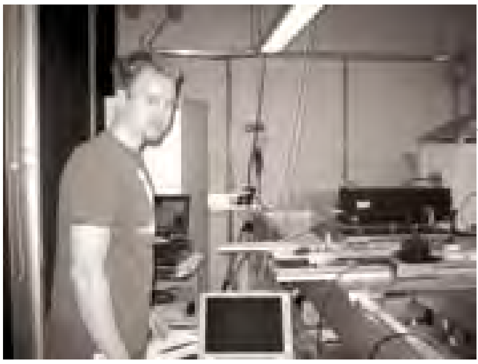
MIKES
Mittatekniikan keskus
Centre for metrology
and accreditation

Finnish National Standards Laboratories

Annual Report 2005

www.mikes.fi



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Centre for Metrology and Accreditation

Publication J2/2006
Editorial board: Martti Heinonen, Jaana Järvinen, Antti Lassila and Antti Manninen
Layout: Jenni Kuva

Espoo 2006

New MIKES in a new building

Finland is a self-service society. We are able to witness it everywhere. We take our lunch portion on a plate then return the empty plates back to the kitchen. Shops are self-service shops. On our cars, we change the tires twice a year in our backyard. We buy a train ticket from a machine and show it to another machine on the train. We fill petrol tanks of our cars on our own. All of us, including elderly citizens, serve ourselves in our daily life. – One exception is that we would like to repair our cars, but we cannot do this even if we want to.

The recommendations of the international evaluation of MIKES suggested that new facilities should be built into the middle of the science centre in Otaniemi and gather the metrology activities under one roof. On the other hand we had learnt our lesson during the years of self-service: from the very beginning we felt natural to be part of the building process. First was the basic-principle designing period. It was performed together with experts from different fields: vibration, ventilation and electricity. After the first stage in the designing we made a tour to four recently built or started metrology facilities: METAS, PTB, NPL and JV. The trip was very successful – one indication of the well working cooperation between EUROMET members - good hints were received. After the trip we partly redesigned the work and started digging a three-floor-deep hole in the middle of the 31 000 experts' science centre in Otaniemi, some 10 km from Helsinki. First constructors rejected our non-professional supervision and constant comments, but after they pulled the building down and built the part again constructors realised that laboratory specifications were demanding, but not unrealistic. As a consequence, we succeeded in keeping electrically shielded rooms grounded through a single point, vibration preventing gaps in the room in a room structures empty and noise in the acoustics laboratory below specification. - One exception: we wished to have lights on by self-service in our offices, but motion detectors turn off the lights every half an hour if we do not walk around the room every now and then.

How did the new life begin in the new facility? The building did not survive the first cold period of -30 °C. Main ventilation was frozen and needed hard manual labour, during weekend of course. Now all the machines are working and we are waiting for the heat wave to come to Finland. Let us see what is the temperature and humidity in the laboratories during the possible +30 °C period. We have written a short description about the current status of the house in this annual report. Temperature, humidity and vibration measurements are reported from some of the laboratories. Some of the laboratories still have too big temperature differences between different parts of the laboratory and some others need higher flow to remove the extra generated heat from the laboratory. These will begin to work as the main part of the laboratories already works – I am sure. An optimising phase will lead to reduce the huge energy bill, this is rather a necessity than a hope.

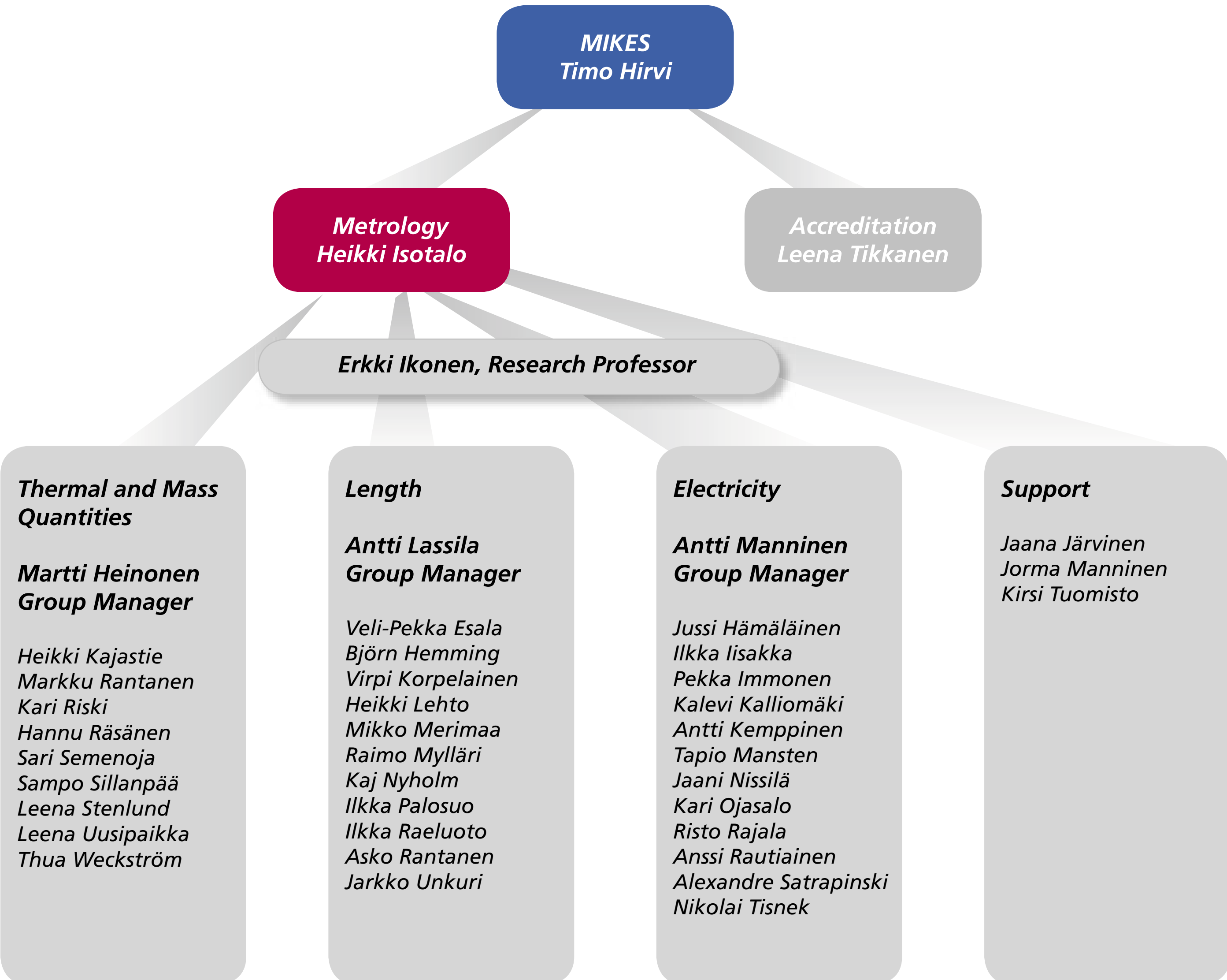
Last few years construction has taken several labour years and at the same time has given huge amount of courage and trust to do the undoable. It certainly has been worth doing and I am sure that MIKES Metrology has clearly an increasing impact on the Finnish society and on iMERA research projects, as well.

Otaniemi 1.5.2006
Heikki Isotalo
Director of Metrology

Mission of MIKES Metrology

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

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



International Co-operation

MIKES participates in European and international research programmes and in scientific and technical activities promoted by European and international bodies in metrology, such as 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.

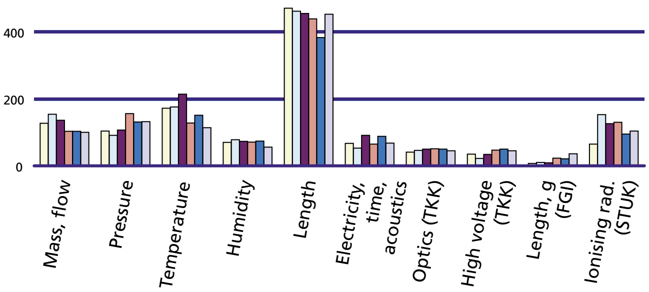
Within MIKES, the Metrology Department is responsible for tasks relating to the maintenance and supervision of the national measurement standards system. Below is the organisation of the National Standards Laboratories in Finland.

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

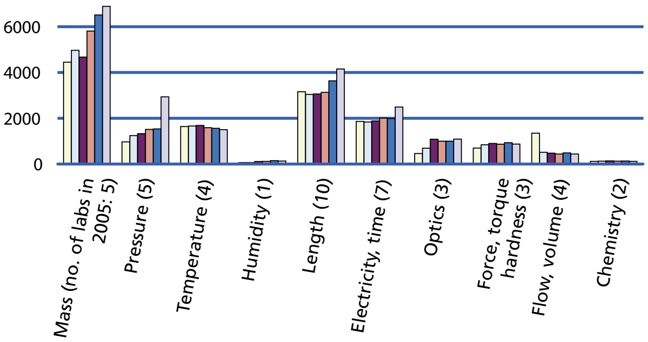
2005 in numbers

NUMBER OF CALIBRATION CERTIFICATES 2000-2005

NSLs

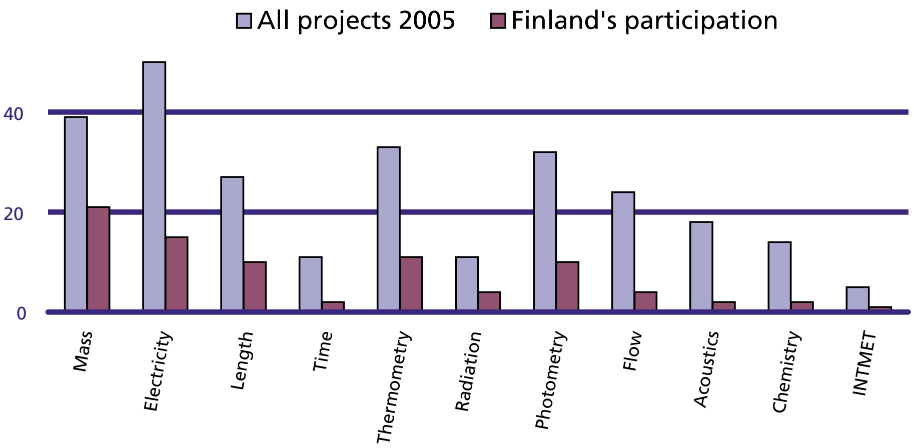


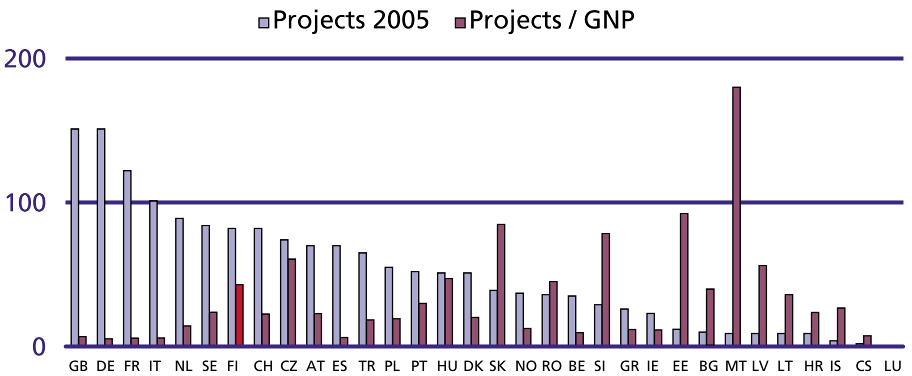
ACCREDITED CALIBRATION LABORATORIES



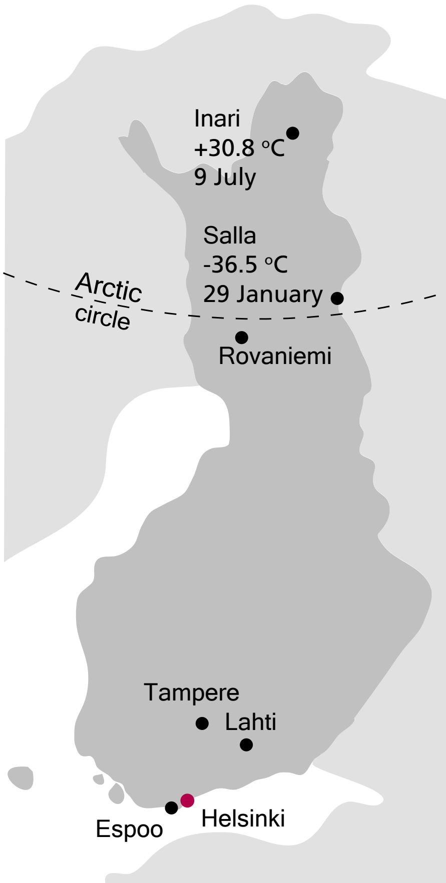
PARTICIPATION IN EUROMET SUBJECT FIELDS

AGREED AND PROPOSED PROJECTS





The volume of the calibration service in Finnish National Standards Laboratories (NSLs) was roughly the same as during the previous years. In the future, Nordic and European (EUROMET) co-operation will update standards to a higher level for the future needs of industry. Attempts in this direction are e.g. EUROMET initiated MERA (Metrology Research Area) project and its successor iMERA. In accredited calibration laboratories the volume of calibrations is tenfold compared to the NSLs. Number of calibration laboratories increased in length and decreased in temperature and electricity.

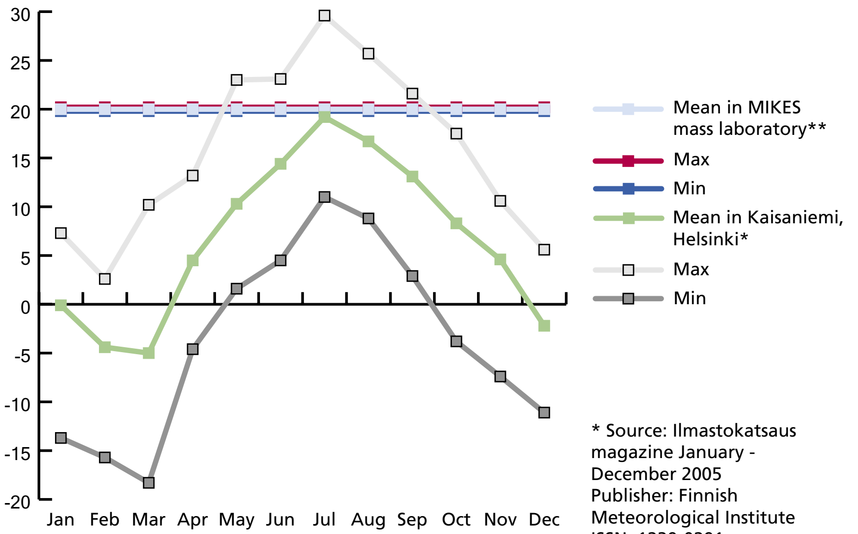


FACTS ABOUT FINLAND

5 255 580 (12/2005) inhabitants
338 436 km²
188 000 lakes
Currency: euro
Gross national product: $155 \cdot 10^9$ €
Official languages: Finnish and Swedish
5 biggest trade partners (export, 2005): RU, SE, DE, GB, USA

Source: Statistics Finland

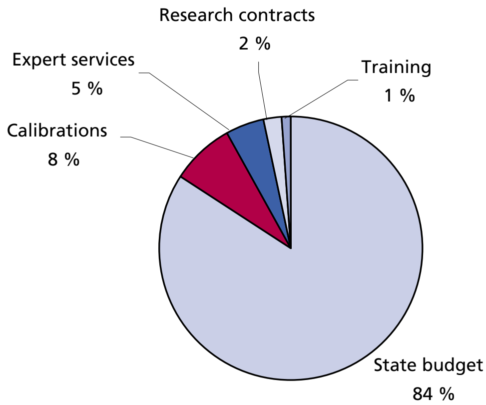
MONTHLY TEMPERATURES IN HELSINKI AND IN THE METROLOGY LABORATORY (˚C)



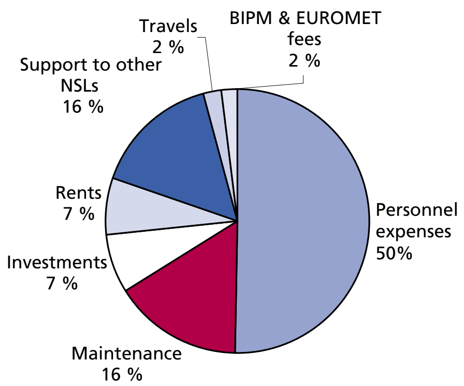
* Source: Ilmastokatsaus magazine January - December 2005
Publisher: Finnish Meteorological Institute
ISSN: 1239-0291
** Measurement

FACTS ABOUT MIKES METROLOGY

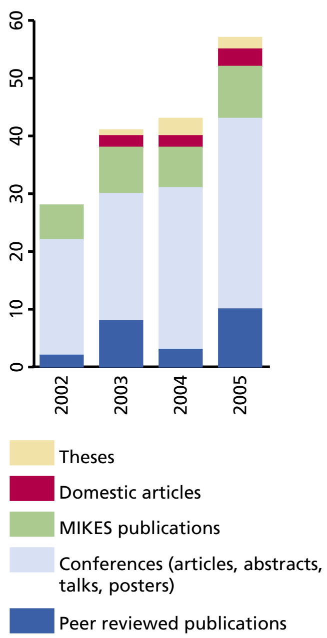
PROCEEDS 3.6 M€



COSTS 3.6 M€



PUBLICATIONS (MIKES ONLY)



