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Industrial innovation for economic growth

A summary of the outputs and impact of EMRP joint research projects in the second industrial innovation theme.

Measurement research has developed methods and techniques to support innovation in manufacturing, improved quality and increased productivity across diverse industrial sectors. Projects focused on next generation ICT, light technology innovation for factory environments and improving the measurement infrastructure needed for ensuring product quality and regulatory compliance.

Measurement matters

Measurement underpins virtually every aspect of our daily lives, helping to ensure quality and safety, support technological innovation and keep our economy competitive.

Supported by the European Commission, EURAMET's **European Metrology Research Programme (EMRP)** brings together National Measurement Institutes in 23 countries to pool scientific and financial resources to address key measurement challenges at a European level.

The programme is designed to ensure that measurement science meets the future needs of industry and wider society. Research is structured around six themes – Energy, Environment, Health and Industry – as well as the measurement needs of emerging technologies and the fundamentals of the SI measurement units that form the basis of Europe's measurement infrastructure.

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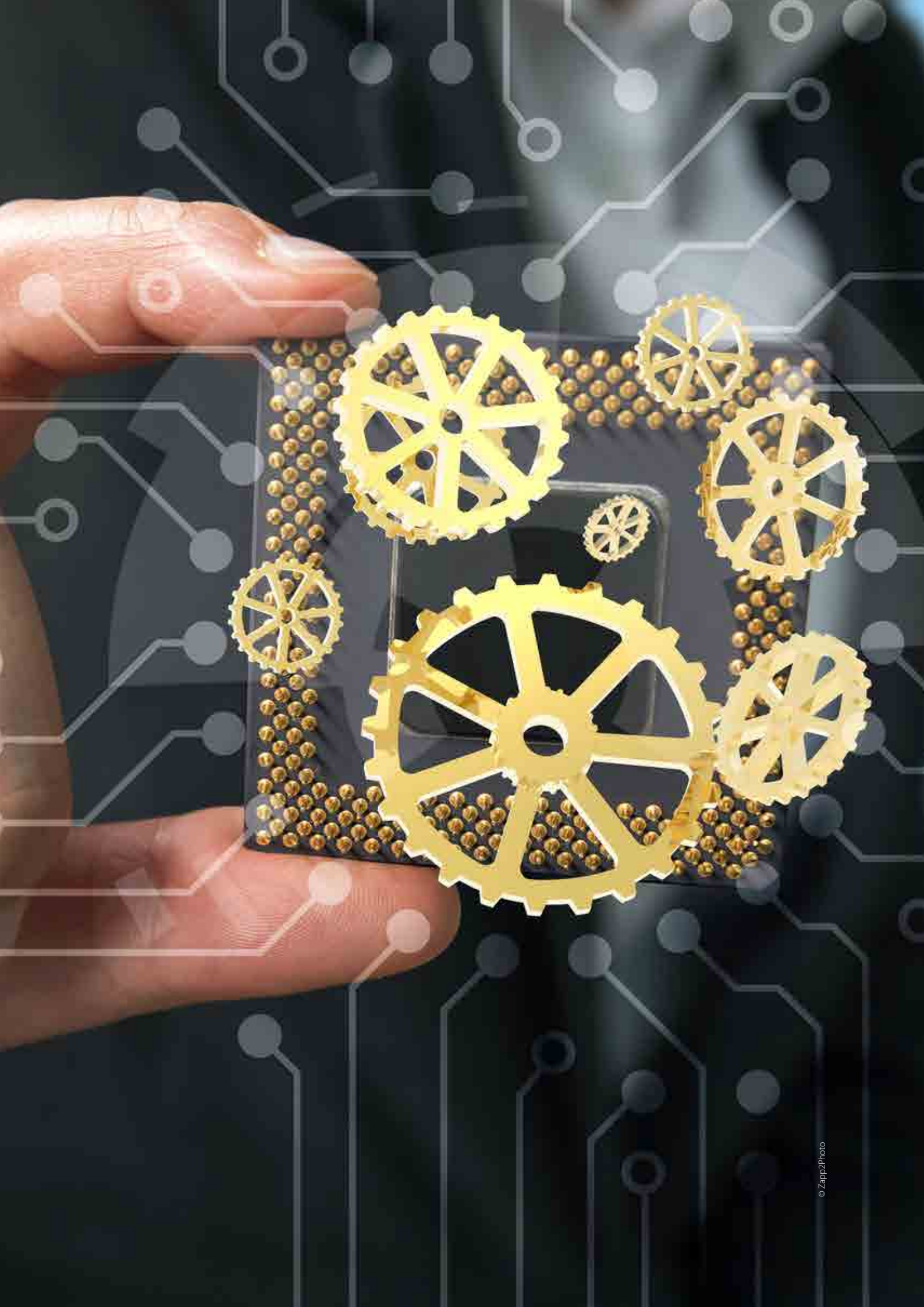
Introduction: Industrial innovation for economic growth

