometers are needed for radiometric temperature determinations. Independent laser-based calibration facilities at the Metrology Research Institute, Finland, and the National Institute of Standards and Technology (NIST), United States, used for the realization of the detector-based spectral irradiance scale have been compared in the near-infrared (NIR) region. The results of the comparison of the laser-based facilities were compared to the spectral irradiance scale obtained with the NIST monochromator-based calibration facility. The comparison was carried out by calibrating a narrow-bandwidth filter radiometer on each facility. The results of the comparison showed agreement between the integrated responsivities of the radiometer within 0.1 %, well within the standard uncertainty of the comparison. The work also covers the study of out-of-band responsivity measurements and the ageing properties of the filter radiometer used. The results give additional evidence on the suitability of lasers as sources for the realization of absolute spectral irradiance scales in the NIR region enabling, e.g. the development of the radiometric temperature scales with lower uncertainties.

EXTENSION OF THE WAVELENGTH RANGE OF SPECTRAL IRRADIANCE MEASUREMENTS

The wavelength range of spectral irradiance measurements was extended to 250 – 290 nm in the ultraviolet region and to 900 – 1500 nm in the near infrared region. GaAsP trap detector and ultraviolet filters were used in the ultraviolet region, and Ge detector and infrared filters were used in the near infrared region. In the visible region Si trap detector was used. Three FEL-type standard lamps (Fig. P7) calibrated by NPL were measured with all three filter radiometers. As a result the spectral irradiance could be measured for the first time in the wavelengths 260 nm, 980 nm, 1100 nm, 1300 nm and 1500 nm and the wavelength range of spectral irradiance was extended to 250 – 1500 nm region. The expanded uncertainty (k=2) is 2.8 % in the ultraviolet region and 3.0 % in the infrared region. The comparison with NPL indicates that we are measuring an average of 2.5 % higher spectral irradiance values than NPL in the ultraviolet region. The deviation between spectral irradiances is less than 4.7 % in the near infrared region, but in the visible region the differences are only in the range of 0.5 %.

Figure P7. Aligning the detector and the lamp to the same optical axis using a two-output laser source.

SPECTRAL EMISSIVITY MODEL FOR TUNGSTEN-HALOGEN LAMPS

Spectral irradiance measurement with a filter radiometer requires prior knowledge of the object's emissivity. The tungsten filament of a lamp has an emissivity which is wavelength and temperature dependent. The method of irradiance measurement currently in use at the Metrology Research Institute is based on a complex error minimization algorithm, where the emissivity of the source is modeled with a polynomial using linear regression. To simplify the algorithm, a fixed spectral emissivity model for tungsten lamps was tested, which was obtained using spectral irradiance data of three NPL calibrated 1 kW lamps. Results differ significantly from the spectral emissivity values for tungsten found in literature. The difference is wavelength dependent and it is up to 20 % over a broad spectral range. Possible physical explanations include losses in halogen gas and quartz glass, impurities in tungsten filament and surface preparation.

GONIOFLUOROMETER FOR CHARACTERIZATION OF FLUORESCENT MATERIALS [156, 157]

The colour of a fluorescent specimen depends on the illuminating source and the observer. It can be calculated for the desired source and observer with the help of the source and observer independent bispectral radiance factors. We have characterized our goniofluorometer for measuring bispectral luminescent radiance factors in the wavelength range of 250 – 800 nm.

In 2007 we purchased a new monochromator for the excitation system to improve the accuracy and reliability of the instrument. We also purchased components for building a sample holder for liquid samples. The holders can hold both liquid and solid samples. Incident angles can be varied from 0° to 90°. Investigations have been initiated on possible non-Lambertian behaviour of the opaque fluorescent standard materials [139].

Extensive measurements of the fluorescence spectra of several well known fluorophores such as fluorescein, rhodamine 101, and quinine sulphate as liquid samples were performed in 2008. Measurement results show that the fluorescence measurements of liquids are possible but specially a high fluorophore concentration in the sample may cause unwanted effects on the emission spectrum. Also the measurement geometry was revealed to have significant effect on emission spectrum whereas moderate changes in the intensity of incident beam do not affect the spectra significantly.

DETECTOR RESPONSIVITY AT INFRARED

Many radiometric applications require the determination of the spectral radiant power responsivity function of infrared (IR) detectors. Applications of IR detectors in various fields such as thermal imaging, night vision and surveillance, low temperature measurements, and testing of micromechanical devices have brought demanding requirements for accurate calibration of infrared standard detectors. To accommodate accurate measurement of spectral power responsivity in the wavelength range from 0.2 µm out to 15 µm a spectrometer facility has been developed at the Metrology Research Institute.