THE NEW MIKES BUILDING

MIKES Metrology

– a house for precise measurements

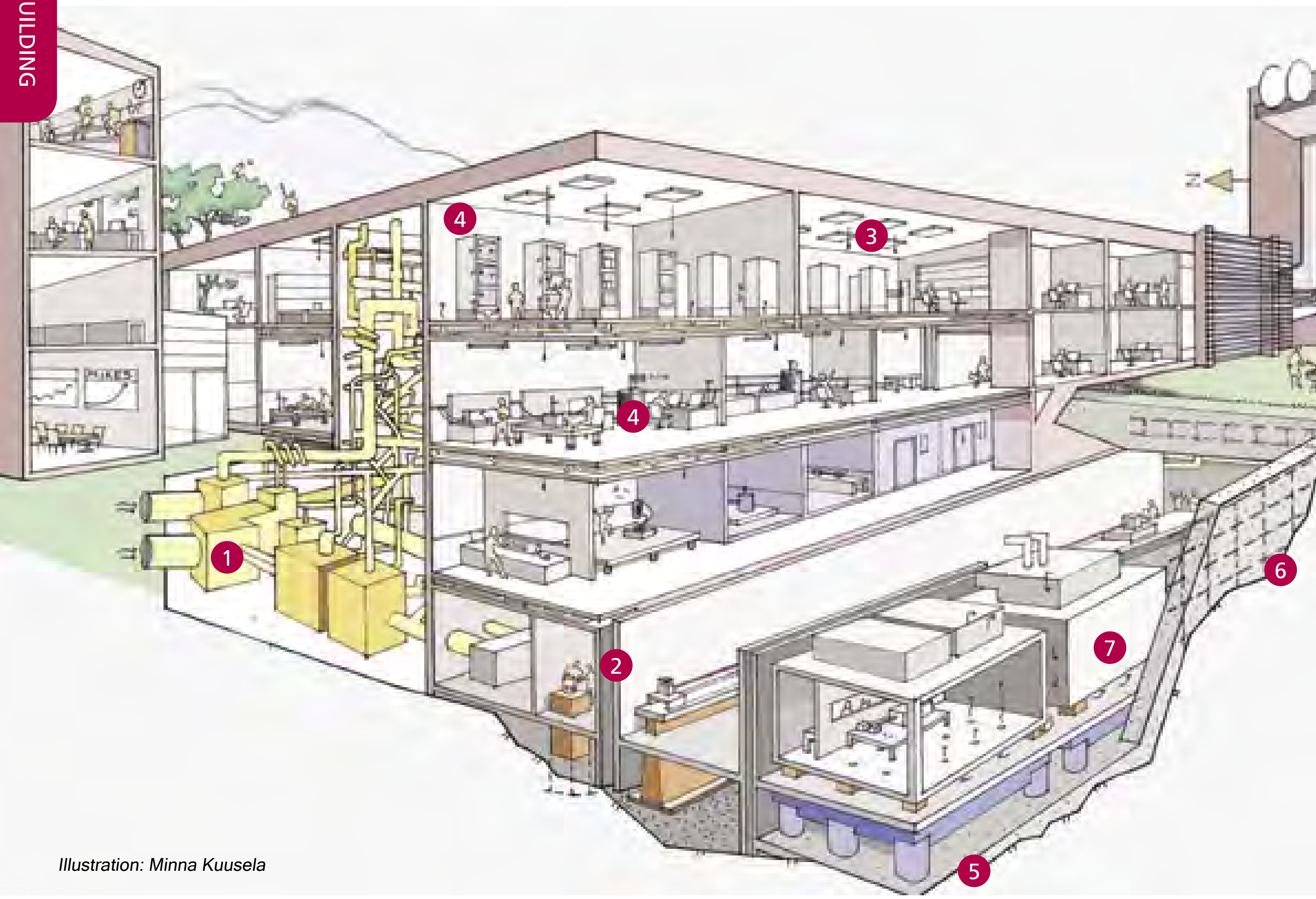


Illustration: Minna Kuusela

- Year of completion: 2005
- Owner: Senate Properties
- User: MIKES – Centre for metrology and accreditation
- Architectural design: Virta Palaste Leinonen Arkkitehdit Oy
- Structural design: Aaro Kohonen Oy
- HPAC design: AX-LVI Consulting Ltd.
- Electrical design: Insinööritoimisto Veikko Vahvaselkä Ky
- Custom automation design: Alfamatic Oy
- Geotechnical design: Fundus Oy
- Project management consulting: ISS Proko Oy

TECHNICAL SPECIFICATIONS

- Building volume: 51 000 m^3
- Total building area: 9 100 m^2; net floor area: 6 500 m^2
- Number of employees: 80; number of office rooms: 60
- Number of laboratories: 36; Total laboratory floor area: 1 700 m^2, out of which 670 m^2 is underground
- Number of measurement table bases with active or passive vibration isolation: 62
- Number of custom automation controlled/ventilated equipment cabinets: 37
- Total length of air conditioning ducts: 6 km; number of air conditioning units: 41
- Number of floor vents: 3 284; number of raised floor panels: 4 600
- Number of ventilated lighting fixtures: 375
- Total length of signal cable: 50 km; length of power cable: 100 km; number of power supply filters: 132;
- number of electrical outlets: 5 000
- Estimated energy consumption: 3 600 MWh/year

1 BUILDING MAINTENANCE TECHNOLOGY WITH A FOCUS ON AIR CONDITIONING

About 30% of the total building area is devoted to building maintenance technology, mainly ventilation equipment, required for creating laboratory conditions. Potential sources of electromagnetic interference and mechanical vibrations, such as compressors and the emergency power generator, are located as far away from the laboratories as possible. There are 36 laboratories that are divided in 20 sections, each of which has its own dedicated ventilation system used for the fine tuning of temperature. This means, for example, that switching on heat-generating equipment in one laboratory will not be detectable in other laboratories located in different sections.

2 EXPANSION JOINTS AND DOUBLE WALLS

The propagation of internal vibrations caused by building maintenance technology and the movement of people has been inhibited by dividing the building into several separate sections using expansion joints. In the surface laboratories, the basic idea is an onion-like structure, in which the laboratories at the core are protected from external temperature variations by a corridor, an office room and outer protective shutters. To optimise vibration performance, the walls, floor and ceiling of each laboratory are joined together by steel rods and poured concrete in such a way that each laboratory behaves as a rigid body.

3 ISOLATION OF HEAT SOURCES

Because of the strict room temperature requirements, the air heated by, for example, laboratory light fixtures and hot furnaces, is drawn directly away from the laboratory. The temperature, humidity and pressure of the air in laboratory facilities, as well as the mechanical vibrations between floors are constantly monitored.

4 STABLE TEMPERATURE

Instruments requiring high temperature stability are mounted in enclosed equipment cabinets supplied with air temperature-regulated to an accuracy of ±0.01 °C, or liquid baths that can achieve accuracies of a few millidegrees. For vibration-sensitive equipment, the laboratories use granite tables or optical tables with natural rubber isolators.

5 VIBRATION ISOLATION

Extremely vibration-sensitive length and mass metrology equipment is mounted on either air-spring supported 80–140 ton concrete slabs or gravel/insulation carpeting/solid slab structures. These provide attenuation of bedrock vibrations at around 1 Hz and higher frequencies. The building is founded on competent bedrock.

6 ELECTRICAL INTERFERENCE AND ELECTROMAGNETICALLY SHIELDED LABORATORIES

Steel reinforcements within the concrete frame of the building are welded together at 1.2 m intervals to provide a continuous mesh. This type of a “Faraday Cage” protects the laboratories from external electrical interference up to the radio frequency range (f_{cutoff} ~200 MHz). The thick concrete walls and the underground placement of the laboratories also reduce interference. For extremely sensitive electrical measurements, the building has 12 electromagnetically shielded rooms in three different sections. For external fields, their minimum shielding attenuation has been measured to be either at least 60 dB or 100 dB over the frequency range from 10 kHz to 20 GHz.

7 VENTILATION AND DIFFUSION TECHNOLOGY

The laboratories with the strictest temperature stability requirements have been constructed in naturally constant temperature underground floors based on the “room within a room” principle. This solution enables the maintenance of a set temperature of 20 °C to an accuracy of 0.01 °C. Most of the laboratories are constructed using the floor diffusion principle. Exceptions are mass metrology laboratories, where ceiling diffusion is used because of the required cleaner conditions, and the humidity laboratory, where wall diffusion is used. A room where you can set the temperature at 20±5 °C allows you to study the temperature dependence of devices and meters.

8 ATOMIC CLOCKS

The atomic clocks used by MIKES are continuously compared against UTC using a GPS satellite receiver. An antenna tower provides optimum satellite visibility in the southern sky.

State of the art

October 1st, 2005, meant the beginning of a new era for metrology in Finland. Then MIKES moved into its new facilities. The quality of the laboratories is second to few internationally. In the following the main design ideas, specifications and measured preliminary results of the laboratory conditions are presented.

For precision measurements stability of ambient conditions, like temperature and humidity, is of utmost importance. Low level of mechanical vibrations and electromagnetic noise are often necessities, as well. In our new laboratories different principles have been applied to achieve very stable conditions either locally in a small instrument cabinet or in a whole laboratory. Attention has been paid to shelter the measurement spots from external interferences from outside world as well as from disturbances created in other laboratories.

The laboratories have been placed partly underground and partly above ground. Going underground has some key advantages: the surrounding earth with its huge thermal inertia provides a naturally constant temperature environment enabling stable temperature control most economically. In addition, the rock at 15 m below earth was measured to be about 100 times more stable in the vibrational sense than the surface suffering from nearby heavy traffic. And finally electromagnetic noise decreases markedly. The advantage of top-of-the-surface labs is that they are close to offices.

Figure 1. 140-ton slab on top of which are the measurement tables of two mass laboratories. For somewhat more modest vibration isolation some laboratories have been based on gravel–isolation carpet-concrete slab -structures. The third main solution is concrete plinths mounted on solid rock.

To make the laboratories insensitive to each other and the technical space, e.g. air conditioning machine rooms, the building has been divided into several smaller in-house buildings by vibration isolation joints. That is, the subbuildings with rigid walls are separated by 5-10 cm thick air gaps preventing the transfer of mechanical vibrations from one part to another. The thermal insulation layers surrounding all the labs have been plated with metal which decreases the amount of electromagnetic noise propagating between laboratories. For the most sensitive labs of electrical metrology we have 12 shielded rooms which have been measured to attenuate external EM noise in the range 10 kHz-20 GHz by 60 dB -120 dB.

The primary standards labs of mass and length metrology are most sensitive to fluctuations in the laboratory conditions and were therefore located underground. The laboratories are sandwiched by two stories with the vibration isolation structures on the bottom and air handling units on top. The best known vibration isolation concept starting at the critical low frequencies of around 1 Hz is to support the measurement tables on massive concrete slabs floating on air springs, see Fig. 1. Fig. 2 shows vibration spectra measured at the optical table for the Atomic Force Microscope (AFM) interferometrically traceable to the SI meter. The black line shows the specification stated in the beginning of the building design process which is more demanding than in most national metrology institutes. Actual AFM measurements with a test sample have demonstrated that the achievable noise level is much lower than in our previous premises.

To reach the very strict temperature stability required, the length and mass laboratories were built with the "room within a room" –principle. The laboratory itself is built within a slightly larger room which acts as an air duct. This means that the air flowing through the lab upward or downward is returned back to the air recirculation machine in the intermediate space thereby washing out the influence of possible external heat sources. To reduce gradients inside the lab, devices generating heat are connected to exhaust air ductwork and the light fixtures have been ventilated and equipped with IR and UV filter windows. Researchers follow and control measurements in monitoring rooms next to the labs. The temperature is stable within ±0.02 °C even though the special control equipment with fast electrical heating batteries is still not in use, see Fig. 3. Ultimately when the whole air handling system is operational, the air temperature will evidently be within ±0.01 °C which is excellent for mass and interferometric measurement of highest accuracy.

Reliability and purity of electrical power is essential for many metrological activities. There are two main transformers which convert the local utility company's rigid 20 kV supply voltage into 400 V (1000 kVA), see Fig. 4. One of the transformers is reserved for noisier loads like the air conditioning equipment whereas the other feeds laboratories. For power breaks there is a 80 kVA UPS system fed by a diesel generator. This guarantees uninterrupted power for e.g. atomic clocks. For most sensitive measurements the working light can be replaced by optical fibre lightning.

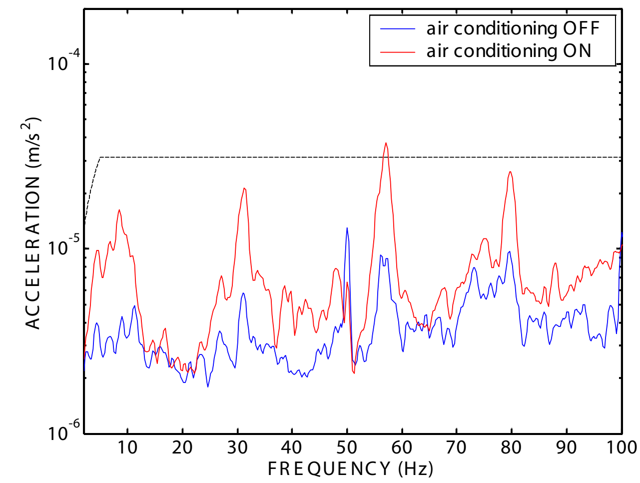


Figure 2. Vibration spectra measured at the optical table for the Atomic Force Microscope interferometically traceable to the SI meter. Vertical acceleration is shown as a function of frequency when the air conditioning has been switched off (blue) and while it is on (red).

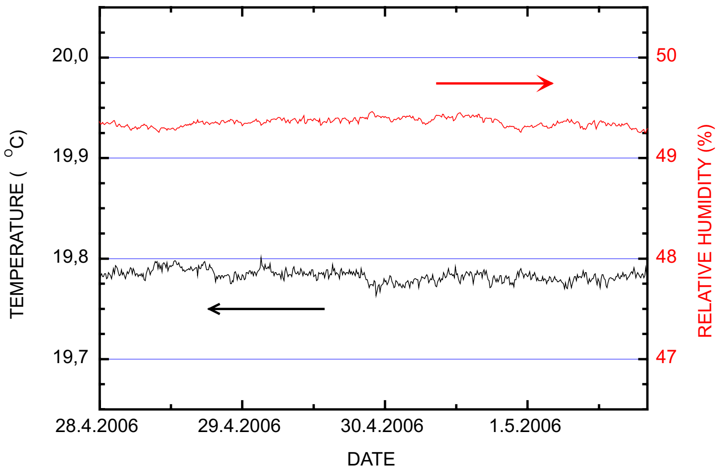


Figure 3. Temperature and relative humidity of incoming air measured in the 1 kg primary mass standard laboratory. The stability of both quantities will still become better after the fast special control system is taken into use. The design specifications were ±0.1 °C for temperature and ±2 % for relative humidity.

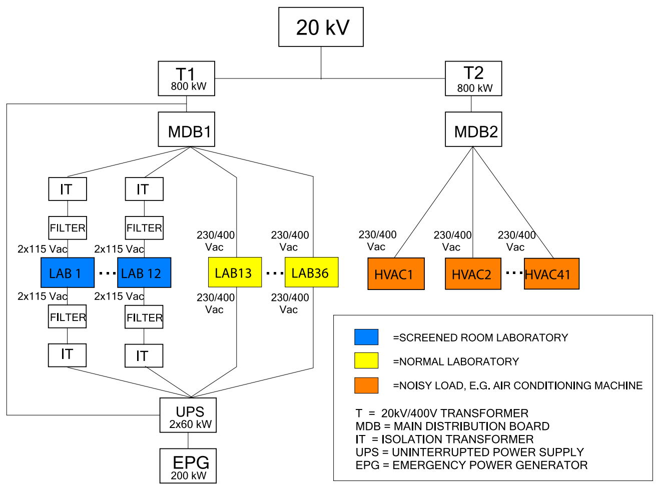


Figure 4. The principle of electrical power distribution. Each laboratory is connected to the main transformer with its own shielded power cable. This star-like distribution network eliminates interference between the labs arising from changes in loading. In the EM shielded rooms the power is heavily filtered with feedthrough filters and isolation transformers. The 230 V voltage is symmetrized into 2x115 V by grounding the center tap of the secondary coil. This arrangement notably decreases the 50 Hz electric field inside the laboratory.

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*
M.Sc. Leena Uusipaikka	*Research Scientist*
Mr. Jorma Manninen	*Laboratory Engineer*
Mr. Hannu Räsänen	*Assistant Research Scientist*
Mr. Juha Koppinen	*Trainee*

MIKES-Raute

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	*Research Manager, Head of Laboratory*
M.Sc. Hannu Ruotsalainen	*Research Scientist, Deputy Head of Laboratory*
M.Sc. Mirjam Bilker-Koivula	*Research Scientist*
Lic.Sc. Heikki Virtanen	*Senior 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, dew-point temperature and relative humidity. Research activities are focused in measurement standards and calibration methods. The expert service for customers provided by the Group covers training, co-operative development projects and consultation. The Group issued about 400 calibration certificates for customers at accredited laboratories, research institutes and industry during 2005.

MIKES has a contract with Raute 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 2005

DETERMINATION OF THE DENSITY OF AIR USING DENSITY ARTEFACTS

The density of air was determined by weighing two density artefacts in air and in vacuum. The artefacts have the same nominal mass and surface area but different volumes. Weighing results in vacuum depends only on the mass difference of the artefacts. In addition to mass difference the weighing result in air depends also on volume difference and on the density of air. The volume difference has been determined by hydrostatic weighing. The density of air obtained from weighing results was compared with a value calculated from the CIPM formula. The measured air density was $2.2 \cdot 10^{-5}$ times larger than the calculated density. Similar results have been obtained also by other laboratories. The reason for the discrepancy is the concentration of Argon in air which has been incorrect.

