METROLOGY: THE SCIENCE OF MEASUREMENT
Metrology is the science of measurements and is the backbone of our high-tech society. Most aspects of daily life are influenced by metrology, and increasingly accurate and reliable measurements are essential to drive innovation and economic growth.

DFM PROFILE
DFM is appointed as the Danish National Metrology Institute and contributes to the integrity, efficiency and impartiality of the world metrology system. DFM is also responsible for coordinating the Danish metrology infrastructure. DFM is a fully owned subsidiary of DTU, the Technical University of Denmark.

DFM ACTIVITIES
DFM’s scientific research results in new knowledge, measurement techniques and standards, which support the needs of Danish industry and authorities for accurate measurements.

The services offered are high-level calibrations and reference materials traceable to national primary or reference standards, training courses related to metrology and consultancy services.

DFM has a special role in developing measurement capabilities needed by small and medium sized high-tech companies in order for them to evolve and prosper.

DFM works to ensure global confidence in Danish metrology services, which are critical for competing in the global marketplace.

ANNUAL REPORT 2017 EDITED BY
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DESIGN
www.faenodesign.dk 5420 - 0518

May 2018
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact of Metrology</td>
<td>4</td>
</tr>
<tr>
<td>Management Report 2017</td>
<td>5</td>
</tr>
<tr>
<td>Quality Assurance of the Biggest European Mirror Telescope</td>
<td>6</td>
</tr>
<tr>
<td>Reliable Measurements to Document the State of Wind Turbine Blades</td>
<td>7</td>
</tr>
<tr>
<td>High Accuracy Secondary pH Buffer Measurement</td>
<td>8</td>
</tr>
<tr>
<td>Towards In-line Control of Mass-produced Nanostructures</td>
<td>9</td>
</tr>
<tr>
<td>Raman Spectroscopy – a Powerful Analytical Tool for Pharmaceutical Formulation Development</td>
<td>10</td>
</tr>
<tr>
<td>Photocatalysis under the Microscope</td>
<td>11</td>
</tr>
<tr>
<td>New Part-time Education in Measurement Technology</td>
<td>12</td>
</tr>
<tr>
<td>International Comparability of Electrolytic Conductivity</td>
<td>13</td>
</tr>
<tr>
<td>Accounts of Particular Activities</td>
<td>14</td>
</tr>
<tr>
<td>Income Statement and Balance Sheet</td>
<td>18</td>
</tr>
<tr>
<td>Key Figures</td>
<td>19</td>
</tr>
<tr>
<td>Danish Metrology Institutes</td>
<td>20</td>
</tr>
<tr>
<td>The 12 Subject Fields of Metrology</td>
<td>21</td>
</tr>
<tr>
<td>Details of Personnel</td>
<td>22</td>
</tr>
</tbody>
</table>
Measurement plays a critical role in providing a basis for accurate and fair trade, optimization of production, the promotion of consumer and business confidence in products, the development of new technologies, and continued innovation.

Measurements of physical and chemical quantities are part of our everyday lives. Industry relies heavily on accurate measurements to foster innovation and develop efficient manufacturing methods. A wide range of measurements are occurring daily, with the extent of their benefits on our daily lives generally going unnoticed. Fair trade, consumer protection, health & safety, law and order, and environment monitoring are just some of the areas of modern life, in which the benefits of accurate, trustworthy measurements have real impact.

Metrology links science and economic activity closely, as measurement is a cornerstone for economic transactions, optimization of production, consumer and business confidence, and innovation.

Key economic benefits include reduced transaction costs, increased economic efficiency, and support for innovation.

Greater market efficiency arises from trust. Accurate measurements, based on agreed upon standards, methods, and systems of units, enable a common basis for quantification and quality assurance. Under this framework, a buyer can trust the specifications ascribed to a product, as supplied by the manufacturer/trader partner or assured by a third party (accredited laboratory), including the quality of the trade goods. Hence, time and money are saved through avoidance of re-verification of such properties. Dependable measurements thus facilitate more numerous and efficient economic transactions.

National measurement institutes, such as DFM, play a key role in managing and developing national measurement systems, providing measurement standards and calibration-testing facilities, and enabling businesses to make accurate and traceable measurements.
DFM has experienced significant growth in recent years, and at the end of 2016 it was decided to move all activities to a new and larger facility. The relocation was completed in December 2017. DFM’s total revenue for the year grew 11% to 35.0 million DKK - the highest in DFM’s history. The profit was 0.5 million DKK in line with the budget. The management is pleased with DFM’s growth, and considers both revenue and profit as satisfactory.

Overall research activities increased in 2017, partly due to increased participation in H2020 projects as well as other national and international projects, partly due to entering into a new metrology area “metrology for drones”. The activities have led to introduction of new metrology services for Danish industry and ensured that DFM maintained a high number of publications in international refereed journals.

DFM invested 15.9 million DKK in new, improved and expanded laboratory infrastructure at the new facility. The infrastructure is optimized for future metrology requirements by Danish industry. The investment is by far the largest in DFM’s history, and will ensure that DFM can continue to expand activities in the future as well as provide opportunities for industry to directly make use of DFM’s infrastructure.

Sales of calibration services grew 36% driven primarily by increased demand from the pharmaceutical sector. The total number of customers also increased, demonstrating the increasing need for advanced metrology competences and services.

DFM continues to support Danish SMEs by providing new technology to underpin their growth. This is partly accomplished on a commercial basis, partly by collaboration in funded projects. There was an increase in total project activities as well as the number of involved SMEs. DFM was awarded a range of new H2020 projects in 2017 including Eurostars, Eureka Turbo and EMPIR projects.

DFM will continue to focus on developing new advanced metrology services required by industry and expects to continue to grow in the future, as demand continues to increase.
QUALITY ASSURANCE OF THE BIGGEST EUROPEAN MIRROR TELESCOPE

As part of the maintenance of the reflective European Extremely Large Telescope, the development of a new beyond state-of-the-art procedure has been required. DFM has used its advanced nanometrology facilities to measure surface roughness with sub-nanometer accuracy, which is required to provide a performance 16 times better than the Hubble Space telescope.