In the year 2007, three cabinets equipped with dry Nitrogen purging system were built for measuring spectral power responsivity of detectors in the wavelength range from 1.1 μm to 3.1 μm, including the atmospheric absorption bands. Several working reference detectors were developed with the possibility of mounting them onto an integrating sphere. In addition, integrating sphere detectors were utilised for measurement of relative diffuse transmittance of paper samples in the near infrared spectral range in order to study their water content [142]. In the year 2008, a new reference pyroelectric detector has been developed.

EFFECTS OF UV RADIATION ON MATERIALS (UVEMA) [158, 159]

In this two-year project in collaboration with Finnish Meteorological Institute, Tampere University of Technology and several industrial partners, the Metrology Research Institute built a device that can be used for studying the effect of wavelength on the UV ageing of materials. The device is based on a concave flat-field holographic grating that disperses the radiation collected from a 1-kW Xe-lamp, and images it onto a sample plane. The device causes noticeable damage to newspaper in hours. Plastic samples age in a matter of days so that the action spectrum can be defined.

During 2007 the device was finalized and delivered to the customer. Thorough measurements were conducted to ensure that the alignment of the setup did not change in the transfer. The device is to be operated by technicians so detailed operating instructions were produced.

EFFECTS OF UV RADIATION ON MATERIALS 2 (UVEMA-2)

This two-year project funded by TEKES is a continuation of an earlier project. Metrology Research Institute builds an improved version of the device that can be used for studying the effect of wavelength on the UV ageing of materials.

The improved device, as its predecessor, is based on a concave flat-field holographic grating and a 1-kW Xe-lamp. The major improvement is that the sample can be heated up to 80 °C to accelerate the ageing. The output spectrum is limited to wavelengths 280 – 420 nm to avoid the problems associated with higher order refraction. The extended wavelength regions of the prototype do not contain useful information and are thus sacrificed to increase dispersion. There will be an additional sample port for the zero order refraction.

During 2008, the device was designed and all the parts were purchased. The work will continue with assembly and testing.

Comparisons

INTERNATIONAL COMPARISONS

Key comparison CCPR-K2.a: spectral responsivity 900-1600 nm, pilot NIST
Draft A-3 is nearly completed and Draft B will be distributed during 2009.

Key comparison CCPR-K2.c: spectral responsivity 200-400 nm, pilot PTB
There has been a delay due to damage of a transfer standard detector, but the measurement is now completed and pre-Draft A process is in progress.

Key comparison CCPR-K5: spectral diffuse reflectance, pilot NIST
Draft A was distributed to all participants during 2008. The comments deadline was passed in December 2008 and Draft B is expected during 2009.

Key comparison CCPR-K6: spectral regular transmittance, pilot LNE
The participants carried out their measurements during the year 2000 and the final report of this comparison was published in the beginning of 2009 [G. Obein and J. Bastie, Metrologia 46, Tech. Suppl. 02002 (2009)]. Each participant performed measurements of five filters of different optical densities at eight wavelengths between 380 nm and 1000 nm. The comparison of the results of measurements carried out by the pilot laboratory before and after the circulation of the filters points out that the stability of most of the filters was rather poor. As a consequence, altogether 13 participants out of 15 had two or more measurement values outside the expanded uncertainty limits. The deviation of three MIKES data points from the key comparison reference value of three filters at the wave-length of 380 nm was larger than the calibration and measurement capability (CMC) listed in the BIPM key comparison database. However, these results do not cause any re-evaluation of the CMC uncertainties of MIKES, because of the stability problems of the filters, long time elapsed since the measurements, and improvements in the measuring equipment in the meantime.

Key comparison EURAMET.PR-K6: spectral regular transmittance, pilot LNE
MIKES acts as one of the seven EURAMET link laboratories in this regional key comparison to be linked to CCPR-K6. The measurement results from the year 2000 of CCPR-K6 will be used for the linkage.

Key comparison EURAMET.PR-K3.a: luminous intensity, pilot PTB
MIKES and pilot measurements of four transfer standard lamps of luminous intensity were completed during 2008. The return measurements by MIKES are scheduled for 2009.

Key comparison EURAMET.PR-K4: luminous flux, pilot PTB
MIKES measurements of four transfer standard lamps of luminous flux were completed during 2008. The pilot measurements and return measurements by MIKES are scheduled for 2009.

Supplementary regional comparisons APMP.PR-S3.a, APMP.PR-S3.b, and APMP.PR-S3.c: LED related quantities, pilot KRISS
The measured quantities in these comparisons include the CIE averaged luminous intensity B, total luminous flux, and chromaticity coordinates x, y of LEDs. The MIKES measurements were completed during 2008.

