MIKES
Mittatekniikan keskus
Centre for metrology
and accreditation

FINNISH NATIONAL
STANDARDS LABORATORIES

# ANNUAL REPORT 2006

www.mikes.fi

# 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 2007

## DEAR READER,

Finland is a land of extremes. Our country is among the top medallists of most competitive countries. The number of women acting as ministers is a record high 12 out of 20. The European song contest was won by remarkable points by the monster band Lordi* from Rovaniemi, the biggest city in Europe measured by area. Finland ranks near the top among OECD countries in terms of R&D investments as a percentage of GDP: 3.5 %. The mining industry is also active: Suurikuusisto is the biggest goldmine under development in Europe. A nickel deposit of the same importance has been discovered as well. Finland is the first to close analogue TV broadcasting service and to start using a digital system. 96 % of citizens have a mobile phone and the number of subscribed connections is well above the number of inhabitants. We have 1 000 000 saunas. In metrology, I think, we have a world record in paying the investment and energy bill of our new building. The bill is over one third of our annual budget.

We have spent about 1.5 years in our new building. A fairly long article has been written about design principles, specifications and achieved performance of the laboratories. This paper will be soon submitted for publication in a scientific journal. As a whole, measurements have shown that specifications were met, and in many cases, better circumstances than expected were achieved. The new building gathered our metrology activities under one roof. In addition we made a decision to take the CMM (Co-ordinate Measuring Machine) activity into the new building. Mitutoyo Legex 9106 was purchased. The consequence of this was that we terminated CMM activity as our designated laboratory at Tampere University of Technology headed by Professor Heikki Tikka. His laboratory has been a pioneer in CMM measurements in Finland and quality of work has been excellent.

Highlights from the year 2006 include a new national standards laboratory at MIKES. This laboratory was nominated in the field of high frequency electrical measurements. Final statement of the metrological competence of the laboratory was given by Klas Yhland from SP, Sweden. Development of the laboratory took many years and now it is time for active customer relations and training in the field. Another issue concerns electrical metrology, too. MIKES-TKK, the designated laboratory in the field of high voltage metrology, licensed the developed impulse voltage calibrator technology to Highvolt Prüftechnik Dresden GmbH. Third topic to mention concerns our working profile: MIKES Metrology was increasingly active in research and development work with enterprises. Partly this is due to a better visibility in the Otaniemi science campus.

In the near future EMRP (European Metrology Research Programme) under ERA-NET Plus is important from our point of view. Active participation is our intention. It also seems that working hours are becoming busier constantly. One indication is this annual report, which has been delayed by several months. Maybe, from now on, we will publish it biannually.

*Otaniemi 1.6.2007*
*Heikki Isotalo*
*Director*
*MIKES Metrology*

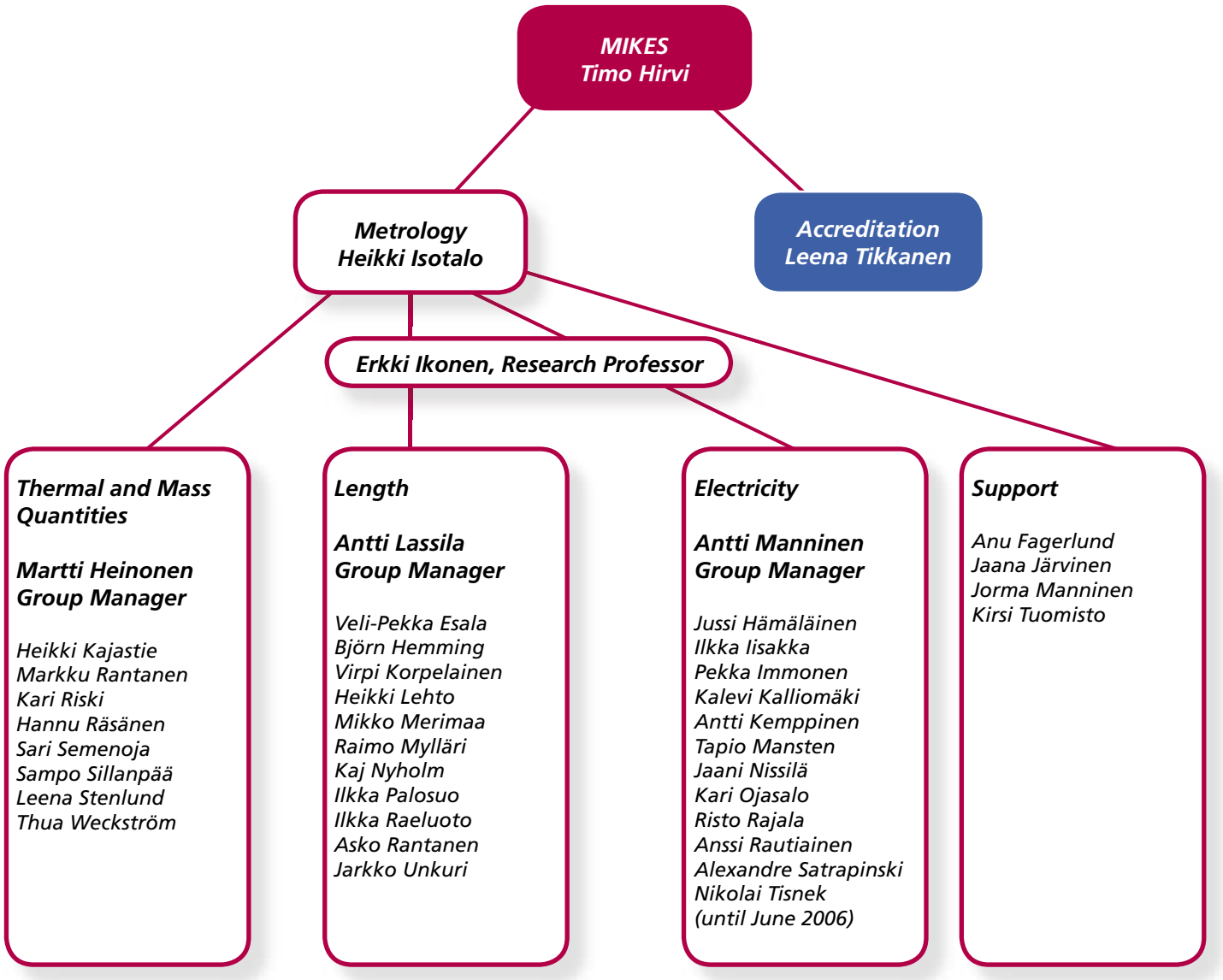
* Lordi is short for Land of Research, Development and Innovation. At least this is the interpretation of the research community.


***An aerial shot of the MIKES building, surrounded by other representatives in the Otaniemi technology hub.***

# 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 EUROMET, 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, high voltage, 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, coordinate measurements, 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.

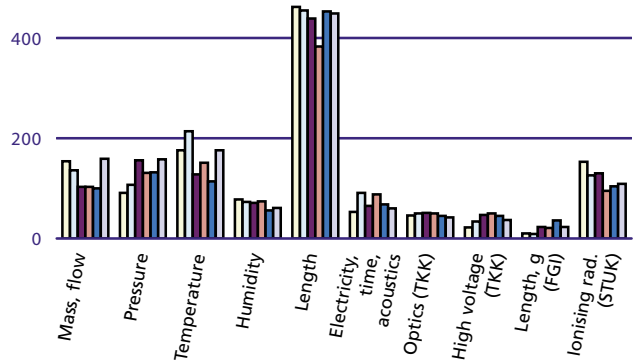
***Within MIKES, the Metrology Department is responsible for tasks relating to the maintenance and supervision of the national measurement standards system. Below is the organisation of the National Standards Laboratories in Finland.***


*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, TUT = Tampere University of Technology.*

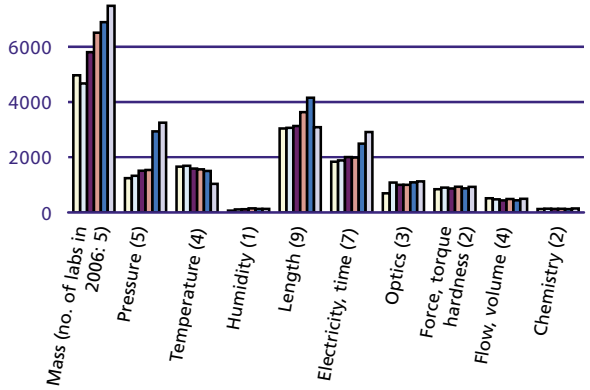
# 2006 in numbers

## National calibration certificates 2001-2006

### NSLs

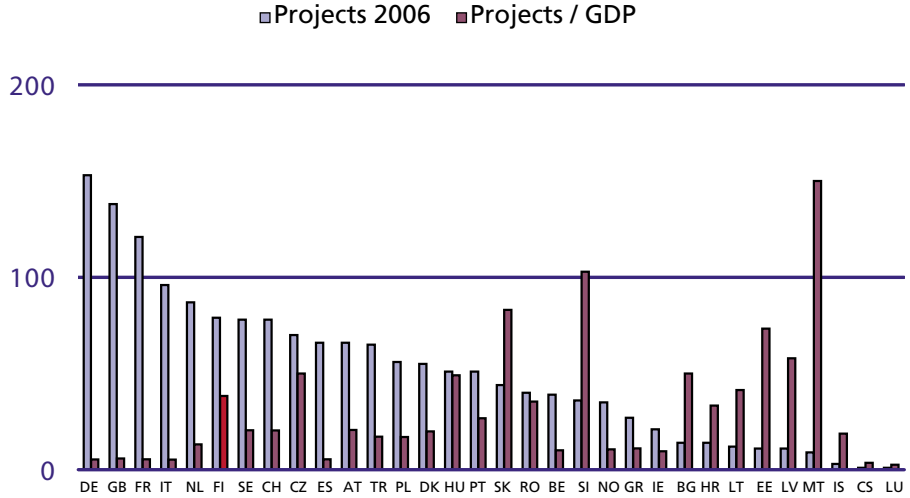


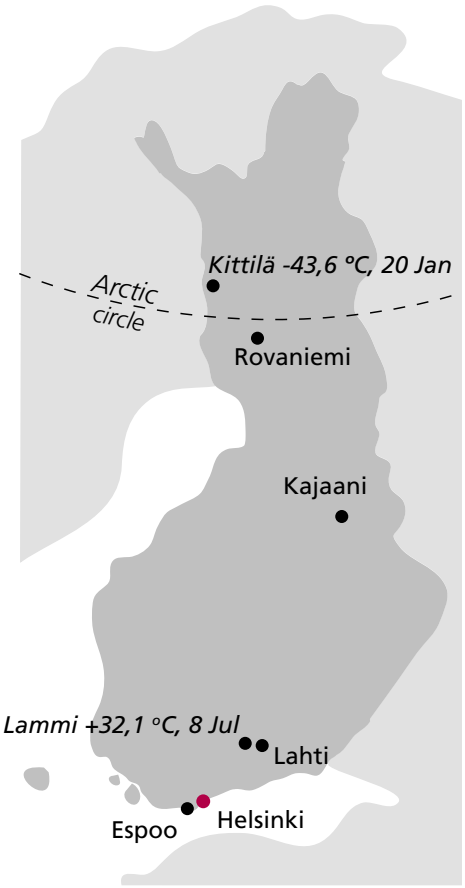

### ACCREDITED CALIBRATION LABORATORIES




## EUROMET projects

### AGREED AND PROPOSED PROJECTS

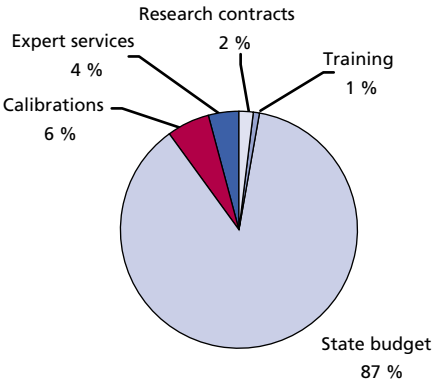



## FACTS ABOUT FINLAND

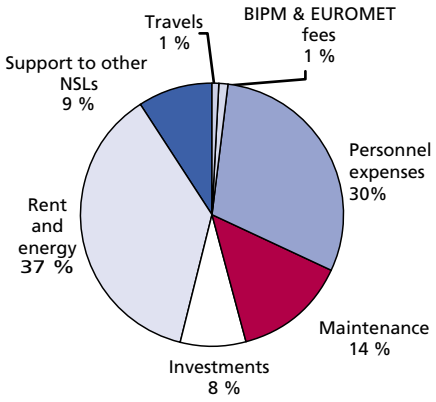
5 276 955 (12/2006) inhabitants
338 417 km$^2$
188 000 lakes
Currency: euro
Gross domestic product: 168·10$^9$ €
Official languages: Finnish and Swedish
5 biggest trade partners (export, 2006): DE, SE, RU, USA, GB
R & D investments: 3.5 % of the GDP
Source: Statistics Finland

## FACTS ABOUT MIKES METROLOGY

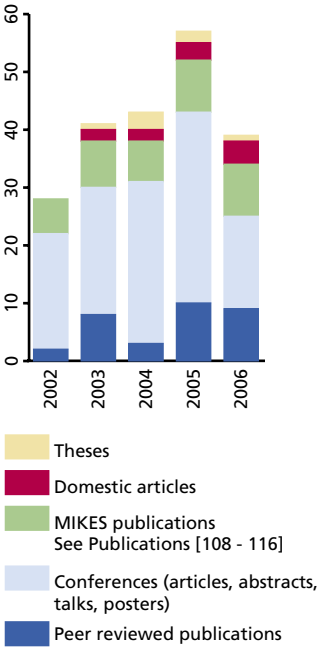
### PROCEEDS 6.1 M€



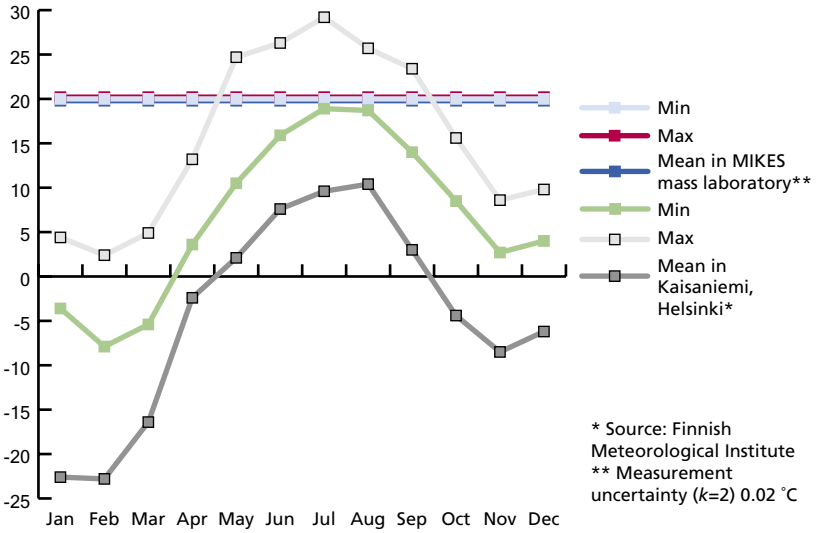

### COSTS 6.1 M€




### PUBLICATIONS (MIKES ONLY)




## MONTHLY TEMPERATURES IN HELSINKI AND IN THE METROLOGY LABORATORY (˚C)




* Source: Finnish Meteorological Institute
** Measurement uncertainty ($k$=2) 0.02 ˚C

# Thermometry and Mass

***Personnel***
***MIKES***

| | |
|---|---|
| *Dr. Martti Heinonen* | *Group Manager* |
| *M.Sc. Markku Rantanen* | *Head of Pressure Laboratory* |
| *Dr. Kari Riski* | *Head of Mass Laboratory* |
| *Dr. Thua Weckström* | *Head of Thermometry Laboratory* |
| *Lic.Sc. Heikki Kajastie* | *Research Scientist* |
| *M.Sc. Leena Stenlund* | *Research Scientist* |
| *M.Sc. Sari Semenoja* | *Research Scientist* |
| *M.Sc. Sampo Sillanpää* | *Research Scientist* |
| *Mr. Hannu Räsänen* | *Assistant Research Scientist* |
| *Mr. Tuomas Perälä* | *Trainee* |
| *Mr. Jouko Kinnari* | *Trainee* |

***MIKES-Lahti Precision***

| | |
|---|---|
| *B.Sc. Aimo Pusa* | *Head of the Laboratory* |
| *M.Sc. Michael Sachs* | *Research Scientist* |
| *Mr. Mikko Mäntylä* | *Supervisor* |

***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 Group has been organized in four national standards laboratories. The laboratories realise units for mass, temperature, pressure, small mass and volume gas flow, density, dewpoint 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 550 calibration certificates for customers at accredited laboratories, research institutes, industry and MIKES during 2006.

MIKES has a contract with Lahti Precision Oy nominating its Mass and Force 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 2006

## DETERMINATION OF THE SURFACE CHARACTERISTICS WITH STAINLESS STEEL PLATES

Coated and uncoated stainless steel plates (surface area about 58 $cm^2$) were used to study surface phenomena which occur on the surfaces of weights. The surface polish and the material of the plates were nearly identical with that of a high quality weight. Some plates were coated with different materials. These materials were chosen because they were supposed to be very hard, durable and suitable for keeping the surface clean. One plate was coated with diamond coating and one with nanocomposite coating. Two plates were coated with $TiO_2$ which was chosen for the property of natural self-cleaning (see Fig. T1). The physical surface structure of $TiO_2$ is dirt repellent and it also disperses biological compounds when lighted with UV lamp. Non-coated plates were used as a reference. The research was carried out in order to gather information about the surface phenomena and about the possibility to increase the stability of weights by coating.

In the first stage of the study, the main focus was to monitor the masses of the plates. The masses of plates were found to change according to the measures they had gone through. The variation in mass was found to be approximately 30 µg with non-coated plates, which is less than 1 ppm of the total mass (about 45 g). For coated plates the variation was somewhat larger, 35-50 µg, probably due to cleaning and more frequent handling of the weights.

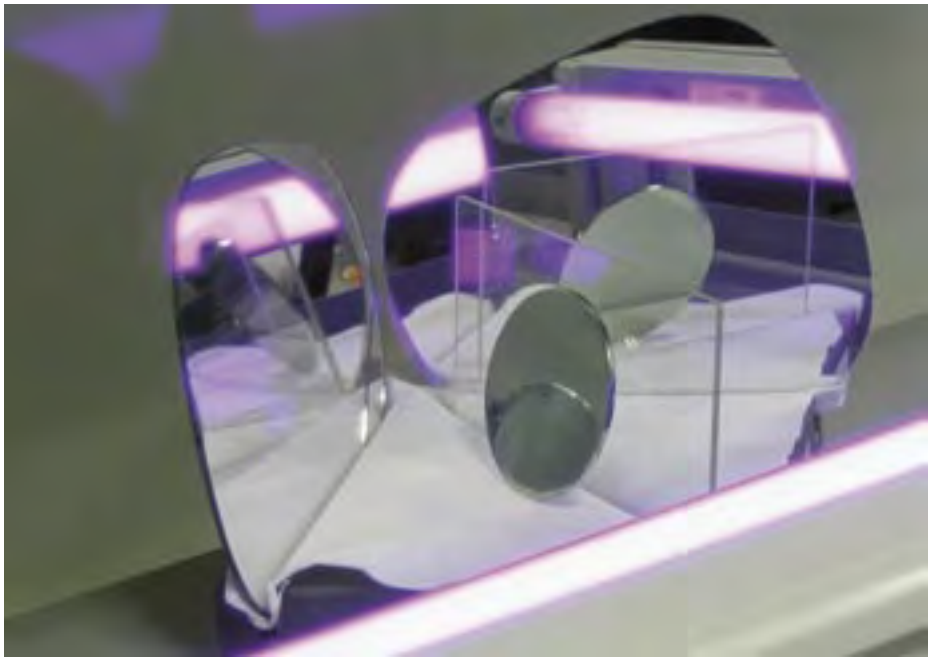


*Figure T1. $TiO_2$ coated stainless steel plate is being irradiated with ultraviolet light. The ultraviolet light is supposed to dissolve biological compounds due to catalysis on the surface with photo-electrochemical reaction.*

*Figure T2. Participants of the EUROMET TC-T meeting in the MIKES lobby.*

## EUROMET MEETINGS ON THERMOMETRY AND HYGROMETRY

MIKES hosted the meetings of the EUROMET Technical Committee for Thermometry (TC-T) and its sub-field for humidity on 3 to 5 April 2006. Martti Heinonen was chairing the humidity meeting. There were 53 participants from 29 countries. One of the most important topics was to finalize the roadmaps describing the outlines of European research on temperature and humidity metrology in the next 15 years.