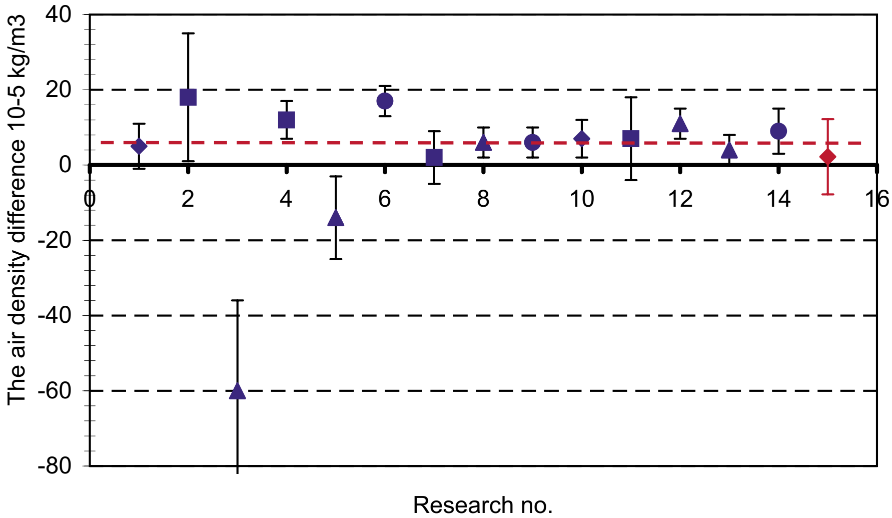


Figure T1. Difference of measured and calculated air density as determined by different laboratories. The blue dots show results reported by other laboratories [Picard et al, Metrologia 41 (2004) 396-400]. The MIKES results is marked with the red dot. The red dotted line is the weighed mean of the results.

DEVELOPMENT IN GAS FLOW CALIBRATIONS

Based on a successful evaluation of the metrological competence, MIKES small gas flow standards and liquid density standards were recognised as the Finnish national standards on 20 January 2005. The measurement range of the laboratory is for gas volume flows from 5 ml/min to 30 l/min at the expanded uncertainty level from 0.9 % (for flow rates 5 ml/min to10ml/min) to 0.4 %. For density measurements, the range covers liquids with densities from 600 kg/m³ to 2000 kg/m³ at the temperature range from 10 °C to 40 °C. At the best, the expanded relative uncertainty of liquid density measurement is under 15 ppm. For hydrometers, the measurement scale is from 600 kg/m³ to 2000 kg/m³ with the expanded uncertainty of 0.05 %.

A new primary standard was developed and tested for the range 30 l /min to 100 l/min. Also, a sonic nozzle based element was designed and manufactured to operate in this range as a secondary flow standard. The relative measurement uncertainty of the primary standard is 0.3 % to 0.5 % (k=2). Research on thermal effects on the dynamic gravimetric standards were carried out theoretically and experimentally. The effect of the decreasing surface temperature of the weighed gas cylinder during the measurement process was studied with a thermographic camera.

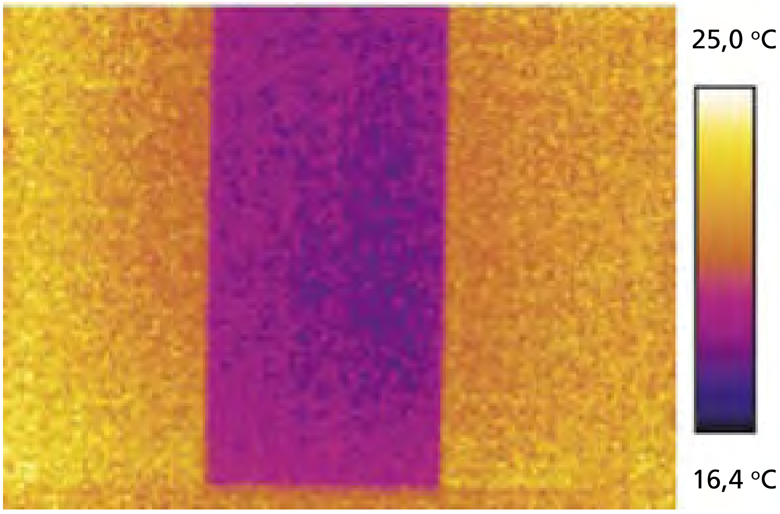


Figure T2. The thermal effects were studied with a thermographic camera.

INVESTIGATION OF THERMAL RADIATION BASED TEMPERATURE MEASUREMENTS

The MIKES-TKK project on radiation temperature measurements was continued in 2005. In this project, ITS-90 based measurement standards have been compared to absolute radiometric temperature standards. In 2005, the results from 2004 were improved, showing smaller discrepancy between the filter radiator scale and the ITS-90. The IKE pyrometer was upgraded by the manufacturer (new detector, new filters, new optics and a new power supply). Results of the project were published in Mart Noorma's doctoral thesis approved at Helsinki University of Technology in 2005.

Figure T3. Ville Ahtee with the filter radiometer and the IKE pyrometer at MIKES.

NEW LABORATORIES

In October 2005 the laboratories moved into a new MIKES building in Otaniemi. Significant efforts were made during construction of the laboratories and the moving and after it ensure the high quality of the new premises and metrological service in the new location. In the new building the Group has more laboratory rooms and better environmental conditions (temperature and humidity control, isolation from vibrations and electrical disturbances).

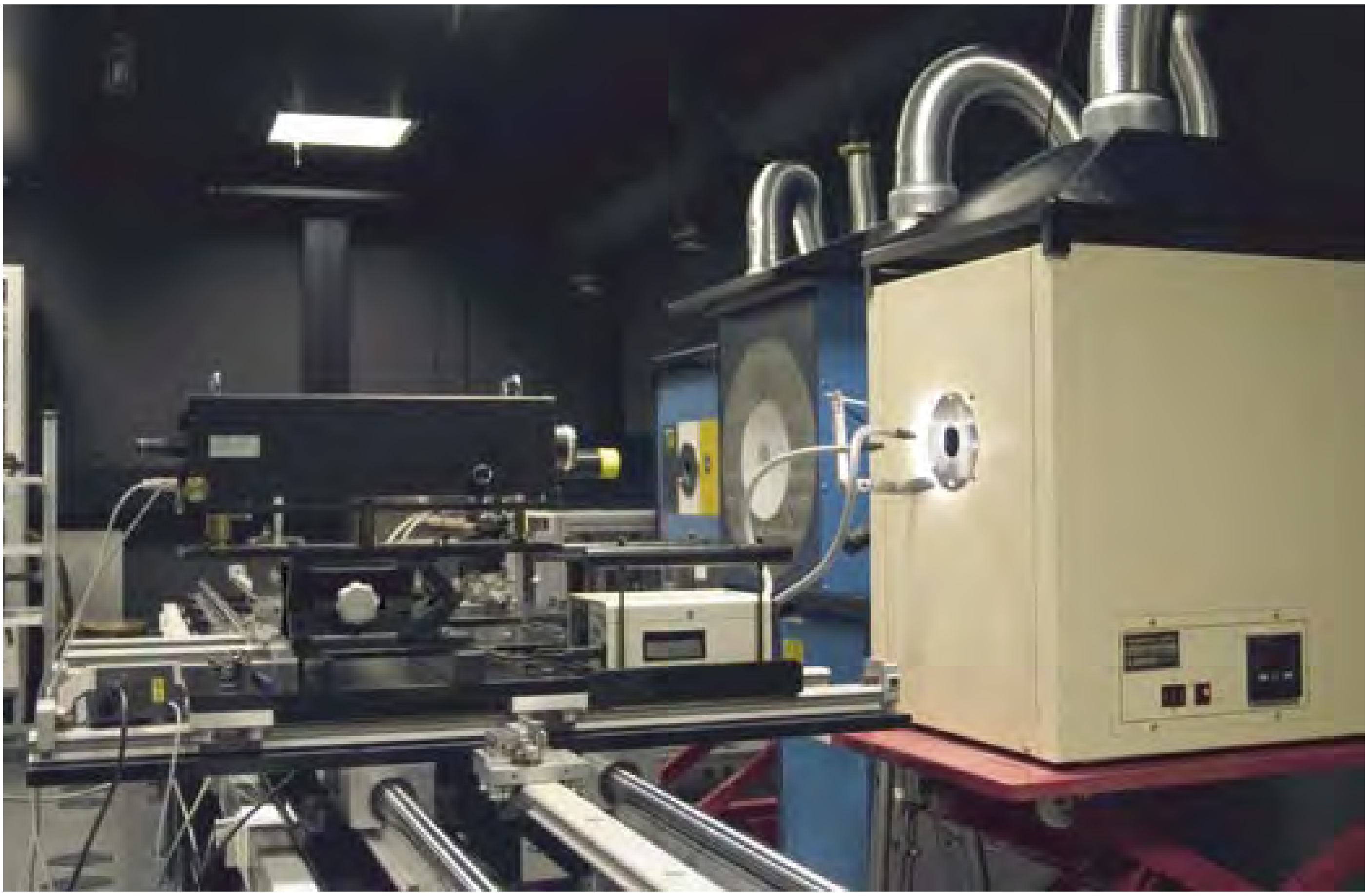


Figure T4. New laboratory room for pyrometry provides excellent environment for research and calibration activities on radiation temperature measurements.

Research Projects

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 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 1K.

It has been discovered that the sensor lay-out should be developed further to improve the electron thermalization at the lowest temperatures. In 2005, theoretical research was carried out to find most advantageous geometry for a CBT sensor. New sensor structures were designed and fabricated for testing. Tests will be completed in 2006.

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. The method can be realised in two different configurations. If there are no significant energy losses the electrical energy of a superconducting coil is directly converted to the mechanical energy of a levitating body. If the energy losses are significant a force compensation measurement and an induction measurement must be performed separately. In the first stage of the project energy losses in superconductors have been determined with a cryogenic calorimeter operating at 4.2 K. So far significant energy losses have been found. The losses are so high that a direct energy conversion is not possible. The project has been carried out in co-operation with VNIIM (Russia) and VTT Information Technology. The research will continue in 2006.

VACUUM WEIGHING (MIKES)

The aim of this project is to determine and analyse mass changes when the weights are moved between ambient pressure and vacuum. The vacuum reached was below 1 mPa. Mass changes in several 1 kg weights have been determined. Changes in surface structure after vacuum exposure has been investigated with an atomic force microscope (AFM) in parallel with mass measurement. The research will continue in 2006.

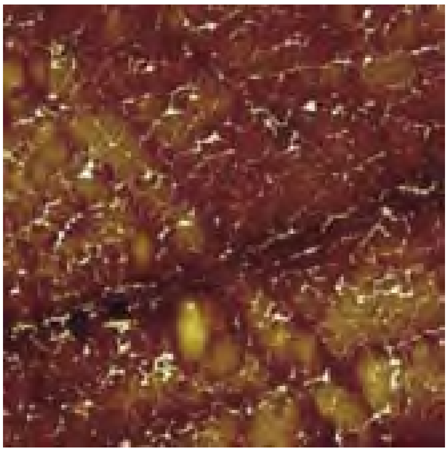


Figure T5. Surface of a weight after 40 hours in air after vacuum treatment. The 3 µm x 3 µm figure was taken with an atomic force microscope at MIKES.

USE OF FPG-TYPE DIGITAL PISTON MANOMETERS (MIKES)

MIKES is coordinating a EUROMET project on FPG-type digital piston manometers (EUROMET Project no. 803). The pressure laboratories of BNM-LNE in France, CMI in Czech Republic, SP in Sweden and MIKES use this novel type of pressure standard for absolute and gauge pressures in the range 1 Pa to 15 kPa. In this project, information is exchanged between the participating laboratories on characterisation of the instrument, estimation of uncertainty and maintenance and stability. In 2005, the results of MIKES on the stability of the effective area were presented in the 4th CCM conference on Pressure and as an article in *Metrologia*.

DETERMINATION OF EFFECTIVE AREA (MIKES)

MIKES is developing a method to determine effective area of a the 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. The measurements will be carried out in 2006.

COMPARISON METHODS FOR HUMIDITY STANDARDS (MIKES)

New methods to compare humidity standards are developed to improve the comparison uncertainty: 1) A new saturator-based humidity comparator; 2) improved procedures to use of chilled mirror and capacitive hygrometers as transfer standards. In 2005, the effect of leaks in low dew-point temperature measurements was studied theoretically and empirically. Also, methods for comparing dew-point generators directly to each other were investigated. A new relative humidity calibrator was developed further. Software was developed for the calibrator and the humidity comparator. This project continues in 2006 and results will be presented in *International Symposium on Humidity and Moisture, ISHM 2006*.

A NEW LOW DEW-POINT TEMPERATURE GENERATOR (MIKES)

In this co-operative project (EUROMET P737) with the Swedish National Testing and Research Institute (SP), a new dew-point generator has been designed, constructed and tested at SP. The generator covers the dew-point temperature range from –50 °C to +20 °C. A comparison with the MIKES dew-point standards was delayed due to the EUROMET key comparison.

INVESTIGATING FREEZING OF SUPERCOOLED WATER (MIKES)

Supercooled water has a significant effect on dew-point temperature measurements in the range –20 °C to 0 °C. In this project we are studying possibilities to control the freezing. The project is carried out in co-operation with Helsinki University. It has been shown that an electric field has a significant impact to the freezing. The effect of ultrasound is under study. The project will continue in 2006.

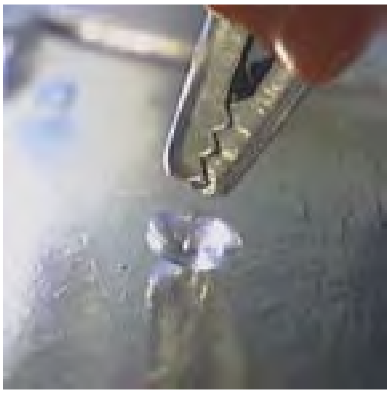


Figure T6. Studying the effect of ultrasound and electric field on freezing of a supercooled water droplet.

THE EFFECT OF CONTAMINATION ON VARIOUS WATER RELATED PARAMETERS (MIKES)

In humidity and density calibration equipment electric conductivity measurements are often used for investigating the purity of water. In this project, effects of salt contamination on the electric conductivity, density and equilibrium vapour pressure of water are studied experimentally. Results will be compared with theoretically derived results which are based on the assumption of ideal solution. The project is carried out in co-operation with Metrosert AS and it will continue in 2006.

ABSOLUTE GRAVITY MEASUREMENTS IN THE ANTARCTIC (FGI)

In December, FGI performed absolute gravity measurements at the Finnish Antarctic base Aboa. Previously, FGI measured at the site in 1994, 2001 and 2004. Repeated measurements are used for geodynamical studies. Single occupations provide much-needed reference values for gravity surveys. The work is a part of the Finnarp 2005 expedition and continues in January and February 2006 with absolute gravity measurements at the South African Base Sanae IV and the Russian base Novolazarevskaya.

NORDIC ABSOLUTE GRAVITY PROJECT (FGI)

The project was launched 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. The time series will be compared with estimates of regional mantle inflow (due to the Fennoscandian postglacial rebound) 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 (University of Hanover), by the Department of Mathematical Sciences and Technology (Norwegian University of Life Sciences), and by the FGI, in cooperation with the Danish Space Center, the Norwegian Mapping Authority, and Lantmäteriet (Sweden). In 2005 FGI observed at 7 sites. The project is coordinated by the Working Group for Geodynamics of the Nordic Geodetic Commission (NKG), as a part of the Nordic Geodetic and Geodynamic Observation System (NGGOS) of the NKG.

EUROPEAN SEA LEVEL SERVICE—RESEARCH INFRASTRUCTURE (FGI)

In this project, financed by the European Commission, repeated measurements with absolute gravimeters are used to monitor the stability of the vertical position of tide gauges. As a method of height control, repeated absolute gravity refers to the Earth's centre of mass and is in this sense independent of any reference frame issues, unlike, say, GPS methods. FGI made a first measurement at the Władysławowo tide gauge in 2004 in cooperation with the Polish Space Center. In 2005 the measurement was repeated.

TEMPORAL VARIATION IN GRAVITY (FGI)

The main tool in this work is the superconducting gravimeter (SG) GWR T020 in Metsähovi. Depending on the frequency, it is capable of detecting gravity variations as small as 0.01 nm s^{-2}. For single events (e.g., steps) the detection limit is about 1 nm s^{-2}. The T020 belongs to the Global Geodynamics Project (GGP), where 20 SGs are deployed worldwide.

FGI participated in global and European studies where the variation in surface gravity observed pointwise with the SGs is correlated with variation in regional gravity observed with the satellites GRACE, and with the variation in regional gravity predicted from global models of terrestrial water storage. On the whole, a good correlation was found.

Investigation of the local hydrology in Metsähovi was continued in the project Modelling and Monitoring Local Hydrological Effects in Gravity, in co-operation with Laboratory of Geoenvironmental Technology, Helsinki University of Technology, the Finnish Environment Institute and the Geological Survey of Finland. The detailed mapping of fractures in the bedrock was pursued further with ground penetrating radar (GPR) techniques. The gravity effect of groundwater in the fractures was modelled.

Hydrological loading effects were calculated using both the high accurate model for Finland (Watershed Simulation and forecasting System, WSFS) and the Climate Prediction Center global soil moisture data set (CPC). Results were compared and evaluated with SG and local permanent GPS observations.

Modelling of the Influence of Atmospheric Masses and Baltic Sea Level on Gravity in cooperation with the Finnish Meteorological Institute and the Finnish Institute of Marine Research continued.

RENEWING OF THE 2 kNm TORQUE STANDARD MACHINE AND COMPARISON WITH THE PTB (RAUTE)

The main change of the construction was new construction of the shaft and the control of the position of the beam to horizontal level. The new control has double function; the first control is based on the force, when level has tilted after loading. The control drives the beam to horizontal level in two phases. When the force is approaching the zero, the control changes from force measurement to distance control, which has been realised by laser sensor. The range for distance control is less than 1 mm. This two-range control system has the advance to make the position of beam quickly but also very smooth at the end phase. The transducer-level-mass system is also a mass-spring construction and can occur to swinging. The results has indicated that with mechanical ball bearing system and good control is possible to get relative uncertainties clearly lower than $1 \cdot 10^{-4}$. The measurement results has shown uniformity with PTB measurements on the level $5 \cdot 10^{-5}$. The measurements have been made on nominal value from 50 Nm up to 2 kNm.