The European Southern Observatory agency is currently constructing the European Extremely Large Telescope (E-ELT) on a Chilean mountain at 3000 m above sea level. The 39.3 m diameter reflecting telescope consists of 798 mirror segments that can be individually corrected for atmospheric disturbances by active optics (laser guide star units), complemented by adaptive optics. The observatory aims to gather 100 million times more light than the human eye is capable of, which is 13 times greater than the largest optical telescopes have achieved so far. It has around 256 times the light gathering area of the Hubble Space Telescope and, according its specifications, should provide images 16 times sharper than Hubble’s. The E-ELT is planned to “see first light” (be operational) in 2024.

These ambitions require beyond state-of-the-art maintenance procedures for all the mirror segments, which need to undergo, periodically, a thorough recoating process. During this process, the reflection layer of each mirror is chemically stripped from the underlying glass substrate, followed by fresh re-deposition in order to consistently produce a high-quality reflective surface, with a surface roughness in the order of 1 nanometer. Existing state-of-the-art procedures are not applicable, as the observatory’s isolated location poses huge logistic challenges for both the sourcing of stripping chemicals, as well as waste disposal. In addition, the sheer size of each hexagonal mirror segment (1.4 m across) requires a high level of homogeneity and thoroughness in each treatment. The situation gets further complicated by the anticipated occasional earth-quakes in the Chilean mountain region.

The existing stripping processes have been reviewed by DTU IPU and Professor P. Møller (DTU Mechanical Engineering). DFM has participated in this process with its accredited measurement capability for surface roughness with sub-nanometer accuracy. During the development of the highly sophisticated new cleaning procedure, DFM measured on various glass samples before and after they had undergone a series of cleaning sequences, which simulated the wear during a mirror’s lifetime on the mountain top. Measuring methods have been applied using both optical non-contact interferometric microscopy and tactile atomic force microscopy in order to produce 3D images of the glass surfaces on the nanometer scale. With these high-resolution imaging techniques capable of seeing steps of single atomic layers on the substrate, DFM has contributed to assuring the partners that each mirror segment, over its total expected life time, with up to 20 cleaning processes anticipated, can be stripped and recoated with the same high-quality reflective finish over and over again. We look forward to 2024 and the E-ELT’s “first light”!
Erosion of wind turbine blades has a vital effect on their energy production capability. DFM is partner in a project developing a new blade inspection system that will provide reliable quantification of the erosion. This is highly correlated to the annual energy production of wind turbines.

Over time, an increasing leading edge roughness (LER) of wind turbine blades due to erosion reduces the aerodynamic performance and hence the annual energy production (AEP). With increasing erosion, the turbine owners have to decide if the loss in AEP becomes large enough to warrant repair. However, current methods of visual inspection of erosion give very limited information to aid in this decisionmaking. Accordingly, no tools currently exist for quantitatively linking the state of a blade to the aerodynamic performance and loss in AEP.

This is why DFM is partnering with DTU Wind, AAU, and Power Curve to develop a quantitative LER inspection tool in the EUDP project “Leading Edge Roughness of wind turbine blades”. The system uses a flying drone developed by AAU to do high resolution 3D reconstruction of the blades’ surface and quantify the amount of erosion. Subsequently, DTU Wind are turning these erosion measurements into estimates of reduced AEP. Ultimately, this system is to be sold by Power Curve.

To ensure an accurate estimate of the AEP loss, the role of DFM is to validate the accuracy of the 3D reconstructions and ensure a reliable quantification of the erosion. DFM carried out 3D topography measurements on reference artefacts using microscopy methods. DFM then compared these results with the 3D reconstructions from the AAU system. Since very little knowledge about the geometry of blade erosion is available, a quantitative description has to be developed in the project. In order to study the topography of the erosion on real-life blades in the laboratory, DFM copied the selected area of the blade by replication molding. Then, DFM carried out a 3D measurement of the replica by means of microscopy.

“We have chosen to work with DFM because they have unique skills required to validate our ‘eyes’ in the air. They develop validation and quality assurance tools for the 3D reconstructions as the accuracy is absolutely crucial” says Niels Fiiil Brønnum (CEO of Power Curve). He continues: “When I sell the product, it is also a quality stamp to the customer that DFM has been involved to document the reliability of our measurements. The involvement of experts means a lot for the credibility of our product.”
The lowest possible uncertainties in pH values can be attributed to primary buffers: an internationally agreed set of 8 buffers, which have their pH values certified using the primary method. While DFM produces five of these buffers (pH 4-10) annually, the complexity of their production and certification, as well as extremely short shelf-lives, make their routine use for pH electrode calibration prohibitive. In 2017, DFM developed a system for the certification of secondary pH buffers. The certification setup includes a thermostated chamber, allowing temperature control of 0.005°C between 25 and 37°C. The certification of an unknown buffered solution is performed by a high quality pH electrode, which is calibrated in-situ, under identical temperature and mixing/flow conditions. The calibration procedure is bracketing (i.e., one pH value higher, and one lower than the solution under test), with two certified secondary pH buffers, traceable to DFM’s primary pH buffers. Depending on the bracketing pH buffer combinations, the uncertainty of pH measurements of unknown solutions can be as low as 0.008 pH units (expanded uncertainty). This is demonstrated for a non-standard buffer, pH(X), at 25°C in the graph above.

As a response to industrial demand, DFM can now provide secondary pH buffer measurements with lower uncertainty than previously available. Buffers used by industry generally have long shelf life and relative high uncertainty. DFM’s new service will aid in reducing the uncertainties for the benefit of medical applications.

In chemistry, pH measurements are one of the most frequently measured parameters of aqueous solutions, in a wide variety of industries: manufacturing, pharmaceuticals, water treatment etc. Routine pH measurements are carried out using commercially-available pH electrodes: a very common tool, found everywhere from the classroom to the production floor. These deliver measurements which can be fast, reliable, and depending on the solution under measurement, dependable over the span of years. However, they are extremely sensitive, requiring stringent storage conditions, frequent regeneration and calibration procedures.