Bilateral key comparison EURAMET.PR-K1.a.1: spectral irradiance, pilot MIKES
The bilateral comparison EURAMET-K1.a.1 of the spectral irradiance scales between MIKES (Finland) and NIMT (Thailand) in the spectral range of 290 to 900 nm was completed. MIKES acted as the pilot and link to the results of the key comparison CCPR-K1.a. The comparison artefacts were three transfer standard lamps. The lamps were 1 kW tungsten halogen FEL type lamps. The measurements at MIKES were made in December 2006 and in February 2008 to monitor a possible drift. NIMT calibrated the transfer standard lamps in November 2007. The spectral irradiance values measured by NIMT and MIKES agree generally within the expanded uncertainty. The only exceptions are results at wavelengths 450 nm and 500 nm, where

the average difference exceeds the $k = 3$ and $k = 2$ uncertainty limits, respectively. The difference between the NIMT results and the key comparison reference value (KCRV) of CCPR-K1.a is seen in Fig. P8. The final report of the comparison has been accepted for publication in Metrologia as Technical Supplement [M. Ojanen, M. Shpak, P. Kärhä, R. Leecharoen, and E. Ikonen, Report of the Spectral Irradiance Comparison EURAMET. PR-K1.a.1 between MIKES (Finland) and NIMT (Thailand)].

Bilateral comparison MIKES - NMC A*STAR in spectral irradiance using a multi-wavelength filter radiometer
The spectral irradiance scales of NMC A*STAR (Singapore) and MIKES (Finland) in the spectral range from 280 nm to 900 nm were compared at NMC A*STAR using an automatic multi-wavelength filter radiometer (MWFR) (Fig. P9). The comparison artefacts were three tungsten halogen lamps: one 1 kW FEL lamp of MIKES, one 1 kW FEL lamp of NMC, and one Osram 400W HLX64665 lamp of NMC. The results were analyzed using the algorithm developed at the Metrology Research Institute. The agreement of the standard values assigned to the lamps by both NMIs with the measured values using the MWFR were well within their expanded measurement uncertainties. The report of the research has been accepted for publication in Metrologia (Y. J. Liu, G. Xu, M. Ojanen, and E. Ikonen, Spectral Irradiance Comparison Using a Multi-Wavelength Filter Radiometer) [145].

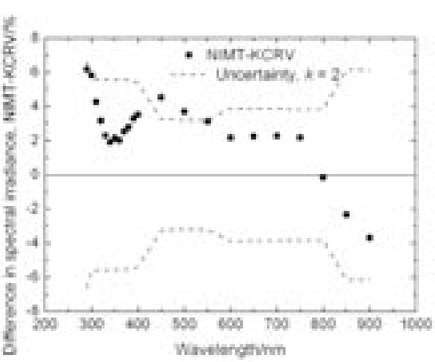


Figure P8. Degrees of equivalence of NIMT. The expanded uncertainty is marked with the dashed lines.

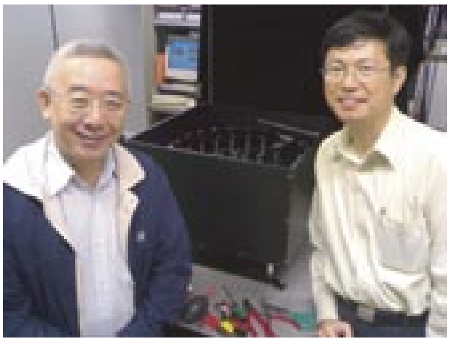


Figure P9. Dr. Gan Xu and Dr. Yuanjie Liu (right) in front of the NMC filter radiometer consisting of rotating filters and a trap detector. The black-walled lamp enclosure is seen behind the filter wheel container.

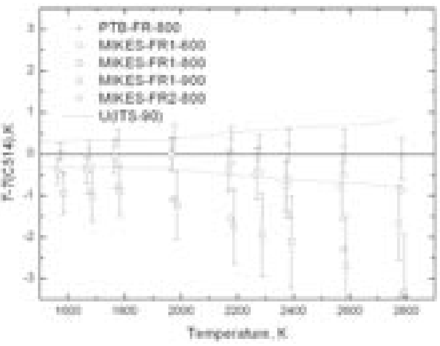


Figure P10. Filter radiometer measurement results and their differences to the ITS-90 reference. The dashed lines represent the expanded uncertainty (k=2) of the ITS-90 reference.