POSSIBILITIES AND NEED FOR EXTENSION OF THE FORCE CALIBRATION OVER 1.1 MN IN FINLAND (RAUTE)

The report describes the need to calibrate forces over 1.1 MN and gives also calculation for different solutions and for different uncertainties. The evaluation of the present transducers in Finland is ca. 60 pieces (±15) and 95 % of them have the capacities < 3 MN.

INVESTIGATIONS MADE OF THE CREEP EFFECT BY USING STRAIN GAUGE REFERENCE TRANSDUCERS FOR CALIBRATION (RAUTE)

The dynamic or quasistatic calibration changes the situation by calibration regarding to behaviour of reference transducer, the signal of the transducers is not more stable. The investigation gives the information about uncertainty of the transducers in dynamic situation and methods to evaluate it.

Figure T7. 2 kNm torque standard machine.

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 is available. The stability of the 20 g weights were poor. For these weights the variation of results between laboratories was large. For other weights 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 come out. 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. Results of MIKES are in agreement with other laboratories.

EUROMET 832: Comparison of 50 kg weights between MIKES, Metrosert, LNMC, JV and EIM. MIKES was the pilot laboratory. Also the transfer standard comes from MIKES. Measurements are nearly finished. Draft report is under construction.

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 measurements are still going on.

NIC Project No 04164: Comparison of the reference surface temperature apparatus at NMIs by comparison of transfer surface temperature standards, participants SP, Risö, JV, OMH and MIKES.

A bilateral comparison between MIKES and Metrosert, Estonia was carried out in October 2004. The results, showing a good agreement, were reported in: M. Rantanen and G. Peterson: Pressure comparison between MIKES and Metrosert: Ranges 95 kPa to 105 kPa absolute and 0.5 MPa to 1.75 MPa gauge. MIKES Publication J2/2005. 12 p.

Comparison in the pressure range from 0.2 MPa to 1.75 MPa absolute and gauge. MIKES purchased in 2004 a new piston-cylinder assembly for this range. MIKES, SP of Sweden and Metrosert of Estonia determined the effective area. The results were reported in: M. Rantanen and S. Semenoja: Results on the effective area of a DHI piston-cylinder unit with the nominal area of 196 mm^2. MIKES Publication J5/2005. 14 p.

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 was asked to join in, and the project was registered as EUROMET No. 881. The project, coordinated by MIKES, will be completed in 2006.

CCT-K6 Key comparison of humidity standards: Partners are in the order of the comparison scheme: NPL (UK), NMIJ (JP), MIKES (FI), IMGC (IT), INTA (ES), NIST (USA), SPRING (Singapore), NRC-CRM (China), VNIIM (RU). Measurements are on-going.

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. MIKES is piloting one of the loops. The measurements are expected to be completed in 2006.

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.

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 702: Comparison of the calibrations of high resolution hydrometers for liquid density determinations. Other participants of the comparison are IMGC – CNR (IT) (pilot laboratory), IPQ (PT), BNM-LNE (FR), BEV (AT), PTB (DE) (co-pilot laboratory), OMH (HU), UME (TR), VNIIM (RU), GUM (PL) and SMU (SK). The comparison scheme was changed due to broken transfer standard hydrometers. The measurements were completed. The Draft A report will be available in 2006.

RAUTE

Comparison on force and on torque measurement has been made with PTB in June. The results have shown good coherence with accredited bmc.

The Key Comparison report for CCM.F-K1.a and CCM.F-K1.b has been given to CCM. It has been accepted by the way to add a calculation for the references as a mean value of all transducers.

The regional Key Comparison for force is running as EUROMET 535 project, the measurements are ready, but there are still some laboratories missing the results.

FGI

The seventh international comparison of absolute gravimeters (ICAG-2005) took place at the BIPM in Sèvres in September. 19 instruments from 16 countries participated. Participating instruments were 12 FG5's, 2 JILAg's, 1 A10, 1 FGC, 1 IMGC, 1 GABL-G, and 1 TBG. The FGI occupied three sites with the FG5-221.

A bilateral comparison between Central Research Institute of Geodesy, Aerial Surveying and Cartography (TsNIIGAiK, Moscow; gravimeters GBL-P001 and FG5-110) and FGI (gravimeter FG5-221) took place in October in Zvenigorod, Russia.

Bilateral comparisons between Institut für Erdmessung (University of Hanover; gravimeter FG5-220) and the FGI (gravimeter FG5-221) took place in May and August in Metsähovi. The maximum difference between the gravimeters on three sites was 42 nm s^{-2}.

National intercomparisons

Comparison of 610 g balance with 0.1 mg resolution. Participants: four accredited laboratories.

Five laboratories took part in a comparison measurement of a digital thermometer in the range from –80 °C to 400 °C. The results are published in a report (see MIKES publications).

An intercomparison in the gauge pressure range from -95 kPa to +100 kPa for the Finnish pressure laboratories was arranged in 2005. Five laboratories participated. The report will come out in 2006 as MIKES Publication J1/2006.

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M. Rantanen and S. Semenoja: *Results on the effective area of a DHI piston-cylinder unit with the nominal area of 196 mm^2*. MIKES Publication J5/2005. 14 p.

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Length

In 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 two length laboratories of MIKES were merged in the new institute to a single length group, which improves co-operation and yields synergy benefits.

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 contract laboratory for co-ordinate measuring machine (CMM) metrology. The operation of the Finnish Geodetic Institute (FGI) is based on its own legislation. FGI is the 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 523 calibration certificates for over 200 different customers in accredited laboratories, research institutes, and industry during 2005. The total number of calibrated measurement standards and devices was over 2000.

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Lis.Sc. Heikki Lehto	*Senior Research Scientist*
M.Sc. Björn Hemming	*Senior Research Scientist*
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M.Sc. Tero Ristonen	*Laboratory Manager*
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Prof. Markku Poutanen	*Head of Department of Geodesy and Geodynamics, Quality Manager*
Lic.Sc. Jorma Jokela	*Head of Laboratory*
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Highlights in 2005

INCREASING ACTIVITIES (MIKES)

In 2005, the personnel of MIKES was burdened with additional construction related tasks due to approaching completion of the new building. No effort was spared to verify, together with designers and constructors, that all details affecting the essential properties of laboratories are appropriately designed and implemented. A new 30 m interferometric bench was also designed and constructed simultaneously with the building.

The successful research work of the last decade yielded new research projects, as the length group got several new projects funded by Academy of Finland or Finnish Technology Agency (TEKES). In the following a few of them are mentioned:

A small project was started to help an accredited laboratory, JMK-Instruments, to strengthen the traceability chain for property measurements of paper. This project is funded by TEKES TUPAS programme. Research work in the field of machine vision measurement uncertainty was granted financial support from the Academy of Finland. A project "Single-Frequency Synthesis at Telecommunication Wavelengths" got three year funding from Academy of Finland. In addition, two TEKES funded nanotechnology projects, with the length group as a partner, were stated within the FinNano technology programme.

Figure L1. Transport of stone table to 010PIT large measurement room of Length.

Figure L2. Transfer of co-ordinate measuring machine to underground laboratory.

NEW LABORATORIES OF LENGTH (MIKES)

In October 2005, MIKES moved into the new building. Over 30 measurement set-ups were transferred from their old locations to the new laboratories (see Figs. L1 and L2).

At the new institute, the length group has eight laboratory rooms: 01PIT Primary interferometers, 02PIT Nanometrology, 03PIT Stabilised lasers, 06PIT Form measurements, 07PIT co-ordinate measurements, 09PIT Measuring rail, 010PIT large measurement room, and 011PIT Special calibrations. Six of the laboratories are situated two floors underground while the rest are at the ground floor. The first three laboratories (01PIT – 03PIT) have the tightest temperature stability and vibration isolation specifications. The laboratory tables of these rooms have active vibration damping based on 80 tonne concrete blocks laying on pneumatic vibration isolators. The supports of the tables are taken through a separate walking floor to the underlying vibration damped concrete block. Rooms with the tightest environment specifications have separate monitoring rooms from where the measurements are controlled (see Fig. L3). The temperature specification of these laboratories is 20±0.05 °C, with maximum permissible drift of 0.02 °C in one hour. In order have the best possible temperature stability, an upward laminar airflow is used. In order to minimise temperature gradients in the laboratory space, heat generated in devices is removed with local ventilation (see Fig. L4). Devices are preferentially placed into ventilated rack enclosures or, alternatively, they are equipped with separate extractor hoods.

Temperatures of the laboratories are almost within specifications, even though a temporary control system with slower feedback is used, as fine-tuning of the high-precision air-conditioning is still underway. Essentially all calibration services have been brought back on line, but some time is still needed to reach the highest accuracy and performance with all devices.

Figure L4. Mikko Merimaa presenting the ventilated rack enclosure for control electronics of the 633 nm HeNe lasers.

MEASUREMENT OF NUMMELA STANDARD BASELINE BY VÄISÄLÄ INTERFEROMETER (FGI)

The renowned Nummela Standard Baseline serves calibration and testing of the most precise electronic distance measurement (EDM) instruments in field conditions and traceable scale transfers for various geodetic applications.

In 2005 the baseline was measured with the Väisälä interference comparator for the 14th time since 1947 (see Fig. L5). A setback was that only half of the 864-m baseline could be measured during the three months observation period, due to exceptional weather conditions. For the 432 m measurement, preliminary results show conventional ±0.05 mm standard uncertainties in lengths and 0.1-mm-level stability after previous measurements.

When measuring geodetic baselines with the Väisälä interference comparator, 1-m-long quartz bars are used to determine the scale. The quartz metre system has been maintained with interferometrical comparisons in the Tuorla Observatory of University of Turku for more than 70 years. Again, a change of generation for persons in charge was topical, and two researchers of the FGI have recently got acquainted with the comparison method. The new results are utilized in the computation of the new interference measurements. An absolute calibration system for quartz bars was developed at MIKES in 2000. Formerly, this uncommon service was provided (e.g.) by PTB in Germany.

Figure L3. Laboratory room 01PIT as seen from the monitoring room. The device behind the window is a line scale interferometer.

Figure L5. Väisälä interference comparator equipment.

NEW CO-ORDINATE MEASURING MACHINE (MIKES)

The increased laboratory space allowed the length group to incorporate co-ordinate measurements to its activities. A new instrument, Mitutoyo Legex 9106, was bought and installed to the laboratory room 07PIT (see Fig. L6). Accuracy of the machine is one of the best among commercially available devices of this size. This instrument allows MIKES to start research and measurement service for Finnish and international customers. The specified maximum permissible error of the machine is (0.35+L/1000) µm (ISO 10360-2) when measurement volume is X-910 mm, Y-1010 mm ja Z-610 mm.

Figure L6. Adjustments for error mapping of new Mitutoyo LEGEX 9106 at 07PIT by experts of seller.

SEMINAR "LASERISTA KAIKKI TARKKUUS IRTI " 10.2.2005 (MIKES)

On 10th of February 2005 MIKES length group arranged a seminar "Laserista kaikki tarkkuus irti" (see Fig. L7).

When properly used, a laser interferometer has excellent accuracy in laboratory conditions. However, in practical measurements at workshops, there are several error sources which may surprisingly increase the measurement uncertainty to magnitudes unacceptable in high precision machine tools. The focus of the seminar was on understanding of error sources caused by the environment and measurement setup. The seminar was targeted to experienced users of commercial laser interferometers. Approximately 20 persons participated the seminar.

Figure L7. Seminar on laser interferometric measurements.

Research Projects

NANOMETROLOGY (MIKES)

In order to realise traceable length scale on nanometre region and to offer related calibration and measurement services, MIKES has a project to engineer a metrological AFM. As a part of this project MIKES has purchased a commercial AFM. In 2005, we concentrated on traceability and calibration of the commercial AFM. The x, y, and z scales of the AFM are calibrated interferometrically (see Fig. L8). Orthogonality errors between x- and y-axes were determined by calibration grating and error separation method. Out-off-plane movement and signal noise were measured. Development of the metrological AFM has continued with design of the integration of the AFM head and 3D interferometer.

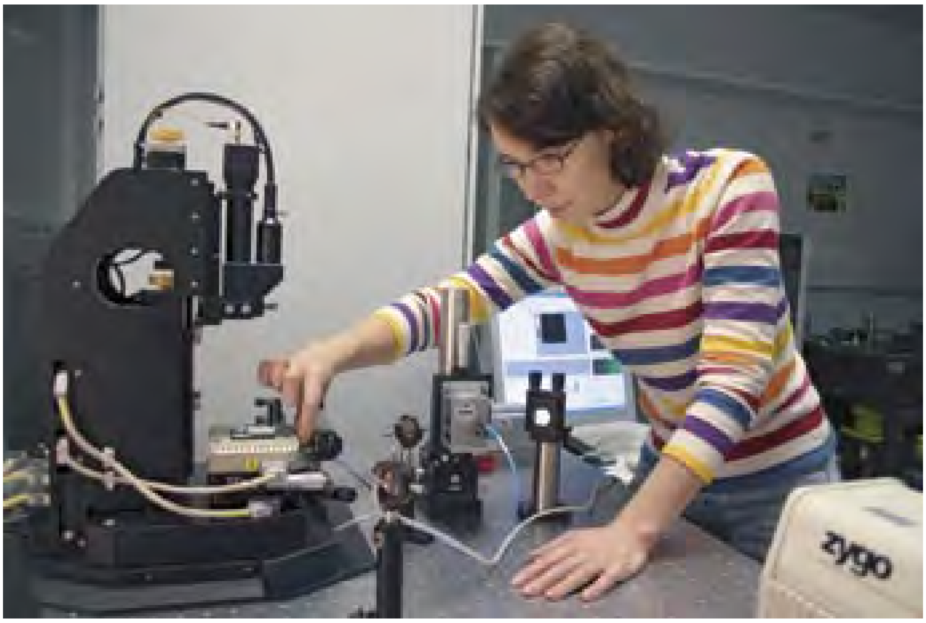

Figure L8. Virpi Korpelainen aligning laser beams for interferometric calibration of y-axis of the commercial AFM.

TRACEABILITY OF ANGLE MEASUREMENTS (MIKES)

The aim of this project is to develop our accuracy and routines for calibration of polygons, angle gauge blocks, angle optics of laser-interferometer, autocollimators, theodolites, and several other angle measuring instruments. During the year 2005 we have calibrated angle measurement equipment and improved the system for fixing the collimator during calibration of theodolites. We also built a new angle measuring machine for calibration of squareness standards (see Fig. L9). The accuracy of the machine is 0.3 µm and capacity is 1000 x 150 mm.

Figure L9. Antti Korhonen is working on a new device for squareness measurements for his thesis.

DESIGN OF 30 m INTERFEROMETRIC BENCH (MIKES)

Due to moving to the new institute, the old 30 m measurement bench came inaccessible. Therefore a design and implementation project was started for construction of a new interferometric bench. The main design targets were the following: range 30 m, pitch, yaw and roll <50" over the range, straightness <1 mm, stable structure which is not affected by small ambient temperature changes and adjustable linear guide. After few months of use, it appears that the design targets were well reached. Angular errors of the movement are less than 30". The rail is suitable for calibrations of various length standards or instruments like: tapes, plumb tapes, circometres, machinist scales, total stations, laser trackers etc. The room where the rail is has good temperature control and the interferometer is equipped with high quality air & material temperature, pressure, and humidity meters. In calibrations, uncertainties down to 0.1 ppm can be reached for high quality distance measuring devices.

Figure L10. New 30 m interferometric bench.

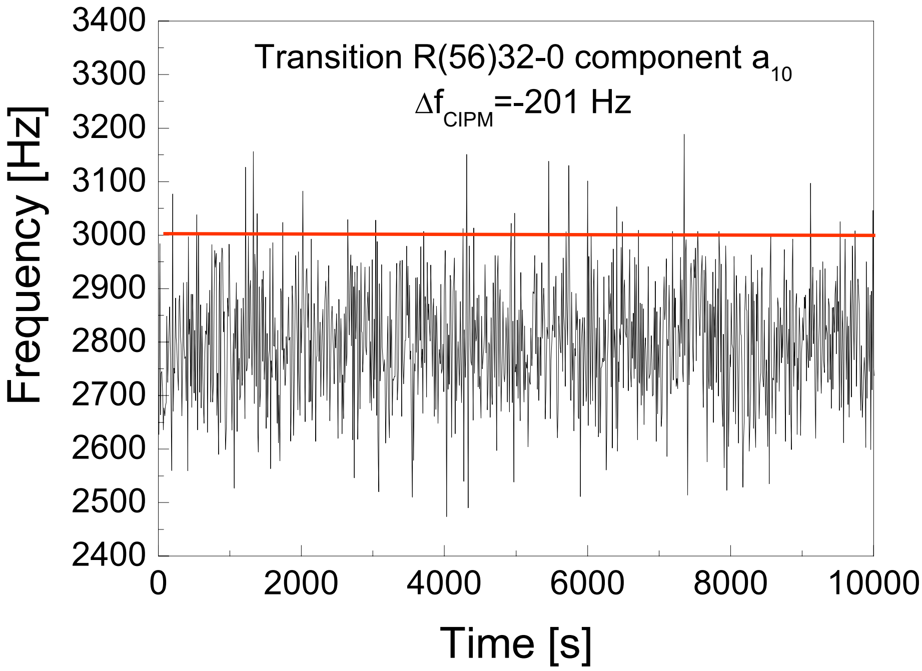

Figure L11. Absolute frequency measurement of MIKESY1 iodine-stabilized Nd:YAG-laser stabilised on the hyperfine spectrum of iodine at 532 nm. The red line indicates the CIPM recommended value. For clarity, only last four digits of the frequency value are shown.

OPTICAL FREQUENCY COMB (MIKES)

The optical frequency comb generator at MIKES was developed for absolute frequency measurements and calibrations of iodine-stabilised lasers, which are subsequently used as secondary frequency standards for calibrations of lasers that are used in interferometric length measurements. The comb generator is referenced to a hydrogen maser, which is a member of the ensemble of atomic clocks at MIKES, that also participate in the keeping of the international time.