The accuracy of pH measurements made with commercial electrodes are dependent on the quality of the solutions employed for calibration. The pH of standard buffers, and the behavior of pH electrodes are temperature dependent. Such that, ideally, pH electrode calibration and routine measurements should be done under identical temperature conditions. Calibration buffers are available from a wide range of suppliers. These may come with a range of features, including added colorants for ease of use, but are all relatively cheap and have long shelf-lives, spanning multiple years. To accommodate the bottle-to-bottle differences of production batches, and gradual change over time, these commercial buffers may have relatively high uncertainties in their pH values.

The certification of an unknown buffered solution is performed by a high quality pH electrode, which is calibrated in-situ, under identical temperature and mixing/flow conditions. The calibration procedure is bracketing (i.e., one pH value higher, and one lower than the solution under test), with two certified secondary pH buffers, traceable to DFM’s primary pH buffers. Depending on the bracketing pH buffer combinations, the uncertainty of pH measurements of unknown solutions can be as low as 0.008 pH units (expanded uncertainty). This is demonstrated for a non-standard buffer, pH(X), at 25°C in the graph above.

At 25°C, using two bracketing pH standards (pH(S1) = 7.413 and pH(S2) = 9.18), measurement of an unknown buffered solution with nominal pH(X) = 7.96 ± 0.03. Demonstrating the agreement between measured and nominal values, within manufacturer’s uncertainty, improved expanded uncertainty of each measurement, and agreement between experimental replicates.

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By accurate engineering on the nanometer scale, surfaces can be imparted functionalities such as colors without paint and self-cleaning properties. A common method for mass production of components is injection molding. To ensure that the nanostructures result in the desired physical properties (i.e., imparting colors to the molded parts), injection molded parts have very strict tolerances on the nanoscale. However, it is a challenge to perform quality control on the nanoscale in the short production time between mass-produced parts. This creates high market entry barriers for companies that want to implement nanostructures in their production. New fast, accurate, and user-friendly metrology solutions are needed, before nano-structured products can be mass produced reliably.

A promising technique for in-line nanoscale metrology is scatterometry. Scatterometry is an optical method, where nanostructures are reconstructed through inverse modelling based on an optical “fingerprint” of the sample. In several recently completed projects, DFM has aimed at improving the use of scatterometry for routine quality control. The InFoScat project has developed algorithms for simulation and comparison of these fingerprints. The algorithms have been implemented in a user-friendly software package by Image Metrology. During the SuperLens project a portable scatterometer was constructed for experimental measurements. This scatterometer uses the InFoScat software to characterize nanostructures in milliseconds. This scatterometer was tested at Polyoptics GmbH. There, the scatterometer demonstrated the required speed (less than one minute), accuracy, and robustness for in-line characterization of nano-textured injection molded samples. Furthermore, the scatterometer could be used to optimize injection molding recipes governed by a large number of system parameters.

DFM has developed a portable scatterometer, including user-friendly software, for high-speed measurement of injection molded functional nanostructures. The instrument is well suited for in-line quality control of all produced items and thus contribute to minimizing faulty products and reducing costs for these highly demanded consumer products.

By performing quality control on all parts, companies will be able to move from a good practice approach, where selected components are checked daily, to an approach whereby all components are checked for defects and production failures. This will result in fewer faults, and thereby cheaper and better products. Such rigorous quality control could be performed by means of scatterometry.

The DFM scatterometer and the InFoScat software helped us improving the injection molding process in such a short time with direct feedback on the quality of the replicated nanostructures.

Lars Nakotte, Project manager at Polyoptics
RAMAN SPECTROSCOPY – A POWERFUL ANALYTICAL TOOL FOR PHARMACEUTICAL FORMULATION DEVELOPMENT

For several decades, infrared spectroscopy has been commonly used in pharmaceutical analysis for its capacity to provide reliable quantitative measurements of substances. Nowadays Raman spectroscopy is catching up by offering higher selectivity and versatility towards detection and quantification of different substances, especially in aqueous samples. It offers the possibility of non-destructive in-situ quantitative measurements, which are highly sought after in pharmaceutical and biomedical sciences. Due to the high specificity of Raman spectra, Raman spectroscopy also enables identification of material properties beyond chemical composition, such as protein structure and crystal structures.

A large number of new drug candidates have poor aqueous solubility, which strongly limits their bioavailability in conventional formulations. A solution is to use the amorphous form of the drugs, which has higher solubility, faster dissolution rates, and enhanced oral bioavailability. However, amorphous solids are unstable and tend to crystallize during preparation and storage. The bioavailability and stability of amorphous drug formulations are both major research topics in pharmaceutical sciences.

In 2017, DFM and Bioneer collaborated with the department of pharmacy at KU, in a pharmaceutical formulation study aimed at preparing amorphous solid dispersions of drugs in polymer, in order to achieve improved stability and bioavailability. The study investigated the efficiency of a novel preparation method, which consists of irradiating mixed tablets of drug and polymer in a commercial microwave oven. The resulting amorphous content of the microwaved tablets was measured by quantitative transmission Raman spectroscopy. Compared to conventional Raman spectroscopy, transmission Raman spectroscopy probes the bulk content of a sample thereby allowing for quantification of the proportion of amorphous and crystalline drug within the tablets.

The result of the study proved the effectiveness of Raman spectroscopy for acquiring accurate and reliable quantification of the solid-state properties of a drug formulation and confirmed its benefits for the pharmaceutical industry.

Raman spectroscopy has a large potential for quality assurance in the pharmaceutical industry. DFM is developing new methods and services for quantitative measurements of drugs, during each step in the manufacturing process, in close collaboration with actors in the field.