## REPEATED ABSOLUTE GRAVITY MEASUREMENTS IN THE ANTARCTIC

During the Finnarp 2005 expedition, FGI performed absolute gravity measurements with the FG5-221 at three Antarctic stations: Aboa (Finland), Sanae IV (South Africa), and Novolazarevskaya (Russia) [1] (Fig. T3).

Essential support was received from the South African National Antarctic Program (Department of Environmental Affairs and Tourism), and from the Arctic and Antarctic Research Institute (St. Petersburg). Previously, FGI had measured at Aboa in 1994, 2001, and 2004, at Sanae IV in 2004 and at Novolazarevskaya in 2004. Gravity changes at Aboa and Novolazarevskaya have been small, while mass variation in the surrounding glacier (Fig. T4) caused a large change in gravity at Sanae IV. The modelling of local glacier effects on gravity is under way.

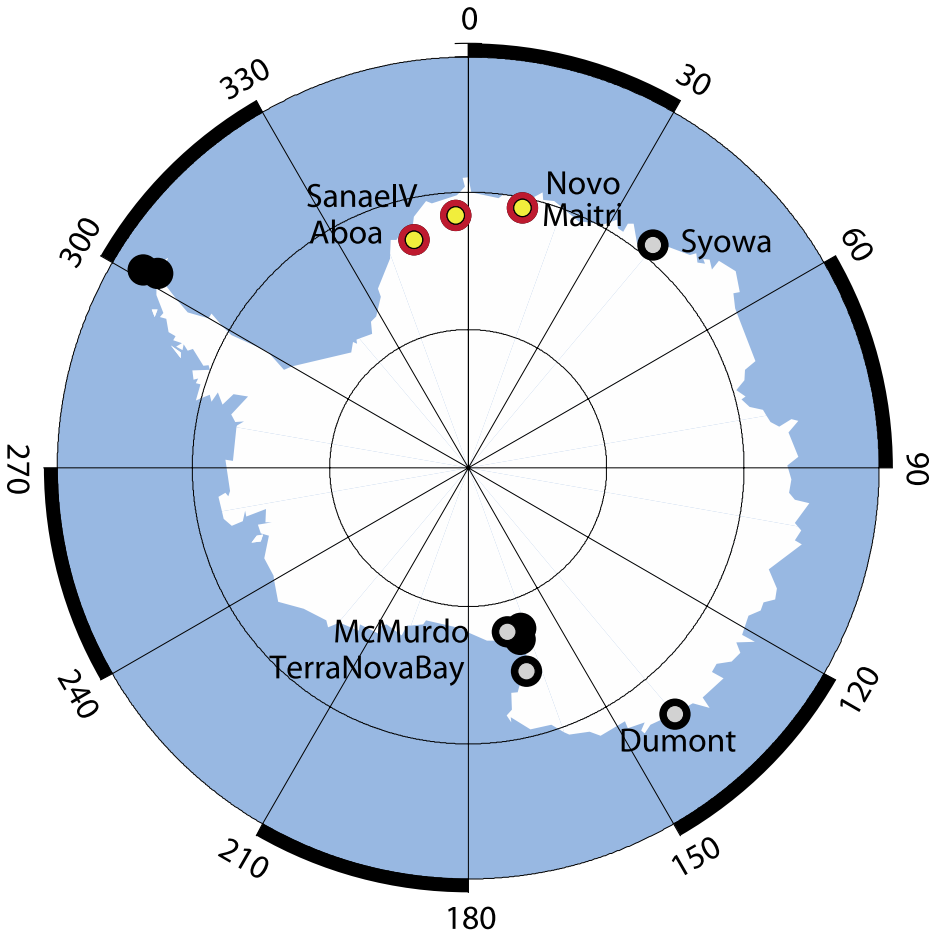



*Figure T3. Absolute gravity stations in the Antarctic, status December 2006. Open circles = repeatedly observed stations, red circles = stations observed by the FGI.*

# Research projects

## REALISATION OF THE KILOGRAM (MIKES)

The purpose of the project is to determine the mass of a levitating body in terms of other quantities (length, time, current, voltage) by using the superconducting magnetic levitation method. In the initial approach the electrical energy of a superconducting coil is directly converted to the mechanical energy of a levitating body. This can be done if there are no significant energy losses. In the first stage of the project energy losses in superconductors were determined with a cryogenic calorimeter operating at 4.2 K. Results obtained with a cryogenic calorimeter constructed earlier [2] show energy losses larger than acceptable in the direct energy conversion method. Other approaches are currently under consideration. The project has been carried out in co-operation with VNIIM (Russia) and VTT.

*Figure T4. The north face of the mountain Vesleskarvet on which the South African Antarctic station Sanae IV is situated rises steeply 150 m above the surrounding glacier. The mass of snow and firn below varies strongly from year to year mainly depending on wind-driven accumulation and ablation, and dominates the variation in gravity at this site.*

## VACUUM WEIGHING (MIKES)

In this project, mass changes of weights have been determined when the weights are moved between ambient pressure and vacuum. Also the density of air has been determined by weighing density artefacts in air and in vacuum. The effect of different coatings (e.g. $TiO_2$) on stainless steel discs on the stability of the mass was investigated at ambient pressure. An atomic force microscope (AFM) was used for studying changes in surface structure after vacuum exposure [3]. The coatings have been made in the Chemistry Department of University of Helsinki.

## DEVELOPING A NEW MEASUREMENT STANDARD FOR A CRYOGENIC TEMPERATURE RANGE (MIKES)

In 2003 MIKES began the project "Metrological CBT – A Thermometer Based on Coulomb Blockade" together with the Low Temperature Laboratory (LTL) at the Helsinki University of Technology. The principle of CBT was invented in 1994 by professor Jukka Pekola in Finland, and it is applied in commercial thermometers covering the range 20 mK – 30 K. The operation of the CBT is based on the current limiting effect of the charging energy created by individual electrons in a series of tunnel junctions. MIKES and the LTL have focused on investigating the suitability of the CBT as a scale defining instrument for the range 20 mK to 1 K.

For improving the electron thermalization at the lowest temperatures a new sensor lay-out was designed in 2005 and investigated theoretically (Fig. T5). In 2006, manufacturing methods were studied to achieve the required properties in the test sensors. Due to difficulties in the manufacturing process further development in sensor design was initiated. The project will continue in 2007.

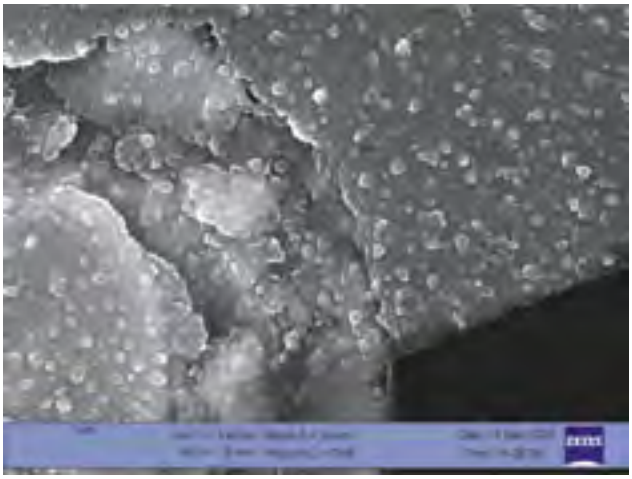


*Figure T5. A detail of a first new sensor. It shows a copper layer unsatisfactorily attached to the silicon substrate.*

## FILTER RADIOMETERS AS A TOOL FOR QUALITY ASSURANCE OF TEMPERATURE MEASUREMENTS WITH LINEAR PYROMETERS (MIKES)

Results obtained earlier in studies with filter radiometers showed a clear difference between the pyrometer used for realising ITS-90 and the filter radiometers. The agreement was good at the Ag point (961.78 °C), but the difference increased with increasing temperature. At the maximum, the difference was as high as 4.7 °C at 1350 °C. The cause was tracked to malfunctioning of the pyrometer, which was then sent to be fully rebuilt by the manufacturer. In a new set of measurements with the new improved pyrometer, the agreement of the temperature results was good, the mean difference being 0.47 K with standard deviation of 0.59 K. The difference showed no temperature dependence. The results will be published in Tempmeko 2007 conference.

## PRELIMINARY STUDIES ON APPLYING IR METHOD IN MEASURING SURFACE TEMPERATURE OF A HEATED PAPER MILL ROLL (MIKES)

In co-operation with Helsinki University of Technology Machine Design, the infrared temperature measurement technique was applied in measuring surface temperature of a polished steel. The goal was to estimate the applicability of the method in measuring the surface temperature of heated rolls in paper mills. It was shown that the method can be used in the application but it is very sensitive to many environmental parameters.

## HEAT FLUX IN MEASUREMENTS WITH A MINI-TPW CELL (MIKES)

Small triple point of water cells (mini-TPW) are used in laboratories to monitor the stability of PRTs. Compared with a standard TPW cell, heat flow in the thermometer well usually disturbs the apparent equilibrium temperature in a larger extent in a mini-TPW cell due to smaller dimensions. In this project, the heat flow effects are studied on the basis of experimental data. Especially, the thermal conduction along a thin thermometer probe and self-heating of the probe are thoroughly analysed. The project will continue in 2007 and the results will be published in Tempmeko 2007 conference.

## 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 e.g. coordinate measuring machine at MIKES. An analysis method is developed for determining the effective area from the dimensional data. In 2005, a large diameter (50 mm) piston-cylinder assembly was purchased. Measurements on the assembly were done in 2006.

## PTU-CALIBRATION SYSTEM (MIKES)

Devices measuring pressure, temperature and humidity simultaneously are known as PTU devices (see Fig. T6). Typical applications for this kind of devices are e.g. weather observation systems and wrist computers. MIKES is developing a calibration system for these devices as there are hardly any commercial systems capable operating in temperatures below 0 °C.

The nominal operating ranges of the MIKES system will be 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 system is under construction. Tests will be carried out in 2007.

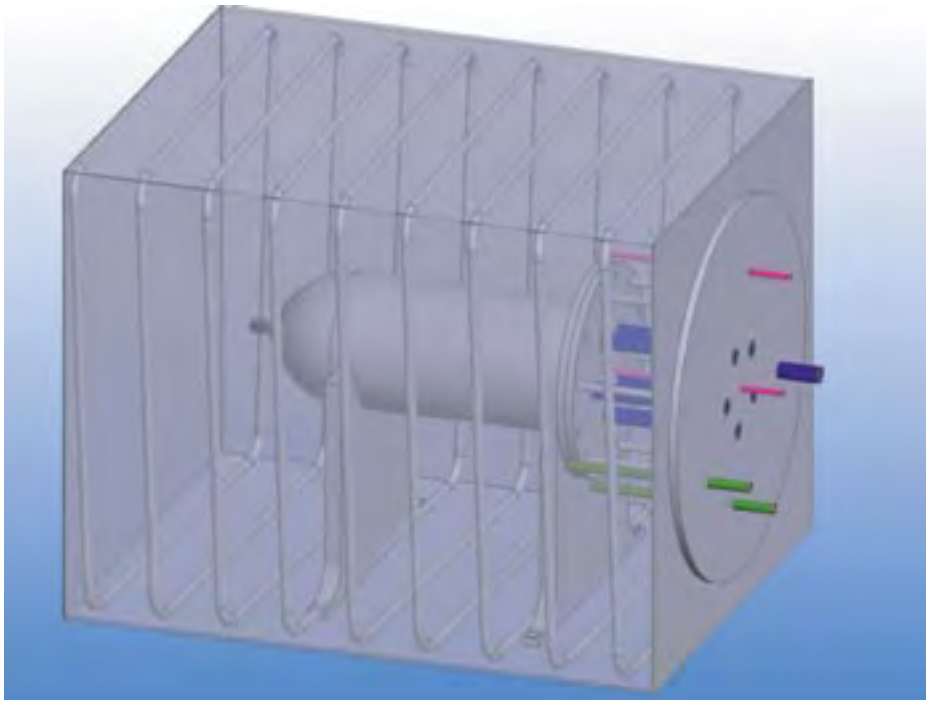


*Figure T6. Drawing of the measurement chamber of the PTU calibration system.*

## METHODS TO INVESTIGATE A DEW-POINT TEMPERATURE STANDARD IN AN EXTENDED RANGE (MIKES)

An internal method was developed to validate the uncertainty analysis carried out for one of our primary dew-point generators in the ranges -80 °C to -55 °C and +75 °C to +84 °C. Two-pressure and flow-mixing comparison methods were combined with a linearity analysis for chilled mirror hygrometers. Results obtained by applying the method show the validity of uncertainties of 0.2 °C in the low range and 0.06 °C in the high range. The results were reported in the ISHM 2006 conference [4].

## A PORTABLE HUMIDITY CALIBRATOR (MIKES)

A portable humidity calibrator was developed applying the single pressure generator principle (see Fig. T7). A saturator was designed to be used in a dry-block temperature calibrator. Measurement chambers of two kinds were under study. One of them has shown to be handy when calibrating wall mounted hygrometer probes. Measurement results show that the system is fast in use and very stable. Further development and tests are needed before covering the whole range 10 %rh to 95 %rh (+10 °C to +75 °C). The results were reported in the ISHM 2006 conference [5].

## 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. In the work (see Fig. T8), the significance was studied experimentally and theoretically. The effects of leaking VCR® and Swagelok® connectors are studied experimentally and analysed by comparing the results to the outcomes of investigations with leak holes. Theoretical calculations with a simplified combined convection-diffusion model are used for evaluating the results. Results obtained so far indicate that the minimum leak flow rate required to prevent any water vapour from back-diffusing into the tubing can be successfully predicted. The project is carried out in co-operation with University of Tartu and it will continue in 2007. Results of the project will be reported in TEMPMEKO 2007 conference.


*Figure T7. Portable humidity calibrator developed at MIKES.*

*Figure T8. A detail of a measurement cell developed for studying the back-diffusion effect.*

## TOWARDS CONTROLLED FREEZING OF SUPERCOOLED WATER (MIKES)

In the temperature range below 0 °C water can exist in both liquid and solid state. The equilibrium water vapour pressure is highly affected by the phase water. This is one of the most significant error sources when using chilled mirror hygrometers in humidity measurements. In this project we studied methods to initiate freezing of supercooled water droplets on a metal surface. Experiments with ultrasound were not successful. High static electric field (order of $10^6$ V/m), however, was shown to induce the freezing [6]. The project was carried out in co-operation with University of Helsinki.

## DEVELOPMENT OF NEW DEW-POINT GENERATORS (MIKES)

In co-operation with University of Zagreb (EUROMET P912), two single pressure dew-point generators will be designed, constructed and validated. The generators will cover the range from -70 °C to +60 °C. The generators will be used as the national humidity standards of Croatia. In 2006, saturators were designed for the generators. The project will continue in 2007.

## EFFECT OF NATURAL CONVECTION ON GRAVIMETRIC FLOW STANDARD (MIKES)

A theoretical analysis for the effects of shear stress rate on the gas cylinder surface caused by natural convection flow was carried out. Based on the theory, a computational model for shear stress as a function of temperature was developed and validated against experimental results. It can be seen that increasing temperature difference between the cylinder wall and ambient air can lead to significant measurement errors and should be taken into account in uncertainty calculations.

## LINKING THE TRACEABILITY OF AIR VELOCITY MEASUREMENTS TO MASS STANDARDS (MIKES)

A wind tunnel project was started to develop a new traceability link for air speed. The purpose of the project is to link the air velocity to mass flow rate using a mass transfer method. During the year 2006, characteristics of a blower and a design of the wind tunnel channels, diffusers and a settling chamber were carried out.

## ABSOLUTE GRAVITY MEASUREMENTS IN SOUTH AFRICA (FGI)

After the Antarctic campaign, absolute measurements were made in the Republic of South Africa at Paarl (previously measured in 1994, 2001 and 2004), in cooperation with University of Cape Town and the Chief Directorate: Surveys and Mapping. Paarl is a station of the South African gravity reference network and also serves as a control station for Antarctic absolute-gravity work by FGI and other institutions. In addition, measurements were made next to the superconducting gravimeter (SG) of the GeoForschungsZentrum Potsdam (GFZ), at the South African Astronomical Observatory in Sutherland. The site was previously occupied by FGI in 2001 and 2004. The measurements give a calibration for the SG, and the combination of the SG record with absolute measurements strengthens the control provided by Paarl.

## GRAVITY EFFECTS OF THE FENNOSCANDIAN POSTGLACIAL REBOUND (FGI)

The *Nordic Absolute Gravity Project* started in 2003. It aims at producing a time series of absolute gravity measurements (1/year) at about 20 Nordic sites at least over the next 5 years [7]. The time series are compared with estimates of regional mantle inflow (due to the Fennoscandian postglacial rebound PGR) obtained from the ongoing mission of the GRACE gravity satellite. As a by-product, a highly accurate gravity reference network with estimates of gravity change rates will be produced. The absolute measurements are performed by the Institut für Erdmessung (IfE, University of Hanover), by the Department of Mathematical Sciences and Technology of the Norwegian University of Life Sciences (UMB), by the Federal Agency of Cartography and Geodesy (BKG, Frankfurt), and by the FGI, in cooperation with the Danish Space Center, the Norwegian Mapping Authority, and Lantmäteriet (Sweden). In 2006 FGI observed at 7 sites [8]. The project is coordinated by the Working Group for Geodynamics of the Nordic Geodetic Commission (NKG), as a part

of the Nordic Geodetic Observation System (NGOS) of the NKG [9]. The absolute-gravity time series at some of the stations started already in 1976 (with modern instrumentation 1988-1993). The observed ratio of gravity change to elevation change on them ([8], [10]) is close to the –2 nm $s^{-2}$/mm determined with relative meters on the Fennoscandian land uplift gravity lines [11] since 1966.

## TEMPORAL VARIATION IN GRAVITY (FGI)

The main tools in this work are the superconducting gravimeter (SG) GWR T020 in Metsähovi [12], and the gravity satellite GRACE [13]. The SG gives a point measurement. Though it samples the entire Earth, it is heavily influenced by density variations close to the sensor. The T020 belongs to the *Global Geodynamics Project (GGP)*, where 20 SGs are deployed worldwide. GRACE routinely provides monthly solutions of the global gravity field, where the resolution for gravity variation is 600–1000 km. Using tailored regional processing of the sensor data, GRACE is at present capable of detecting mass variation corresponding to a water layer of 1–2 cm over an area the size of Finland.

The combination of SG and GRACE is a challenging task in which the local effects at the SG site must carefully be accounted for. In Metsähovi the project *Modelling and Monitoring Local Hydrological Effects in Gravity* was continued, in co-operation with the Laboratory of Geoenvironmental Engineering (Helsinki University of Technology TKK), the Finnish Environment Institute (SYKE) and the Geological Survey of Finland. The gravity effect of groundwater in bedrock fractures was modelled [14]. Soil moisture sensors based on Time Domain Reflectometry (TDR) were installed by SYKE. The effect of rainfall events on gravity was studied using numerical derivatives of the SG record. The SG detects rainfall events (a momentary increase in surface density) even when the water quickly evaporates instead of percolating, as is often the case with isolated events in the summer. The work has been partly financed by the Academy of Finland in the project "Nanogal".
Supported by the local modelling, the SG record and GRACE were compared with each other and with gravity change predicted from regional ([15], [16]) and global ([15], [16], [17]) models of terrestrial water storage. Of especial interest here is the highly accurate Watershed Simulation and Forecasting System (WSFS) of SYKE for Finland. The work is continued in cooperation with TKK and SYKE in a new project "Hydrograv" financed by the Academy of Finland.

The modelling of the influence of atmospheric masses and of Baltic Sea level on gravity continued in cooperation with the Finnish Meteorological Institute and the Finnish Institute of Marine Research.

The accuracy of gravity measurements in many cases already surpasses the accuracy of standard (i.e., easily-constructed) physical models that describe the variation of gravity with time. This has important consequences [18] for gravity reference networks, which continue to be widely used to determine the acceleration of free fall for various applications. As height change implies gravity change, there are obvious benefits from integrating the monitoring of gravity with the monitoring of position [9] [19].

## REBUILDING OF THE 20 Nm TORQUE STANDARD MACHINE (LAHTI PRECISION)

The capacity of the air bearing has increased up to 100 Nm. The construction of the torque standard machine is now for this capacity. Only the old gearbox has today capacity of 50 Nm and will be renewed later on. The preliminary intercomparison has shown a relative measurement uncertainty of the level $5 \cdot 10^{-5}$. The length of the beam has been measured by MIKES in the coordinate measurement machine with a measurement uncertainty of 1 µm. However the comparison has shown difference about 15 µm in the length and the reason for this difference will be investigated.