Repetition rate and carrier-envelope offset of the MIKES frequency comb are synthesised from a hydrogen maser to achieve good short-term stability and short integration times when measuring low-noise laser frequency standards. The comb spacing is controlled by phase-locking the repetition rate to a low-noise RF-signal generator, while the offset-frequency control is based on the self-referencing technique, which requires an octave-spanning comb. The spectrum of our commercial mode-locked Ti:S-laser spans the full octave, when broadened in a non-linear microstructure fibre. The self-referencing set-up is conventional and utilises the high and low frequency ends of the comb.

In year 2005, the original objectives of the research project were largely met. Frequency measurements of various iodine-stabilised lasers were performed with consistent results and good agreement with the CIPM recommended values. At present, the frequency comb generator, ensemble of atomic clocks, and iodine-stabilised lasers allow completely independent realisation of the definition of the metre at MIKES with direct traceability to the SI-second. In future, the MIKES frequency comb generator will be also serving the absolute frequency measurement needs of other Northern European countries.

RESEARCH AT FINNISH GEODETIC INSTITUTE (FGI)

The metrological research performed in the Finnish Geodetic Institute is concentrated on geodetic applications.

A 10-station control network around the Olkiluoto nuclear power plant and final disposal facility has been measured in 20 GPS observation campaigns since year 1995. The time series allow exploration of the possible deformations in the bedrock. The standard uncertainties are on the order of ±0.1 mm/a. A problem is that the lengths of GPS vectors are not traceable, and the measurements are often influenced by irregular and unknown scale variations. These variations are mainly caused by deficiencies in ionospheric and tropospheric modelling. To make the measurements traceable and to control the scale, the network is complemented with a 511-m baseline. Since 2002 the baseline has been measured half-yearly with regularly calibrated high precision EDM instruments. Possible changes in height differences are controlled by precise leveling every two years, which were started in 2003. The design benefits both deformation research and metrology of lengths derived from GPS measurements.

Studies for water crossing in height determination were continued at Otsolahti in Espoo (see Fig. L12). Precise trigonometric levelling and digital levelling using long sightings have been compared. Regularly repeated digital levelling was continued at the Metsähovi test field. Scale determination and stability of benchmarks are essential subjects in these studies.

RESEARCH AND MAINTENANCE AT MIKES-TUT

The Co-ordinate Measuring Machine (CMM) SIP CMM5, used as reference measuring machine, is calibrated by step gauge and other reference normal in order to use substitution method. No special maintenance was done.

The reference standards used in the Substitution method are calibrated according to the K003 time schedule by MIKES.

Figure L12. Preparing for water crossing with precise trigonometric levelling.

Comparisons

INTERNATIONAL COMPARISONS

CCL-NANO5 – key comparison of 2D gratings (MIKES)
Participants are DFM, METAS, PTB, BIPM, NPL, IMGC, NMi, CMI, NIST, VNIIM, NIM, NRLM, CMS, KRISS and MIKES. Comparison measurements at MIKES were done in December 2005.

EUROMET.L-K2 Long gauge blocks (2002-2005) (MIKES)
Keycomparison has proceeded to draft B phase. The MIKES results for calibration of 4 steel gauge blocks were excellent (see Fig. L13). MIKES standard uncertainties were as follows: 150 mm u_c=17 nm; 500 mm u_c=26 nm;1 m u_c=41 nm. When MIKES maximum deviation from reference values was -25 nm (1 m).

Digital levelling (FGI)
A bilateral comparison of digital levelling was performed between the FGI and the Technical University of Graz, Austria, in March. Discrepancies in results of the new methods require further analysis, and reporting is unfinished.

EDM calibration (FGI)
A bilateral comparison of EDM instruments was performed between the FGI and the NMIJ/AIST in Tsukuba, Japan, in year 2003. As a continuation of this, calibrations were performed at the Nummela Standard Baseline in May and August 2005, just before the interference measurements. Another bilateral comparison is planned for year 2007.

National comparison for accredited calibration laboratories

MIKES.D8
During 2005 length group organised gauge clock comparison MIKES.D8 for four accredited and one industrial laboratory. The subject of the comparison was calibration of five gauge blocks from 3.5 mm to 300 mm of length. Preliminary results show good agreement between results and reported uncertainty values. The report is still under processing.

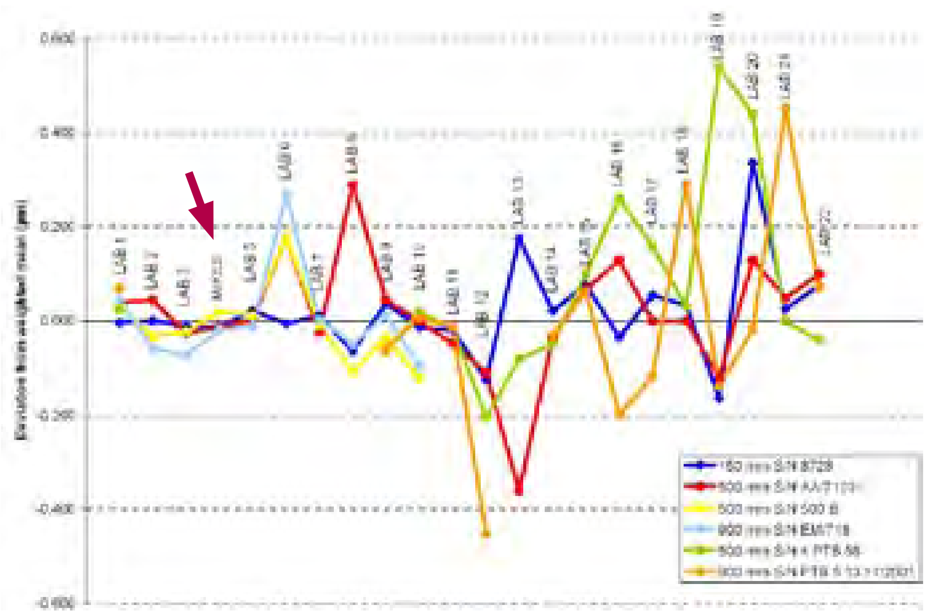

Figure L13. Results of EUROMET.L-K2 Long gauge blocks comparison.

Publications

Articles in International Journals

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M. Vainio, M. Merimaa, and K. Nyholm, *Optical amplifier for femtosecond frequency comb measurements near 633 nm*, Applied Physics B, 81 (2005) 1053-1057.

M. Vainio, M. Merimaa, and E. Ikonen, *Iodine spectrometer based on a 633-nm transmission-grating diode laser*, Measurement Science and Technology, 16 (2005) 1305-1311.

Conference Presentations

MIKES

V.-P. Esala, B. Hemming, K. Nyholm, and A. Lassila, *MIKES' facility for calibration of commercial laser interferometers*, in Proc. of Euspen 2005 Conference, Montpellier 8.-12.5.2005, 4 p.

M. Merimaa, K. Nyholm, and M. Vainio, *Frequency comb generator for calibration of laser frequency standards*, IEEE LEOS Summer Topicals 2005, Optical frequency & time measurement and generation, San Diego, USA, July 25-27, 2005, pp. 33-34. (talk).

M. Vainio, M. Merimaa, K. Nyholm, and E. Ikonen, *External-cavity diode laser based spectrometer for absolute determination of iodine lines around 633 nm*, Optical Sensing and Spectroscopy, in Proc. SPIE Opto-Ireland 2005. Eds. G. D. O'Sullivan, H. J. Byrne, E. McGlynn, A. G. Ryder, and B. D. MacCraith, 2005, pp. 331-339.

V. Korpelainen, K. Nyholm, A. Lassila, *Traceability of SPM measurements*, Scandinavian Scanning Probe Microscopy Conference and Users Meeting 2005, Espoo, Finland, 29 April 2005.

M. Vainio, M. Merimaa, and K. Nyholm, *Use of injection locking for reducing optical feedback effects and residual amplitude modulation in wavelength modulation spectroscopy*, in proceedings of 5th International Conference on Tunable Diode Laser Spectroscopy 2005, July 11-15, 2005, Florence, Italy, 2005, p. 100.

M. Merimaa, K. Nyholm, and M. Vainio, *MIKES frequency comb generator and absolute frequency measurements of iodine-stabilized lasers*, in Proceedings of 12th International Conference on Metrology, Lyon, France, June 20-23, 2005.

A. Lassila, V. Korpelainen, B. Hemming, I. Palosuo, *Recent developments at nanometre scale metrology at MIKES*, Nanotechnology in Northern Europe, Helsinki, Finland, 26-28 April 2005.

M. Vainio, M. Merimaa, K. Nyholm, and E. Ikonen, *External-cavity diode laser based spectrometer for absolute determination of iodine lines around 633 nm*, in Proc. SPIE/Optical Sensing and Spectroscopy, Dublin, Ireland, April 4-6, 2005.

M. Merimaa, K. Nyholm, and M. Vainio, *Measuring optical frequencies at 10^{-13} level: absolute frequency determinations of laser frequency standards*, in Proceedings of the Finnish Optics Days 2005, Jyväskylä, May 12-13, 2005.

V. Korpelainen, A. Lassila, *Quantitative microscopy at MIKES - traceability of AFM measurements*, Nanotechnology in Northern Europe, Helsinki, Finland, 26-28 April 2005

K. Nyholm, M. Merimaa, and M. Vainio, *MIKES' femtosecond frequency comb generator*, in Proceedings of the Finnish Optics Days 2005, Jyväskylä, May 12-13, 2005.

M. Vainio, M. Merimaa, and K. Nyholm, *Optical amplifier for laser frequency measurements near 633 nm with a frequency comb generator*, in Proceedings of the Finnish Optics Days 2005, Jyväskylä, May 12-13, 2005.

M. Vainio, M. Merimaa, and K. Nyholm, *Iodine spectrometer for absolute frequency determination of iodine hyperfine components near 633 nm*, in Proceedings of the XXXIX Annual Confrence of the Finnish Physical Society, Espoo, March 17-19, 2005, p. 386.

V. Korpelainen and A. Lassila, *Traceable quantitative microscopy at MIKES*, Proceedings of the XXXIX Annual Conference of the Finnish Physical Society, Espoo, Finland, March 17-19, 2005, p 212.

FGI

J. Ahola, *Tarkkoihin GPS-mittauksiin perustuva kallioperän deformaatiotutkimus Olkiluodossa*, Maanmittaustieteiden päivät, 17.–18.11.2005, TKK, Espoo. Maanmittaustieteiden Seuran julkaisu n:o 42, s. 66 – 74.

P. Lehmuskoski, P. Rouhiainen, V. Saaranen, M. Takalo and H. Virtanen, *Liikkuvatko kalliokiintopisteet – tapaus Metsähov*i, Geofysiikan päivät, 19.-20.5.2005, Helsinki. 6 p.

M. Ollikainen and J. Ahola, *Monitoring Crustal Deformations Using High Precision GPS Network*, Dynamic Planet, A Joint Assembly of the IAG, IAPSO and IABO, August 22 - 26, 2005, Cairns, Australia.

M. Ollikainen, J. Jokela, R. Chen and J. Mäkinen, *National Report of Finland*, EUREF 2005 Symposium of the IAG Reference Frame Subcommission for Europe, June 1 – 3, 2005, Wien, Austria. 8 p. (to be published in the proceedings).

M. Takalo, *National Report*, Presentation at the Meeting of the NKG Working Group for Height Determination, June 13 - 14, 2005, Akranes, Iceland.

M. Takalo, *Problems of Zeiss DiNi12*, Presentation at the Meeting of the NKG Working Group for Height Determination, June 13 - 14, 2005, Akranes, Iceland.

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V-P. Esala, *Pituuden vertailumittaus D7*, MIKES Publication J9/2005, 15 p.

Other Publications

MIKES

M. Vainio, M. Merimaa, and K. Nyholm, *Modulation transfer characteristics of injection-locked diode lasers*, Metrology Research Institute Report 29/2005.

Electricity, Time and Acoustics

Personnel
MIKES

Dr. Antti Manninen	*Group Manager*
Mr. Jaakko Alajoki	*Trainee (23 May - 31 August)*
M. Sc. Anu Fagerlund (Tanninen)	*Software Analyst*
M. Sc. Jussi Hämäläinen	*Research Scientist*
M.Sc. Ilkka Iisakka	*Research Scientist*
M.Sc. Pekka Immonen	*Research Scientist*
Prof. Kalevi Kalliomäki	*Senior Research Scientist, Head of Time and Frequency Laboratory*
M.Sc. Antti Kemppinen	*Research Scientist*
Mr. Heikki Koivula	*Trainee (1 August -)*
Mr. Kimmo Könönen	*Trainee (23 May - 31 August)*
M.Sc. Tapio Mansten	*Senior Research Scientist*
Dr. Jaani Nissilä	*Senior Research Scientist*
M.Sc. Kari Ojasalo	*Research Scientist*
B.Sc. Risto Rajala	*Research Engineer*
B.Sc. Anssi Rautiainen	*Research Engineer (Permanent position: VTT)*
Dr. Alexandre Satrapinski	*Senior Research Scientist*
Mr. Pekka Sipilä	*Trainee (10 January - 26 August), also at Metrology Research Institute, TKK*
Dr. Nikolai Tisnek	*Research Scientist*

MIKES-TKK

Dr. Jari Hällström	*Senior Research Scientist, Group Leader*
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*

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), time and frequency, and acoustics (sound pressure). The group is staffed permanently by 12 metrologists. 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, and impulse charge.

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 2005, the number of calibration certificates was 68 at the Electricity Group of MIKES and 45 at MIKES-TKK. Several calibrations were performed to customers abroad: MIKES to Estonia and MIKES-TKK to the USA, South Korea, and the Netherlands.

Highlights in 2005

MIKES MOVED INTO THE NEW BUILDING

The most important highlight of the year for the MIKES Electricity Group was the move into the new building in the beginning of October, 2005. The premises of Electricity Group include 12 electromagnetically shielded rooms for electrical measurements, one silent room for acoustic measurements, three other laboratory rooms, and a well-equipped workshop for electronics. The temperature in most laboratory premises is regulated to (23 ± 0.5) °C, but in practice the temperature stability is much better. Temperature and humidity of each laboratory room is monitored and stored continuously using a system based on FieldPoint of National Instruments and Vaisala T/RH sensors. For the most temperature sensitive devices, 18 temperature controlled equipment cabinets have been constructed, whose temperature can be kept constant within ±0.06 °C at best. Several rooms include a granite table with natural rubber isolators for vibration-sensitive equipment. All electromagnetically shielded laboratories are equipped with optical fibre lighting to minimise power supply interference.

MIKES STARTED CONTRIBUTING TO UTC

International Atomic Time (TAI) and Coordinated Universal Time (UTC) are obtained from a combination of data from some 300 atomic clocks world-wide. For collecting and comparing data from different atomic clocks, the BIPM organises an international network of time links, which are mostly based on observation of GPS satellites in common views. The TAI and UTC time scales and the local representations of UTC are disseminated monthly in BIPM Circular T. In 2003 and 2004, MIKES developed a GPS common view measurement system based on a Topcon Legacy-E geodetic GPS receiver and a self-made software, and in 2005 the four atomic clocks of MIKES (two caesium clocks and two hydrogen masers) started contributing to TAI and UTC: on 12 May, 2005, "MIKE" appeared for the first time in BIPM Circular T (Circ. T 208).

SEMINARS (MIKES)

In November 2005, MIKES Electricity Group arranged two successful seminars in collaboration with the Advisory Committee for Metrology. The Ambient noise seminar had 38 participants, including the 8 speakers who gave interesting talks about physiological effects, legislation, modelling, standards, measurements, traceability, and other aspects related with ambient acoustic noise. In the Seminar on measurement of electric power quality, the 62 participants got a good overview of the field from the 12 speakers, whose topics included, e.g., connection between EMC and power quality, improvement of power quality by UPS, traceability issues, and reliability of power quality measurements.

Figure E1. Dr. Heikki Isotalo, director of MIKES Metrology, testing the new electronics workshop facilities.

Figure E2. The antenna and receiver for the GPS common view measurements are located in the "clock tower" of the new MIKES building.

COMMERCIAL PROTOTYPE OF IMPULSE VOLTAGE CALIBRATOR (MIKES-TKK)

MIKES-TKK signed an agreement with Highvolt Prüftechnik Dresden GmbH about licensing the impulse voltage calibrator technology in Helsinki University of Technology. The impulse voltage calibrator delivers accurate surge impulses for calibration of impulse voltage digitizers used in high voltage test laboratories. As a first step towards commercial version, MIKES-TKK delivered a prototype to Highvolt in December 2005 (see Fig. E4).

Figure E3. The lecture room Aari of MIKES was filled by the participants of Seminar on measurement of electric power quality on 22 November.

AC VOLTAGE RATIO COMPARISON (MIKES-TKK)

MIKES-TKK took part in a supplementary comparison EUROMET. EM-S21 of AC voltage ratio. The comparison was coordinated by CMI (Czech), and the measurements were carried out between 2000 and 2002. MIKES-TKK performed the measurements in July 2001. Final results were published in 2005 in the Technical Appendix of Metrologia. Two instrument voltage transformers (22 and 5/10 kV) were circulated among 8 European NMIs. The ratio error and phase displacement of both transformers were calibrated on 5 voltage levels. Results of MIKES-TKK were well in line with other participants. The confidence coefficients, E_n, of MIKES-TKK were low (less than 0.4). This suggests that the uncertainty estimates of MIKES-TKK were too pessimistic.

Figure E4. The prototype of the commercial impulse voltage calibrator developed for Highvolt GmbH by MIKES-TKK.