The Raman spectra of the crystalline and amorphous forms of a drug (e.g., carbamazepine) often display clear differences. These enable identification and quantification of the solid-state properties of the drug. Typically, amorphous solids have Raman spectra with broader peaks that can appear slightly shifted, with different heights compared to their crystalline counterparts.
SKPFM 3D image showing two rectangularly shaped TiO$_2$ nanoparticles on top of each other. Due to the photocatalytic activity of the TiO$_2$ nanoparticles there is a drop in the contact potential at the nanoparticles’ position compared to the rest of the surface. This drop in contact potential is seen as a red color in the image.

**TiO$_2$ nanomaterials are known for their numerous and diverse applications. DFM, as partner in an EU project, has correlated a number of physical properties to the photocatalytic activity of TiO$_2$, which industry can use for optimizing the photocatalytic performance of TiO$_2$.**

Titanium dioxide (TiO$_2$) has many remarkable properties, and is widely applied in a variety of industries, including cosmetics, paint and solar cell industries. Some of these properties were addressed in the pan-European SetNano-Metro project, where focus was on the use of TiO$_2$ in solar cell applications and TiO$_2$ as a self-cleaning coating: when illuminating TiO$_2$ with UV light, reactive radicals are created on the surface, which in turn will degrade organic material like dirt or oil, keeping the surface clean.

DFM can now characterize TiO$_2$ nanoparticles and coatings using a Scanning Kelvin Probe Force Microscope (SKPFM), where the contact surface potential enables distinction between materials with regard to their electronic properties. DFM’s contributions to the SetNanoMetro project consisted of measuring the photocatalytic activity using this technique. Due to the high resolution of SKPFM, it was possible to study single TiO$_2$ nanoparticles and their photocatalytic response to UV light. Various nanoparticles of different shape, size, and phase crystallinity were characterized in order to correlate these parameters to the photocatalytic activity of TiO$_2$. This approach resulted in some general design rules, which the industry can utilize to optimize the photocatalytic performance of TiO$_2$ nanoparticles and coatings.

DFM has developed a measurement procedure, which establishes traceability between nano- and macroscopic scale photocatalytic measurements. This has resulted in

**The SetNanoMetro Project**

The SetNanoMetro project was supported by the European Commission under the 7th Framework Programme. Besides DFM, the project involved a total of 15 partners from nine European countries, and lasted for three years. The main task of the project was to analyze nano-crystals made of titanium dioxide (TiO$_2$). The project resulted in 1) the design and production of certified reference materials of TiO$_2$, and 2) the development of standard characterization procedures for obtaining knowledge of the size, shape, and crystalline phase of TiO$_2$ nanoparticles. DFM’s expertise was needed in order to establish proper traceability and determination of uncertainty for the quantification of the photocatalytic effect of TiO$_2$ on the nanometer-scale.

DFM providing a new service, verifying the photocatalytic activity of TiO2 nanomaterial samples and references, accompanied by a measurement report. The applied reference material is highly pure and produced in various morphologies, such as nano-sized rods and flat .nano-platelets, and is provided by the partners in SetNano-Metro.
NEW PART-TIME EDUCATION IN MEASUREMENT TECHNOLOGY

DFM has led a project aiming at strengthening education in metrology in Denmark. A survey has demonstrated the need. In consultancy with educators, the project has generated substantial written material which support education in measurement technology, starting in 2018. This initiative will allow industry to hire well qualified metrology technicians in the future.

New education: Technical personnel who have a solid understanding of measurements, calibrations, and basic statistics are in high demand. However, the absence of a dedicated technical education in the field may pose a challenge to recruitment. This was substantiated in a questionnaire survey executed by DFM, Zealand Institute of Business and Technology, and Business Academy Aarhus. The 85 responding companies with relevant measurement activities were geographically well distributed across the nation, with a wide variety of sectors represented (50% Production, 30% Calibration & Consulting, and 16% R&D companies). Within the last couple of years, 82% of these companies had had troubles hiring personnel with practical competences within quality and technical measurement. Nearly 70% of companies supported that a new part-time education on quality and measurement technology should be created. Based on the responses, the nation wide need for upqualification of employees was estimated to be more than 5000 over the coming five years. The companies also requested that a full-time education be initiated. In spring 2017, the Ministry permissioned the establishment of the new 2 year, part-time education, granting the title “måleteknolog”; the first classes will start summer 2018.

Activities: During spring 2017, a large emphasis was put on establishing new contacts with educators, by having more than 15 meetings at 10 different institutions. These meetings were crucial in establishing a better understanding of their requirements and in bringing about the realization that the demand for the teaching material was much greater than at first anticipated. During 2017, a new web-portal for metrology.dk was launched. The portal provides open access to all the teaching material. The latest statistics on the site show more than 6000 hits within a month, and that material has been downloaded by more than 30 users within the same period. Small-to-medium enterprises have also found the material helpful. Over the course of the first two years a total of 20 teaching packets have been developed by DFM and FORCE Technology. The material puts emphasis on providing the students with critical insight towards measurements and setting up uncertainty budgets. Preliminary evaluations provided by the educators are generally positive and there is a widespread request for more material. Therefore, a continuation of the project beyond 2018 will be applied for, seeking to establish an official network for metrology teaching material with representatives from GTS, industry and education, making metrologi.dk a common reference point.

Viewpoints and requirements for educational training needs on measurement technology and metrology, were fruitfully discussed at the two Stakeholder workshops held in Århus and Roskilde, with participation from Danish production industries, business academies (EAAA and EASJ) and the metrology.dk partners.
INTERNATIONAL COMPARABILITY OF ELECTROLYTIC CONDUCTIVITY

A particular highlight this year for Electrochemistry, was participation in an international key comparison, CCQM-K36 “Electrolytic Conductivity at 0.5 S m$^{-1}$ and 5 mS m$^{-1}$”, organized by the Consultative Committee on the Quantity of Material (CCQM), part of the Bureau International des Poids et Mesures (BIPM). This comparison helps to ensure that measurement services offered by Electrochemistry are of the highest standard, by testing the measurement capabilities of DFM relative to other National Metrology Institutes (NMIs). These comparisons are therefore very important, not only in DFM’s role as the national metrology institute, but also for those who rely on DFM’s services in electrolytic conductivity. By benchmarking our measurement capacity against global NMIs, we offer continued evidence of our world-class measurement proficiency, all traceable to the SI.