## TORQUE CALIBRATION PROCEDURES FOR DIFFERENT TYPE OF DEVICES AND PROCEDURES AND THE CONFIRMATION OF THEM (LAHTI PRECISION)

The usual way to calibrate a torque transducer is a static calibration. However, for high capacity transducer the costs for this kind of torque standard machine are very high. The high quality of reference torque transducer gives possibility to calibrate torque transducers for practical purposes against a reference transducer. In practice it is very difficult to get stable load for comparing the measurement values from calibration object and reference to each other. Therefore a constant change in the load gives better possibility to eliminate the stability problem. In this case the measurement is made dynamically but relatively slowly. The dynamic behaviour constitutes another problem: the dynamic behaviour of transducer, mainly the creep effect (investigated in year 2005); the filtering of the measurement signals and the synchronous reading of the results. The investigation has led to changes in the measurement instruments to obtain a better control of the filtering. Also, a measurement program software was developed for synchronous reading and good control of the readings of signal [20, 21].

# Comparisons

## INTERNATIONAL COMPARISONS

### MIKES

EUROMET.M.M-K2: EUROMET key comparison of multiples and sub-multiples of the kilogram.
Participants: most EUROMET members. Measurement at MIKES in January and February 2003. Draft B has been accepted. The final report is still in progress. The results of MIKES were in good agreement with other participants.

EUROMET.M.M-K4: EUROMET 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. Draft B has been accepted. The final report is still in progress. Results of MIKES were in good agreement with other participants.

EUROMET 509: Intercomparison of Pt-Ir kilogram standards.
Participants: BE, CH, CZ, DE, DK, ES, FI, FR, GB, HU, IT, NO, PL, SE, SI, SK. Results available. The results of MIKES were in agreement with other laboratories.

EUROMET 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. Draft B has been accepted. The results of MIKES are in agreement with other laboratories.

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, measurements completed, no report.

EUROMET 552: Key comparison EUROMET T-K3, Comparison of the realisations of the ITS-90 from 83.8058 K to 692.677 K, Final report. The MIKES results are well in line with the reference values.

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. The results will be presented at Tempmeko 2007.

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 results will be presented at Tempmeko 2007. The MIKES results differ from the mean by less than 50 mK, which is very good, as MIKES did not have experience of PtPd thermocouples.

EUROMET 881: A comparison in the gauge pressure range from 50 MPa to 500 MPa between MIKES, Metas of Switzerland, NMi of the Netherlands and CMI of the Czech Republic was started in June 2005. Later PTB of Germany, SMD of Belgium ans SP of Sweden joined in. The project is coordinated by MIKES. The measurements were completed in 2006 and the report will be published in 2007. The preliminary results show a good agreement of the results from all the participants.

EUROMET 921: A trilateral comparison between MIKES, Metrosert of Estonia and FORCE Technology of Denmark was arranged in 2006 in gauge pressure range from -2000 Pa to +2000 Pa. The project is coordinated by MIKES. The transfer standard was not as stable as expected, and the uncertainties of some reference values were high. However, a good agreement was found. The report will come out in 2007.

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 2008.

EUROMET 621: Key comparison in humidity (dew-point temperature). MIKES is coordinating 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 is realised in three parallel loops piloted by MIKES, NMi and METAS. MBW Calibration Ltd has delivered the first of six chilled mirror hygrometers that will be used as the transfer standards. The measurements are expected to be completed in 2007.

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. The hygrometer arrived at MIKES in December 2006.

EUROMET 717: Comparison in dew-point temperature (high range): A dew-point comparison in the range +20 °C to +80 °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. The actual measurements have not been started yet.

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 will be reported in TEMPMEKO 2007 conference.

EUROMET P806: Intercomparison of low pressure gas flow facilities using a molbox1/molbloc transfer package: Partners are in the order of the comparison scheme: NEL (UK), EIM (GR), NMi (NL), CMI (CZ), INRiM (IT), MIKES (FI), METAS (CH), PTB (DE), LNE (FR), FI (DE) and UMI (TR). Primary small gas flow facilities are compared to each other using a transfer standard based on laminar flow elements. The comparison covers flow rates from 100 ml/min to 25 l/min, in six measurement points (100 ml/min, 500 ml/min, 1.0 l/min, 4.0 l/min, 15.0 l/min and 25.0 l/min) and was splitted into two circulation rounds. In the first round, nitrogen was used as a test gas and synthetic air in the second one. At MIKES measurements were done in 2006. After some changes in the comparison schedule, the second circulation round is estimated to start at the end of the year 2007.

### Lahti Precision

Force and torque comparison between Lahti Precision and PTB. The results of this bilateral comparison are under evaluation.
Torque Comparison between Lahti Precision, SP (Sweden) and Luna (Sweden). The report is ready and the participants are using the results to confirm the measurement capability.

### FGI

ICAG-2005: The results of the Seventh International Comparison of Absolute Gravimeters held at the BIPM in 2005 were presented at the IGFS2006 conference in Istanbul in August. The report is in preparation. Some sites were occupied by only few gravimeters and this makes the construction of the reference value somewhat problematic. The results of the FGI (gravimeter FG5-221) were in good agreement with the reference value shown.

International Comparisons of Absolute Gravimeters in the Nordic Absolute Gravity Project: A bilateral comparison with the IfE (gravimeter FG5-220) was conducted in August at Metsähovi. The maximum difference with the FG5-221 of the FGI was 22 nm $s^{-2}$. A report of all comparisons 2003–2006 is in preparation.

A joint report of the 4-partipant comparison (FGI, IfE, BKG, TsNIIGAiK Moscow) in Metsähovi in July 2004 and of the bilateral comparison (FGI, TsNIIGAiK) in Zvenigorod in October 2005 is in preparation.

## NATIONAL INTERCOMPARISONS

Mass comparison: 610 g balance with 0.1 mg resolution. Six participants from four accredited laboratories. Report: Kari Riski, Leena Stenlund, Mass Comparison: 610 g laboratory balance. MIKES publication J3/2006, 15 p.

An intercomparison in the gauge pressure range from -95 kPa to +100 kPa for the Finnish pressure laboratories was arranged in 2005 - 2006. Five laboratories participated. Report: M. Rantanen and S. Semenoja, Intercomparison in Gauge Pressure range from -95 kPa to 100 kPa, MIKES Publication J1/2006, 15 p. + appendix.

# Length

***Personnel***
***MIKES***

| | |
|---|---|
| *Dr. Antti Lassila* | *Group Manager* |
| *Dr. Kaj Nyholm* | *Senior Research Scientist* |
| *Dr. Mikko Merimaa* | *Senior Research Scientist* |
| *Lis.Sc. Heikki Lehto* | *Senior Research Scientist* |
| *M.Sc. Veli-Pekka Esala* | *Senior Research Scientist* |
| *M.Sc. Björn Hemming* | *Senior Research Scientist* |
| *M.Sc. Ilkka Palosuo* | *Research Scientist* |
| *M.Sc. Jarkko Unkuri* | *Research Scientist* |
| *M.Sc. Virpi Korpelainen* | *Research Scientist* |
| *M.Sc. Ville Ahtee* | *Research Scientist* |
| *Mr. Raimo Mylläri* | *Research Assistant* |
| *Mr. Ilkka Raeluoto* | *Research Assistant* |
| *Mr. Asko Rantanen* | *Research Assistant* |
| *Mr. Jeremias Seppä* | *M.Sc. Student* |

***MIKES-TUT***

| | |
|---|---|
| *Prof. Heikki Tikka* | *Manager of the laboratory* |
| *M.Sc. Tero Ristonen* | *Substitute of manager* |
| *B.Sc. Timo Antila* | *Laboratory Technician* |

***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, Deputy Head of Laboratory* |
| *M.Sc. Joel Ahola* | *Senior Research Scientist* |
| *M.Sc. Pasi Häkli* | *Senior Research Scientist* |
| *M.Sc. Paavo Rouhiainen* | *Senior Research Scientist* |

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 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. In addition, MIKES has entrusted the Institute of Production Engineering at Tampere University of Technology (TUT) to be the reference laboratory for co-ordinate measuring machine (CMM) metrology. This contract was closed after several fruitful years at the end of 2006 due to the fact that MIKES had started own activity at CMM metrology and therefore took the responsibility as national metrology laboratory also at this area of length metrology.

The operation of the Finnish Geodetic Institute (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, MIKES-TUT, and FGI, made altogether 496 calibration certificates for over 200 different customers in accredited laboratories, research institutes, and industry during 2006. The total number of calibrated measurement standards and devices was over 2000.

# Highlights in 2006

## OPERATION AT NEW MIKES

During year 2006 the new MIKES building was put into full operation at Otaniemi. New operational environment has catalysed existing partnerships [22] and promoted new ones.

## SINGLE-FREQUENCY SYNTHESIS AT TELECOMMUNICATION WAVELENGTHS (MIKES)

A project funded by the Academy of Finland was started in 2006. In this three-year project a 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 is developed. The device will augment the MIKES full-octave optical frequency comb generator (see Fig. L1), which is presently used for absolute frequency calibrations of laser frequency standards. Unlike conventional frequency comb generators that produce a multitude of frequency components, the device under construction will provide a single selectable 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, whose characterisation requires high frequency accuracy, are lasers, fibre gratings, and dense wavelength division multiplexers. Numerous parameters could be of interest. For instance, for lasers wavelength stability and accuracy, spectral purity, ageing properties, frequency chirp etc. are all important parameters. In future, the development and characterisation of increasingly sophisticated optical components and technologies will demand improved frequency measurement capabilities.

*Figure L1. Ville Ahtee adjusts the frequency comb generator. (Photo: M. Merimaa)*

A phase-coherent link between an external-cavity diode-laser (ECDL), which provides continuously tuneable output within the frequency band of interest, and the MIKES full-octave optical frequency comb limited to frequencies outside of this band, was constructed and tested in 2006. The link includes, e.g., a system for frequency doubling the output of the ECDL laser, and a digital phase-locked loop (PLL) circuit. Moreover, development of a program to control the various components of the synthesiser, including the PLL circuits and the frequency comb generator, was started. The software uses measured information and known properties of the system to set the system parameters such that the output is at the entered frequency.

## APMP EDM COMPARISON (FGI)

The FGI participated in the Asia-Pacific Metrology Programme (APMP) Comparison for pilot study on calibration of EDM. The comparison was arranged by the Korea Research Institute of Standards and Science (KRISS) at a 280-m 7-pillar Heerbrugg-type baseline in Daejeon (Fig. L2). The purpose of the comparison was to determine the lengths at the baseline with the best possible accuracy from different traceability chains and to study the field procedures for testing high precision surveying instruments according to the ISO 17123-4 standard. The FGI and ITRI, Taiwan, participated with Kern ME5000 precise distancers and the KRISS and AIST, Japan, with Leica precision tacheometers. The FGI transferred the traceable scale from the Nummela Standard Baseline of the FGI with the Kern ME5000 of the Department of Surveying of Helsinki University of Technology. The scale of the instrument was also checked in KRISS in a brief comparison with laser interferometers at a baseline indoors and with a rubidium frequency standard. As a second part of the comparison the Japanese team also tested a new apparatus utilising femtosecond frequency comb technology.

*Figure L2. Jorma Jokela at the APMP EDM comparison in Daejeon, Korea.*

## TRACEABILITY FOR PAPER GRAMMAGE MEASUREMENTS (MIKES)

JMK Instruments is an innovative Finnish company that offers measurement and calibration services for the pulp and paper industry. One measurement service is related to grammage, the weight of one square meter of paper. Grammage is perhaps the most significant property of paper usually noted as g/m$^2$. It is quite easy to measure grammage but it is harder to make an accurate measurement, and it is a real challenge to make a measurement traceable to SI-units, both quickly and at high precision, at factory floor. Therefore, JMK Instruments asked MIKES for help to develop a new method for the calibration of grammage reference standards (see Fig. L3). The reference standards are round pieces of paper with different grammage.

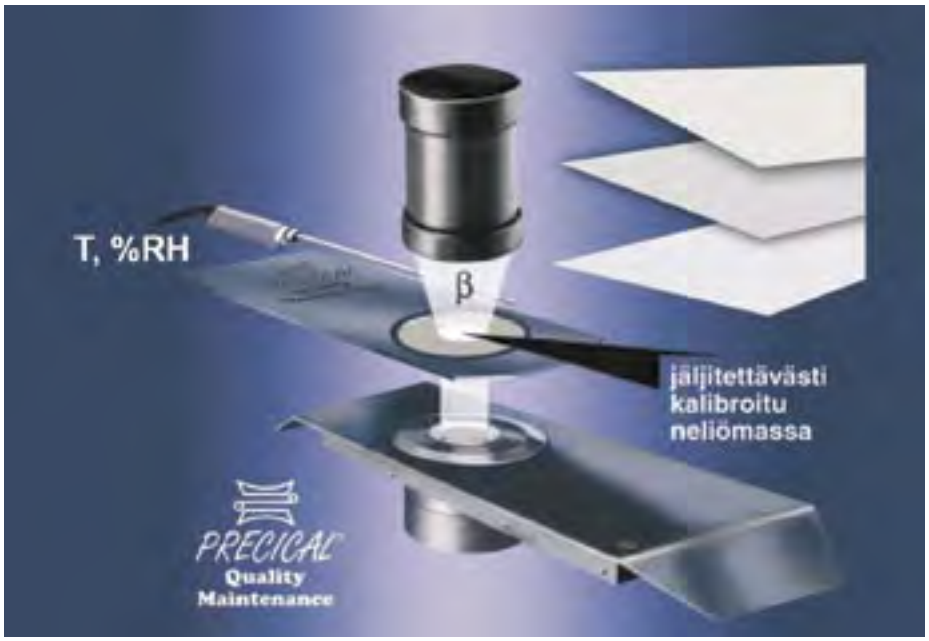



*Figure L3. Grammage measurement based on beta radiation is calibrated using traceable reference standards at JMK Instruments.*

MIKES studied the possibility to use a flatbed scanner for the measurement of the area of a reference standard, and in co-operation with JMK Instruments one scanner was selected for further studies. The metrological properties of the scanner were studied. Error compensation and measurement strategies for sample area characterisation were developed. Also weighting studies were done to grammage standards under different conditions. In addition, overall uncertainty study was performed for the method. The benefit for JMK Instruments and its customers was an improvement of the traceability and accuracy of on-line quality measurements used in the paper industry.

## CHARACTERISATION OF PIEZO PROPERTIES (MIKES)

Piezoelectric materials are attractive candidates for acoustic actuators for various applications. However, they have some non-ideal properties, such as hysteresis and relaxation, which degrade their value. Lack of scientific knowledge prevents industry to develop better piezoelectric devices.

In this research MIKES studied properties of commercial grade piezoelectric sheets by an atomic force microscope (AFM). The research was done for Nokia Research Centre (NRC). It was a part of a co-operational piezo hysteresis modelling project with NRC and TKK/Laboratory of Physics.

In Fig. L4 are presented some of the results. In this case topography of the piezo sheet was measured before and after applied DC voltage. Fig. L4 shows changes in the sheet topography i.e. domain structure due to the applied voltage and relaxation. The voltage (150 V) was turned on and off between the measurements, but there was no voltage during the measurement. Some new swell structures were seen to appear and disappear. The heights of the swells were ~20...300 nm. Relaxation time for a swell was also measured. The swell was seen to disappear quite suddenly after ~150 min. However, time scales in the AFM measurements are seconds or minutes, thus any fast changes cannot be seen. More results will be presented in Nanotech in Northern Europe 2007 conference [23].

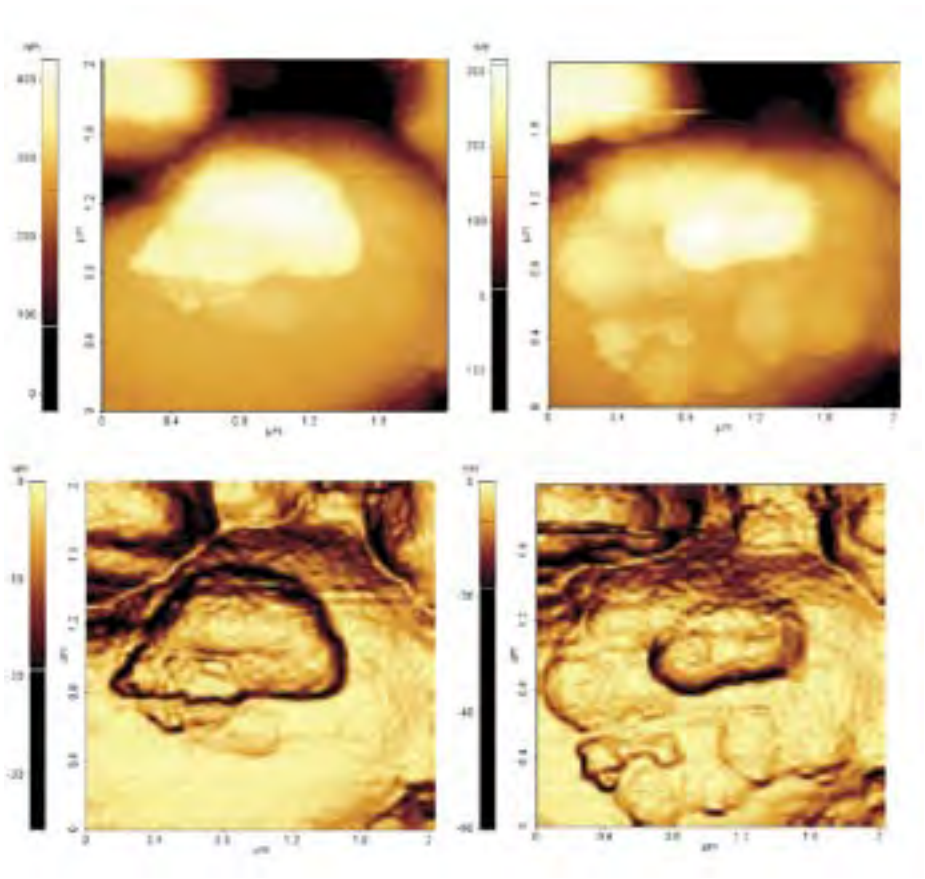


*Figure L4. Changes in piezo sheet topography due to applied voltage and relaxation. Upper images are topographies and lower images are gradients of the topographies.*

## SEMINAR ON DIMENSIONAL MEASUREMENTS AT WORKSHOP (TUT, MIKES)

Annual seminar on "Dimensional measurements at workshop" was arrange this by TUT at Tyrväntö 8.-9.6.2006. The seminar is organised in turns by MIKES, the Institute of Production Engineering at Tampere University and some other parties of metrology section of Excellence Finland (SLY). Approximately 60 persons from industry and research institutes were particpating (see Fig. L5).

*Figure L5. Heikki Lehto (MIKES) is giving lecture about measurement uncertainty at "Dimensional measurements at workshop" seminar.*

# Research Projects

## MEASUREMENT ELECTRONICS FOR A GAS SENSOR (MIKES)

Gasmet Technologies Oy is among the world leading manufacturers and developers of Fourier Transform Infrared (FTIR) gas analysers. Primary market for the gas analysers is in environmental monitoring and process control. Measurement of oxygen in e.g. process control is often desirable or mandated by regulation. For instance, accurate oxygen measurement allows better control of combustion processes, thus improving efficiency and reducing emissions.

*Figure L6. Matti Sillantaka is measuring the operation of the gas sensor electronics. (Photo: H. Koivula)*

As the FTIR-based gas analysers operate in the mid-infrared region, where measurement of oxygen is not possible, Gasmet Technologies has developed a diode-laser-based sensor for oxygen concentration measurement. Product development was done in collaboration with MIKES, whose role in the project was to design and test measurement electronics for the sensor. MIKES has a long experience in using diode lasers for spectroscopy and has accumulated considerable knowledge and skills in making electronics for measurement instrumentation (see Fig. L6). This expertise and the flexible organisation of MIKES, where a team of experts is formed to cover the needs of each customer project, allowed the work to be completed at the speed and cost-efficiency that is required in an industrial R&D project. The measurement method developed in the project can be used for other gases as well, and the collaboration between Gasmet Technologies and MIKES in refining the technology continues.