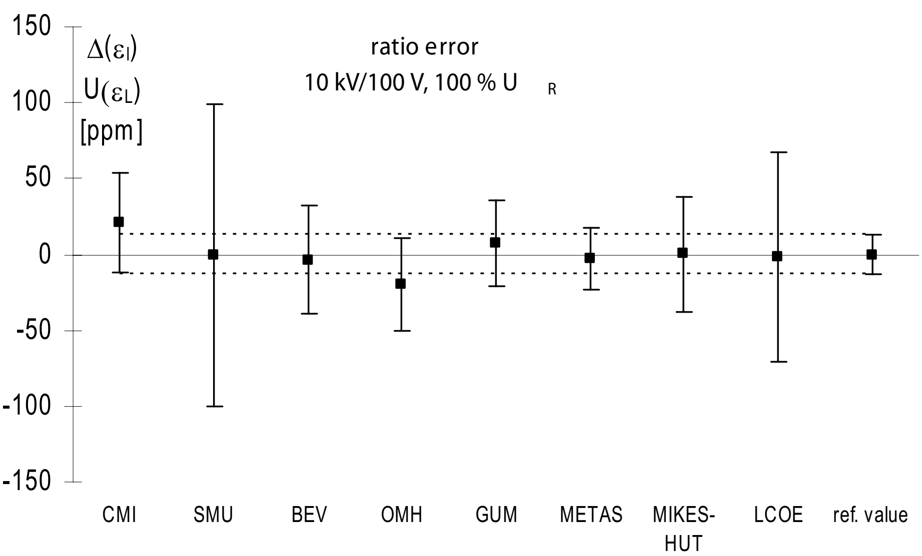

Figure E5. Results of supplementary comparison EUROMET.EM-S21. The ratio of an AC transformer at 50 Hz was under study. Results for the ratio error of 10 kV / 100 V ratio at nominal voltage are shown.

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. In spring 2005, MIKES started real activities towards closing the triangle. Collaboration was started with the Low Temperature Laboratory of Helsinki University of Technology (TKK) to investigate and develop the so-called "Cooper pair sluice", a superconducting nanostructure which can be used for accurate charge pumping. The sluice consists of two mesoscopic SQUIDs and of a single capacitively controlled island.

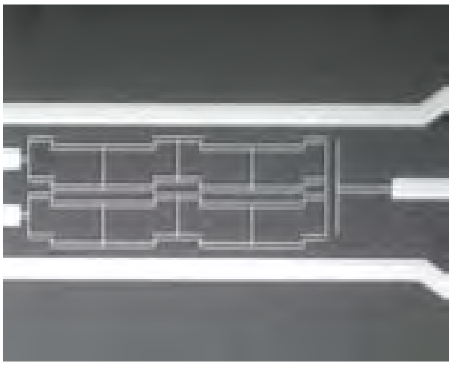

Figure E6. A scanning electron micrograph of a modified Cooper pair sluice which has been investigated by MIKES and TKK.

It was invented by the researchers of TKK and VTT in 2003, and the same groups made the first proof-of-principle experiments in 2004. The main problem turned out to be the unwanted leakage current caused by the non-identical tunnel junctions of the SQUIDs. Work in 2005 has focused on investigating the possibility to eliminate the leakage current by connecting several SQUIDs in series (see Fig. E6). The experiments have indicated that a more promising way would be to replace one junction of each SQUID by another SQUID, which can be controlled by a magnetic field. The work has been funded by the Finnish Academy of Science and Letters / Vilho, Yrjö and Kalle Väisälä Foundation. In November 2005, the Academy of Finland made a funding decision of 202 060 € for the MIKES's project proposal Quantum metrology triangle for the years 2006 - 2009.

AC JOSEPHSON VOLTAGE STANDARD (MIKES)

The collaboration between MIKES and VTT to realise a 1 V quantum AC voltage standard at 10 Hz - 10 kHz has continued. The standard is based on externally shunted Josephson junction arrays designed and fabricated by VTT. The idea is to generate a square-wave voltage whose amplitude is of fundamental accuracy depending only on fundamental constants and the atomic clock frequency. The main frequency component of this waveform is then used to control the amplitude of a stable sinusoid voltage source. In 2005 we have developed more accurate unity-gain amplifiers and a new active filter to remove the higher harmonics. Preliminary tests with the whole setup suggest that the accuracy of the output amplitude is in the ppm range. Work to verify this with thermal converters is in progress. New Josephson junction array components have been fabricated at VTT. The chips include two identical 1.5 V arrays which allows simultaneous generation of two fundamentally accurate voltage signals with adjustable amplitude and phase. Besides voltage metrology these will be especially suitable for impedance and power metrology. Among the new arrays, a record 1.7 V step with 160 μA width has been measured. This gives evidence that the design has been successful, and in particular, the problem of self-generated microwave power, which destroyed the previous fabrication process components (in 2003), is now well understood.

EMMA - ELECTROMECHANICAL MICROCOMPONENTS FOR PRECISION APPLICATIONS (MIKES)

The European Union funded EMMA project, which started in autumn 2001, finished in the end of February, 2005. Other partners were VTT (coordinator), VTI Technologies, NMi-VSL, PTB, Fluke PM, and University of Twente. The main goal of the project was to develop applications of stable microelectromechanical components (MEMS) for electrical metrology. The main result was a MEMS-based AC voltage reference, whose output voltage at 100 kHz stayed constant during a 3-week measuring period at MIKES within the measurement accuracy of about 2 ppm. The final seminar of the project was arranged in February 2005 at VTT, Espoo. After the EMMA project was finished, MIKES has investigated the possibility of making a DC voltage reference based on the stable AC voltage obtained from the MEMS component.

IMPEDANCE METROLOGY DEVELOPMENT (MIKES)

Development of a system to link capacitance with quantum Hall resistance started in the year 2000. Construction of the measurement system was finished in 2004, and it was rebuilt into the new premises by the end of 2005. Temperature controlled enclosures for AC/DC standards, 10 kΩ and 1 kΩ, and for a combined transfer capacitance standard, which includes 1 nF, 10 nF, 100 nF and 1 μF capacitors, have been built and tested. Measurements of 1 nF capacitors in terms of the QHR have been performed with uncertainty of about 2 μF/F. In the end of 2005, a bilateral comparison with SP, Sweden, was arranged on scaling the capacitance value from 100 pF up to 1 μF with one decade step. Frequency dependence measurements of transfer ceramic 1 nF capacitors were also performed during the comparison. The results, which will be published in CPEM'06 conference, showed good agreement between MIKES and SP, and indicate essential improvement in traceable capacitance measurement capabilities of MIKES.

DEVELOPMENT OF HIGH FREQUENCY MEASUREMENTS (MIKES)

The goal of the project was to develop the RF and microwave measurement capabilities of MIKES to the level required from National Standards Laboratory. In spring 2005, MIKES finished measurements and analysis related with EUROMET. EM.RF-K8.1.CL, bilateral comparison with NMi-VSL about calibration factor of thermistor mounts up to 18 GHz. Preliminary results of the comparison indicate good agreement between the participants. Improvements have been made to measurement procedures both in power and S-parameter measurements. These procedures have also been included in the measurement and uncertainty calculation software. Study for expanding the frequency range from 18 GHz to 26.5 GHz has been conducted in 2005. Connector and air line measurements have been made, utilising the 3D measurement capabilities of the MIKES Length Group. Modifications have been made to microwave VNA, enabling measurements of voltage reflection coefficients with higher power levels. Working instructions and other quality documents have been finalised. Much of the work was done by Mr. Heikki Koivula as a part of his Master's Thesis studies to be finalised in 2006. By the end of 2005, MIKES was ready for a peer review of the metrological competence of RF and microwave measurements. The review was implemented in February 2006 by Dr. Klas Yhland of SP, Sweden.

DEVELOPMENT OF CALIBRATION SERVICE FOR LOW CURRENTS (MIKES)

MIKES started development of measurement facilities of very low currents by the Master's Thesis of Mr. Pekka Sipilä in 2005. The method was based on applying a constant voltage across a high-value resistor. The work included voltage and temperature characterisation of resistance standards ranging from 10 GΩ to 100 TΩ. A temperature controlled enclosure was designed and built for the resistance standards. It was used as a prototype of the temperature controlled equipment cabinets of the new MIKES building. As a final result, a current-to-voltage converter of Metrology Research Institute of TKK was calibrated, with uncertainty of 3.6 mA/A at 1 pA. The uncertainty was dominated by the 1/*f* noise of the calibrated instrument itself. In 2006, measurements of even smaller currents will be developed, based on charging a capacitor with a linear voltage ramp.

Figure E7. Pekka Sipilä preparing for measurements of 1 TΩ resistance standard using the self-constructed temperature controlled enclosure.

Figure E8. Ilkka Iisakka making voltage stepup measurements in the new ACDC laboratory of MIKES.

ENHANCEMENT OF TRACEABILITY IN AC VOLTAGE AND CURRENT (MIKES)

The main achievement of the project in 2005 was education of Mr. Ilkka Iisakka to AC/DC voltage transfer measurements. Comparison measurements between the thermal converters of MIKES were performed before moving into the new MIKES building, and measurement instructions and uncertainty analysis were updated. The AC/DC measurement setup was reconstructed in the new MIKES building by the end of 2005 (see Fig. E8), and the comparison measurements between the thermal converters were repeated. Voltage stepup measurements were started in spring 2006. Resistive voltage dividers were calibrated at SP and a new planar thermal converter was purchased from IPHT, Jena.

DEVELOPMENT OF ACCELERATION CALIBRATION FACILITIES (MIKES)

Development project of vibration transducer measurements, which was started in 2004, was continued in 2005 but not with the anticipated volume. A secondary working standard was acquired. A special mount for the shaker and the interferometer has been constructed into the new premises. The goal is to start measurements at secondary level during 2006.

DEVELOPMENT OF A BROWSER BASED DATA MANAGEMENT SYSTEM (MIKES)

Development of a browser-based data management system (SERVERBASE) for the whole Metrology Department of MIKES started in the beginning of 2004. The system became operational summer 2005, well before moving into the new premises. It includes, for example, equipment register and management of calibration commissions, measurement data, certificates, and invoicing.

TRACEABILITY OF HIGH AC CURRENT CALIBRATION CAPABILITIES (MIKES-TKK)

This project was triggered by the demand of Finnish industry for high current AC calibrations. The aim is to build a setup for calibration of AC current transformer ratio error and phase displacement, also on site, for currents up to 10 kA. The current is measured by a temperature compensated Rogowski coil. The measured temperature coefficient of the system is less than ±2 ppm/K. The structure of the busbar is open, and no forced cooling is needed. The current linearity has been checked up to 3 kA. Extension of the current range to 10 kA and magnetic coupling effects will be studied in 2006. Target overall uncertainty is 50 ppm for ratio error and 30 µrad for phase displacement.

During 2005 three current shunts were designed and built for calibration of Rogowski coil on low current level. The new shunts (333 mΩ / 2 A, 111 mΩ / 6 A, and 26 mΩ / 25 A) have temperature coefficients below ±5 ppm/K. Characterisation of the shunts is still going on.

EXTENSION OF ESD CALIBRATION BANDWIDTH (MIKES-TKK)

The main factor limiting the accuracy of calibration of ESD testers at MIKES-TKK has been the limited bandwidth of the digital oscilloscope. As the relevant standard is under revision and it will require extension of the bandwidth, too, MIKES-TKK acquired in 2005 a wideband (6 GHz) oscilloscope to overcome the problem. While the process of revising the uncertainty budget is going on, MIKES-TKK took part in an informal comparison with PTB and three testing laboratories from Central Europe in October 2005.

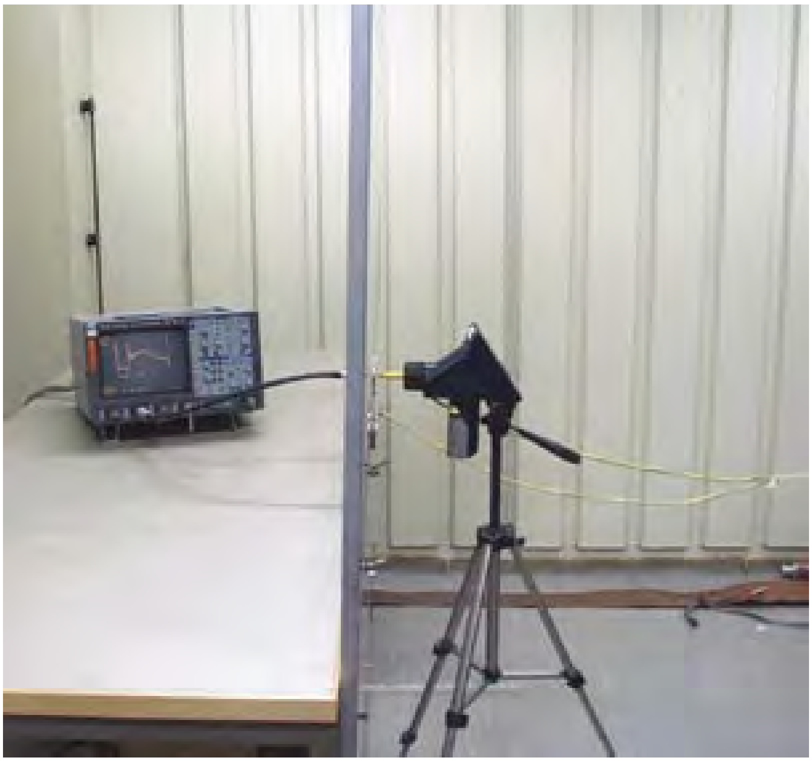

Figure E9. ESD-tester (on the right) is calibrated using a target mounted on a conducting plane. The signal is measured by a wide-band oscilloscope. MIKES-TKK participated in an informal comparison in October 2005.

Comparisons

International comparisons

MIKES

CCEM-K10, DC resistance 100 Ω. Key comparison. Participants: BIPM, CEM, CSIR-NML, CSIRO-NML, METAS, MIKES, NIM, NIST, NMIJ, NRC, PTB (pilot), SMU. The QHR measurements in MIKES were made in 2002. Draft A of the final report was distributed for participants in June 2005. The difference of the MIKES result from the key comparison reference value is well below the comparison uncertainty of about 18 nΩ/Ω (k = 2).

EUROMET.EM.BIPM-K10.a (EUROMET project no. 723), Comparison of Josephson array voltage standards. Key comparison linked with BIPM.EM-K10.a. Participants: BIPM, CMI, DFM, EIM, GUM, IEN, MIKES, NMi-VSL, NPL, PTB (pilot), SP, UME, VNIIM. Josephson array voltage standards of the participants were compared against the portable one of VNIIM at 1 V level. Measurements at MIKES were performed in March, 2004. The comparison was approved for equivalence in 2005 and the results are published in Metrologia 42 (2005), Tech. Suppl., 01005. The results of MIKES are excellent: DoE with respect to the key comparison reference value at 1 V level is (0.1 ± 0.4) nV (k = 2).

EUROMET.EM-K5.1 (EUROMET project no. 687), AC power measurement at 50 Hz. Key comparison to be linked with CCEM-K5. Participants: INM(RO), MIKES, MIRS/SIQ, NCM, NMi-VSL, NPLI, OMH, PTB, SMU, UkrCSM, UME (pilot), ZMDM. Measurements in MIKES were performed in September 2005. Comparison is continuing.

EUROMET.EM-K9 (EUROMET project no. 557), Calibration of high voltage thermal converters. Key comparison linked with CCEM-K9. Participants: AREPA, BEV, BNM-LNE (pilot), CEM, CMI, IEN, INETI, JV, METAS, MIKES, NMi-VSL, NPL, OMH, PTB, SP, UME. Measurements in MIKES were made in May 2000. Draft B of the final report of the comparison appeared in October 2005, and it was approved to the BIPM key comparison database in January 2006. MIKES had some problems with 500 V and 1000 V measurements, particularly at highest frequencies: at 50 kHz and 100 kHz, the MIKES results deviated from the comparison reference value by as much as 20 µV/V to 40 µV/V, and at three points the difference was larger than the uncertainty (k = 2). At 200 V, the difference of MIKES results at all frequencies (1 kHz - 100 kHz) was smaller than the uncertainty (k = 2), which varied between 7 µV/V and 10 µV/V, depending on frequency.

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 A of the final report is under preparation. According to a preliminary report, the results of MIKES show good agreement with the reference value obtained in EUROMET.EM.RF-K8.CL.

EUROMET.EM-S18 (EUROMET project no. 710), Comparison of resistance standards. Supplementary comparison. Participants: DFM, JV (pilot for 1Ω), MIKES, SP (pilot for 10 kΩ). A Nordic comparison on 1Ω and 10 kΩ resistance standards. The measurements in MIKES were made in July/August 2003. The final report of the comparison was approved to the BIPM key comparison database in 2005 and is published in Metrologia 42 (2005), Tech. Suppl., 01009. The comparison was a success. DoE of MIKES with respect to the comparison reference value was (-9 ± 28) nΩ/Ω and (0 ± 49) nΩ/Ω for 1Ω and 10 kΩ, respectively.

EUROMET 860, Time comparison using transportable Cs-clock. In November 2005, MIKES organised a time comparison in which one of the Cs clocks of MIKES was transported by car to SP and back. It was planned that JV would participate the comparison, too, but customs problems prevented transportation of the Cs clock across the border between Sweden and Norway. According to preliminary analysis, the agreement between MIKES and SP is very good.

Bilateral comparison of capacitance standards with SP, Sweden, was arranged in November-December 2005 on scaling the capacitance value from 100 pF up to 1 µF with one decade step. The results, which will be published in CPEM'06 conference, showed good agreement between MIKES and SP.

MIKES-TKK

EUROMET.EM-S12 (EUROMET project no. 488), Impulse voltages. Supplementary comparison. 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. This project has been going on under MIKES-TKK co-ordination since 1999. In 2004 the participants decided not to write the formal final report of the comparison for the BIPM key comparison database but, instead, to present the results in CPEM'06 conference and to publish them in an international journal. The reference measuring system prepared by MIKES-TKK showed excellent performance, and MIKES-TKK comparison results were among the best ones. The feedback from the participants has been very positive.