Bilateral comparison of spectral diffuse reflectance [141]
A comparison between the absolute gonioreflectometric scales at the Metrology Research Institute and the Physikalisch-Technische Bundesanstalt (PTB) has been accomplished. Six different reflection standards were measured for their 0/45 spectral radiance factor between 250 nm and 1650 nm in 10 nm intervals. Also, the 0/d reflectance factor between 400 nm and 1600 nm in 100 nm intervals was determined from the goniometric reflectance measurements over polar angles with subsequent integration within the hemisphere above the sample. The report of the results was submitted for publication.

Supplementary comparison CCPR-S2: aperture area, pilot NIST
Final report [160] was published in Metrologia Technical Supplement in 2007: Metrologia 44, Tech. Suppl. 02002, 84 pages.

Chromatic dispersion comparison EUROMET-PR.S1.1 (bilateral with METAS):
Final report [161] was published in Metrologia Technical Supplement in 2007: Metrologia 44, Tech. Suppl. 02003, 12 pages.

Comparison of absolute spectral irradiance responsivity measurement techniques using wavelength-tuneable lasers
Independent methods for measuring the absolute spectral irradiance responsivity of detectors have been compared between the Metrology Research Institute and the National Institute of Standards and Technology (NIST), USA [155, 162]. The results of the comparison published in 2007 demonstrate agreement at the uncertainty level of less than 0.1 %.

Comparison of the radiation temperature scales
The radiation temperature scales of PTB and MIKES were compared in the range of 1570 K to 2770 K at Physikalisch-Technische Bundesanstalt (PTB), Germany. The measurement artifact was a high temperature black body, and a strip lamp was used as an ITS-90 reference. The measurement equipment consisted of four filter radiometers from TKK, one filter radiometer from PTB and linear pyrometers from MIKES and PTB. The results of two filter radiometers agree within k=2 uncertainty limits between the scales (Fig. P10). The average difference to ITS-90 of the linear pyrometer from MIKES was -0.28 K and the standard deviation was 0.52 K. For the linear pyrometer from PTB, the average difference was 0.18 K and the standard deviation 0.36 K.

Ionising radiation

Personnel
STUK

Dr. Antti Kosunen	*Head of Laboratory*
Dr. Teemu Siiskonen	*Senior Scientist*
M.Sc. Markku Tapiovaara	*Senior Scientist*
M.Sc. Petri Sipilä	*Senior Inspector*
M.Sc. Ilkka Jokelainen	*Physicist*
Dr. Arvi Hakanen	*Scientist*
M.Sc. Paula Pöyry	*Scientist*
Eng. Panu Pousi	*Laboratory Engineer*
Tech. Teuvo Parviainen	*Technician*
Tech. Harri Lindroos	*Technician*
Tech. Ilkka Aropalo	*Technician*
Mrs. Carita Ruuhonen	*Secretary*

On the basis of its own legislation, Radiation and Nuclear Safety Authority (STUK), Radiation Metrology Laboratory, maintains the national standards for units of ionising radiation quantities. The quantities are: air kerma, reference air kerma rate, absorbed dose to water, absorbed dose to soft tissue, ambient dose equivalent, directional dose equivalent, personal dose equivalent, and surface emission rate.

Highlights in 2007-2008

The calibration method developed for kerma-area product (KAP) meters and the investigation of the energy dependence of the KAP meters were published [163, 164].

For commissioning and use of ^{85}Kr standard beeta source the dosimetry and spectral characteristics of source were studied [165]. Laboratory had also participated in the dosimetric studies of alpha particles. The dosimetric evaluation of a ^{238}Pu alpha particle irradiator for biological experiments and the development of methods for alpha spectrometry were published [166]. The radiation quality factor of myons was studied by Siiskonen [167].

A joint study with the University of Leuven, Belgium, for choice of the optimal anode/filter combination for digital mammography was published [168].

A Monte Carlo study for evaluation of the personal dose of a radiologist was published [169]. The results of the study are used for the evaluation of the accuracy of use of personal dosemeters in Finland. The geometry and the results used were also implemented in the European CONRAD-project by The European Radiation Dosimetry Group (EURADOS).

A temperature controlled water phantom for irradiations of biological samples was designed and taken in use. Samples are irradiated in terms of absorbed dose to water with ^{137}Cs and ^{60}Co gamma radiation.

Realisation, Maintenance

The renewal of ^{137}Cs and ^{60}Co gamma radiation sources used mainly for calibration of radiation protection survey instruments was started in 2007. The first sources are expected to be installed and commissioned in 2009.

The laboratory participates regularly in the annual dosimetry audits organised by IAEA/WHO secondary standard laboratory network using postal thermoluminescent dosimeters. The stated difference between the results of STUK and IAEA for absorbed dose to water in a ^{60}Co gamma radiation beam were -0.8 % in 2007 and +1.5 % in 2008. The tolerance level for the difference by IAEA is +/- 3.5 %.