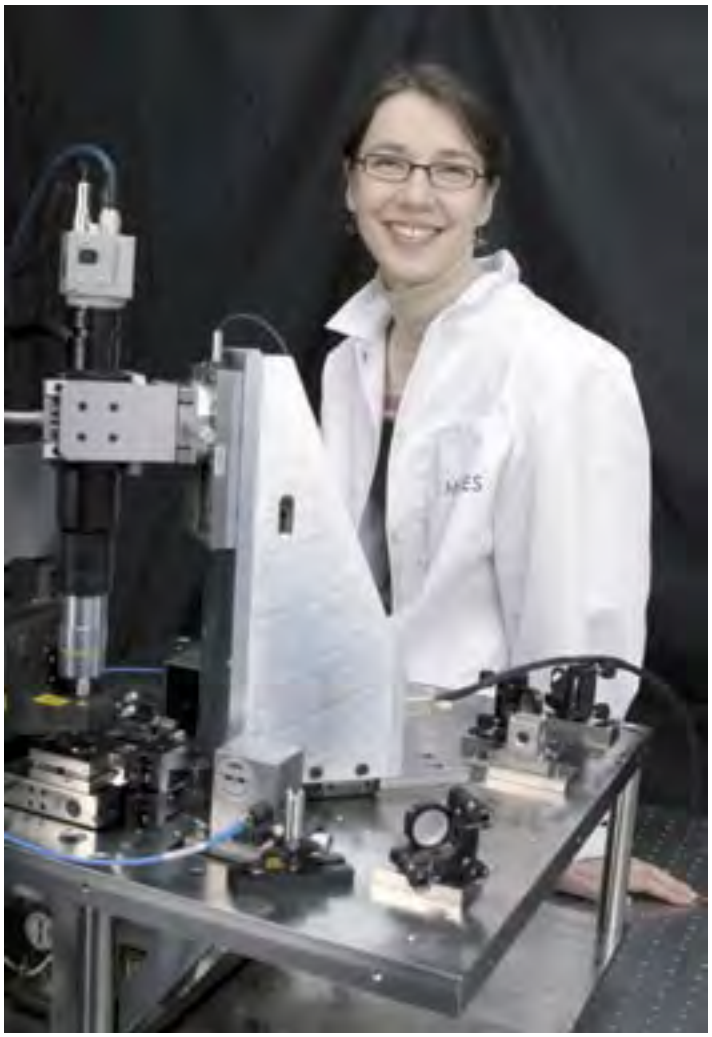


*Figure L7. Virpi Korpelainen is aligning the interferometrically traceable metrology AFM developed at MIKES. (Photo: M. Merimaa)*

## NANOMETROLOGY (MIKES)

Traceable length scale is needed also in nanometre scale measurements and after few years of R&D work MIKES is capable to offer calibration services for AFM transfer standards. 1D and 2D grids and step height standards can now be calibrated by a commercial AFM, which is traceably calibrated [24, 25, 26]. The calibration included calibrations of scales of x-, y- and z-axes by laser interferometer or by grid standard calibrated by laser diffraction. Orthogonality of all axes was measured by calibration grids and error separation method. Out-of-plane movement of z-axis was measured by flatness standard. The developed calibration method was reported [25] and used as a reference in guideline for the dimensional calibration and characterisation of SPM systems (VDI/VDE 2656 Part 1). The calibrated AFM is used also for various scientific studies [3].

MIKES is also developing an interferometrically traceable metrology AFM (IT-MAFM) (see Fig. L7). In 2006 that project developed in a fast pace. Mechanical set-up for integration of AFM head, piezo stages, interferometers, optical microscope and stepper motors is almost completed. Electronics for the AFM head and stepper motors have been designed and produced. Software for the control and synchronisation of all the parts of the device is developed. The software includes interferometric feedback to the xy piezo stage as well as self calibration of non-linearities of both laser interferometers and capasitive sensors of the piezo stages. Feedback from the AFM head to the z-piezo and automatic approach will be added to the software in year 2007.

## TRACEABILITY OF ANGLE MEASUREMENTS (MIKES)

The aim of this project is to develop our accuracy and routine for calibration of polygons, angle gauge blocks, angle optics of laser-interferometer, autocollimators, theodolites, and several other angle measuring instruments. During the year 2006, we have calibrated angle measurement equipment and improved system fixing the collimator during calibration of theodolites. We have also taken in use and improved measuring machine for straightness and squareness developed during 2005 (see Fig. L8). Its uncertainty is 0,2 µm ($k$=1) for straightness and 0,2" ($k$=1) for squareness. The capacity of the machine is 1200 x 150 mm for straightness (flatness) and 1000 x 800 x 150 mm for squareness.

*Figure L8. Asko Rantanen is adjusting squareness measuring instrument.*

## PRACTICAL REALISATION OF THE METRE (MIKES)

The optical frequency comb generator at MIKES was constructed to enable absolute optical frequency measurements and hence traceable calibrations of iodine-stabilised lasers (primary wavelength standards). The frequency comb improves the practical realisation of the metre in Finland by allowing a direct link to the SI-second (see Fig. L9), more accurate frequency determinations, a wider calibration spectrum (500 nm … 1200 nm), and more frequent calibrations due to the ease of operation. The metre is realised by calculating the vacuum wavelength of an iodine-stabilised laser from its absolute frequency measured with the comb and from the value for the speed of light in vacuum. The realisation is transferred to lasers used in interferometers by calibrating their frequency with an iodine-stabilised laser. Altogether six iodine-stabilised lasers at wavelengths 532 nm/1064 nm, 543.5 nm, and 633 nm are maintained at MIKES. The absolute frequencies of these lasers are regularly determined [27, 28, 29].

In 2006, we expanded the comb's measurement capability to include low-power He-Ne lasers at 543.5 nm, whose absolute frequencies had earlier to be measured at BIPM [30]. Moreover, we studied in detail the transfer of modulation in injection locking [31], as we optically amplify

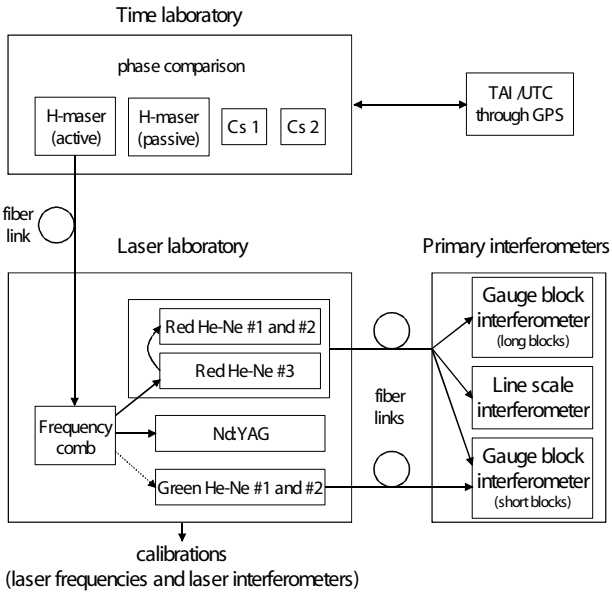



*Figure L9. The traceability chain of length measurements at MIKES.*

the output power of frequency-dithered low-power lasers by injection locking to the level required in comb measurements. From the beginning of 2007, MIKES is one of the host sites for the international key comparison of primary wavelength standards.

## CHARACTERISATION OF AN ACOUSTIC WAVELENGTH COMPENSATOR IN CO-OPERATION WITH ACWACO (MIKES)

In the research, equations for calculation of effective air temperature and refractive index of air from group velocity of ultrasound ($f$ = 200 kHz), air pressure, and humidity were developed based on experimental data. These equations are needed in the acoustic wavelength compensator [32] of AcWaCo Ltd, which is developed within the FinNano Nanotechnology Programme of TEKES.

First, the time of flight of ultrasound was measured in different environmental conditions (ambient temperature, barometric pressure and relative humidity) in order to get input data for the equations. A double-pass plane-mirror laser interferometer recorded the distance that the ultrasound travelled. The time of flight of ultrasound was measured by using three acoustic piezo transducers: one transmitting a short ultrasound burst in a narrow angle and two receiving the signal reflected from the interferometer

mirror. The transducers were positioned symmetrically around the laser beams to minimise the Abbé error.

The speed of ultrasound was calculated from the measured time of flight and the length of the acoustic path. Equations for the effective temperature and for the refractive index of air as functions of speed of sound, humidity (mole fraction of water), pressure, and $CO_2$ mole fraction were fitted to the measured data using least-squares method.

## CORRECTION OF CMM MEASUREMENTS BY CALIBRATION DATA (MIKES, TUT)

In this co-operational project of MIKES and TUT, two different methods for mapping and correcting the errors of CMM are studied. In the first method the 21 systematic geometrical error components are determined by traditional separate measurements. The second method uses error separation technique with ball plate aligned and measured in different orientations by CMM (see Fig. L10). The results from both error modelling techniques are compared and the reasons for differences are resolved. Then kinematical error chain is created for error compensation and methods for online correction of the CMM readings are developed. Best measurement practises and uncertainty evaluation are also studied during the project.

During the first year the traditional and ball plate measurement were done and analysed for SIP CMM of TUT and LEGEX CMM of MIKES.

## NUMMELA STANDARD BASELINE (FGI)

The Nummela Standard Baseline was equipped again for calibration after the measurements with the Väisälä interference comparator in autumn 2005. Comparing the results from interference measurements in 1996 and 2005, the differences for three pillar intervals, 72 m, 216 m, and 432 m, were rather insignificant, +0.11 mm, +0.00 mm, and +0.13 mm, respectively. The difference for 24 m, –0.18 mm, was significant, and obviously caused by the construction works in autumn 2004. Reports on the new results and about the activities in length metrology were published in several international meetings [33, 34, 35]. Instructions on how to maintain the quartz gauge system of the Väisälä comparator were improved. The comparisons needed for this are performed at the Tuorla Observatory of University of Turku. New comparisons and interference measurements up to 864 m are planned for autumn 2007.


*Figure L10. Ilkka Palosuo is performing error separation measurement with a ball plate and CMM.*

## LEVELLING TECHNIQUES (FGI)

Precise levelling equipment is used in measurements of height differences. Calibration on digital levels and bar code and traditional levelling rods is an essential part of length metrology in the FGI. Since this service is not widely available in Europe, customers are mostly from abroad, from Nordic and Baltic countries. Presentations and activity reports were given in connection with Nordic co-operation [36, 37, 38]. New measurement methods were tested, such as digital levelling technique applied in water crossing [39, 40]. System calibration also includes studies of common thermal behaviour of levels and rods. The precise levelling test field at Metsähovi serves both in testing of instruments and in small-scale geodynamical studies [41].

## LOCAL TIES AT GEODETIC STATIONS (FGI)

Local ties at co-located global geodetic fundamental stations are an important new application area of geodetic metrology (see Fig. L11). The Metsähovi research station of the FGI is a multi-technique site of all basic space geodetic techniques hosting permanent geodetic VLBI, SLR, GNSS and DORIS. Data are provided for respective IAG services. Additionally, there exist a cryogenic gravimeter in the GGP network and a seismometer of the Seismological Institute of the University of Helsinki. There is also the main point of the Finnish gravity network, and Metsähovi is the only Northern European site for intercomparison of absolute gravimeters. Datum of the new Finnish height system also refers to the geopotential value of a benchmark at Metsähovi. An updated review of local ties determined with precision tacheometry and GPS measurements was completed [42], and the work will continue on a more regular basis.

## CO-OPERATION WITH POSIVA OY (FGI)

A 511-m calibration baseline was established at the Olkiluoto nuclear power plant in 2002 to research the scaling problems of GPS observations. The EDM baseline is a part of investigation area, where local crustal deformations at the disposal site of spent nuclear fuel have been studied since 1996. The EDM baseline has been measured simultaneously with a GPS network since 2002. The observations have been carried out semi-annually, except in 2006, when only one measurement could be made, because of construction works. The length of the baseline is traceable to the definition of the metre through the Nummela Standard Baseline. The scale problem is expected to be solved from the time series of GPS observations and EDM results [43]. Now the measurements at Olkiluoto also include precise levellings.

## HISTORY OF GEODETIC METROLOGY (FGI)

Material for a historical documentary about triangulation was filmed at the Nummela Standard Baseline, where calibration of invar wires was performed for scale determination (Fig. L12).

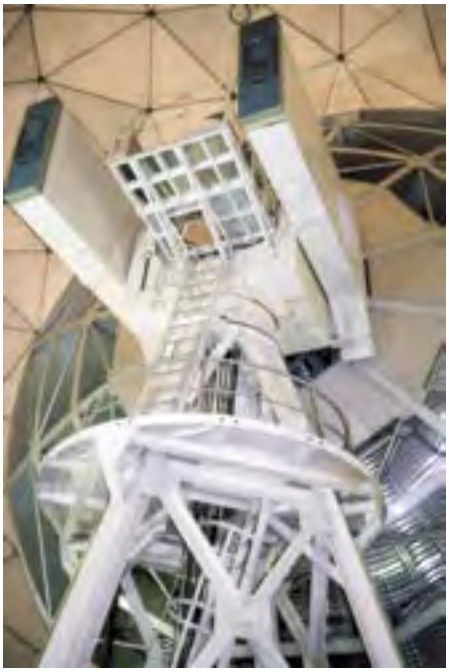


*Figure L11. The VLBI telescope at Metsähovi need to be tied and monitored with 1-mm-level 3D-uncertainties in complex local control networks.*

*Figure L12. The FGI has made documentary films to preserve the heritage of old measurement skills and methods. Here Professor (emeritus) Jussi Kääriäinen demonstrates the use of invar wire at the Nummela Standard Baseline.*

# Comparisons

## INTERNATIONAL COMPARISONS

EUROMET.L-K6: 2D CMM artefacts (TUT)
The calibration subject in EUROMET.L-K6 was a ball plate. The measurements at TUT were performed June 2004. The first information of results were received in 2006. The results of TUT were very close the mean values calculated from all participants. Uncertainty of TUT seemed to cover very well the small differences.

EUROMET 905: Comparison of the squareness measurements (MIKES)
Participants are SMU and MIKES. Comparison measurements at MIKES were done in September 2006. SMU has until now reported only partly the results. The reported results for the squareness (Angle between "envelope - LS regression" fitting lines) are 1,4" (MIKES) and 1,24" (SMU) the uncertainty for both laboratories is 0,2" ($k$=1). The straightness results are also very similar especially when we notice that the tip radius at MIKES was 2 mm and at SMU 8 mm.

EUROMET.L-K5.2004: Calibration of a step gauge (MIKES)
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 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. MIKES results are reported to the pilot laboratory. Comparison measurements are not yet analyzed.

CCL-Nano5: Key comparison of 2D gratings (MIKES)
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 at December 2005 and March 2006. Report is still in preparation, but preliminary results for MIKES were good.

APMP.L-K6: 2D CMM artefacts (MIKES)
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 aim of the comparison is to calibrate Calibration of Coordinate Measuring Machine (CMM). The comparison started May 2006 an it ends October 2007. Comparison measurements at MIKES are scheduled May 2007.

## NATIONAL COMPARISON FOR ACCREDITED CALIBRATION LABORATORIES AND INDUSTRY

Comparison on calibration of length measuring machines (MIKES)
In October 2006 MIKES length group organised comparison for four laboratories. The object was a length measuring machine borrowed by Grönblom Oy. Preliminary results show good agreement between results but the reported uncertainty values were partly too small or large. The report is still under processing.

Calibration of gauge blocks (MIKES)
The interlaboratory comparison D8 for length was arranged between April 2005 and August 2005. MIKES operated as reference laboratory of the comparison. Participants were five accredited laboratories and one non-accredited laboratory. The measurands of the comparison were central length at five gauge blocks. The differences of results of blocks to reference values were within the uncertainty estimates and all of the results were acceptable according to $E_n$ criteria [115].

# Electricity, Time and Acoustics

***Personnel***
***MIKES***

| | |
|---|---|
| *Dr. Antti Manninen* | *Group Manager* |
| *Prof. Kalevi Kalliomäki* | *Head of Time and Frequency Laboratory* |
| *M.Sc. Tapio Mansten* | *Senior Research Scientist* |
| *Dr. Jaani Nissilä* | *Senior Research Scientist* |
| *Dr. Alexandre Satrapinski* | *Senior Research Scientist* |
| *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. Kari Ojasalo* | *Research Scientist* |
| *B.Sc. Risto Rajala* | *Research Scientist* |
| *Dr. Nikolai Tisnek* | *Research Scientist (until 30 June)* |
| *B.Sc. Anssi Rautiainen* | *Research Engineer (Permanent position: VTT)* |
| *Mr. Heikki Koivula* | *M.Sc. Student* |
| *Mr. Ilari Suorsa* | *M.Sc. Student* |
| *Mr. Jussi Kaasalainen* | *Trainee* |
| *Mr. Ville Maisi* | *Trainee* |

**MIKES-TKK**

| | |
|---|---|
| *Dr. Jari Hällström* | *Senior Research Scientist, Group Manager* |
| *Lic.Sc Esa-Pekka Suomalainen* | *Senior Research Scientist* |
| *Lic.Sc Marja-Leena Pykälä* | *Quality Manager* |
| *Lic.Sc Jukka Piiroinen* | *Research Scientist* |
| *M.Sc. Juri Chekurov* | *Research Scientist* |
| *Mr. Olli Kara* | *M.Sc. Student* |
| *Mr. Matti Löytty* | *M.Sc. Student* |

The Electricity Group of MIKES includes the National Standards Laboratories of electrical quantities (DC voltage, DC current, AC voltage, AC current, resistance, capacitance, electric power, high frequency quantities), time and frequency, and acoustics (sound pressure). The group is staffed permanently by 10 metrologists and temporarily by several students. Metrology of high voltage quantities is in the responsibility of Helsinki University of Technology (TKK), Department of Electrical and Communications Engineering, Power Systems and High Voltage Engineering (MIKES-TKK). MIKES-TKK has national standards of DC and AC voltage and current, capacitance and inductance at high voltages (> 1 kV) and currents (>1 kA), and of impulse voltage, impulse current, apparent charge, and ESD discharge.

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 2006, the number of calibration certificates was 60 at the Electricity Group of MIKES and 37 at MIKES-TKK. Several calibrations were performed to customers abroad: MIKES to Estonia and MIKES-TKK to South Korea and the Netherlands.

# Highlights in 2006

## EXTENSION OF THE SCOPE OF THE NSL OF ELECTRICITY TO RF AND MICROWAVE QUANTITIES (MIKES)

In summer 2006, development of RF and microwave calibrations at MIKES reached an important step: high frequency electrical metrology was included in the scope of the MIKES National Standards Laboratory of electricity. The decision was preceded by about 5 years of development work, partly in collaboration with Dr Jan de Vreede from NMi-VSL (the Netherlands), participation in two international comparisons (CCEM.RF-K19.CL and EUROMET.EM.RF-K8.1.CL), and a technical evaluation by Dr Klas Yhland from SP (Sweden) in spring 2006. The first CMCs of MIKES in the field of radio frequency measurements were submitted to inter-EUROMET review in December 2006. They include power, calibration factor, reflection coefficient and attenuation in coaxials at frequencies up to 18 GHz. Development towards higher frequencies is in progress.

*Figure E1. Klas Yhland from SP Sweden performing the technical evaluation of RF and microwave calibrations at MIKES.*

## RESEARCH AND DEVELOPMENT FOR INDUSTRY (MIKES)

Co-operation of MIKES with Finnish industry is continuously expanding from traditional calibration work towards new forms. In 2006, the volume of research and development projects between the Electricity Group and industrial collaborators was larger than ever, partly thanks to the TUPAS programme of Tekes (Finnish Funding Agency for Technology and Innovation). One example of such projects was investigation of noise properties of current and voltage obtained from silicon solar cells for Endeas Oy. The results will be exploited in development of the next generation of Endeas's solar simulators, which are used in characterisation of solar cells. As another example, MIKES developed measurement electronics for an oxygen sensor, which will be used in the gas analyser of Gasmet Technologies Oy.