For CCQM-K36, two solutions of nominal conductivity and composition: 0.5 S/m KCl$_{(aq)}$ and 5 mS/m HCl$_{(aq)}$, were prepared at the coordinating NMI. Measurement of the 0.5 S/m KCl$_{(aq)}$ solution was straightforward; particularly given that we regularly produce CRM KCl$_{(aq)}$ solutions in the range 0.01 S/m to 10 S/m. The 5 mS/m HCl$_{(aq)}$ solution was observed, by the organizing laboratory, to drift with time, this made measurement of the sample and comparison of the obtained results more complex.

The 5 mS/m HCl$_{(aq)}$ solution was chosen as it is not possible to use purely aqueous salt solutions as reference standards for electrolytic conductivity at 5 mS/m or below. This is as the contribution from dissolved atmospheric carbon dioxide (CO$_2$) becomes significant, and the solutions are often unstable. CO$_2$ reacts with water to form carbonic acid, this is a source of charge carrying ions, thus contributing to solution conductivity. The instability is due to the variability of CO$_2$ in the solution, which changes with ambient atmospheric CO$_2$ and pressure. For this reason, non-aqueous, HCl$_{(aq)}$ or mixed solvent solutions must be used for CRMs in these low conductivity ranges. In these solutions, a lower CO$_2$ solubility results in the suppression of its effect on solution conductivity.

During CCQM-K36, the observed drift was determined to be approximately linear, this was compensated for during measurement at DFM and, between measurements, at the organizing laboratory. The final report for this comparison is available via Metrologia and the BIPM websites. From this report, it can be seen that the values obtained using DFM’s equipment and procedures are in excellent agreement with the reported reference values for each solution.

Excellent results in international key comparisons ensure that measurement services offered by DFM are of the highest international standard. Equivalence assures that Danish companies may operate and expand on international markets.
PARTICIPATION IN COMMITTEES AND WORKING GROUPS UNDER THE METRE CONVENTION AND EURAMET

- EMPIR Committee
- Consultative Committee for Amount of Substance (CCQM)
- Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV)
- EURAMET General Assembly EURAMET Board of Directors
- EURAMET Technical Committee for Mass (TC-M)
- EURAMET Technical Committee for Electricity and Magnetism (TC-EM)
- EURAMET Technical Committee for Length (TC-L)
- EURAMET Technical Committee for Photometry and Radiometry (TC-PR)
- EURAMET Technical Committee for Acoustics, Ultrasound and Vibration (TC-AUV)
- EURAMET Technical Committee for Time and Frequency (TC-TF)
- EURAMET Technical Committee for Interdisciplinary Metrology (TC-IM)
- EURAMET Technical Committee for Quality (TC-Q)
- EURAMET Technical Committee for Metrology in Chemistry (TC-MC)
- EURAMET TC-MC Sub Committee for Electrochemistry
- BIPM Director’s ad hoc Advisory Group on Uncertainty
- Joint Committee for Guides in Metrology - Working Group 1. Guide to the Expression of Uncertainty in Measurement (JCGM-WG1)
- Consultative Committee for Length - Working Group on Dimensional Nanometrology (CCL-WG-N)
- Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology - Working Group on Electrochemical Analysis (CCQM-EAWG)
- Consultative Committee for Mass and Related Quantities -Working Group on the Realization of the kilogram (CCM-WGR-kg)
- Consultative Committee for Mass and Related Quantities -Working Group on the Dissemination of the kilogram (CCM-WGD-kg)
- Consultative Committee for Acoustics, Ultrasound and Vibration - Working Group for Key Comparisons (CCAUV-KCWG)
- Consultative Committee for Ultrasound and Vibration - Working Group for RMO Coordination (CCAUV-RMO)
- Consultative Committee for Ultrasound and Vibration - Working Group on Strategic Planning (CCAUV-SPWG)
- NMI Directors Meeting

PARTICIPATION IN NATIONAL AND INTERNATIONAL PROJECTS

- Scanning Neutral Helium Microscopy (NEMI), EU FP7
- Center for LED metrology (LedMet), IF
- Advanced laser-based heat sensor for fire detection (Firedetect), IF/Eurostars
- A Novel Non-Invasive Trace Gas Analyser Platform Targeting Breath Analysis (NnPAS), IF/Eurostars
- Industrial Fourier Scatterometer (InFoScat), IF/Eurostars
- Metrology for Highly-Parallel Manufacturing (MetHPM), SIU/EMPIR
- Metrology for Innovative Nanoparticles (Innanopart), SIU/EMPIR
- Leading Edge Roughness Wind Turbine Blades (LER), EUPD
- Optical Plastic Lenses with Super-Hydrophobic Surface Properties (SuperLens), IF/Eurostars
- Photo-Acoustic Sensor for Oil Detection in Compressed Air (PASOCA), IF/Eurostars
- Metrology for Additively Manufactured Medical Implants (MetAMMI), SIU/EMPIR
- Metrology for Modern Hearing Assessment and Protecting Public Health from Emerging Noise Sources (Ears II), SIU/EMPIR
- Underwater Acoustic Calibration Standards for Frequencies Below 1 kHz (UNAC-LOW), SIU/EMPIR
- Traceable Three-Dimensional Nanometrology (3DNano), SIU/EMPIR
- Continuous Pesticide Sensing in the Environment (CoPS), IF/Eurostars
- Photoacoustic Infrared Microscope for Automated Histopathology (PIRMAH), IF/Eurostars
- Corrosion detection on offshore platforms by drones (OFFSHORE), the European Regional Development Fund “EU’s Regional Fond”
- Traceable in-line Optical Measurement of Nano and Micro Roughness (OptoRough), IF/Eurostars
- Quantum Measurement Enhanced Gravitational Wave Detection (Q-GWD), IF/Eureka Turbo
- Shape-Engineered TiO2 Nanoparticles for Metrology of Functional Properties (SETNanoMetro), EU FP7
- Metrology for High-Impact Greenhouse Gases (HighGas), SIU/EMRP
- Metrology for Ammonia in Ambient Air (MetNH3), SIU/EMRP
- Traceable Characterisation of Thin-Film Materials for Energy Applications (ThinErgy), SIU/EMRP
- UV-induceret biofilmforebyggelse (BIOFORS), IF
The list of DFM research projects includes no less than 8 Eurostars projects. Eurostars is a joint programme between EUREKA and the European Commission, and the projects are co-funded by EU and Innovation Fund Denmark. Eurostars supports SMEs in the development of innovative products and requires participation from at least two member states.