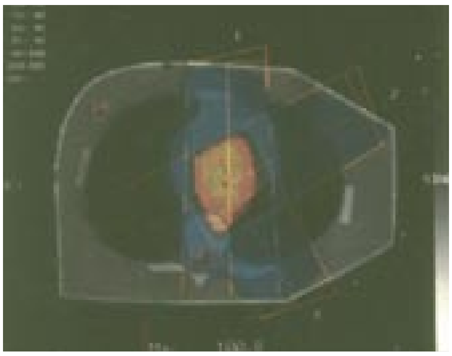


Figure I1. A computed tomography image of a water filled phantom with inserts simulating tissues at thorax region. Similar phantoms are to be developed and characteristics of dosemeters investigated in the EMRP project for external beam cancer therapy.

Research Projects

The Laboratory was participating in an IAEA Coordinated Research Project "Testing of the Implementation of the Code of Practice on Dosimetry in X-ray Diagnostic Radiology" (years 2005 - 2008). The main topics for STUK were testing of the calibration methods for kerma area product meters and the clinical measurement techniques for general radiology, computed tomography and mammography. The report of the project is to be expected to be published by IAEA in 2009.

The Laboratory is participating in two EMRP projects for metrology of ionising radiation. Both projects are related to dosimetry of radiation therapy; JRP6, brachytherapy dosimetry and JRP7, external beam cancer therapy. The contribution is aimed for evaluation of accuracies of different dosimetry techniques and for developing a semi-antropomorfic phantom for experimental evaluation of the calculated doses by treatment planning systems. [Fig. I1].

Comparisons

INTERNATIONAL COMPARISONS

In recent years laboratory has participated in all EUROMET comparisons relevant for the secondary level standards and quantities maintained. The latest calibration and measurement comparisons are:

- EUROMET 545, ISO Narrow series x-rays , air kerma, 2005.
- EUROMET 738, ISO Narrow series x-rays, personal dose equivalent, 2005.
- EUROMET 739, Beeta ^{90}Sr/^{90}Y, absorbed dose to tissue, 2005.
- EUROMET 813, ^{60}Co gamma radiation, absorbed dose to water, 2006.

For comparison 545, 738 and 813 the final results have not been published. The preliminary results for comparisons of 738 and 813 are well within the stated uncertainties and at the same level as the results for other laboratories using secondary level standards. For comparison 545 the results for STUK were generally good except the slight deviation for radiation quality of ISO narrow of 60 kV x-ray tube voltage and for the smallest, 30 cm^3 ionisation chamber used in the comparison. The deviation was 2.8 % and the estimated uncertainty 2.46 % (1sd %, k = 2). The reason for the deviated result was traced to the instability of the x-ray output at the low energy region.

For comparison 739 STUK participated by ^{90}Sr beeta radiation and the results were in very good agreement (difference of -0.8 %) to the reference value [170].

Other activities

Staff of the Laboratory participated also as experts in development of radiation dosimetry laboratories in the EU support program project for Bulgaria *"Strengthening of administrative structures for radiation protection and safety use of ionizing radiation in diagnostics and therapy"* and in the EU Nuclear Safety Action Programme for Belarus *"Transfer of Western European Regulatory Methodology and Practices to the Nuclear Safety Authorities of Belarus. Regulatory Assistance and Technical Support in the Field of Radiation Protection and Emergency Preparedness"*.

Chemistry

Personnel
MIKES-FMI

Phil.Lic. Jari Walden	*Technical Manager of the Laboratory*
Dr. Pirjo Kuronen	*Senior Researcher*
M.Sc. Veijo Pohjola	*Senior Researcher, Quality Manager*
M.Sc. Kaisa Lusa	*Researcher*
M.Sc. Minna-Kristiina Sassi	*Researcher*
M.Sc. Antti Wemberg	*Researcher (until 31.8.2008)*
Ms. Sisko Laurila	*Research Assistant*

The Finnish Meteorological Institute (FMI) is a governmental research and service institute. The main objective of the FMI is to provide the best possible information about the atmosphere above and around Finland, to ensure public safety relating to atmospheric and airborne hazards and to satisfy requirements for specialised meteorological products. The measurements have therefore been one of the most important activities throughout the history of the institute and measurements of air quality play an important role in it.