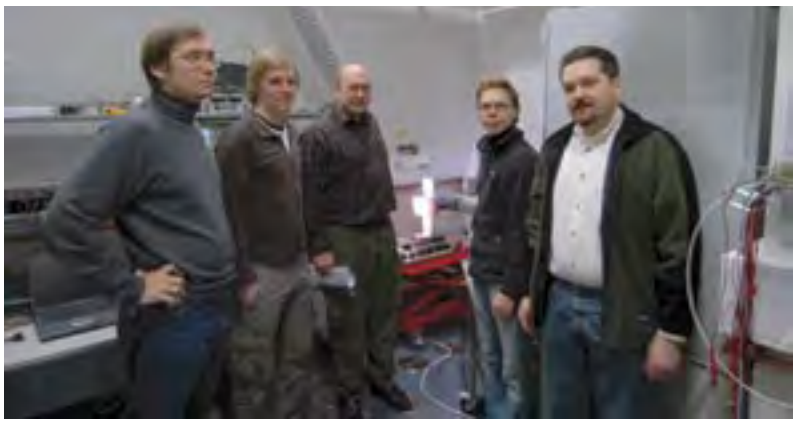


*Figure E2. The Endeas team - Juha Karila (left), Antti Tolvanen and Jaakko Hyvärinen - getting acquainted with the solar cell noise measurements at MIKES and discussing the results and conclusions with Jussi Hämäläinen and Kari Ojasalo (right).*

## SEMINAR ON HIGH FREQUENCY MEASUREMENTS AND THEIR TRACEABILITY (MIKES)

In 2006, MIKES arranged its first seminar in the field of RF and microwaves: Seminar on high frequency measurements and their traceability was held at MIKES on 15 November, 2006. Topics of the 7 speakers included frequency and pulse calibrations, safety measurements of electromagnetic fields, CISPR requirements for EMC measurement devices, antenna calibration and characterisation, practical challenges of high frequency measurements, and presentation of MIKES activities at RF and microwaves. The 50 participants of the seminar were very satisfied with the day.

## COMMERCIAL PROTOTYPE OF IMPULSE VOLTAGE CALIBRATOR (MIKES-TKK)

MIKES-TKK signed a technology licensing agreement about licensing the impulse voltage calibrator technology developed in Helsinki University of Technology with Highvolt Prüftechnik Dresden GmbH. Commercial impulse voltage calibrator should be available on the market in 2007.

# Research Projects

## QUANTUM METROLOGY TRIANGLE (MIKES)

A major challenge of fundamental electrical metrology is the quantum metrology triangle, 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 pumping.

MIKES started the project in 2005. In 2006, MIKES and the Low Temperature Laboratory of Helsinki University of Technology (TKK/LTL) have continued development of the "sluice" [44], [45], a new type of a Cooper pair transport device which was invented earlier by TKK/LTL and VTT Technical Research Centre of Finland. In 2006, syncronized charge pumping could be demonstrated at record-high current level of 1 nA, albeit with accuracy which is still far from the level required in metrological applications [46]. Work towards improving accuracy and suppressing undesirable leak current has been continued by investigating the effect of additional, magnetically controlled tunnel junctions in the component, and also by reconstructing the wiring of the test cryostat in order to decrease the effects of electromagnetic interference. MIKES in collaboration with TKK has also started developing stable cryogenic high-value thin-film resistors, which would be used as a transfer standard in the triangle experiment.

The volume of the quantum metrological triangle project increased substantially in autumn 2006, when MIKES, TKK/LTL and VTT obtained a research grant from the Technology Industries of Finland Centennial Foundation for a three-year collaboration. Other financiers of the project are Academy of Finland, and Vilho, Yrjö and Kalle Väisälä Foundation.

*Figure E3. Ville Maisi experimenting with the new cryoprobe for AC voltage and power quantum standards. The new probe exhibits a minimal liquid helium boil-off rate of about 1 litre/day.*

## AC JOSEPHSON VOLTAGE STANDARD (MIKES)

Development of AC voltage standard based on a programmable Josephson array has been continued in collaboration with VTT Technical Research Centre of Finland. The 1-V nonhysteretic arrays of VTT, with externally shunted (es) SIS junctions, are used. 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.

Two problems have been addressed in 2006: firstly, the voltage resolution of commercial AC-sources is not sufficient for 0.1 ppm accuracy, and secondly, the VTT array chips have unfortunately aged rapidly due to freezing of moisture on the chips (despite conventional passivation layer). A new floating sine-

wave source with amplitude resolution of 10 nV has been designed and is under construction and test. With this source we also get rid of the uncontrollable noise problems observed with calibrators. To prevent freezing of moisture on the arrays we have designed and set up a new cryoprobe with which the array surroundings is first evacuated and then filled with helium heat exchange gas. In the design we also paid attention to the excess liquid helium consumption due to the probe. The outcome, a total boil-off rate of 1 litre/day is very satistactory in our opinion. MIKES has also participated in investigations of properties and possible applications of millimeter wave power generation in Josephson junction arrays in collaboration with VTT [47].

MIKES is participating in a European BJAPS (Binary Josephson array power standard) project, too. Our aim is to provide a quantum power standard based on our AC-JVS scheme and then take part in the final comparison of the different standards at the end of the project in 2008 and 2009. Our idea is to measure the voltages across a shunt and a divider of a power standard directly against adjusted square wave voltages from Josephson arrays. For this purpose we have chips in which two binary arrays on a single chip obtain the same microwave power but are biased independently. These chips were fabricated by VTT in 2005.

## IMPEDANCE METROLOGY DEVELOPMENT (MIKES)

Measurement equipment for realization of the link between the QHR and the farad has been improved. Four terminal pair 10:1 ac resistance bridge was built in May 2006 and the study of frequency dependence of acdc resistors with the ratios 10:1 and 1:1 was started. Preliminary results of the measurements of 10 kΩ / 1 kΩ bifilar type resistors showed that the ratio is increased by about 0.2 ppm in 1 kHz – 2 kHz range. These changes are probably due to uncorrected frequency dependence of the 1:10 ratio of the main transformer. Temperature enclosures for 10 kΩ / 1 kΩ acdc resistors were modified and the maintained temperature was increased to 27 °C. Sources of systematic uncertainties in four terminal pair ac resistance bridge have been studied. Behaviour of the 1 kΩ and 10 kΩ acdc resistors of different types has been investigated in collaboration with LNE (France). Results of a bilateral MIKES-SP comparison of 1 nF, 10 nF, 100 nF and 1 µF capacitance standards, which was organized in the end of 2005, were analyzed and published in the CPEM 2006 conference [48]. Results showed good agreement within combined expanded uncertainties at each capacitance level.

## DEVELOPMENT OF HIGH FREQUENCY MEASUREMENTS (MIKES)

The most important achievement of the project was that high frequency electrical metrology was included in the scope of the MIKES National Standards Laboratory of electricity in summer 2006 (see highlights). The first customer calibrations were made soon after that. The first VNA measurements to 26.5 GHz air lines and power splitter have been made. An extensive measurement series has been performed for broadband 18 GHz thermocouple power sensor, but unfortunately the measurements indicated that the sensor was defective. Temperature control of the RF laboratory was finalised in September. Modifications were made to the air ducts to reduce noise and to remove excess heat from the laboratory. Temperature stability of thermistor mounts during calibration was improved with a special measurement chamber. Much of the work of the project has been done by Mr Heikki Koivula as a part of his Master's Thesis "Measurement system for microwave power sensors", which was accepted by the Helsinki University of Technology in March 2007.

## DEVELOPMENT OF CALIBRATION SERVICE FOR LOW CURRENTS (MIKES)

MIKES continued development of calibration facilities of very low currents by Mr Ilari Suorsa's Master's Thesis, which was finalised in December 2006 [49]. An accurate generator was developed for very low currents, 10 pA or below. The method is based on charging an air capacitor with a linear voltage ramp, which corresponds to a constant charging current $I = C\,dV/dt$, where $C$ is the known capacitance of the air capacitor and $dV/dt$ is the measured slope of the voltage ramp. The voltage ramp is generated by an integrator, which integrates a relatively large constant current (10 nA, for example) obtained by applying a constant voltage across a resistor. Nonidealities of the integrator cause nonlinearity into the voltage ramp, and that is corrected by applying a small, slowly varying compensating current into the integrator input. The method was tested in calibration of an electrometer at 10 pA: the output current of the generator was stable and repeatable with standard deviation of about ±0.5 fA. The work was carried out in collaboration with STUK (Radiation and Nuclear Safety Authority of Finland).

## DEVELOPMENT OF ACCELERATION CALIBRATION FACILITIES (MIKES)

Development project of vibration transducer measurements, which was started in 2004, was continued in 2006 but not with the anticipated volume. A charge amplifier, 24-bit data acquisition card and back-to-back-type secondary working standard accelerometer were acquired and taken into use. With

*Figure E4. Jussi Hämäläinen testing the accelerometer comparison setup, which is based on a homemade shaker.*

help of these devices and a vector signal analyzer, the improvement of the homemade shaker and its mounting has advanced well. Parts of the measurement software have been developed. The goal is to start measurements at secondary level during 2007.

## OTHER PROGRESS AT MIKES

During 2006, activities of MIKES in the field of metrological applications of microelectromechanical structures (MEMS) have mainly concentrated on reporting the results achieved in the EMMA project, which finished in spring 2005. Design and properties of the stable MEMS-based AC voltage reference have been reported [50], [51], and an invited review article on applications of MEMS components in electrical metrology has been written [52]. Practical activities with MEMS will be continued in 2007.

MIKES and Nokia Corporation Technology Platform have investigated applicability of coaxial cables at picosecond range timing [53]. The results revealed that the conventional tick pulse is not usable for accurate measurements below 1 ns, but the pulse shape has to be changed to fit the properties like bandwidth and velocity dispersion of cables. Environmental effects may change the cable delay up to 100 ps. These investigations were partly motivated by the cable delay comparison EUROMET.TF.TI-K1 (EUROMET project no. 828).

## TRACEABILITY OF POWER QUALITY MEASUREMENTS (MIKES-TKK)

One of the quantities measured by power quality meters is the flicker index. Flicker index is a number, which is related to the irritation effect of flickering of lighting due to changes in the mains voltage. In this project MIKES-TKK developed a system for calibration of flicker meters. 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. The system was developed during autumn of 2006, and first calibrations will be performed in spring 2007.

## EXTENSION OF THE BANDWIDTH ESD TESTER CALIBRATION SYSTEM (MIKES-TKK)

ESD testers are calibrated using a special target designed for measuring the current produced by pulse delivered from the tester. Accurate measurement of this pulse having a rise time of less than 1 nanosecond requires a bandwidth of several GHz.

A new wideband (6 GHz) oscilloscope to provide the required bandwidth was purchased in 2005. During 2006 the emphasis was on the characterization of the bandwidth of the target-attenuator-cable chain. Methods and adapter for the calibration were developed in the autumn. The system is expected to be fully calibrated in spring 2007.

## OTHER PROGRESS AT MIKES-TKK

The traceability of capacitance loss measurements has been improved. An absolute determination of capacitor dissipation factor was performed using a variable capacitor guard ring capacitor together with a capacitance bridge for this task. The estimated uncertainty in the determination of the dissipation factor of a 100 pF capacitor was less than 10 ppm [54].

The results of the work for improving the high alternating current calibration capabilities of MIKES-TKK was published in the CPEM 2006 conference [55]. There are plans to continue the verification for higher current levels in future. The system is now verified up to 3 kA.

*Figure E5. ESD calibration target waiting for tests with a network analyzer. The frequency response of the target-attenuator-cable chain is calibrated up to 6 GHz.*

# Comparisons

## INTERNATIONAL COMPARISONS

### MIKES

CCEM-K10: DC resistance 100 Ω. Key comparison. Participants: BIPM, METAS, MIKES, NIM, NIST, NMIA, NMIJ, NRC, PTB (pilot). The QHR measurements in MIKES were made in 2002. Draft B of the final report appeared in April 2006, and the results were published in the BIPM key comparison database in February 2007. The degree of equivalence of the MIKES result with respect to the key comparison reference value was (12.15 ± 17.1) nΩ/Ω ($k$ = 2). The results were limited by the transportability of the resistors and not by the capability of the participants.

CCEM.RF-K19.CL: Attenuation at 60 MHz and 5 GHz using a 50 ohm Type-N step attenuator. Key comparison. Participants: BNM-LNE, CMI, CSIR-NML, INRIM, KRISS, METAS, MIKES, MIRS/SIQ, NIM, NIST, NMIJ, NMi-VSL, NPL (pilot), NPLI, NRC, PTB, SP, SPRING Singapore, UME, VNIIFTRI. Measurements in MIKES were made in October 2004. The first version of Draft A of the final report was distributed for participants in April 2006. All results of MIKES are consistent with the key comparison reference value within the claimed uncertainties, and the uncertainties of MIKES are very similar to 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, CEM, CMI, CSIR-NML, GUM, INETI, INM(RO), JV, LNE, LNMC, METAS (pilot), MIKES, MIRS/SIQ, NMi-VSL, NML(IE), NPL, OMH, PTB, SMD, SMU, UME, VMT/PFI. Measurements in 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).

EUROMET.EM-K5 (EUROMET project no. 385): AC power measurement at 50 Hz. Key comparison linked with CCEM-K5. Participants: AREPA, BEV, CEM, CMI, GUM, IEN, INETI, JV, METAS, MIKES, NMi-VSL, NPL, OMH, PTB (pilot), SMD, SP, UME. Measurements in MIKES/VTT were finished in December 1999. Draft B of the final report appeared in June 2006, and the results were published in the BIPM key comparison database in November 2006. Most results of MIKES were consistent with the corresponding reference value of CCEM-K5 within the claimed uncertainties ($k$ = 2), but in some points the deviation was somewhat larger than expected, 42 μW/(VA) at maximum. At two values of the power factor, 0.5 lag and 0.0 lead, the deviation exceeded slightly the comparison uncertainty. After this comparison the measurement system at MIKES has been improved considerably, and in September 2005 MIKES participated in a new, still ongoing key comparison EUROMET. EM-K5.1 using the improved setup.

*Figure E6. Measurement of the 1 GΩ travelling standard from the MIKES reference 100 MΩ standard in EUROMET.EM-K2 comparison by two methods: DCC resistance bridge (left) and modified Wheatstone bridge based on two calibrators (right).*

EUROMET.EM-K10 (EUROMET project no. 636): 100 Ω standard resistor. Key comparison to be linked with CCEM-K10. Participants: BEV, BIPM, CEM, CMI, CSIR-NML, DFM, EIM, GUM, INETI, INRIM, JV, LNE, LNMC, METAS, MIKES, MINECO, MIRS/SIQ, NMi-VSL, NML(IE), NPL, OMH, PTB (pilot), SASM, SP, UME, VMT, VNIIM, ZMDM. Measurements in 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 A of the final report was distributed for the participants in March 2006. The results of the Nordic loop organised by MIKES agreed 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.

EUROMET.EM-K11 (EUROMET project no. 464): AC/DC voltage transfer difference at low voltages. Key comparison to be linked with CCEM-K11. Participants: AREPA, BEV, CEM, CSIR-NML, EIM, GUM, IEN, INETI, JV, LNE, METAS, MIKES, MIRS/SIQ, NMi-VSL, NPLI, OMH, PTB, SMD, SP (pilot), UME, VNIIM. Measurements in MIKES were made in September 2006.

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. Participants: MIKES, NMi-VSL (pilot). Thermistor mounts of MIKES and NMi-VSL were measured in both laboratories. MIKES made the measurements in December 2004 and February 2005. Draft B of the final report was sent for approval in December 2006. Deviation of MIKES results from the reference value of EUROMET.EM.RF-K8.CL was smaller than 0.4 % at all frequencies except 18 GHz, where deviation was -1.38 % ± 2.25 %. 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.

Bilateral comparison of capacitance standards with SP, Sweden, was arranged in the end of 2005 on scaling the capacitance value from 100 pF up to 1 μF with one decade step. The results, which were published in CPEM 2006 conference, showed good agreement between MIKES and SP [48]. Relative differences between MIKES and SP were less than 1.5 μF/F at capacitance values from 1 nF to 100 nF, and the difference at 1 μF was (11.5 ± 16.6) μF/F.

EUROMET.TF.TI-K1 (EUROMET project no. 828): Time interval (cable delay) measurement. Supplementary comparison. Participants: BEV (pilot), EIM, GUM, IEN, INM, IPQ, IREE/CMI, JV, MIKES, METAS, NCM, NMi-VSL, NPL, NPLI, OMH, OP/SYRTE, PTB, ROA, SIQ, SMD, SMU, SP, UME, VMT/PFI, ZMDM. Measurements in MIKES were made in February 2006. Draft A of the final report was distributed for participants in August 2006. The delays in the three measured cables had values from 20 ns to 175 ns, and the uncertainties of MIKES results were between 75 ps and 215 ps. Deviation between the MIKES results and the weigted mean of all participants was smaller than the claimed uncertainty for all cables.

EUROMET 860: Time comparison using a transportable atomic clock. In November 2005, MIKES organised a time comparison in which one of the Cs clocks of MIKES was transported by car to SP (Sweden) and back. The comparison was continued in May 2006 by transporting a Rb clock from MIKES to Metrosert (Estonia) and VMT/PFI (Lithuania) and back. Analysis of the results is in progress.

EUROMET.AUV.A-K3 (EUROMET project no. 674): Laboratory standard microphone calibrations. Key comparison to be linked with CCAUV.A-K3. Participants: BEV, CEM, CMI, DPLA, INRIM (pilot), METAS, MIKES, NMi-VSL, SP. Measurements in MIKES were performed in March - April, 2004. Draft B of the final report appeared in April 2006. Deviations of MIKES results from the comparison reference value were 0.025 dB or less for all frequencies between 31.5 Hz and 16 kHz, and at the highest frequency of MIKES, 20 kHz, the deviation was (0.0836 ± 0.0850) dB.

### MIKES-TKK

EUROMET 488: Impulse voltages. 26 participating laboratories, including National Standards Laboratories from five EUROMET countries (FI, FR, DE, ES, SE), and from Australia (NMIA), Russia (VNIIMS), and China (WHVRI). Pilot MIKES-TKK. The comparison was of lightning impulse voltages, from 50 mV to 1000 V and from 80 kV to 400 kV, and of switching impulse voltages from 50 mV to 300 V. This project started in 1999 and the measurements were completed by October 2002. Analysis of the results was agreed on during 2003. Final results were presented in CPEM 2006 [56] and will be published in IEEE Trans. Instrum. Meas. [57].

*Figure E7. Kalevi Kalliomäki investigating the transfer standard of comparison EUROMET.TF.TI-K1. The transfer standard (middle up) consists of three microwave cables of different lengths fitted in a box and equipped with BNC connectors.*

Trilateral high accuracy comparison of impulse voltage calibrators. Participants: MIKES-TKK, PTB, NIT (Japan). The comparison was arranged in December 2005. The results were presented in CPEM 2006 conference [58], and the agreement on the peak value of the calculable impulse voltage calibrators was better than 0.05 % on all measured voltage levels, both for lightning and switching impulse [59].

## NATIONAL COMPARISONS

### MIKES

A comparison on calibration of digital multimeters was arranged in spring 2006. The travelling device was a HP 3458A multimeter, and the comparison included DC voltage between 50 mV and 100 V, DC current between 1 mA and 100 mA, AC voltage at 1 V and 10 V at frequencies from 400 Hz to 1 MHz, AC current at 10 mA and 100 mA at frequencies 400 Hz and 10 kHz, and resistance between 100 Ω and 10 kΩ. Six laboratories, all from Finland, participated the comparison.

A bilateral comparison on frequency measurements at 10 MHz was arranged between MIKES and Nemko Oy in March 2006.

# 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. Goëry Genty* | *Senior Research Scientist* |
| *Dr. Jari Hovila* | *Senior Research Scientist* |
| *Dr. Jouni Envall* | *Senior Research Scientist* |
| *Dr. Markku Vainio* | *Senior Research Scientist* |
| *Dr. Antti Lamminpää* | *Senior Research Scientist* |
| *M.Sc. Ville Ahtee* | *Research Scientist* |
| *M.Sc. Silja Holopainen* | *Research Scientist* |
| *M.Sc. Pasi Manninen* | *Research Scientist* |
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| *M. Sc. Maija Ojanen* | *Research Scientist* |
| *M.Sc. Tuomas Hieta* | *Research Scientist* |
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| *Ms. Liisa Ollikka* | *Research Assistant* |
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| *Mr. Markku Valkonen* | *Research Assistant* |
| *Mrs. Jaana Hänninen* | *Coordinator* |
| *Mr. Tarmo Simonen* | *Network and PC Administration* |

Metrology Research Institute 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, chromatic dispersion.

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

# Highlights in 2006

A new model was developed to determine the luminous intensity of LED sources in an unambiguous way over a large distance range. The achieved results were accepted for publication in a refereed journal and they will be useful in illumination design using LEDs. The figure shows an example of a large-area LED source with lens, which can be successfully modelled to an equivalent optical arrangement containing just a virtual source and an aperture.

In fibre nonlinearity measurements, a breakthrough was achieved by decreasing the measurement uncertainty by a factor of three. This is based on improved fibre optic power measurements and successful dispersion modelling in the nonlinear fibre. The results were accepted for publication in a refereed journal. Two of the three Doctoral dissertations of 2006 at the Metrology Research Institute are related to these studies.