DFM REPORTS

- A. Brusch, M. Lassen FaunaPhotonics, Opticstudio optimization. DFM-2017-R006

CALIBRATION CERTIFICATES AND MEASUREMENT REPORTS

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Electricity</td>
<td>2</td>
</tr>
<tr>
<td>Electrochemistry</td>
<td>448</td>
</tr>
<tr>
<td>Mass</td>
<td>11</td>
</tr>
<tr>
<td>Length</td>
<td>46</td>
</tr>
<tr>
<td>Optical Radiometry</td>
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<tr>
<td>Nano Structures</td>
<td>13</td>
</tr>
<tr>
<td>Acoustics</td>
<td>73</td>
</tr>
<tr>
<td>Particle Metrology</td>
<td>96</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>717</strong></td>
</tr>
</tbody>
</table>

PUBLICATIONS IN REFEREED JOURNALS


CONFIDENTIAL REPORTS
CONTRIBUTION AT CONFERENCES

- **A. Brusch.** Detection of leaks in food packing - “Detektion af lækk i fødevarepåkninger”. DFM-2017-F05
- **S.R. Johanssen, A.T. Rosell, K. Dirschler, C.S. Jeppesen, S. Louring.** Design rules correlating photocatalytic activity with the NPs/films properties at molecular level. DFM-2017-F06
- **L. Deleebeeck.** A review of the use of Electrochemical Impedance Spectroscopy in the study of Li-ion battery. DFM-2017-F07
- **M.S. Nielsen.** Investigating the performance in replication of height structures. DFM-2017-F08
- **M.S. Nielsen.** Measurement report on step-height artefact and sandpaper. DFM-2017-F09
- **J. Hald, M.R. Henriksen, J.E. Pedersen, M. Drewsen.** Qubiz quarterly reporting WP2b - status after 12 months.
- **D. B.-Harder, J. Nwaboh, O. Werhahn.** Fully validated and implemented optical transfer standard for CO and CO₂. DFM-2017-F10
- **J. Nwaboh, J. Mohn, A. Manninen, D. B.-Harder, J.C. Petersen, O. Werhahn.** Validation of OIRS $^{13}\text{C}/^{12}\text{C}$, $^{18}\text{O}/^{16}\text{O}$ and $^{4}\text{He}/^{2}\text{He}$ in (CO₂, N₂O and CH₄). DFM-2017-F12

- **P.-E. Hansen, M.H. Madsen, J.S. Madsen, M. Karamehmedovic.** Rough surface scattering for thin films and nanostructured surfaces. SPIE Optical Metrology International Symposium, Munich, Germany, June 2017
- **H. Kerdoncuff, M.R. Pollard, P.G. Westergaard, J.C. Petersen, M. Lassen.** Polarization-sensitive stimulated Raman spectroscopy with a compact and versatile laser system. 9th International Conference on Advanced Vibrational Spectroscopy (ICAVS9), Victoria, Canada, June 2017
- **A. Snedden, C. Thirstrup.** Traceable High Precision Biofuel Conductivity Measurement. 68th Annual Meeting of the international Society of Electrochemistry, Providence, USA, August 2017
- **S. B.-Figueroa.** Environmental coefficients of the free-field sensitivity of measurement microphones. 46th International Congress and Exposition on Noise Control Engineering, Internoise, Hong Kong, August 2017
- **H. Kerdoncuff.** Raman enhancement techniques and their applications in biotechnology. Drug Research Academy symposium on advanced Raman spectroscopy techniques for pharmaceuticals Faculty of Health and Medical Sciences, University of Copenhagen, Copenhagen, Denmark, November 2017
- **S. Veltzé, L.C. Deleebeeck.** Assessment of Li-ion Batteries by Electrochemical Impedance Spectroscopy. Electrochemical Science and Technology Conference, Kgs. Lyngby, Denmark, November 2017
### INCOME STATEMENT (1000 DKK) 2017/2016

<table>
<thead>
<tr>
<th></th>
<th>2017</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial revenue</td>
<td>4,047</td>
<td>4,536</td>
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<td>Project revenue</td>
<td>9,446</td>
<td>6,547</td>
</tr>
<tr>
<td>Government funding</td>
<td>22,510</td>
<td>20,474</td>
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<tr>
<td><strong>Total revenue</strong></td>
<td>35,003</td>
<td>31,557</td>
</tr>
<tr>
<td>Travel and out-of-pocket expenses</td>
<td>12,120</td>
<td>10,358</td>
</tr>
<tr>
<td><strong>Total out-of-pocket expenses</strong></td>
<td>12,120</td>
<td>10,358</td>
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<tr>
<td>Gross profit</td>
<td>22,883</td>
<td>21,199</td>
</tr>
<tr>
<td>Staff costs</td>
<td>19,809</td>
<td>17,759</td>
</tr>
<tr>
<td><strong>Total costs</strong></td>
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<td>17,759</td>
</tr>
<tr>
<td>Operating profit before depreciation and impairment losses</td>
<td>3,074</td>
<td>3,440</td>
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<tr>
<td>Depreciation and impairment losses on property, plant and equipment</td>
<td>2,567</td>
<td>3,018</td>
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<tr>
<td><strong>Operating profit before financial income and expenses</strong></td>
<td>507</td>
<td>422</td>
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<td>Financial income</td>
<td>45</td>
<td>2</td>
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<tr>
<td>Financial expenses</td>
<td>48</td>
<td>35</td>
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<tr>
<td><strong>Profit before tax</strong></td>
<td>504</td>
<td>389</td>
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<td><strong>Tax on profit for the year</strong></td>
<td>103</td>
<td>42</td>
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<tr>
<td><strong>Profit for the year</strong></td>
<td>401</td>
<td>347</td>
</tr>
<tr>
<td>Profit for the year to be carried forward</td>
<td></td>
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### BALANCE SHEET AT 31 DECEMBER (1000 DKK)