To improve the traceability of the air quality measurements the Finnish Meteorological Institute and MIKES made a contract for the maintenance of calibration service in the field of air quality according to the requirements by the CIPM. In the contract the MIKES designated the FMI as a National Standards Laboratory (NSL) in the field of gas metrology (amount of substance). In addition the FMI was also nominated as a National Reference Laboratory (NRL) in the field of air quality by the Ministry of the Environment. The FMI Calibration Laboratory at the department of Air Quality Research carries out both of the duties. The quality system of the laboratory is accredited according to ISO 17025 standard as a calibration laboratory.

Mission of the FMI Calibration Laboratory

The responsibility of the laboratory is to carry out the task of

- the National Reference Laboratory of atmospheric pollutants
- the National Standards Laboratory on gas metrology, the maintenance and support of the national reference standards in the field of air quality
- the maintenance of the calibration laboratory
- co-operation on research projects and expert service.

The calibration laboratory performs the calibrations to the customers which come from the industry, local authorities or consultants in the field of air quality measurements, universities and research institutes and background air quality assessment programmes carried out at the Finnish Meteorological Institute. Calibration service includes calibration of the calibration facilities or analyzers. The calibration concentrations are traceable to the SI or to the international standards.

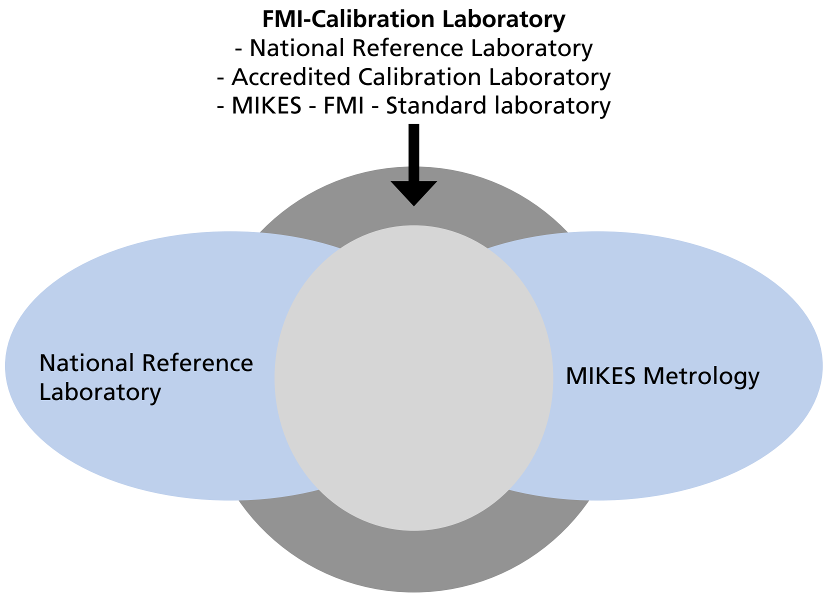


Figure C1. The schematic presentation of the tasks of FMI Calibration Laboratory (grey circle). The responsibility of the designated laboratory, MIKES-FMI Standards Laboratory (Air Quality, on the right) and the National Reference Laboratory (on the left). The scope of accreditation (smaller circle in the middle) covers both of the activities of the NRL and NSL and in addition few other gas components in the FMI Calibration Laboratory.

Organisation of the subject field

The metrology in chemistry in Finland is focused on gas metrology at the Finnish Meteorological Institute. The FMI Calibration Laboratory is nominated as a National Reference Laboratory for air pollution by the Ministry of Environment. Also as a designated laboratory by MIKES to EURAMET, the FMI Calibration Laboratory is also a Standards Laboratory in the field of gas metrology (Air Quality), see in Fig. C1. The MIKES-FMI Standards Laboratory maintains calibration and measurement service for atmospheric gaseous pollutants such as carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2), and the BTEX-compounds including benzene (C_6H_6), toluene (C_7H_8), ethylbenzene (C_8H_{10}), and o-, m-, and p-xylenes (C_8H_{10}). The traceability of the calibration concentration produced in the laboratory is to SI via National Metrology Institutes: National Physical Laboratory, NPL (UK); Nederlands Meetinstituut, NMi (NL); Laboratoire National D'Essais, LNE (FR), Bureau International des Poids et Measures (BIPM), and MIKES (FI). The reference gas standards of the laboratory for carbon monoxide, nitrogen monoxide, sulphur dioxide and Benzene, Toluene, Ethylbenzebe and o-, m-, and p-Xylene (BTEX-compounds) are those of the primary gas standard of the NPL and NMi. The ozone reference standard is the Standard Reference Photometer (SRP) by NIST. It fulfils the criteria for being as a Primary Method of Measurement. The SRP is compared at regular intervals to similar SRP by NIST at the BIPM. The reference standard for nitrogen dioxide is the gas phase titration of nitrogen monoxide (NO) with ozone (O_3). As secondary standards for nitrogen dioxide, sulphur dioxide, benzene, toluene, o- and m-xylenes the FMI Calibration Laboratory maintains the permeation method. The gas concentrations are produced by dynamic dilution method or by static injection of the reference or secondary gas standards.