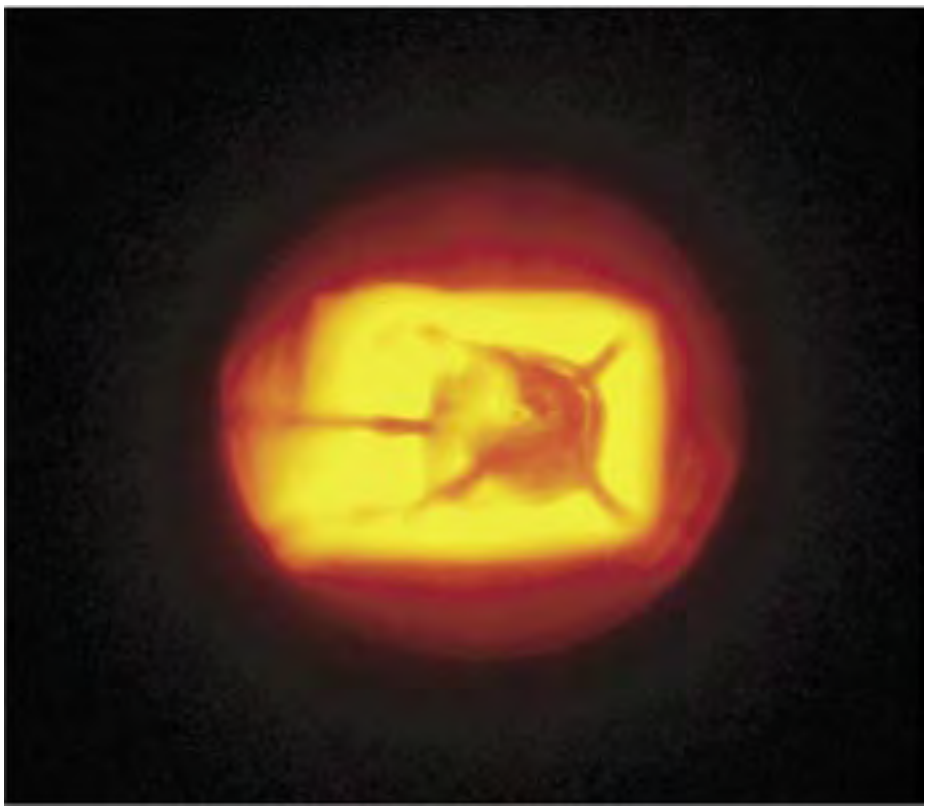

*Figure P1. Image of an LED as seen by an observer in the direction of optical axis.*

# Realisation, maintenance

## MODIFICATIONS IN GONIOREFLECTOMETER LIGHT SOURCE SYSTEM

A gonioreflectometer for measuring diffuse reflectance was designed and constructed in the laboratory in 2004. The system measures full intensity in a certain reference position behind the sample, scans the reflected radiation from the sample in polar angles, and calculates the bidirectional reflectance factors from the ratios of the reflected radiation in each angle to the full radiant intensity at the reference position. Due to inherent scattering properties of optical components there is always some scattered light around the measurement beam. Because of this scatter and because the full intensity is measured at different distance from the source optics as compared to the sample intensity, not all the light incident on the sample is seen by the detector at the reference position. Therefore, a correction must be applied to take care of this problem.

Some modifications have been done in the light source system of the gonioreflectometer in 2005 and 2006 leading to improved properties of the measurement beam [60]. The determined wavelength-dependent correction was on the average as high as -1.1 % and reduced to -0.2 % after the improvements. The measurement results for our diffuse reflectance reference materials are in excellent agreement which indicates that the scattering of light around the main beam is under control in our system. Considering the magnitude of the correction required before the modifications, it is obvious that definite errors will occur if light scattering about the main beam is not taken into account when designing and characterizing a gonioreflectometer.

## SIGNIFICANT PUBLICATIONS AND PRESENTATIONS

As the result of other maintenance work, following journal articles were published in 2006 [29, 31, 61, 62, 63, 64]. In addition, several conference presentations and other publications were given during the year 2006 [65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75].

# Research Projects

## CALIBRATION FACILITY FOR COLOUR DISPLAYS AND COLORIMETERS

The quality of colour displays continues to improve and customers demand higher accuracy in colour reproduction. Commercial colorimeters and spectroradiometers are commonly used to measure the chromaticity and luminance of displays. The instruments are typically calibrated at factory using incandescent standard lamps. Such a practice causes errors in determining the colour of displays whose spectra are very different from those of the standard lamps. Such measurement errors would significantly degrade the quality control of the display products and the performance of any colour management systems. To address the needs for improving and certifying the measurement uncertainties of such colour measuring instruments for the Finnish industry, a facility has been developed for spectrometric and colorimetric calibration of displays, colorimeters, and spectroradiometers. During the year 2006, investigation was carried out regarding the use of a CCD-camera in determining the luminance uniformity of LCD devices using a dedicated laboratory space. Work was also done in developing the low-luminance measurement capability using filters and a sphere-source [76].

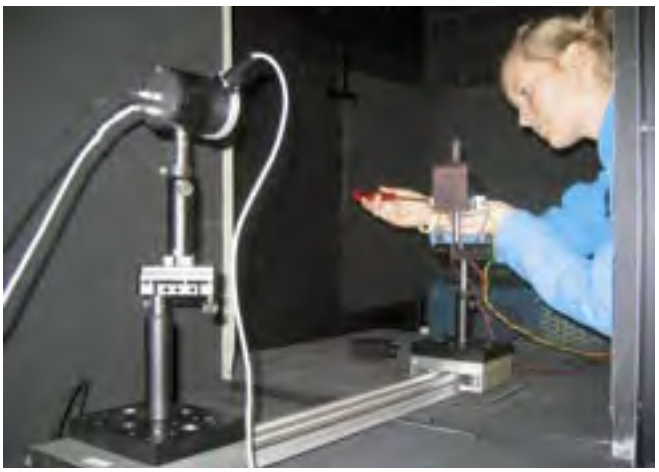

*Figure P2. Measurement facility for spectral irradiance. The signal from the lamp is measured at the reference detector in accurately defined solid angle. The wavelength dependence is obtained by using interference filters in front of the detector.*

## EXTENSION OF THE WAVELENGTH REGIONS OF SPECTRAL IRRADIANCE AND RADIANCE MEASUREMENTS

The purpose of this project is to extend the wavelength regions of the spectral irradiance and radiance scales to 200 nm – 2.5 µm. The project has now come to a stage where spectral irradiance measurements cover the spectral region 250 nm – 1500 nm. In the visible region, an improved uncertainty evaluation was developed [77]. In the UV region, a trap detector based on GaP photodiodes is used [78]. In the IR region, a Ge photodiode is used [79]. Comparison measurements with NPL-traceable lamps show good agreement in the visible and IR regions. Measurement facility for spectral irradiance is illustrated in Fig. P2.

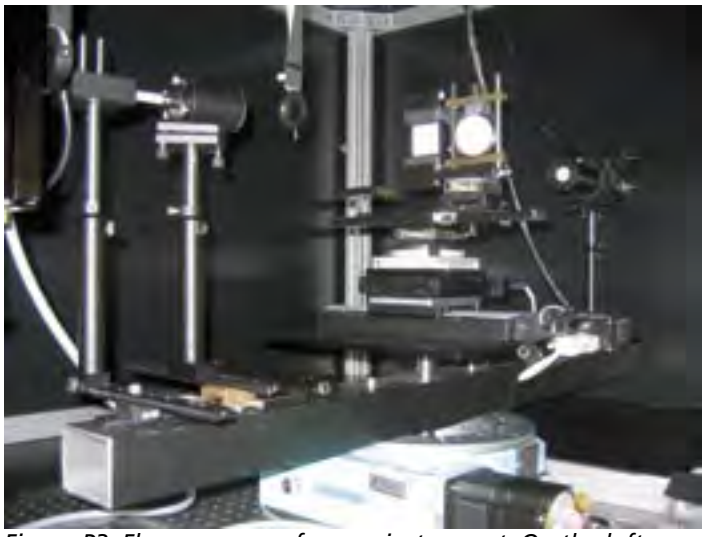

*Figure P3. Fluorescence reference instrument. On the left: fluorescence collection lens and fibre guide. Holders for fluorescence sample and a non-fluorescent reference are located on a linear translator and in the background is seen the reference detector for the calibration of the detection system.*

## REFERENCE INSTRUMENT FOR FLUORESCENCE MEASUREMENTS

The objective of the project is to develop a reference instrument for measuring spectral fluorescent quantum yield of samples in the wavelength range 250-830 nm. The structure of the facility will be designed so that different types and sizes of samples can be measured. The measurements are to be made essentially in the CIE recommended geometries of illumination and collection. The goal is to reach uncertainty of less than 3 % in determining the absolute quantum yield with a repeatability of better than 1 % within several years. In 2006 the automation of the measurement system was improved and the detection system was inspected and found to be reliable. The instrument (Fig. P3) was presented at the 5th Oxford Conference on Spectrometry in Teddington, United Kingdom [80].

## MEASUREMENT SETUP FOR NON-LINEARITY OF OPTICAL FIBRES

The goal of this project is to determine the nonlinear coefficient of the optical fibre accurately [81, 82, 83]. During 2006, improved setup with integrating sphere detector and simulation software was successfully established. The obtained accuracy for determining the nonlinear coefficient is now 2 % ($k$=2) [84] (6.4 % in 2005) [85, 86]. To get the actual nonlinear refractive ($n_2$) index from the nonlinear coefficient ($n_2/A_{eff}$), the effective area of the fibre had to be determined. Setup based on far-field scanning technique standardized by International Telecommunication Union was built and characterized (Fig. P4). An uncertainty of about 4 % ($k$ = 2) was obtained for the effective area [87].

## REFERENCE SPECTROMETER FOR INFRARED DETECTOR MEASUREMENTS

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. Accurate measurement of spectral power responsivity in the visible spectral region has been a service provided by the Metrology Research Institute for several years. The Metrology Research Institute has recently moved to expand the spectral range of spectral irradiance scale to cover the UV and near infrared regions. Ongoing projects for spectral irradiance scale will require the availability of a spectral power responsivity of the used detectors in the range from 0.9 µm to 2.5 µm. Recently, spectral responsivity calibration capability has been extended from 0.2 µm out to 1.7 µm [88].

In the initiation phase of the project during the year 2006, a facility was developed using a monochromator

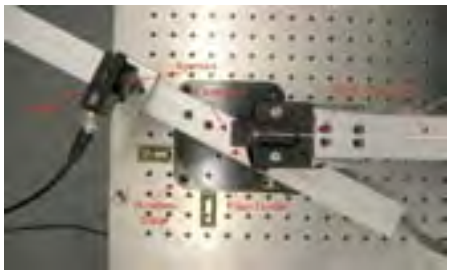

*Figure P4. Device using far-field scanning for effective area determination in optical fibre. The fibre is highlighted with white colour to make it visible.*

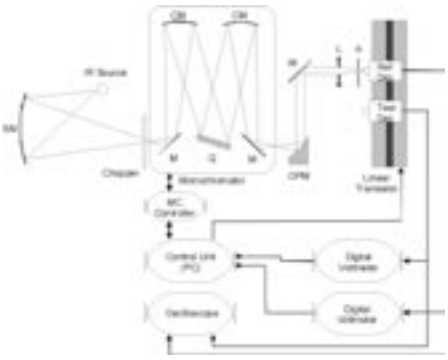

*Figure P5. Schematic of the measurement setup. M indicates a flat mirror, SM a spherical mirror, CM a concave mirror, OPM an off-axis parabolic mirror, L a lens, A a variable size aperture and G a diffraction grating.*

with two IR gratings (Fig. P5). The facility consists of three sections as the light-source / input optics, monochromator, and the comparator / detection system. The coverage of spectral range is for the most part of the 1.1–3.4 µm excluding the atmospheric absorption bands. Measurements have been performed for determining the spectral responsivity of a PbSe and an InAs photodiode using an available pyroelectric radiometer as the reference detector. The uncertainties for the calibration measurements are 1.88 % and 3.32 %, respectively.

## METROLOGY OF LED LIGHT SOURCES

During 2006, the Metrology Research Institute continued its work in developing luminous intensity model for analysing the behaviour of LEDs as a function of distance. The developed model takes into account the geometrical deviations of LEDs from point sources and uses a modified inverse-square law to determine the reference plane of the source using the same type of method as was earlier applied in diffuser studies. Several papers were published on the subject [89, 90, 91, 92, 93, 94]. Work was also carried out to develop measurement methods for flashing light sources. The preliminary results showing the spectral changes of the LEDs during flashing operations are highly interesting.

## DETERMINATION OF RADIATION TEMPERATURE USING FILTER RADIOMETERS

In the collaboration project of the Metrology Research Institute and the temperature laboratory of MIKES, a new approach for measuring the radiation temperature of a black body radiator is tested. Spectral irradiance of the high precision black body is measured with absolutely characterized filter radiometers and linear pyrometer in near-infrared wavelength region. In 2006, one filter radiometer with effective wavelength of 801 nm was calibrated using wavelength-tunable Ti:Sapphire laser. Two dedicated filter radiometers with effective wavelengths of 800 and 900 nm were constructed and their thermodynamical properties were characterized. Thermodynamic temperatures between 1373 K and 1773 K were studied by measuring a variable-temperature black body. The measurements were carried out using a linear pyrometer and four absolutely characterized filter radiometers with effective wavelengths between 600 and 900 nm. The filter radiometer measurements were done in irradiance mode. The results obtained with the pyrometer and the filter radiometers were compared. Before the variable temperature black body measurements, the absolutely characterized filter radiometers were tested on a silver fixed-point cell whose freezing temperature was 1234.93 K. The results will be presented in Tempmeko-conference in 2007.

# Comparisons

## INTERNATIONAL COMPARISONS

K2.a: spectral responsivity, 900-1600 nm, pilot NIST
Draft A-3 is now nearly ready to be distributed to the participants. The major change relative to draft A-2 is a re-evaluation of the transfer uncertainty at NIST and the resulting re-calculation of the data. The uncertainty of the KCRV will be slightly larger than before, but it will hardly affect the overall results.

K2.c: spectral responsivity, 200-400 nm, pilot PTB
The measurements of the first three groups of participants are finished. The final PTB measurement on the detectors of this round is planned for January 2007. Draft A shall be available later in 2007.

K5: spectral diffuse reflectance, pilot NIST
The uncertainty budgets have been sent out for review in October 2006, the relative data will be sent in the beginning of 2007. Additional measurements were carried out on samples belonging to the participants as bilateral comparisons. These data will be analysed later and the results will be published separately from the key comparison results. Draft A is expected in 2007.

K6: spectral regular transmittance, pilot LNE
Draft A report has been distributed in July 2006. Draft B expected in 2007.

S2: aperture area, pilot NIST
Final report was published in 2006. The Metrology Research Institute results were good (see Fig. 6). Of nine participants, only the Metrology Research Institute and National Research Council of Canada had all results within 1σ or 2σ limits.

Chromatic dispersion comparison EUROMET-PR.S1.1 (bilateral with METAS)
Final report has been published in 2006. This was a subsequent bilateral comparison which corrected erroneous results of the Metrology Research Institute in the earlier comparison EUROMET-PR.S1. One zero dispersion result still remained clearly outside 95 % confidence limits.

Comparison methods for UVA irradiance responsivity calibration, piloted by the Metrology Research Institute
A commercial UVA meter was used in the comparison, and each laboratory was instructed to measure its UVA irradiance responsivity using the exact methodology and equipment that they utilise in their regular work. The results were in agreement within ±5 %, which demonstrates a factor of two improvement in the consistency of the results as compared with earlier intercomparisons [95, 96, 97].

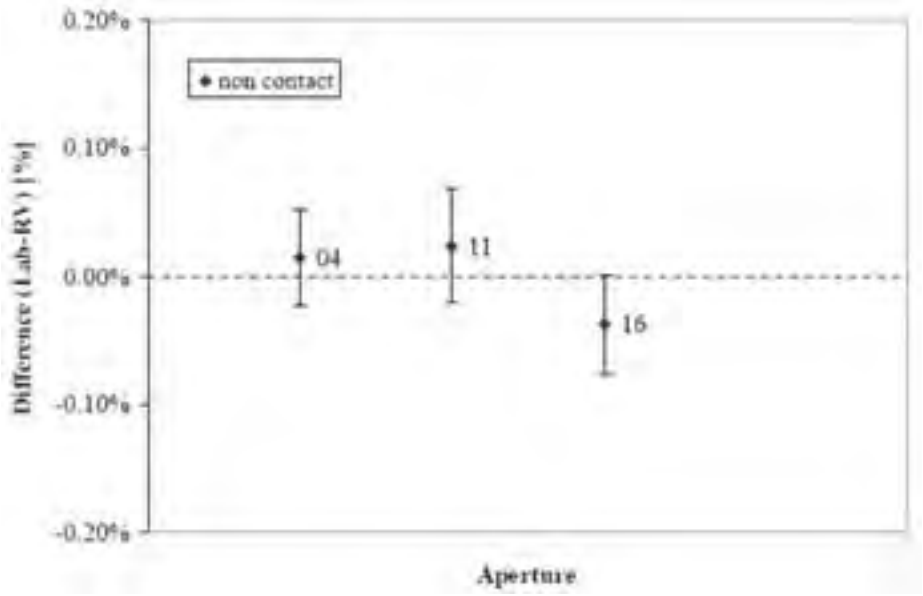


*Figure P6. Aperture area comparison CCPR-S2: measurements 1999-2003 (pilot NIST). Nine participants, only TKK and NRC had all results within 1σ or 2σ limits.*

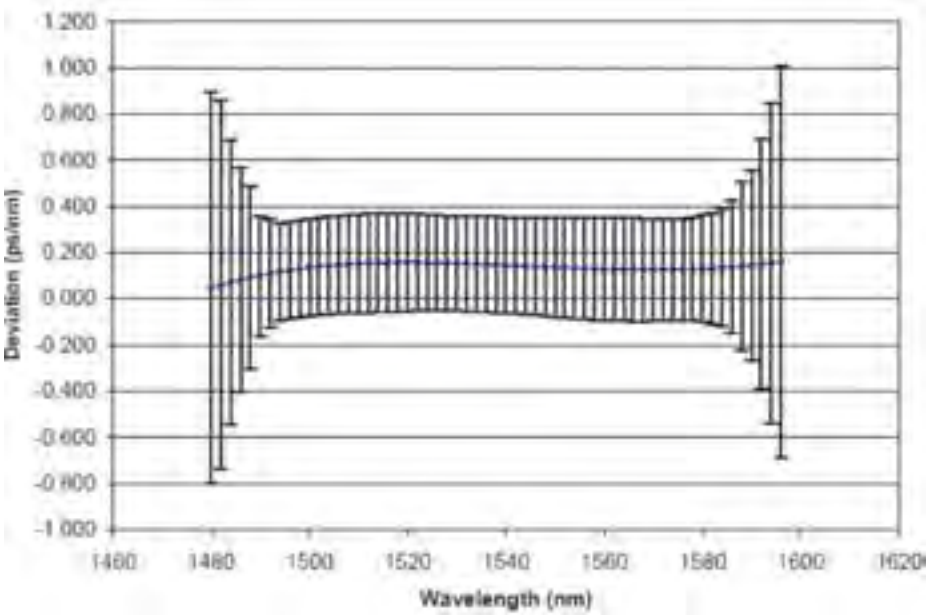


*Figure P7. An example of results of the chromatic dispersion comparison.*

# Ionising radiation

***Personnel***
***STUK***

| | |
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| *Dr. Antti Kosunen* | *Head of Laboratory, Physicist* |
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| *M.Sc. Ilkka Jokelainen* | *Physicist* |
| *Dr. Arvi Hakanen* | *Physicist* |
| *M.Sc. Paula Pöyry* | *Physicist* |
| *Dr. Teemu Siiskonen* | *Physicist* |
| *Tech. Teuvo Parviainen* | *Technician* |
| *Tech. Harri Lindroos* | *Technician* |
| *Tech. Ilkka Aropalo* | *Technician* |
| *M.Sc. Markku Tapiovaara* | *Physicist* |
| *Mrs. Carita Ruuhonen* | *Secretary* |

On the basis of its own legislation, the 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 2006

The diagnostic x-ray radiation qualities according to the Standard IEC 61267 (2005) were established. The calibration method developed for kerma area product meters was presented in Vienna in the IAEA International Conference on Quality Assurance and New Techniques in Radiation Medicine [98, 99]. The principles of the developed method were adopted also in the IAEA Code of Practice on Dosimetry in X-ray Diagnostic Radiology.

The Laboratory partly organised and participated in the Nordic training workshop for Secondary Standard Dosimetry Laboratories in Swedish Radiation Protection Authority (SSI), Sweden. The main topic in the workshop was the measurement techniques of low ionisation currents. Laboratory had also a common master thesis study with MIKES on the measurements of low (pA) currents.