EUROMET.EM-S14 (EUROMET project no. 495), Measurement of direct voltage ratios ranging from 100000/100 V/V to 100000/1 V/V, with input voltages ranging from 1 kV to 100 kV. Supplementary comparison. Participants: BNM-LCIE, MIKES-TKK, IEN, METAS, NMi-VSL, NPL (pilot), PTB, SP. The measurements for this comparison were carried out by MIKES-TKK in 2000. Draft B became available in June 2005. MIKES-TKK uncertainties ranged from 20 ppm to 40 pmm, depending on the applied voltage. En values ranged from –0.4 to 0.4. MIKES-TKK uncertainties were in the middle class of this comparison.

EUROMET.EM-S21 (EUROMET project no. 599), AC voltage ratio standards. Supplementary comparison. Participants: BEV, CMI (pilot), GUM, LCOE, METAS, MIKES-TKK, OMH, SEPS LPT. Final report was published in 2005 (Metrologia 42 (2005), Tech. Suppl., 01004). See highlights for more information.

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Articles in International Journals

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A. Kärkkäinen, N. Pesonen, M. Suhonen, A. Oja, A. Manninen, N. Tisnek, and H. Seppä, *MEMS based AC voltage reference*, IEEE Trans. Instr. Meas. 54 (2005) 595 - 599.

J. Hassel, P. Helistö, L. Grönberg, H. Seppä, J. Nissilä, and A. Kemppinen, *Stimulated power generation in ES-SIS junction arrays*, IEEE Trans. Instr. Meas. 54 (2005) 632 - 635.

J. Nissilä, A. Kemppinen, K. Ojasalo, A. Manninen J. Hassel, P. Helistö, and H. Seppä, *Realization of a square-wave voltage with externally-shunted SIS Josephson junction arrays for a sub-ppm quantum AC voltage standard*, IEEE Trans. Instr. Meas. 54 (2005) 636 - 640.

G. Marullo-Reedtz, R. Cerri, W. Waldmann, J. Streit, P. Immonen, I. Blanc, F. Raso, T. Funck, B. Schumacher, E.F. Dierikx, M. Nunes, P. Vrabček, D. Rudohradský, O. Gunnarsson, K.-E. Rydler, B. Jeanneret, B. Jeckelmann, T. Pulfer, S.S. Turhan, O. Yilmaz, J.M. Williams, H. Slinde, K. Lind, J. Nicolas, M. Lindic, E. Flouda, and G. Erdos, *Comparison EUROMET. EM-K8 of DC voltage ratio: results*, IEEE Trans. Instr. Meas. 54 (2005) 576 - 579.

J. Nissilä, K. Rytsölä, R. Aavikko, A. Laakso, K. Saarinen and P. Hautojärvi, *Performance analysis of a digital positron lifetime spectrometer*, Nuclear Instruments and Methods in Physics Research A 538 (2005) 778 - 789.

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Y. Li, J. Hällström and W. Lucas: *Comparison of Two Impulse Calibrators with a High Resolution Digitiser*, IEEE Trans. Instr. Meas. 54 (2005) 608 - 611.

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A. Kemppinen, J. Nissilä, K. Ojasalo, J. Hassel, A. Manninen, P. Helistö, and H. Seppä, *AC voltage standard based on a nonhysteretic Josephson junction array*, Proceedings of the XXXIX Annual Conference of the Finnish Physical Society, Espoo, Finland, 17 - 19 March, 2005, abstract 4.13. Poster presented by A. Kemppinen.

A. Kärkkäinen, N. Tisnek, N. Pesonen, M. Suhonen, A. Oja, A. Manninen, and H. Seppä, *Towards MEMS based electrical metrology*, Proceedings of the XXXIX Annual Conference of the Finnish Physical Society, Espoo, Finland, 17 - 19 March, 2005, abstract 11.5. Talk given by A. Kärkkäinen (VTT).

A. Satrapinski, T. Mansten, J. Hämäläinen, and N. Tisnek, *Development and maintenance of impedance standards in MIKES*, Proceedings of 12th International Metrology Congress, Lyon, France, 20 - 23 June, 2005. Poster presented by A. Satrapinski.

J. Nissilä, A. Kemppinen, J. Hassel, and P. Helistö, *Development of a quantum AC voltage standard based on externally-shunted Josephson junction arrays*, 12th International Metrology Congress, Lyon, France, 20 - 23 June, 2005. Talk given by J. Nissilä.

A. Manninen, M. Paalanen, J. Pekola, P. Hakonen, H. Seppä, and P. Helistö, *Quantum metrological triangle*, Nanotechnology in Northern Europe (NTNE 2005), Helsinki, Finland, 26 - 28 April, 2005. Poster presented by A. Manninen.

K. Kalliomäki, T. Mansten, and I. Iisakka, *A new 25 MHz standard frequency and time transmitter for local service*, Proceedings of the 19th European Frequency and Time Forum (EFTF'05), Besançon, France, 21 - 24 March, 2005, pp. 478 - 479. Poster presented by T. Mansten and K. Kalliomäki.

K. Kalliomäki, J. Mannermaa, and T. Mansten, *The effect of counter's trigger level on timing below nanosecond*, Proceedings of the 19th European Frequency and Time Forum (EFTF'05), Besançon, France, 21 - 24 March, 2005, pp. 480 - 482. Poster presented by T. Mansten and K. Kalliomäki.

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P. Sipilä, R. Rajala, P. Kärhä, A. Manninen, and E. Ikonen, *Calibration of current-to-voltage converters for radiometric applications at picoampere level*, Proceedings of the 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, 17 - 19 October, 2005, pp. 223 - 224. Poster presented by P. Kärhä (TKK).

A. Kemppinen, J. Nissilä, K. Ojasalo, J. Hassel, A. Manninen, P. Helistö, and H. Seppä, *AC voltage standard based on an externally-shunted SIS Josephson junctio array*, Extended abstracts of the 10th International Superconductive Electronics Conference (ISEC 2005), Noordwijkerhout, The Netherlands, 5 - 9 September, 2005, paper P-K.12. Poster presented by A. Kemppinen.

MIKES-TKK

J. Hällström, S. Berlijn, M. Gamlin, F. Garnacho, E. Gockenbach, T. Kato, Y. Li, and J. Rungis, *Applicability of different implementations of K-factor filtering schemes for the revision of IEC60060-1 and -2*, XIVth International Symposium on High Voltage Engineering, Beijing, China, 25 - 29 August, 2005, B-32, 1-6.

M. Denicolai and J. Hällström, *A Self-balanced, Liquid Resistive, High Impedance HV Divider*, XIVth International Symposium on High Voltage Engineering, Beijing, China, 25 - 29 August, 2005, J-05, 1-6.

Theses

MIKES

P. Sipilä, *Calibration method for low currents*, Master's Thesis, Helsinki University of Technology, 2005, 93 p.

Photometry and radiometry

Personnel
MIKES-TKK

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Lic.Sc. Markku Vainio	*Research Scientist*
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M.Sc. Meelis-Mait Sildoja	*Research Scientist*
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MBA Johanna Mattila	*Administrative Officer*
Mrs. Jaana Hänninen	*Coordinator*

Helsinki University of Technology (TKK), 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.

According to the agreement made at the end of the year 2004 between MIKES and TKK, the Metrology Research Institute is a joint laboratory of TKK and MIKES with a joint research professorship. Prof. Erkki Ikonen acts as a head of the laboratory and as a research professor.

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

Highlights in 2005

NEWRAD 2005

The largest and most significant international conference in the field of radiometry and photometry was organised in 2005, when the 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD) was held in Davos, Switzerland, in October. In the conference, Erkki Ikonen was elected as the Chairman of the Scientific Committee of NEWRAD. The conference was followed by the 6th Workshop on Ultraviolet Radiation Measurements, organised jointly by PMOD/WRC and the Metrology Research Institute. The Metrology Research Institute had a considerable number of participants in both events and the scientific contribution was extensive with more than ten presentations.

Figure P1. Group photo of the Newrad 2005.

MEASUREMENT GEOMETRIES IN RADIOMETRY

Diffusers are commonly used in radiometric measurements to improve the cosine responses of the measuring heads. However, the translucency of the diffuser material (usually PTFE) may vary with wavelength. This phenomenon shifts the distance reference plane beyond the surface of the diffuser.

Spectroradiometers are usually calibrated at a distance of 500 mm from a spectral irradiance standard lamp. If the distance is measured from the outermost surface of the diffuser, as is a common practice, a possible source of error is introduced: the effective distance reference plane may be inside the diffuser and the calibration distance is too long.

A series of measurements was conducted with spectroradiometer diffusers of TKK and STUK to determine the true locations of the distance reference planes. The results showed that these planes may be several millimetres inside the diffusers, the magnitude of the shift depending on the diffuser material and thickness. If the shift of the distance reference plane is not taken into account during the spectroradiometer calibration, subsequent measurement errors of several per cent, exceeding measurement uncertainties, can be obtained in spectral irradiance measurements. This finding concerns also the measurements of solar UV radiation, and therefore it has high global significance.

Research Projects

INTENSE UV RADIATION FACILITY FOR CALIBRATION OF RADIOMETERS

In this project a calibration facility for spectral irradiance responsivity of UV meters was developed. The setup consists of a single-grating monochromator, a 450-W Xe light source, and apertured reference photodiodes. In 2005, an international pilot comparison was organised, in order to compare the scales of UVA irradiance responsivity of five European institutes. In this pilot comparison, a novel method was introduced to compare the results of different laboratories. This method enabled direct comparison between laboratories utilising different calibration methods and radiation sources. 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. The results are published in the NEWRAD 2005 special edition of Metrologia [J. Envall et al, "Investigation of comparison methods for UVA irradiance responsivity calibration facilities," Metrologia 43, S27-S30, 2006].

Figure P2. Scientists Lamminpää (left) and Envall (the principal author of the UVA meter comparison paper) enjoying the magnificent landscape of Swiss Alps during the NEWRAD conference.

EXTENSION OF THE WAVELENGTH REGIONS OF SPECTRAL IRRADIANCE AND RADIANCE

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 extension in UV region was completed in 2004. In 2005, characterisation of the Ge trap detector for IR region was finished. Results were submitted and accepted to Measurement Science and Technology. The Ge trap detector (Fig. P3) will establish a reliable scale of spectral responsivity up to 1700 nm. The TKK now has a group of spectral irradiance standard lamps, calibrated by NPL, for wavelength region 200 nm - 2.5 µm. These lamps enable a bilateral intercomparison of the extended measurement scales of spectral irradiance and radiance between TKK and NPL.

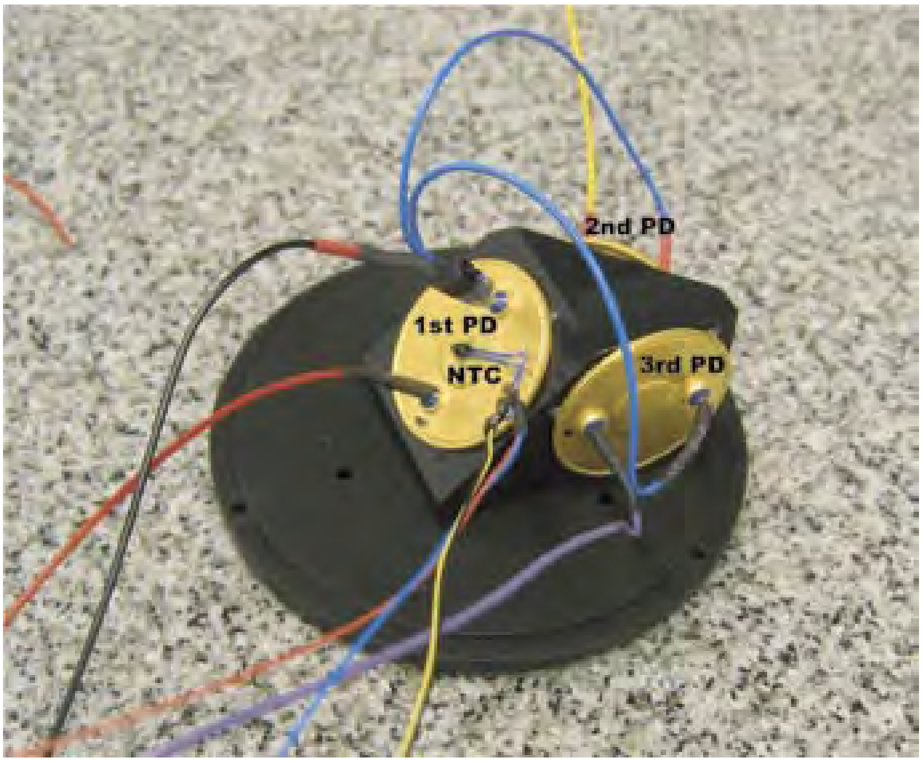


Figure P3. The body part of the Ge trap detector, where the photodiodes (PD) and the NTC temperature sensor are marked. Light enters to the trap from the direction of the table.

DETERMINATION OF RADIATION TEMPERATURE USING FILTER RADIOMETERS

In this collaboration project of TKK and the temperature laboratory of MIKES, a new approach for measuring the radiation temperature of a blackbody radiator is tested. Spectral irradiance of the high precision black-body is measured with absolutely characterised filter radio-meters in near-IR wavelength region. In 2005 the work was focused on extending the measurement range towards lower temperatures. To accomplish this, the measurement accuracy of currents in picoampere level was improved and a filter radiometer based on a Ge-diode was tested. The freezing temperature of aluminium (660.32 °C) was measured. A comparison of laser-based calibration methods for filter radiometers with the NIST was started.

MEASUREMENT SETUP FOR NONLINEARITY OF OPTICAL FIBRES

The ever growing need of transmission capacity in optical networks demands high optical power levels and dense wavelength spacing. Due to these facts, the total light intensity inside the fibre becomes high and therefore nonlinear effects become significant. In optical fibres, this intensity dependent part of the refractive index is called as nonlinear refractive index, n_2.

In TKK we have improved traditional continuous-wave self-phase modulation method by combining simulations and measurements. Another important issue related to this research has been extension of the measurement range of high fibre optic power up to 650 mW. With this approach we have been able to reduce the uncertainty in the determination of nonlinear coefficient of optical fibres, n_2/A_{eff}, from the level of 6.4 % to 2.0 % (k = 2). This allows us to study more accurately for instance effect of different dopants used in the optical fibres.

CALIBRATION FACILITY FOR COLOUR DISPLAYS AND COLORIMETERS

The aim of this project is to develop a calibration facility for colour displays and colorimeters. The calibration facility is intended for measuring the relative spectral radiance of colour displays with expanded uncertainty of lower than 0.7 % (k = 2). The facility comprises of an automated setup built by using a heavy-duty linear translator, a rotational table, and a spectroradiometer. The project progressed in the year 2005 with test measurements of display devices for luminance using our transfer standard spectroradiometer traceable to the laboratory's primary scale. The facility also has a scanning spectroradiometer as its reference device with a high accuracy wavelength and spectral responsivity scales.

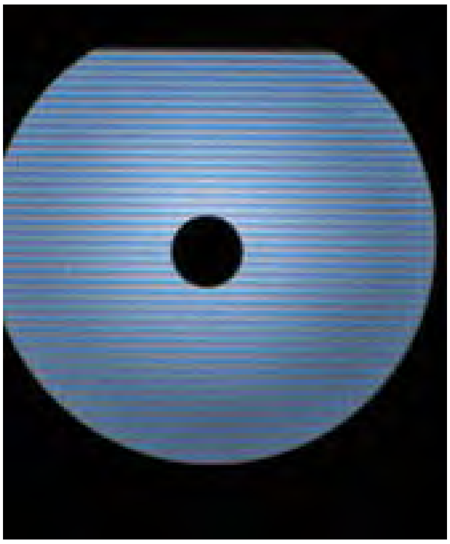


Figure P4. Measurement of an LCD display in progress.

METROLOGY OF LED LIGHT SOURCES

In this project, the previously developed method for determination of the luminous intensity of light emitting diodes (LEDs) was tested for several LEDs with different sizes, packages and lenses. The data analysis is based on modified inverse-square law; the illuminance values, measured at several distances from the LED, are fitted to a mathematical model that includes parameters also for the location and the size of the LED source. The results were very consistent regardless of type of LED. It was also noticed that the modelled size of the LED source is a function of the size of the light beam of the LED.

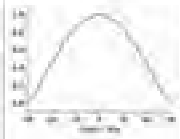
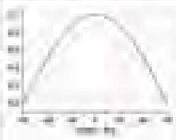
MEASUREMENT GEOMETRIES IN RADIOMETRY

During 2005, offsets of the distance reference planes of four spectroradiometer diffusers were studied at four wavelengths from UV to NIR (see Table P5). The measured distance offsets and the cosine responses of the diffusers were found to be wavelength-dependent. Also, a clear correlation between the cosine response and the distance offset at different wavelengths was observed. The most remarkable result was that one diffuser, commonly used in solar UV measurements, causes a calibration error of 2.5 % if the calibration is performed as usual and the actual distance reference plane of the diffuser is not determined. An article about the calibration distance errors in spectroradiometer calibrations has been accepted for publication in Metrologia.

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 %. In the year 2005 we built and characterised a detection system in conjunction with the reference gonioreflectometer. The detection system comprises of a CCD detector, a collection lens, a light guide and a monochromator with necessary electronics. Test measurements of known fluorescent samples were performed for the wavelength range of 300–700 nm. The project will continue for improvements in the automation as well as detection systems.

Table P5. The results for spectroradiometer diffusers. Schreder diffuser is commonly used in solar UV measurements. Surprisingly, it had the largest distance offset, leading to substantial calibration errors if distance reference plane is assumed to be on top of the dome-shaped diffuser.

Manufacturer and type		Bentham D3	Bentham D5	Bentham D7	Schreder J1002-01
Picture of the diffuser					
Material		WF quartz	PTFE	PTFE	PTFE
Offset (mm)	UVA	2.3	0.4	-0.3	6.4
	Green	2.6	1.2	0.1	6.5
	Red	3.6	3.2	0.3	7.8
	NIR	2.5	7.9	0.1	8.3
Cosine response					

Comparisons

International comparisons

CCPR-K1.a International comparison of spectral irradiance in the wavelength region 250 - 2500 nm
In 2005 the final report was published. The results of TKK are good in the wavelength range 290-900 nm used in the comparison.