Highlights in 2007-2008

For the first time an estimate of the atmospheric emissions from shipping has been created by the ShipNODeff-project from observed shipping information in the Baltic Sea [171]. The estimate is based on information from the Automatic Identification System collected by the Baltic Sea countries and is verified against information on fuel consumption obtained from shipping companies and *in situ* measurements of air quality near fairways. The estimate of the total NO_x emissions in the Baltic (370 kton NO_x/year) is likely to be an underestimate at this point; it is higher than other present estimates though.

The Baltic Sea traffic is intense and grows by around 5 % per year. The total number of vessels sailing in the Baltic is 3 500-5 000 each month, depending on the season (See Fig. C2). The largest ship categories are general cargo carriers and oil/chemical tankers. However passenger ships have the highest fuel consumption and second highest NO production.

The NO_x emissions from shipping in Finnish waters alone are higher than emissions from Finnish land traffic. On the Baltic Sea scale, the emissions from shipping estimated are comparable to the combined land-based NO_x emissions from Denmark and Sweden.

The emissions, if they were directly deposited to the sea at the source, would contribute significantly to the dissolved inorganic nitrogen concentrations in the Baltic Sea, and therefore to the eutrophication in the Baltic. A month's worth of ship emissions would increase the nitrogen level in the sea within 10 km of the shipping lane by about 5-20 % of the winter nitrogen concentration.

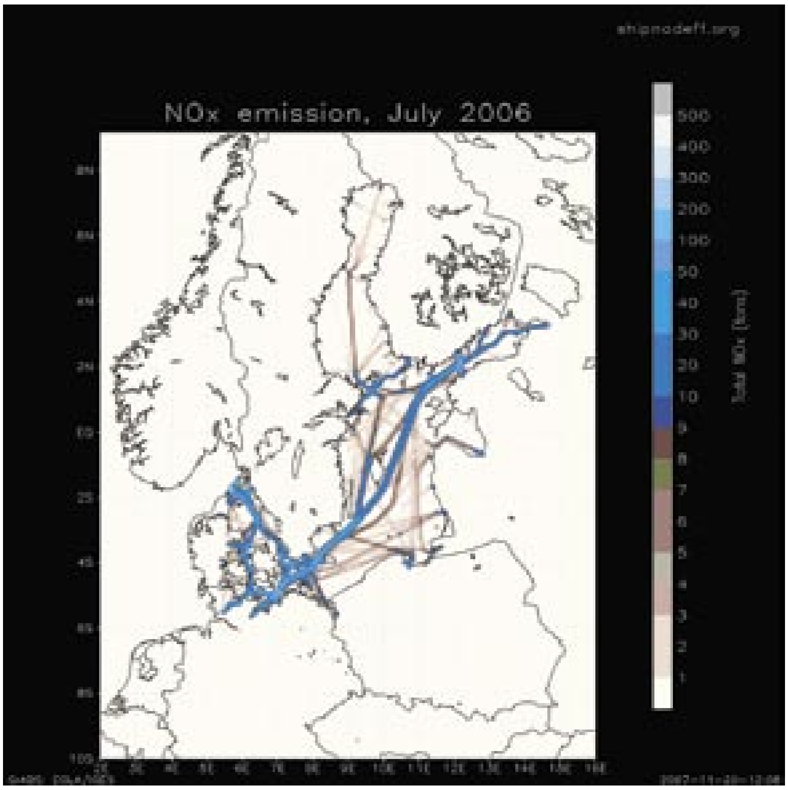


Figure C2. Geographical distribution of NO_x emission in July 2006. The unit is tons of NO_x / grid cell of 0.08° x 0.08° (roughly ~9 km by 9 km) in one month.

Research Projects

The FMI Calibration Laboratory took also part in the project of Air Quality Management-III in St. Petersburg in Russia. The project aimed for exchange of information and best practices between St. Petersburg and Finnish cities in developing local air quality monitoring system as well as raising public awareness. Hands on training on the calibration practises at the FMI Calibration Laboratory was included in the project, see Fig. C3. The Metrology Institute of Russia, VNIIM, participated in the project.

The equivalence of the particulate method against the reference method of the European Union has been studied at the FMI for the particulate sizes of below 10 µm (PM10) and below 2.5 µm (PM2.5). The procedure for the testing of the instruments is via the so called equivalence procedure. The project is still ongoing and final results are not available at the moment.