#### ASSETS 2017/2016

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<th>2017</th>
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<tbody>
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<td>Deposits</td>
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<td>657</td>
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<tr>
<td>Total investments</td>
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<td>657</td>
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<tr>
<td>Equipment</td>
<td>6,215</td>
<td>8,369</td>
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<tr>
<td>Leasehold improvements</td>
<td>15,356</td>
<td>247</td>
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<tr>
<td><strong>Total property, plant and equipment</strong></td>
<td>21,571</td>
<td>8,616</td>
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<tr>
<td>Total non-current assets</td>
<td>22,447</td>
<td>9,273</td>
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<tr>
<td>Contract work in progress</td>
<td>6,918</td>
<td>3,762</td>
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<tr>
<td>Trade receivables</td>
<td>894</td>
<td>695</td>
</tr>
<tr>
<td>Prepayments</td>
<td>134</td>
<td>144</td>
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<tr>
<td>Other receivables</td>
<td>3,025</td>
<td>289</td>
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<tr>
<td><strong>Total receivables</strong></td>
<td>4,053</td>
<td>1,128</td>
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<tr>
<td>Cash at bank and in hand</td>
<td>7,704</td>
<td>21,255</td>
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<tr>
<td><strong>Total current assets</strong></td>
<td>18,675</td>
<td>26,145</td>
</tr>
<tr>
<td><strong>Total assets</strong></td>
<td>41,122</td>
<td>35,418</td>
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#### EQUITY AND LIABILITIES 2017/2016

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<td>Share capital</td>
<td>1,000</td>
<td>1,000</td>
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<tr>
<td>Retained earnings</td>
<td>16,654</td>
<td>16,253</td>
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<tr>
<td><strong>Total equity</strong></td>
<td>17,654</td>
<td>17,253</td>
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<tr>
<td>Prepayments from customers and of funding</td>
<td>15,723</td>
<td>15,465</td>
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<tr>
<td>Trade payables</td>
<td>3,491</td>
<td>1,061</td>
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<tr>
<td>Other payables</td>
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<td>1,639</td>
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<tr>
<td><strong>Total current liabilities</strong></td>
<td>23,468</td>
<td>18,165</td>
</tr>
<tr>
<td><strong>Total equity and liabilities</strong></td>
<td>41,122</td>
<td>35,418</td>
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</table>
### Key Figures in Million DKK

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<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
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<tr>
<td><strong>Net sales</strong></td>
<td>25.4</td>
<td>27.3</td>
<td>27.2</td>
<td>31.5</td>
<td>35.0</td>
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<tr>
<td><strong>Gross balance</strong></td>
<td>21.6</td>
<td>23.9</td>
<td>23.7</td>
<td>35.4</td>
<td>41.1</td>
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<tr>
<td><strong>Profit or loss for the financial year</strong></td>
<td>0.5</td>
<td>0.7</td>
<td>0.4</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Net capital</strong></td>
<td>15.8</td>
<td>16.5</td>
<td>16.9</td>
<td>17.2</td>
<td>17.7</td>
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<tr>
<td><strong>Commercial sale</strong></td>
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<td>3.6</td>
<td>5.3</td>
<td>4.6</td>
<td>4.0</td>
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<tr>
<td></td>
<td>0.4</td>
<td>0.6</td>
<td>0.6</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
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<td>0.7</td>
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<td>0.9</td>
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<tr>
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<td>0.8</td>
<td>0.8</td>
<td>1.3</td>
<td>1.1</td>
<td>0.9</td>
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<tr>
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<td>0.0</td>
<td>0.1</td>
<td>0.4</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>1.1</td>
<td>1.4</td>
<td>2.4</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Foreign net sales</strong></td>
<td>6.5</td>
<td>5.9</td>
<td>7.1</td>
<td>3.8</td>
<td>3.3</td>
</tr>
</tbody>
</table>

### Research and Development

- **Number of collaborative projects**
  - 21
  - 23
  - 23
  - 29
  - 29
- **R&D activities (million DKK)**
  - 25.4
  - 26.2
  - 23.2
  - 26.9
  - 30.6
- **R&D work (man-year)**
  - 16.2
  - 19
  - 17.5
  - 17.3
  - 17.5

### Number of Customers

- **Danish private enterprises**
  - 31
  - 33
  - 25
  - 53
  - 54
- **Danish public institutions**
  - 5
  - 3
  - 5
  - 8
  - 3
- **Foreign enterprises and institutions**
  - 18
  - 17
  - 19
  - 28
  - 33

### Number of Staff Categorized by Education (man-year)

- **Dr & PhD**
  - 17
  - 18
  - 19
  - 21
  - 25
- **MSc**
  - 3
  - 4
  - 4
  - 3
  - 3
- **Other technical staff**
  - 3
  - 3
  - 2
  - 2
  - 2
- **Administrative staff**
  - 2
  - 2
  - 3
  - 3
  - 4

### Number of Publications

- **Refereed publications**
  - 12
  - 14
  - 23
  - 19
  - 21
- **PhD and Master theses**
  - 1
  - 0
  - 0
  - 3
  - 0
- **Conference papers**
  - 18
  - 22
  - 15
  - 18
  - 17
- **Press cuttings**
  - 9
  - 27
  - 28
  - 29
  - 32