CCPR-K2.a International comparison of spectral responsivity in the wavelength region 900 - 1600 nm
Draft A-2 was circulated to participants in 2005. Draft B is expected in 2006.

CCPR-K2.c International comparison of spectral responsivity in the wavelength region 200 – 400 nm
TKK measurements were completed in 2004. Draft A is expected in 2007.

CCPR-K5 International comparison of spectral diffuse reflectance in the wavelength region 360 - 830 nm
TKK results were submitted in 2004. Draft A is expected in 2006-2007.

CCPR-K6 International comparison of regular spectral transmittance in the wavelength region 380 - 1000 nm
Measurements completed. No progress in 2005.

CCPR-S2 International comparison of aperture area measurements
Draft A was circulated to participants in 2005.

Bilateral comparison of ultraviolet filter radiometers with NIST
In this project, TKK and NIST characterised spectral irradiance responsivities of ultraviolet filter radiometers and the results are compared. The results were published in the proceedings of NEWRAD 2005 conference and had a good agreement at 365 nm wavelength.

Multilateral comparison of wavelength scales with NIST
In 2005 the final report was published [John C. Travis et al, Journal of Physical and Chemical Reference Data, 34, 41-56 (2005)]. TKK results indicate good agreement with the consensus average.

EUROMET 666 Intercomparison of Chromatic Dispersion Reference Fibres
Final report was published in 2005. TKK results showed a deviation from the comparison reference value. The measurements of a subsequent bilateral comparison were carried out in 2005 with METAS.

Trilateral comparison of high fibre optic power calibrations with SP and DFM
In 2005, the final report was published [J. Envall et al, Appl. Opt. 44, 5013-5017 (2005)]. The results indicate good agreement (~1%) of the new realisations. This value is well within uncertainties of the measurements.

Bilateral comparison of spectral diffuse reflectance with SPRING Singapore
Measurements at SPRING were completed in 2004. Return measurements at TKK were made in 2005 and the results were published in the NEWRAD 2005 proceedings. The agreement between the results was good.

Bilateral comparison of aperture area and luminous responsivity measurements with KRISS
In 2003, TKK conducted their measurements of this bilateral comparison. The artefacts were transported to Korea. The results were discussed in 2004-2005 and published in the NEWRAD 2005 proceedings. The agreement between the results was approximately within the expanded uncertainties (*k*=2).

Publications

Articles in International Journals

M. Noorma, P. Kärhä, A. Lamminpää, S. Nevas, and E. Ikonen, *Characterization of GaAsP trap detector for radiometric measurements in ultraviolet wavelength range*, Rev. Sci. Instrum. 76, 033110 (2005).

A. Lamminpää, T. Niemi, E. Ikonen, P. Marttila, and H. Ludvigsen, *Effects of dispersion on nonlinearity measurement of optical fibers*, Opt. Fiber Technol. 11, 278-285 (2005).

J. C. Travis, J. C. Acosta, G. Andor, J. Bastie, P. Blattner, C. J. Chunnilall, S. C. Crosson, D. L. Duewer, E. A. Early, F. Hengstberger, C-S. Kim, L. Liedquist, F. Manoocheri, F. Mercader, A. Mito, L.A.G. Monard, S. Nevas, M. Nilsson, M. Noël, A. Corróns Rodriguez, A. Ruíz, A. Schirmacher, M. V. Smith, G. Valencia, N. van Tonder, J. Zwinkels, *Intrinsic wavelength standard absorption bands in holmium oxide solution for UV/visible molecular absorption spectrophotometry*, Journal of Physical and Chemical Reference Data 34, 41-56 (2005).

M. Puranen, P. Eskelinen, and P. Kärhä, *Fiber-optic radar calibration*, IEEE Aerospace and Electronic Systems Magazine 20 (9), 30-33 (2005).

J. Hovila, M. Mustonen, P. Kärhä, E. Ikonen, *Determination of the diffuser reference plane for accurate illuminance responsivity calibrations*, Appl. Opt. 44, 5894-5898 (2005).

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A. Lamminpää, S. Nevas, F. Manoocheri and E. Ikonen, *Characterization of thin films based on reflectance and transmittance measurements at oblique angles of incidence*, Accepted for publication in Appl. Opt., Feature Issue Optical Interference Coatings (2005).

Conference Presentations

M. Noorma, P. Kärhä, T. Jankowski, F. Manoocheri, T. Weckström, L. Uusipaikka, and E. Ikonen, *Absolute detector-based radiometric temperature scale*, in the Proceedings of TEMPMEKO 2004, Cavtat, Croatia, June 21-26, 2004, pp. 101-106. (published in 2005).

E. Ikonen, *Excess coincidences of photons*, in Proceedings of Photonics and Laser Symposium PALS 2005, Kajaani, Finland, February 23-25, 2005; Erkki Ikonen (invited talk).

A. Andersson, J. Envall, P. Kärhä, E. Ikonen, and J. Petersen, *Results and experiences from high fibre optic power calibration comparison*, in Proceedings of 12th International Metrology Congress, Lyon, France, June 20-23, 2005 (CD, 6 p.) (poster).

A. Lamminpää, M. Noorma, T. Hyyppä, F. Manoocheri, P. Kärhä, and E. Ikonen, *Characterization of germanium detectors for applications of spectral irradiance measurements*, in Proceedings of 2005 NCSLI Workshop & Symposium, Advances in Science and Technology – Their Impact on Metrology, Washington D.C., USA, August 7-11, 2005 ISBN 1-58464-046-4, CD (talk).

A. Lamminpää, T. Niemi, J. Envall, H. Ludvigsen, P. Marttila, and E. Ikonen, *Uncertainty contributions related to dispersion and power measurement in determination of fiber nonlinearity using continuous-wave self-phase modulation*, in Proceedings of OFMC 2005, London, UK, September 21-23, 2005, pp. 63-67. (talk).

A. Lamminpää, M. Noorma, T. Hyyppä, F. Manoocheri, P. Kärhä, and E. Ikonen, *Characterization of germanium photodiodes and trap detector*, in Proceedings of 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005, pp. 209-210. (poster).

F. Manoocheri, S. Holopainen, S. Nevas, and E. Ikonen, *On potential discrepancies between goniometric and sphere-based spectral diffuse reflectance*, in Proceedings of 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005, pp. 101-102. (poster).

S. Nevas, A. Lamminpää, P. Kärhä, and E. Ikonen, *Analysis of the uncertainty propagation through fitting spectral irradiance data*, in Proceedings of 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005, pp. 263-264. (poster).

P. Kärhä, P. Manninen, J. Hovila, L. Seppälä and E. Ikonen, *Determination of luminous intensity of light-emitting diodes with modified inverse-square law*, in Proceedings of 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005, pp. 211-212. (talk).

J. Hovila, P. Manninen, L. Seppälä, P. Kärhä, L. Ylianttila and E. Ikonen, *Determination of the diffuser reference plane for accurate photometric and radiometric measurements,* in Proceedings of 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005, pp. 201-202. (poster).

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P. Sipilä, R. Rajala, P. Kärhä, A. Manninen, and E. Ikonen, *Calibration of current-to-voltage converters for radiometric applications at picoampere level*, in Proceedings of 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005, pp. 223-224. (poster).

S. Nevas, S. Holopainen, F. Manoocheri, E. Ikonen, Yuanjie Liu, Tan Hwee Lang, and Gan Xu, *Comparison measurements of spectral diffuse reflectance*, in Proceedings of 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005, pp. 239-240. (poster).

Seung Nam Park, Dong Hoon Lee, Yong-Wan Kim, In-Won Lee, E. Ikonen, M. Noorma, and F. Manoocheri, *Detailed comparison of illuminance scale realizations of KRISS and TKK*, in Proceedings of 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005, pp. 325-326. (poster).

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A. Heikkilä, K. Hanhi, J. Kaurola, T. Koskela, J. Koskinen, P. Kärhä, A. Tanskanen, and T. Ture, *UVEMA: A new project exploring degrading effects of UV radiation on materials*, in Abstracts of Presentations of 6th Workshop on Ultraviolet Radiation Measurements, Davos, Switzerland, October 20–21, 2005, p. 38. (poster).

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,* in Abstracts of Presentations of 6th Workshop on Ultraviolet Radiation Measurements, Davos, Switzerland, October 20–21, 2005, pp. 4-5. (talk).

Other Publications

M. Noorma, V. Ahtee, A. Lamminpää, P. Kärhä, F. Manoocheri, T. Weckström and E. Ikonen, *Radiometric temperature measurements with absolutely characterized filter radiometers in irradiance mode*, Metrology Research Institute, Helsinki University of Technology, Espoo 2005, Metrology Research Institute Report 24/2005, 11 p., ISBN 951-22-7837-5.

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O. Kimmelma (editor), *Biennial report 2003-2004, Metrology Research Institute*, Helsinki University of Technology, Espoo 2005, Metrology Research Institute Report 26/2005, 56 p.

S. Nevas, S. Holopainen, F. Manoocheri, E. Ikonen, Y. Liu, T.H. Lang, G. Xu, *Comparison measurements of spectral diffuse reflectance*, Metrology Research Institute, Helsinki University of Technology, Espoo 2005, Metrology Research Institute Report 27/2005, 7 p., ISBN 951-22-7836-7.

E. Ikonen, *Optiikan perusteet*, 3rd edition, Espoo 2005, 111 p., ISBN 951-22-4709-7 (in Finnish).

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J. Hovila, *New Measurement Standards and Methods for Photometry and Radiometry*, TKK Dissertations 18, Espoo 2005, 44 p.

Ionising radiation

Personnel
STUK

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M.Sc. Petri Sipilä	*Physicist*
M.Sc. Hannu Järvinen	*Physicist*
Ms. Carita Ruuhonen	*Secretary*

On the basis of its own legislation, the Radiation and Nuclear Safety Authority (STUK) 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 2005

The air kerma to dose equivalent conversion factors for reference x-ray radiation qualities of ISO Narrow spectra below 60 kV (International Standard ISO 4037-3, 1999, Draft International Standard ISO/DIS 4037-4, 2002) were determined. The pulse height spectra were measured using a planar high-purity Ge spectrometer and a specially designed lead collimator. The pulse height spectra were unfolded to fluence spectra using Monte Carlo generated data of the spectrometer response. The agreement with ISO 4037-3 was within 1 % for x-ray spectra above 30 kV. For low energy x-rays below 30 kV (ISO 4037-4) the determined conversion factors were taken into use. The results were presented in the workshop of individual monitoring and the original publication was accepted to be published in the proceedings of the workshop.

REALISATION, MAINTENANCE

Secondary standard for brachytherapy dosimetry, a well type ionisation chamber HDR 1000 Plus, was calibrated for reference air kerma rate of ^{192}Ir photon radiation at PTB. X-ray beam collimation and method for calibration of dose length -product meters used in computed tomography was established.

An external audit by Mr. Hans Bjerke from Norwegian Radiation Protection Authority (NRPA) was performed. No severe remarks were made by the auditor. Observations for deficiencies in documentation of verification method of skills of persons performing calibrations, recognition of equipment out of use, documentation of calibrations of thermo and barometers, and improvements for calibration certificates were reported.

Quality control and internal audits were performed according to the established procedures.

Figure I1. Measurement set-up for measurement of half value layers for x-ray radiation beams.

Research Projects

The Radiation Metrology Laboratory of STUK participated in EU shared cost project, SENTINEL, "Safety and efficacy for new techniques and imaging using new equipment to support European legislation" (year 2005 - 2007) and in a IAEA Coordinated Research Project "Testing of the Implementation of the Code of Practice on Dosimetry in X-ray Diagnostic Radiology" (years 2005 - 2007).

Comparisons

International comparisons

In 2005 the laboratory participated in three EUROMET regional key comparisons, comparison of calibrations of reference instruments for air kerma x-rays (comparison project 545), comparison of calibrations of dosemeters for personal dose equivalent (comparison project 738) and comparison of calibrations of radiotherapy dosemeters for absorbed dose to water in ^{60}Co gamma radiation beam (comparison project 813). The results of these comparisons were not yet available.

Laboratory participated also in the annual TLD dosimetry audit for radiotherapy level dosimetry organised by IAEA/WHO secondary standard laboratory network. Measurements were performed in a ^{60}Co gamma radiation beam at the STUK standard laboratory and in a 6 MV photon radiation beam in a linear radiotherapy accelerator. The difference between the results of STUK and IAEA were 0.2 % for ^{60}Co gamma radiation and 0.6 % for 6 MV linear accelerator. These results are well within the stated tolerance level of 3.5 % by IAEA.

Publications

Conference Presentations

P. Pöyry, T. Komppa, A. Kosunen, *Calibration of dose-area product meters for diagnostic X-ray beams*, in Proceedings of the XXXIX Annual Conference of the Finnish Physical Society, 17-19 March 2005, Espoo, Finland. Technical University publications, Espoo, Finland, 2005.

A. Hakanen, A. Kosunen, P. Pöyry, M. Tapiovaara, *Determination of air kerma to dose equivalent conversion factors for X-ray spectra*, Book of Abstracts, IM 2005, European workshop on individual monitoring of ionising radiation 11-15 April 2005, Vienna, Austria. p. 64.

Other Publications

A. Kosunen, P. Sipilä, R. Parkkinen, I. Jokelainen, H. Järvinen, *Sädehoidon annosmittaukset. Ulkoisen sädehoidon suurenergisten fotoni- ja elektronisäteilykeilojen kalibrointi*, STUK-STO-TR 1, Helsinki, Säteilyturvakeskus, 2005. (In Finnish).

P. Pöyry, *DAP-mittarin käyttö*, in book: H. Järvinen (ed.), Säteilyturvallisuus ja laatu röntgendiagnostiikassa 2005, STUK-C4, Helsinki, Säteilyturvakeskus, 2005, pp. 17-21. (In Finnish).

Chemistry

Personnel
MIKES-FMI

Phil.Lic. Jari Walden	*Head of the Laboratory*
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)*
Dr. Pirjo Kuronen	*Researcher*
B.Sc. Markus Talka	*Researcher*
Mr. Kai Lindgren	*Technician*

MIKES has a contract with the Finnish Meteorological Institute (FMI) nominating its laboratory to take care of 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 LABORATORY

The mission of the laboratory is to provide calibration services to our customers according to the requirements by CIPM. The laboratory has also a task as a national reference laboratory in the field of air quality to maintain the quality control of the national air quality measurements, to organise training, and to do research work on the development of calibration and measurement methods for ambient air quality measurements.

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 re-certification of the gas standards or re-calibration of the calibration facilities or analysers. 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 and measurement service for atmospheric gaseous pollutants such as carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2), and the BTEX-compounds including benzene (C_6H_6), toluene (C_7H_8), ethylbenzene (C_8H_{10}), and o-, m-, and p-xylenes (C_8H_{10}). The traceability of the calibration concentration produced in the laboratory is to SI 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 Centre for Metrology and Accreditation, MIKES (FI). The reference gas standards of the laboratory for carbon monoxide, nitrogen monoxide and sulphur dioxide are those of the secondary gas standard of NPL and NMi. The ozone reference standard is the Standard Reference Photometer by NIST (Fig. C1). 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 (Fig. C2). The gas concentrations are produced by dynamic dilution method or by static injection of the reference or secondary gas standards.

The validation of the SRP and the flow measurement system (Fig. C3) were completed in 2005 and were included into the quality system of the laboratory.

Figure C1. The Standard Reference Photometer (SRP no 37) by NIST for ozone calibration. The traceability of the ozone concentration is to BIPM by direct comparison of the two SRPs by NIST. Dr Pirjo Kuronen is preparing the calibration.

Figure C2. Sisko Laurila is operating the permeation method for calibration purpose of NO_2, SO_2, benzene, toluene, o- and m-xylenes.

Research Projects

During the year 2005 the laboratory participated in the research project on the micrometeorological methods for measurements of landfill gas emissions and evaporation. The project consisted of field measurements on a landfill area at the Helsinki metropolitan area. Our responsibility in the project was to measure methane and nitrous oxide fluxes by gradient method. The responsibility supported our task to research and to develop measurement techniques in the area of air quality. The work started in June 2003 and was finished in May, 2005.

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.

Comparisons

The laboratory participated in the 1st EC BTEX Intercomparison Exercise in Ispra 10 – 14 October 2005 organised by European Reference Laboratory for Air Pollution, ERLAP (Fig. C4).

Publications

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C. Libiseller, A. Grimvall, J. Walden and H. Saari, 2005, *Meteorological normalisation and non-parametric smoothing for quality assessment and trend analysis of tropospheric ozone data*, Environmental Monitoring and Assessment, 100, 33-52.

Figure C3. Kaisa Lusa is calibrating the flow meter with the DHI-laminar flow element. The flow measurement system is used for calibration of the flow measurement devices (e.g. mass flow controllers) and the gas dilution devices.

Figure C4. The 1st EC BTEX Intercomparison Exercise at the ERLAP (Ispra) during 10 – 14 October 2005. Dr Pirjo Kuronen from the FMI sitting in the middle.

Contact information of the National Standards Laboratories

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Contact information of the Contract Laboratories

CONTRACT LABORATORY	QUANTITY	HEAD OF LABORATORY	EMAIL ADDRESS
Tampere University of Technology Institute of Production Engineering Measurement laboratory P.O. Box 589 FI-33101 Tampere tel. +358 3 311511 fax +358 3 31152 753	coordinate measurement coordinate measuring machines	Heikki Tikka	heikki.tikka@tut.fi
Raute Precision Oy Mass and Force Laboratory P.O. Box 22 FI-15801 Lahti tel. +358 3 829 21 fax + 358 3 829 4101	force and torque	Aimo Pusa	aimo.pusa@rauteprecision.fi
Finnish Meteorological Institute Air Quality Research Erik Palménin aukio 1 FI-00560 Helsinki tel. +358 9 19291 fax +358 9 1929 5403	air quality	Jari Walden	jari.walden@fmi.fi

Information about Finnish accredited calibration laboratories can be found at www.mikes.fi

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ISBN 952-5610-13-6