The project "Real-time assessment of ship-borne nitrogen emissions and their effects on the marine environment in the Baltic Sea (ShipNODeff)" was funded by the EU through the INTERREG programme. The main objective of the study is to develop a system to estimate the effects of exhaust emissions from ship traffic to the eutrophication of the Baltic Sea. The laboratory conducted the direct deposition measurements of nitrogen and sulphur compounds into the Baltic Sea at the isle of Aegna, close to the ship routs at the city of Tallinn [172].

The MIKES-FMI Standards Laboratory also took part in the EUROMET 888 project "Dynamic measurements of NO_x, CO, and SO_2 at low ambient level and their comparability". The workshop was held to illustrate the state of the art for the preparation of the gas concentrations for calibration purposes by the use of the dilution methods of the gas standards. The workshop concentrated both on the static injection method and the dynamic dilution method. Participants from the expert laboratories and from the NMIs, see Fig. C4, shared their experience and the best practice for the use of both methods. The workshop was organised by Annette Borowiak, from the JRC/Ispra/IES, Martin Milton from NPL, UK and Jari Walden from FMI, Finland.

Comparisons

The MIKES-FMI Standards Laboratory participated in the CCQM-K26b project (sulphur dioxide at ambient level) in 2005, with good success [173]. In 2007 MIKES-FMI Standards Laboratory took part on the key comparison of ozone photometer (BIPM.CM.K1) organized by BIPM and Comparison of primary standards of carbon monoxide in nitrogen (CCQM-K51) in 2008.

At the national level the FMI Calibration Laboratory conducted the intercomparison experiments to the air quality networks for carbon monoxide, nitrogen monoxide, sulphur dioxide, ozone and hydrogen sulphide. Results from the comparison indicated that 94 % of the results were within the acceptable limit [174].

Figure C3. Dr. Pirjo Kuronen is presenting the calibration of ozone analyser with the SRP-37 photometer to Vice-director, Dr. Alexander Koltshov and Mr. Mishka Aleksashin from the State Company Mineral of the St. Petersburg.

Figure C4. The participants of the workshop of the EUROMET 888 project.

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Contact information of the National Standards Laboratories

NATIONAL STANDARDS LABORATORY	QUANTITY	HEAD OF LABORATORY	EMAIL ADDRESS
MIKES Tekniikantie 1 FI-02150 ESPOO tel. +358 10 6054 000 fax +358 10 6054 299	mass pressure length temperature humidity flow electricity time and frequency acoustics	Kari Riski Markku Rantanen Antti Lassila Martti Heinonen Martti Heinonen Martti Heinonen Antti Manninen Kalevi Kalliomäki Kari Ojasalo	kari.riski@mikes.fi markku.rantanen@mikes.fi antti.lassila@mikes.fi martti.heinonen@mikes.fi martti.heinonen@mikes.fi martti.heinonen@mikes.fi antti.manninen@mikes.fi kalevi.kalliomaki@mikes.fi kari.ojasalo@mikes.fi
Helsinki University of Technology and MIKES Metrology Research Institute P.O. Box 3000, FI-02015 TKK tel. +358 9 4511 fax +358 9 451 2222	photometry radiometry	Erkki Ikonen	erkki.ikonen@tkk.fi
Radiation and Nuclear Safety Authority P.O. Box 14, FI-00881 Helsinki tel. +358 9 7598 8446 fax +358 9 7598 8450	ionising radiation	Antti Kosunen	antti.kosunen@stuk.fi
Finnish Geodetic Institute Geodeetinrinne 2 FI-02430 Masala tel. +358 9 295 550 fax +358 9 2955 5200	acceleration of free fall length in geodesy	Jaakko Mäkinen Jorma Jokela	jaakko.makinen@fgi.fi jorma.jokela@fgi.fi

Contact information of the Contract Laboratories

CONTRACT LABORATORY	QUANTITY	HEAD OF LABORATORY	EMAIL ADDRESS
Lahti Precision Oy Force and Mass Laboratory P.O. Box 22 FI-15801 Lahti tel. +358 3 829 21 fax + 358 3 829 4101	force and torque	Michael Sachs	michael.sachs@lahtiprecision.com
Finnish Meteorological Institute Air Quality Research Erik Palménin aukio 1 FI-00560 Helsinki tel. +358 9 19291 fax +358 9 1929 5403	air quality	Jari Walden	jari.walden@fmi.fi

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Mittatekniikan keskus (MIKES)
Centre for Metrology and Accreditation
P.O. Box 9
FI-02151 Espoo
Tel: +358 10 6054 000
Telefax: +358 10 6054 299
www.mikes.fi

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