Calibration for kerma lenght product meters for x-ray computed tomoraphy was taken in use. For validation and description of the method a pro gradu-thesis was made [100].

The Laboratory organised and participated in the Nordic dosimetry group meeting at STUK. A report on the dosimetric capabilities of the Nordic national dosimetry laboratories was published [101].

The methods and results for determination of conversion factors from air kerma to operational dose equivalent quantities were published [102]. 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 [103, 104].

*Figure I1. Calibration of a kerma area product meter with x-rays.*

# Realisation, Maintenance

A new reference standard for air kerma for diagnostic x-ray qualities was taken in use. The reference standard is a plane-parallel ionization chamber of type TB 23344, manufactured by PTW, Germany. The standard was calibrated at PTB, Germany.

Two STUK internal audits were targeted to the Laboratory, covering areas of equipment and registers, staff training, job descriptions, accommodation and environmental conditions, access to laboratory, validation of methods, testing of equipment, handling of equipment, reference standards and assuring the quality of results.

*Figure I2. Set of ionisation chambers. Second from right, 23344-type plane parallel chamber used as a reference standard for x-rays.*

# Research Projects

The Radiation Metrology Laboratory participated in an EU coordinated action, SENTINEL, "Safety and efficacy for new techniques and imaging using new equipment to support European legislation" (year 2005 - 2007). The project is a continuation for the previous DIMONDIII project and contains e.g. issues for dosimetry in interventional radiology [105].

The Laboratory participated also in an IAEA Coordinated Research Project "Testing of the Implementation of the Code of Practice on Dosimetry in X-ray Diagnostic Radiology" (years 2005 - 2007). The main topics for STUK are testing of the calibration methods for kerma area product meters and the clinical measurement techniques for general radiology, computed tomography and mammography.

# Comparisons

**INTERNATIONAL COMPARISONS**

In 2006 the Laboratory participated in the annual radiotherapy level dosimetry audit organised by IAEA/WHO secondary standard laboratory network. Measurements were performed in a $^{60}$Co gamma radiation beam using postal thermoluminescent dosimeters. The stated difference between the results of STUK and IAEA were below the detection limit (difference 0.0 %). The stated tolerance level by IAEA for the difference is 3.5 %.

# Chemistry

***Personnel***
***MIKES-FMI***

| | |
|---|---|
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| *Dr. Pirjo Kuronen* | *Senior Researcher* |
| *M.Sc. Veijo Pohjola* | *Senior Researcher, Quality Manager* |
| *Ms. Sisko Laurila* | *Research Assistant* |
| *M.Sc. Kaisa Lusa* | *Researcher (in her maternity leave)* |
| *M.Sc. Minna-Kristiina Sassi* | *Researcher (in her maternity leave)* |
| *B.Sc. Markus Talka* | *Researcher (on leave of absence)* |
| *M.Sc. Antti Wember* | *Researcher* |
| *Mr. Kai Lindgren* | *Technician* |
| *Mr. Jari Bergius* | *Technician (1.1. – 12.7.06)* |

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 agreement for the maintenance of calibration service in the field of air quality according to the requirements by the CIPM. The FMI is also nominated as a national reference laboratory in the field of air quality by the Ministry of the Environment. The 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 CALIBRATION LABORATORY

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

- the national reference laboratory of atmospheric pollutants
- the national measurement service — 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 unit or to the international standards.

## ORGANISATION OF THE SUBJECT FIELD

The metrology in chemistry is focused on gas metrology at the Finnish Meteorological Institute. The calibration laboratory at the air quality research maintains calibration (Fig. C1) 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 ($C_8H_{10}$) (Fig. C2). The traceability of the calibration concentration produced in the laboratory is to SI unit via national metrological 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 BTEX-compounds are those of the secondary gas standard of NPL and NMi. The ozone reference standard is the Standard Reference Photometer by NIST. 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) gas standard with the ozone ($O_3$). As secondary standards for nitrogen dioxide, sulphur dioxide, benzene, toluene, o- and m-xylenes the 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.

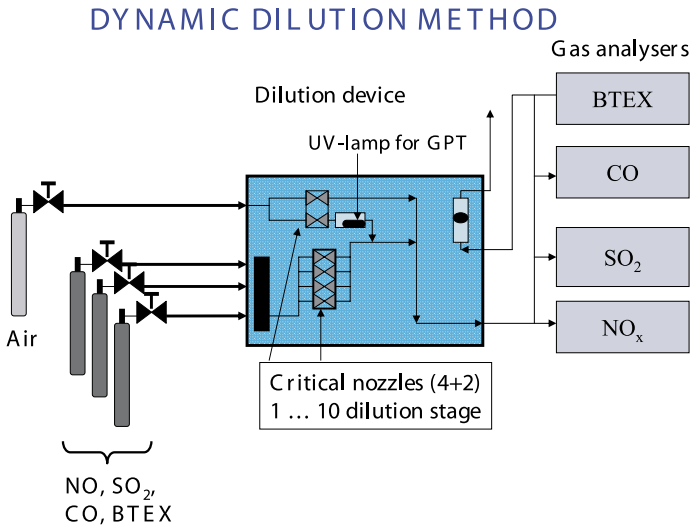



*Figure C1. The schematic of the dynamic dilution method for producing SI-traceable gas mixtures for calibration purposes.*

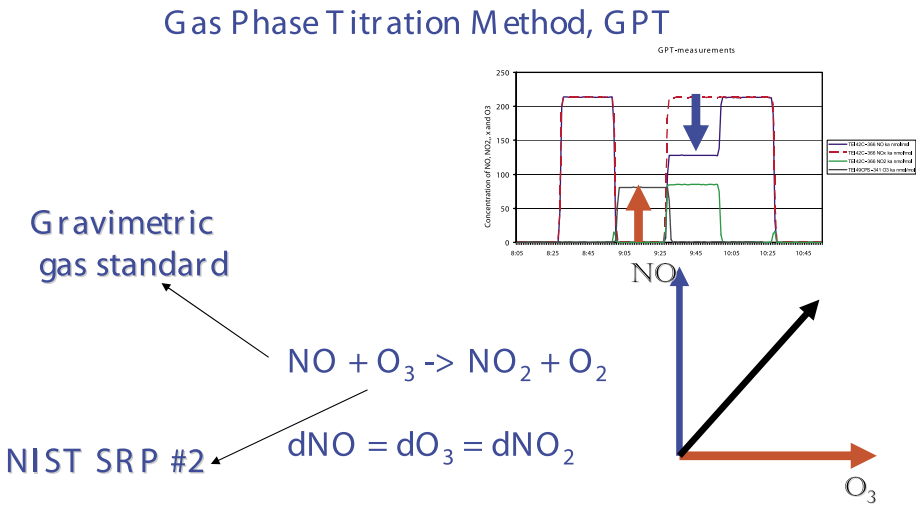
*Figure C2. Antti Wemberg is obtaining calibration of continuous air quality analyzers of oxides of nitrogen, sulphur dioxide and carbon monoxides.*

The validation of the SRP and the flow measurement system were completed in 2006 and were included into the quality system of the laboratory.

# Research Projects

The laboratory took also part in the City-Twinning project between the cities from Finland and 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. The Metrology Institute of Russia, VNIIM, participated in the project.

To demonstrate the agreement between the NO gas standard which is traceable to gravimetric method and the ozone gas standard of SRP-37 by NIST extensive studies were made with the gas phase titration method (see in Fig. C3). A discrepancy of 2.8 % was observed between the two methods which is more than the calculated expanded uncertainty of the methods.




The way to demonstrate the agreement between the gravimetric method and the photometric method

*Figure C3. The cross check of the gravimetrically produced gas standard of nitric oxide (blue line) and the standard reference photometer, SRP-37, (red line). There is about 2.8 % discrepancy from the 1:1 line (black line) between the both methods.*

# Comparisons

The second intercomparison exercise of air quality measurements of carbon monoxide (CO), nitrogen monoxide (NO), ozone ($O_3$), sulphur dioxide ($SO_2$), and hydrogen sulphide ($H_2S$) and the field audit were conducted to local air quality measurement networks in Finland. The field audit was addressed on the quality assurance and the quality control procedures for the air quality measurements. The training for these topics was conducted during the Workshop on "Vertailulaboratoriopäivät" (see in Fig. C4). Results of the second intercomparison exercise will be reported during the next year.

The laboratory took part on the pilot comparison of ozone photometer organized by BIPM [106] and Comparison of primary standards of sulphur dioxide ($SO_2$) in synthetic air (CCQM-K26b) [107], and nitric oxide (NO) in nitrogen (CCQM-K26a).


*Figure C4. Veijo Pohjola is giving a training course on the quality system.*

# Publications


[1] J. Mäkinen, H. Koivula, J. Ahola and M. Poutanen, *Combining absolute gravity and permanent GPS observations in Dronning Maud Land, Antarctica*. SCAR XXIX Open Science Conference, Hobart, Australia, July 12–14, 2006. Abstract and poster.

[2] H. Kajastie, K.K. Nummila and K. Riski, *Losses in Niobium at low frequency magnetic fields*, Conference Digest CPEM 2006 (9-14 July 2006, Turin, Italy).

[3] L. Stenlund, K. Riski and V. Korpelainen, *Surface studies of weights with AFM*, Proceedings of NanoScale 2006, April 24-25, 2006, METAS, Switzerland.

[4] M. Heinonen, *Methods to investigate a dew-point temperature standard in an extended range*, ISHM 2006, May 2 – 5, 2006, Rio de Janeiro, Brazil.

[5] M. Heinonen, *A portable humidity calibrator*, ISHM 2006, May 2 – 5, 2006, Rio de Janeiro, Brazil.

[6] I. Lassila, M. Heinonen, E. Häggström, (2006), *Towards Controlled Freezing of Supercooled Water*, 40th Physics Days of the Finnish Physical Society, Tampere, Finland.

[7] L. Timmen, O. Gitlein, J. Müller, H. Denker, J. Mäkinen, M. Bilker, B.R. Pettersen, D.I. Lysaker, O.C.D. Omang, J.G.G. Svendsen, H. Wilmes, R. Falk, A. Reinhold, W. Hoppe, H.-G. Scherneck, B. Engen, B. G. Harsson, A. Engfeldt, M. Lilje, G. Strykowski and R. Forsberg, *Observing Fennoscandian gravity change by absolute gravimetry*. In: F. Sansò, A.J. Gil (eds.), Geodetic Deformation Monitoring: From Geophysical to Engineering Roles. International Symposium on Geodetic Deformation Monitoring, Jaén, Spain, March 17 to 19, 2005. IAG Symposia 131 (2006), Springer, pp. 193–199.

[8] J. Mäkinen, M. Bilker-Koivula, F. Klopping, R. Falk, O. Gitlein and L. Timmen, *Time series of absolute gravity in Finland*. First International Symposium of the International Gravity Field Service "Gravity Field of the Earth" – IGFS2006, August 28–September 2, Istanbul. Abstract and poster.

[9] M. Poutanen, P. Knudsen, M. Lilje, T. Nørbech, H.-P. Plag and H.-G. Scherneck, *The Nordic Geodetic Observing System (NGOS)*. In: C. Rizos and P. Tregoning (eds), Dynamic Planet - Monitoring and Understanding a Dynamic Planet with Geodetic and Oceanographic Tools, Conference of the International Association of Geodesy, 22-26 August 2005, Cairns, Australia. IAG Symposia 130 (2006), Springer, pp. 749–756.

[10] H. Wilmes, R. Falk, F. Klopping, A. Lothammer, A Reinhold, W. Hoppe, B. Richter, E. Roland, H-P Plag and J. Mäkinen, *Analysis of absolute gravity measurements in the Scandinavian postglacial uplift zone for the period 1991 to 2003*. First International Symposium of the International Gravity Field Service "Gravity Field of the Earth" – IGFS2006, August 28–September 2, 2006, Istanbul. Abstract and poster.

[11] J. Mäkinen, A. Engfeldt, B.G. Harsson, H. Ruotsalainen, G. Strykowski, T. Oja and D. Wolf, *The Fennoscandian Land Uplift Gravity Lines 1966–2005*. 15th General Meeting of the Nordic Geodetic Commission, Copenhagen, May 29 to June 2, 2006. Abstract and poster.

[12] H. Virtanen, *Studies of Earth dynamics with the superconducting gravimeter*. Publ. Finn. Geod. Inst. 133 (2006), 130 p.

[13] M. Bilker-Koivula, *Global gravity field models from satellite measurements*. In: I. Kukkonen, O. Eklund, A. Korja, T. Korja, L. Pesonen, M. Poutanen (eds.), Lithosphere 2006 – Fourth symposium on the structure, composition and evolution of the lithosphere in Finland, Espoo, November 9-10, 2006, Institute of Seismology, University of Helsinki, Report S-46. pp. 1-5.

[14] T. Hokkanen, K. Korhonen and H. Virtanen, *Hydrogeological effects on superconducting gravimeter measurements at Metsähovi*, Finland. J. Env. Eng. Geophysics 11 (2006), pp. 261-267.

[15] H. Virtanen, M. Tervo, M. Bilker-Koivula, B. Vehviläinen, M. Huttunen and R. Mäkinen, *Comparison of gravity recovery from superconducting gravimeter with hydrological models of various spatial extents*, Bull. Inf. Marées Terrestres 142 (2006), pp. 11361-11368.

[16] M. Bilker-Koivula, H. Virtanen, J. Mäkinen, M. Tervo, B. Vehviläinen, M. Huttunen, R. Mäkinen: *Analysis of gravity variation in Finland using GRACE, superconducting gravimeter and water storage model time series*. First International Symposium of the International Gravity Field Service "Gravity Field of the Earth" – IGFS2006, August 28–September 2, 2006, Istanbul. Abstract and poster.

[17] J. Neumeyer, F. Barthelmes, O. Dierks, F. Flechtner, M. Harnisch, G. Harnisch, J. Hinderer, Y. Imanishi, C. Kroner,. B. Meurers, S. Petrovic, Ch Reigber, R. Schmidt, P. Schwintzer, H.-P. Sun and H. Virtanen, *Combination of temporal gravity variations resulting from Superconducting Gravimeter (SG) recordings, GRACE satellite observations and global hydrology models*. J. Geodesy (2006), DOI: 10.1007/s00190-005-0014-8.

[18] J. Mäkinen, *The standardization of gravity*, First International Symposium of the International Gravity Field Service "Gravity Field of the Earth" – IGFS2006, August 28–September 2, 2006, Istanbul. Abstract.

[19] J. Ihde, T. Baker, C. Bruyninx, O. Francis, M. Amalvict, A. Kenyeres, J. Mäkinen, S. Shipman, J. Simek and H. Wilmes, *Development of a European Combined Geodetic Network (ECGN)*, J. Geodynamics 40 (2005), pp. 450–460.

[20] A. Pusa, M. Sachs, *Torque Calibration Devices from 0,1 Nm up to 20 kNm*, IMEKO VIII World Congress September 17-22, 2006, Rio de Janeiro , Brazil.

[21] A. Pusa, M. Sachs, *Static, quasistatic and dynamic calibrations with torque reference calibration machines*, The Technical Seminar of Torque Metrology Technology, 30.11.-4.12.2006, Shanghai, China.

[22 ] P. Andersson, M. Wild, J. Levén and B. Hemming, *Transfer of surface texture from silicon nitride rolls to stainless steel wire in cold-rolling*, Journal of Materials Processing Technology 173 (2006) 394 - 400.

[23 ] V. Korpelainen, M. Sarjala, M. Alava, A. Lassila, E. Seppälä, L. Kärkkäinen and A. Kärkkäinen, *Dynamical nonlinearities of piezoelectric materials*, Nanotech in northern Europe 2007, 28. – 29. March 2007, Helsinki, Finland.

[24] V. Korpelainen and A. Lassila, *Calibration of a commercial AFM: interferometric traceability for coordinate system*, talk at nanoscale 2006, Bern, CH, April 24-25, 2006.

[25] V. Korpelainen and A. Lassila, *Calibration of a commercial AFM: traceability for a coordinate system*, Measurement science and technology, 18 (2007) 395-403.

[26] V. Korpelainen and A. Lassila, *Calibration and traceability of a commercial AFM at MIKES*, Nanotechnology in northern Europe 2006, 16. - 18. May 2006, Helsinki, Finland

[27] M. Merimaa, K. Nyholm, and M. Vainio, *Traceability of laser frequency calibrations at MIKES*, in 2006 Conference on Precision Electromagnetic Measurements Digest (CPEM2006), Turin, Italy, July 9–14, 2006, pp. 436–437.

[28] M. Merimaa, K. Nyholm, and M. Vainio, *Frequency comb generator for calibration of stabilized lasers at MIKES*, in Northern Optics 2006, Technical Digest, Bergen, Norway, June 14–16, 2006, p. 131.

[29] M. Merimaa, K. Nyholm, M. Vainio, and A. Lassila, *Traceability of laser frequency calibrations at MIKES*, IEEE Trans. Instrum. Meas. 56 (accepted for publication).

[30] L.-S. Ma, S. Picard, M. Zucco, J.-M. Chartier, L. Robertsson, P. Balling, P. Kren, J. Qian, Z. Liu, Ch. Shi, M. V. Alonso, G. Xu, S. L. Tan, K. Nyholm, J. Henningsen, J. Hald, and R. Windeler, *Absolute frequency measurements of the R(12) 26–0 and R(106) 28–0 transitions in $^{127}I_2$ at 543 nm*, IEEE Trans. Instrum. Meas. 55 (2006) 876–880.

[31] M. Vainio, M. Merimaa, and K. Nyholm, *Modulation transfer characteristics of injection-locked diode lasers*, Opt. Commun. 267 (2006) 455–463.

[32] A. Lassila, V. Korpelainen and L. Mihaljov, *Refractive index of air compensation by acoustic method for plane mirror interferometer*, Proceedings of Nanoscale 2006, 24 – 25 April, Bern, Switzerland.

[33] J. Jokela and P. Häkli, *Current research and development at the Nummela Standard Baseline*, Proceedings of the XXIII FIG Congress "Shaping the Change", Munich, Germany, October 8 - 13, 2006, at http://www.fig.net/pub/fig2006/papers/ps05_02/ps05_02_02_jokela_hakli_0371.pdf, also submitted to FIG Surveyors Reference Library (http://www.fig.net/srl/), 15 p.

[34] J. Jokela, P. Häkli, J. Ahola and J. Uusitalo, *The Nummela Standard Baseline – a world-class length standard*, presented at the NKG General Assembly, Copenhagen, Denmark, May 29 - June 2, 2006, 3 p. submitted to proceedings.

[35] M. Ollikainen, J. Jokela, M. Poutanen, R. Chen and M. Takalo, *National Report of Finland*, presented at the EUREF 2006 Symposium of the IAG Subcommission for Europe (EUREF), June 14 - 17, 2006, Riga, Latvia, 8 p. submitted to proceedings.

[36] M. Takalo, *Digital Levelling system Zeiss/Trimble DiNi12 – From bar code to rod reading*, presentation at the Meeting of the NKG Working Group for Height Determination, April 18 - 19, 2006, Gävle, Sweden.

[37] M. Takalo, *National Report*, presentation at the Meeting of the NKG Working Group for Height Determination, April 18 - 19, 2006, Gävle, Sweden.

[38] M. Takalo, J. Mäkinen, V. Saaranen, M. Lilje, O. Vestöl, R. Svensson and K. Ensager, *Report of the NKG Working Group for Height Determination to the NKG General Assembly*, presentation at the NKG General Assembly, May 29 - June 2, 2006, Copenhagen, Denmark, and submitted to proceedings.

[39] M. Takalo, P. Rouhiainen, P. Lehmuskoski and V. Saaranen, *Digital Levelling Technique Applied in Water Crossing*, presentation at the NKG General Assembly, May 29 - June 2, 2006, Copenhagen, Denmark, and submitted to proceedings.

[40] M. Takalo, P. Rouhiainen, P. Lehmuskoski and V. Saaranen, *Digital Levelling Technique Applied in Water Crossing*, Proceedings of the XXIII FIG Congress "Shaping the Change", Munich, Germany, October 8 - 13, 2006, at http://www.fig.net/pub/fig2006/papers/ts53/ts53_03_takalo_rouhiainen_0507.pdf, also submitted to FIG Surveyors Reference Library (http://www.fig.net/srl/), 10 p.

[41] P. Lehmuskoski, P. Rouhiainen, V. Saaranen, M. Takalo and H. Virtanen, *Seasonal Change of Bedrock Elevation at the Metsähovi Levelling Test Field*, Nordic Journal of Surveying and Real Estate Research 3:1 (2006) 58 - 68.