### Education

- **DFM courses (number of days)**
  - 2
  - 2
  - 2
  - 3
  - 4
- **DFM courses (number of participants)**
  - 4
  - 25
  - 22
  - 18
  - 28
- **Supervision/teaching at universities (number of students/courses)**
  - 0
  - 6
  - 3
  - 3
  - 6
- **Co-supervision of master thesis students (number of theses)**
  - 4
  - 5
  - 4
  - 3
  - 0
- **Contribution to teaching at universities (number of days)**
  - 5
  - 6
  - 4
  - 3
  - 6
- **Committee work (number of committees)**
  - 24
  - 32
  - 29
  - 29
  - 29
- **- thereof international committee work**
  - 21
  - 27
  - 23
  - 23
  - 25

### Efficiency

- **Turnover per employee (1000 DKK)**
  - 1011
  - 1004
  - 994
  - 1011
  - 1129
- **Profit per employee (1000 DKK)**
  - 20
  - 26
  - 15
  - 13
  - 16
- **Commercial turnover per DKK of governmental funding**
  - 0.2
  - 0.3
  - 0.4
  - 0.2
  - 0.2
- **R&D turnover per DKK of governmental funding**
  - 1.5
  - 1.6
  - 1.5
  - 1.3
  - 1.4

1) Excluding extraordinary items
### DANISH METROLOGY INSTITUTES

According to the CIPM Mutual Recognition Arrangement, a country can have one national metrology institute (NMI) and a number of designated institutes (DI). In Denmark, these metrology institutes are appointed by the Danish Safety Technology Authority (www.sik.dk). In the list below, each appointed metrology institute is identified by the acronym used in the BIPM database for Calibration and Measurement Capabilities. The fields covered by the appointments are indicated in the table on the next page.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Institute Name</th>
<th>Address</th>
<th>Contact</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>BKSV-DPLA</td>
<td>Bruel &amp; Kjaer Sound &amp; Vibration Measurement A/S</td>
<td>Skodsborgvej 307, DK 2850 Nærum</td>
<td>Erling Sandermann Olsen</td>
<td>+45 7741 2000</td>
<td><a href="mailto:erling@bksv.com">erling@bksv.com</a></td>
</tr>
<tr>
<td>DFM</td>
<td>DFM A/S, Danish National Metrology Institute</td>
<td>Kogle Allé 5, DK 2970 Hørsholm</td>
<td>Jan Hald</td>
<td>+45 7730 5800</td>
<td><a href="mailto:jha@dfm.dk">jha@dfm.dk</a></td>
</tr>
<tr>
<td>DTU</td>
<td>Technical University of Denmark</td>
<td>Anker Engelunds Vej 1, Building 101A</td>
<td>To be announced</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FORCE</td>
<td>FORCE Technology</td>
<td>Naervej 1, DK 6600 Vejen</td>
<td>Mogens Simonsen</td>
<td>+45 4325 0000</td>
<td><a href="mailto:mss@force.dk">mss@force.dk</a></td>
</tr>
<tr>
<td>TRESCAL</td>
<td>Trescal A/S</td>
<td>Mads Clausens Vej 12, DK 8600 Silkeborg</td>
<td>Torsten Lippert</td>
<td>+45 8720 6969</td>
<td><a href="mailto:torsten.lippert@trescal.com">torsten.lippert@trescal.com</a></td>
</tr>
</tbody>
</table>
Fundamental metrology in Denmark follows the EURAMET division into 12 subject fields, while the subfields reflect a Danish subdivision of metrological activities. Plans of action drawn up for each subject field serve as guidelines for the appointment of metrology institutes and give suggestions for other initiatives. The years in which plans of action have been published are shown in parenthesis.

<table>
<thead>
<tr>
<th>SUBJECT FIELD</th>
<th>CONTACT PERSON</th>
<th>SUBFIELDS</th>
<th>METROLOGY INSTITUTE</th>
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</thead>
<tbody>
<tr>
<td>MASS AND RELATED QUANTITIES</td>
<td>Lars Nielsen, DFM</td>
<td>Mass measurement</td>
<td>DFM</td>
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<tr>
<td>(1989, 1997, 2008)</td>
<td><a href="mailto:ln@dfm.dk">ln@dfm.dk</a></td>
<td>Force and Pressure</td>
<td>FORCE</td>
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<tr>
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<td>Volume and Density</td>
<td>FORCE</td>
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<td>ELECTRICITY AND MAGNETISM</td>
<td>Carsten Thirstrup, DFM</td>
<td>DC electricity</td>
<td>DFM</td>
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<td>(1989, 1994, 2002, 2011)</td>
<td><a href="mailto:cth@dfm.dk">cth@dfm.dk</a></td>
<td>AC electricity</td>
<td>TRESPAL</td>
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<td></td>
<td></td>
<td>HF electricity</td>
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<td>LENGTH</td>
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<td>Basic length measurements</td>
<td>DFM</td>
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<tr>
<td>(1989, 1998, 2007)</td>
<td><a href="mailto:jha@dfm.dk">jha@dfm.dk</a></td>
<td>Dimensional metrology</td>
<td>DFM &amp; DTI</td>
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<td>Micro/Nano</td>
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<td>TIME AND FREQUENCY</td>
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<td>Time measurement</td>
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<td>THERMOMETRY</td>
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<td>Temperature measurement by contact</td>
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<td>(1992, 1999, 2007)</td>
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<td>Arne Miller, DTU</td>
<td>Absorbed radiation dose – Industrial products</td>
<td>DTU</td>
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<td>(1992, 2000)</td>
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<td>Anders Brusch, DFM</td>
<td>Optical radiometry</td>
<td>DFM</td>
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<td>(1990, 1996, 2004, 2014)</td>
<td><a href="mailto:ab@dfm.dk">ab@dfm.dk</a></td>
<td>Photometry</td>
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<td>FLOW</td>
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<td>Gaseous flow (volume)</td>
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<td><a href="mailto:jrb@force.dk">jrb@force.dk</a></td>
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<td>Flow of liquids other than water</td>
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<td>METROLOGY IN CHEMISTRY</td>
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<td>DFM</td>
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<td></td>
<td><a href="mailto:kdi@dfm.dk">kdi@dfm.dk</a></td>
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