[42] J. Jokela, P. Häkli, J. Uusitalo, J. Piironen and M. Poutanen, *Control Measurements between the Geodetic Observation Sites at Metsähovi*, presented at the GRF2006, International IAG/FIG Symposium Geodetic Reference Frames, Munich, Germany, October 9 - 14, 2006, 6 p. submitted to proceedings.

[43] J. Ahola, M. Ollikainen, H. Koivula and J. Jokela, *GPS Operations at Olkiluoto, Kivetty and Romuvaara in 2005*, Posiva Working Report 2006-63, 172 p.

[44] A. Kemppinen, J.J. Vartiainen, A.O. Niskanen, M. Möttönen, K.H.A. Baarman, A. Manninen. H. Seppä and J.P. Pekola, *Development of a Cooper Pair Pump with Combined Flux and Voltage Control*, in 2006 Conference on Precision Electromagnetic Measurements Digest (CPEM 2006), Torino, Italy, July 9 - 14, 2006, pp. 164 - 165.

[45] A. Kemppinen, J.J. Vartiainen, A.O. Niskanen, M. Möttönen, K.H.A. Baarman, A. Manninen, H. Seppä and J.P. Pekola, *Development of a Cooper Pair Pump: towards a Quantum Current Standard*, in Proceedings of the XL Annual Conference of the Finnish Physical Society, Tampere, Finland, March 9 - 11, 2006, abstract 08-16.

[46] J.J. Vartiainen, M. Möttönen, J.P. Pekola and A. Kemppinen, *Nanoampere Pumping of Cooper Pairs*, arXiv:cond-mat/0612556, submitted to Appl. Phys. Lett. (2006).

[47] J. Hassel, L. Grönberg, P. Helistö, H. Seppä, J. Nissilä and A. Manninen, *Millimeter Wave Engineering of Distributed Josephson Junction Arrays*, submitted to IEEE Trans. Appl. Supercond. (2006).

[48] A. Satrapinski and G. Eklund, *Bilateral Comparison MIKES - SP of Calibration of 1 nF, 10 nF, 100 nF and 1 µF Capacitors*, in 2006 Conference on Precision Electromagnetic Measurements Digest (CPEM 2006), Torino, Italy, July 9 - 14, 2006, pp. 202 - 203.

[49] J.J.I. Suorsa, *Low-Level Direct Current Measurement*, Master's Thesis, Helsinki University of Technology, 2006, 58 p.

[50] A. Kärkkäinen, N. Tisnek, A. Manninen, N. Pesonen, A. Oja and H. Seppä, *MEMS-Based AC Voltage Reference Stabilized by Compensation of Built-in Voltage*, in 2006 Conference on Precision Electromagnetic Measurements Digest (CPEM 2006), Torino, Italy, July 9 - 14, 2006, pp. 224 - 225.

[51] A. Kärkkäinen, N. Tisnek, A. Manninen, N. Pesonen, A. Oja and H. Seppä, *Electrical Stability of a MEMS-Based AC Voltage Reference*, submitted to Sensors and Actuators A (2006).

[52] A. Manninen, A. Kärkkäinen, N. Pesonen, A. Oja and H. Seppä, *Microelectromechanical Components in Electrical Metrology*, submitted to Techniques de l'Ingenieur, France (2006).

[53] K. Kalliomäki, J. Mannermaa and T. Mansten, *Applicability of Coaxial Cables at Picosecond Range Timing*, in Proceedings of the 20th European Frequency and Time Forum (EFTF'06), Braunschweig, Germany, March 27 - 30, 2006, pp. 499 - 502.

[54] E.-P. Suomalainen and J. Hällström, *Determination of Absolute Dissipation Factor of Standard Capacitors*, in 2006 Conference on Precision Electromagnetic Measurements Digest (CPEM 2006), Torino, Italy, July 9 - 14, 2006, pp. 348 - 349.

[55] J. Hällström and E.-P. Suomalainen, *Rogowski Coil Setup for Calibration of AC Currents up to 10 kA*, in 2006 Conference on Precision Electromagnetic Measurements Digest (CPEM 2006), Torino, Italy, July 9 - 14, 2006, pp. 210 - 211.

[56] J. Hällström, M. Aro, A. Bergman, V. Bovier-Lapierre, F. Garnacho, J.I. Juvik, V. Kiseliev, Z. Lian Hong, W. Lucas, Y. Li, M.-L. Pykälä, J. Rungis, K. Schon and V.H. Truong, *Worldwide Comparison of Lightning Impulse Voltage Measuring Systems at 400 kV Level*, in 2006 Conference on Precision Electromagnetic Measurements Digest (CPEM 2006), Torino, Italy, July 9 - 14, 2006, pp. 276 - 277.

[57] J. Hällström, M. Aro, A. Bergman, V. Bovier-Lapierre, F. Garnacho, J.I. Juvik, V. Kiseliev, Z. Lian Hong, W. Lucas, Y. Li, M.-L. Pykälä, J. Rungis, K. Schon and V.H. Truong, *Worldwide Comparison of Lightning Impulse Voltage Measuring Systems at the 400-kV Level*, submitted to IEEE Trans. Instrum. Meas. (2006).

[58] J. Hällström, Y. Chekurov, M. Ishii, W. Lucas, J. Piiroinen, H. Shimizu and T. Wakimoto, *High Accuracy Comparison of Lightning and Switching Impulse Calibrators*, in 2006 Conference on Precision Electromagnetic Measurements Digest (CPEM 2006), Torino, Italy, July 9 - 14, 2006, pp. 340 - 341.

[59] T. Wakimoto, J. Hällström, Y. Chekurov, M. Ishii, W. Lucas, J. Piiroinen and H. Shimizu, *High-Accuracy Comparison of Lightning and Switching Impulse Calibrators*, submitted to IEEE Trans. Instrum. Meas. (2006).

[60] S. Holopainen, F. Manoocheri, S. Nevas, and E. Ikonen, *On potential discrepancies between goniometric and sphere-based spectral diffuse reflectance*, in Proceedings of the XL Annual Conference of the Finnish Physical Society, Tampere, Finland, March 9-11, 2006, p. 315.

[61] E. Ikonen, M. Yabashi, and T. Ishikawa, *Excess coincidences of reflected and refracted x rays from a synchrotron-radia-*

*tion beamline*, Phys. Rev. A 74, 013816, 8 pages, (2006).

[62] M. Vainio, *Phase-conjugate external-cavity diode laser*, IEEE Photon. Techn. Lett. 18, 2047-2049 (2006).

[63] A. Lamminpää, S. Nevas, F. Manoocheri and E. Ikonen, *Characterization of thin films based on reflectance and transmittance measurements at oblique angles of incidence*, Appl. Opt. 45, 1392-1396 (2006).

[64] A. Heikkilä, A. Tanskanen, P. Kärhä, and K. Hanhi, *Adjusting timing of weathering test to account for seasonal variations in UV exposure*, Polym. Degrad. Stab. (in press).

[65] M. Puranen, and P. Eskelinen, *Measurement of Short-Term Frequency Stability of Controlled Oscillators*, in Proceedings of 20th European Frequency and Time Forum, Braunschweig, Germany, March 27-30, 2006 pp. 76-79.

[66] P. Kärhä and K. Ruokolainen, *Setup for studying the spectral behavior of ageing of materials under intense UV radiation*, Annual meeting of the Nordic Ozone Group (NOG), Copenhagen, April 27-28, 2006, in NOG 2006 Abstracts (2006).

[67] M. Puranen, P. Eskelinen, J. Ruoskanen, and H. Heikkilä, *Simple 3D Millimetre Clutter Scanner for Field Measurements*, in Proceedings of International Radar Symposium IRS 2006, 2nd Microwave and Radar Week, Krakow, Poland, May 24-27, 2006, pp. 339-342.

[68] V. Ahtee, R. Pfab, R. Lettow, A. Renn, E. Ikonen, and V. Sandoghdar, *Towards indistinguishable photons from two independent molecules*, in Proceedings of Northern Optics 2006, Bergen, Norway, June 14-16, 2006, p. 40.

[69] M. Vainio, *Phase-conjugate external-cavity diode laser*, in Proceedings of Northern Optics 2006, P.070, Bergen, Norway, June 14-16, 2006.

[70] A. Lamminpää, S. Holopainen, F. Manoocheri and E. Ikonen, *Effects of aging and degradations on regular transmittance of interference filters*, a talk in 5th Oxford Conference on Spectrometry, London, UK, June 26-28, 2006.

[71] E. Ikonen, J. Hovila, and Seung Nam Park, *Uncertainties in linking bilateral and regional key comparisons to the CCPR key comparison*, in Proceedings of the 2nd CIE Expert Expert Symposium on Measurement Uncertainty, Braunschweig, Germany, June 12-16, 2006, pp. 173-180.

[72] M. Ojanen, M. Merimaa, J. Laasasenaho, T. Melkas, and E. Ikonen, *Measurement of tree diameters using image processing*, in Proceedings of the XL Annual Conference of the Finnish Physical Society, Tampere, Finland, March 9-11, 2006, p. 118.

[73] M. Vainio, *Spectral narrowing of a diode laser using phase conjugate feedback*, in Proceedings of the XL Annual Conference of the Finnish Physical Society, Tampere, Finland, March 9-11, 2006, p. 291.

[74] M. Vainio, *Diode Lasers with Optical Feedback and Optical Injection: Applications in Metrology*, TKK Dissertations, Espoo 2006, 57 p.

[75] P. Kärhä, *UVNews*, The official newsletter of the Thematic Network for Ultraviolet Measurements, Issue 8, Espoo 2006, 63 p.

[76] I. Kotamäki, *Study of Display Color Measurement Devices*, Diploma thesis, Helsinki University of Technology, Metrology Research Institute, 2006.

[77] S. Nevas, P. Kärhä, and E. Ikonen, *Effect of correlations in fitting spectral irradiance data*, in Proceedings of the 2nd CIE Expert Symposium on Measurement Uncertainty, Braunschweig, Germany, June 12-13, 2006, pp. 143-146.

[78] M. Sildoja, T. Kübarsepp, M. Noorma, P. Kärhä, A. Lamminpää, S. Nevas, and E. Ikonen, *Polarization properties of GaAsP trap detectors*, in Proceedings of Estonian Physics Society's Yearbook 2005, Tallinn, Estonia, March 21-22, 2006, p. 95-96.

[79] A. Lamminpää, M. Noorma, T. Hyyppä, F. Manoocheri, P. Kärhä, and E. Ikonen, *Characterization of germanium photodiodes and trap detector*, Meas. Sci. Technol. 17, 908-912 (2006).

[80] S. Holopainen, F. Manoocheri, M. Laurila and E. Ikonen, *Goniofluorometer for spectral quantum yield measurements*, a talk in 5th Oxford Conference on Spectrometry, London, UK, June 26-28, 2006.

[81] A. Andersson, J. Petersen, E. Ikonen, and P.O. Hedekvist, *Virtual institute for fibre optic measurements*, in Proceedings of Northern Optics 2006, Bergen, Norway, June 14-16, 2006, p. 138.

[82] J. Envall, *Optical Power Measurements: Applications in Fiber Optics and Ultraviolet Radiometry*, TKK Dissertations, Espoo 2006, 50 p.

[83] A. Lamminpää, *High-Accuracy Characterization of Optical Components: Detectors, Coatings and Fibers*, TKK Dissertations 50, Espoo 2006.

[84] A. Lamminpää, T. Hieta, J. Envall and E. Ikonen, *Reliable determination of optical fiber nonlinearity using dispersion simulations and improved power measurements*, Journal of Lightwave Technology (in press).

[85] T. Hieta, A. Lamminpää, and E. Ikonen, *Dispersion analyses and optical power measurement in determination of fiber nonlinearity*, in Proceedings of the XL Annual Conference of the Finnish Physical Society, Tampere, Finland, March 9-11, 2006, p. 307.

[86] A. Lamminpää, T. Hieta, J. Envall, P. Kärhä, and E. Ikonen, *Scale realization of high fiber optic power*, in Proceedings of the XL Annual Conference of the Finnish Physical Society, Tampere, Finland, March 9-11, 2006, p. 314.

[87] A. Kesänen, *Effective Area of Optical Fiber by Far-Field Scanning*, Diploma thesis, Helsinki University of Technology, Metrology Research Institute, 2006.

[88] J. Lano, *Facility for Spectral Responsivity Measurements of Infrared Detectors*, Diploma thesis, Helsinki University of Technology, Metrology Research Institute, 2006.

[89] P. Manninen, J. Hovila, L. Seppälä, P. Kärhä, L. Ylianttila and E. Ikonen, *Determination of distance offsets of diffusers for accurate radiometric measurements*, Metrologia 43, S120-S124 (2006).

[90] P. Manninen, J. Hovila, P. Kärhä, and E. Ikonen, *Method for analyzing luminous intensity of light-emitting diodes*, Meas. Sci. Technol. (in press).

[91] P. Kärhä, P. Manninen, J. Hovila, L. Ylianttila, and E. Ikonen, *Distance offset and angular responsivity measurements of UV spectroradiometer diffusers*, Annual meeting of the Nordic Ozone Group (NOG), Copenhagen, April 27-28, 2006, in NOG 2006 Abstracts (2006).

[92] P. Manninen, J. Hovila, P. Kärhä, L. Ylianttila, and E. Ikonen, *Distance offset of the effective receiving aperture of a diffuser and its relation to angular responsivity curves*, in Proceedings of Northern Optics 2006, Bergen, Norway, June 14-16, 2006, p. 125.

[93] P. Manninen, J. Hovila, P. Kärhä, and E. Ikonen, *Analysis of luminous intensity of light emitting diodes with modified inverse square law*, in Proceedings of Northern Optics 2006, Bergen, Norway, June 14-16, 2006, p. 124.

[94] E. Ikonen, P. Manninen, J. Hovila, and P. Kärhä, *Reference plane position and angular responsivity of spectroradiometer diffusers*, in Proceedings of Metrology Symposium 2006, Queretaro, Mexico, October 25-26, 2006 (CD, 5 p.)

[95] J. Envall, L. Ylianttila, H. Moseley, A. Coleman, M. Durak, P. Kärhä, and E. Ikonen, *Investigation of comparison methods for UVA irradiance responsivity calibration facilities*, Metrologia 43, S27-S30 (2006).

[96] J. Envall, P. Kärhä, and E. Ikonen, *Calibration of broadband ultraviolet detectors by measurement of spectral irradiance responsivity*, Rev. Sci. Instrum. 77, 063110, (2006).

[97] J. Envall, P. Kärhä, and E. Ikonen, *Calibration of broadband ultraviolet detectors by measurement of spectral irradiance responsivity*, Metrology Research Institute, Helsinki University of Technology, Espoo 2006, Metrology Research Institute Report 30/2006, 17 p.

[98] P. Pöyry, T. Komppa, A. Kosunen, *A tandem calibration method for kerma-*

*area product meters*. Book of extended synopses. IAEA-CN-146. International Conference on Quality Assurance and New Techniques in Radiation Medicine. 13-15 November, Vienna, Austria. pp. 290-291.

[99] P. Pöyry, T. Komppa, A. Kosunen, *X ray beam quality specification for kerma area product meters*. Book of extended synopses. IAEA-CN-146. International Conference on Quality Assurance and New Techniques in Radiation Medicine. 13-15 November, Vienna, Austria. pp. 298-299.

[100] K. Nieminen, *Tietokonetomografialaitteen annosmittauksissa käytettävän ionisaatiokammion kalibrointi*. Pro-Gradu-tutkielma, Helsingin Yliopisto, Fysikaalisten tieteiden laitos, 2006. (In Finnish).

[101] *Report on Nordic radiation protection co-operation, No. 8 Nordic dosimetric capabilities. Resources, needs and plans.* The radiation protection and nuclear safety authorities in Denmark, Finland, Iceland, Norway and Sweden. Statens strålevern, Norwegian Radiation Protection Authority, Østerås, Norway, 2006.

[102] A. Hakanen, A. Kosunen, P. Pöyry, M. Tapiovaara, *Determination of conversion factors from air kerma to operational dose equivalent quantities for low energy x-ray spectra*. Radiation Protection Dosimetry 2006; doi:10.1093/rpd/ncl386.

[103] A. Hakanen, T. Siiskonen, R. Pöllänen, A. Kosunen, A. Turunen, O. Belyakov, *Design, spectrum measurements and simulations for a $^{238}$Pu $\alpha$-particle irradiator for bystander effect and genomic instability experiments*. Applied Radiation and Isotopes 2006; 64: 864-867.

[104] T. Siiskonen, R. Pöllänen, *Alpha-electron and alpha-photon coincidences in high-resolution alpha spectrometry*. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 2006; 558 (2): 437–440.

[105] A. Kosunen, T. Komppa, M. Toivonen, *Evaluation of methods to estimate the patient dose in interventional radiology*. Radiation Protection Dosimetry 2005; 117 (1-3): 178-184.

[106] Joële Viallon, Philippe Moussay, Michael Esler, Robert Wielgosz, Wolfram Bremser, Jirí Novák, Miroslav Vokoun, Angelique Botha, Mellisa Janse Van Rensburg, Christoph Zellweger, Sandra Goldthorp, Annette Borowiak, Friedrich Lagler, Jari Walden, Ettore Malgeri, Maria Paola Sassi, Pilar Morillo Gomez, Rosalia Fernandez Patier, David Galan Madruga, Jin-Chun Woo, Yong Doo Kim, Tatiana Macé, Christophe Sutour, Ana Surget, Bernhard Niederhauser, Daniel Schwaller, Beata Frigy, Irén Györgyné Váraljai, Shigeru Hashimoto, Hitoshi Mukai, Hiroshi Tanimoto, Hans Peter Ahleson, Axel Egeløv, Nils Ladegard, Leif Marsteen, Kjersti Tørnkvist, Franklin R Guenther, James E Norris, Theo L Hafkenscheid, Martin M Van Rijn, Paul Quincey, Bryan Sweeney, Sarka Langer, Bertil Magnusson, Juliana Bastian, Volker Stummer, Marina Fröhlich, Andreas Wolf, Leonid A Konopelko, Yuri A Kustikov and Dmitry V Rumyanstev, *International Comparison CCQM-P28: Ozone at ambient level*, 2006 Metrologia 43, Technical Supplement.

[107] M. Maruyama, J. Novak, J. Walden, K. Lusa, F. Dias, A. Borowiak, F. Lagler, J.S. Kim, T. Mace, C. Sutuur, F. Guenther, A. van der Veen, G. Nieuwenkamp, J. van Wijk, M. Milton, G. Leggett, A. Medem, V. Stummer, L. Konopelko, Y. Kustikov, O. Efremova, M. Froehlich, *International Key Comparison CCQM-K26.b and Pilot Study CCQM-P50.b: Comparison of primary standards of sulphur dioxide (SO2) in synthetic air*, Metrologia, 2007, 44, Tech. Suppl., 08007.

[108] M. Rantanen, S. Semenoja, *Intercomparison in Gauge Pressure Range from -95 kPa to +100 kPa*, MIKES Publication J1/2006, 15 p. + appendix.

[109] M. Heinonen, J. Järvinen, A. Lassila, A. Manninen (Eds.), *Finnish National Standards Laboratories, Annual Report 2005*, MIKES Publication J2/2006, 51 p.

[110] K. Riski, L. Stenlund, *Mass Comparison: 610 g laboratory balance*. MIKES Publication J3/2006, 15 p. + appendixes.

[111] M. Heinonen, *Uncertainty in humidity measurements*. Publication of the EUROMET Workshop P758. MIKES Publication J4/2006, 47 p.

[112] T. Ehder (Ed.), *Kvalitatiivisen kemian metrologian opas orgaanisten yhdisteiden tunnistukseen*, Metrologian neuvottelukunta, Advisory Commission for Metrology, MIKES Publication J5/2006, 37 p. + appendixes. (in Finnish).

[113] T. Ehder (Ed.), *Mikrobiologian laboratorion elatusaineiden sisäinen laadunvarmistus*, Metrologian neuvottelukunta, Advisory Commission for Metrology, MIKES Publication J6/2006, 20 p. (in Finnish).

[114] J. Järvinen (Ed.), *Kansallinen mittanormaalitoiminta ja sen kehittäminen 2007-2011*, Metrologian neuvottelukunta, Advisory Commission for Metrology, MIKES Publication J7/2006, 74 p. (in Finnish).

[115] V.-P. Esala, *Pituuden vertailumittaus D8, Loppuraportti*. MIKES Publication J8/2006, 16 p. (in Finnish).

[116] R. Rajala, *Yleismittarin vertailumittaus. Loppuraportti*. MIKES Publication J9/2006, 16 p. (in Finnish).

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