Industrial innovations have significantly changed the world, initially by the introduction of steam engines, then mass production, and more recently through automation based on electronics and information technologies. Now the merging of physical, digital, and biological technologies has great potential to generate new innovations and unimaginable benefits. Technological developments will expand and sustain modern industrial economies by boosting growth, creating jobs, and addressing global challenges such as providing quality healthcare for all and climate change.

Advanced manufacturing represents an important business opportunity with the global market for process and production upgrades estimated to exceed €750 billion by 2020. Europe is the birthplace of many innovations and there is considerable potential for boosting this innovative capacity by better integration of emerging technologies with products and services. To take advantage of this, European industries will need to implement new manufacturing approaches, such as the use of light to automatically control and monitor industrial processes. For these changes to be successfully introduced, measurement science must play its part in underpinning the implementation of new production techniques, and also by developing the characterisation needed for new analytical techniques to enable their use during product quality assessments.

Europe is home to world leading metrology capabilities. These are concentrated in its National Metrology Institutes and Designated Institutes, where knowledge and facilities across the measurement spectrum underpin all aspects of industry and society. EURAMET's second *EMRP Industrial Innovation theme* provided funding to support 14 collaborative research projects which brought together 35 research groups from NMIs and DIs with industry and academia. This report presents the key technical achievements of these research projects and highlights early examples of impact they have had. The theme addressed some of the measurement challenges associated with increasing economic prosperity through industrial innovation, the projects are grouped into sub-themes that support:

- Next generation ICT
- Introducing light technology innovation in manufacturing
- Production quality assurance.

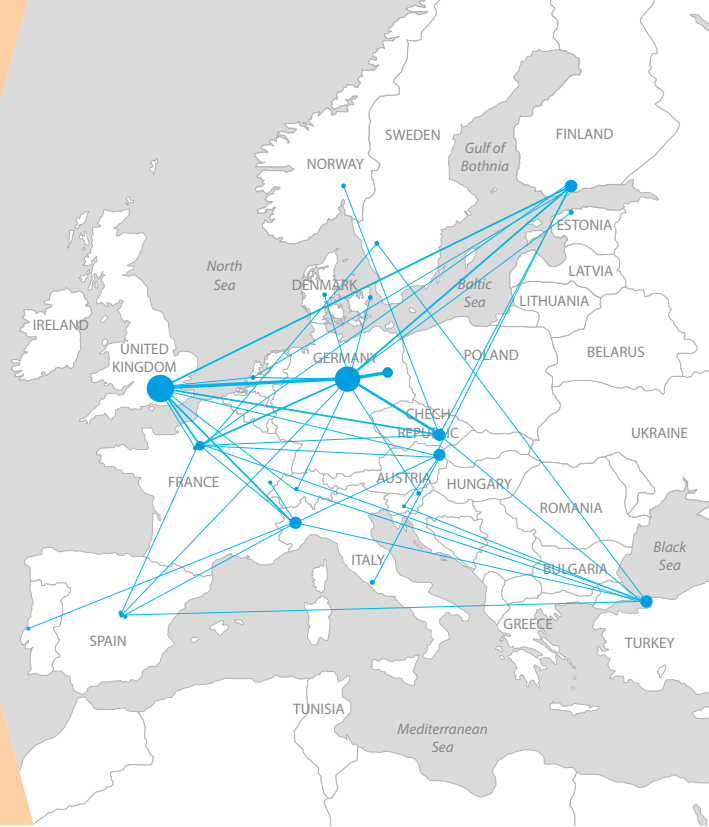


Highlights

Multidisciplinary measurements for Industrial Innovation

This EURAMET EMRP theme has enabled the European metrology community to work collectively towards an improved measurement infrastructure for industrial innovation that has the potential to underpin future economic growth. The projects have brought together metrology expertise in physics, chemistry, and biology to develop new analytical methods and statistical approaches which support increased uptake of innovative materials and processes.

The European Commission together with national governments have invested 45 million euro in collaborative research projects, involving research groups in 35 European NMIs and Designated Institutes (DIs), 37 academic groups, and 21 businesses.



Map of participating NMI and DI

Light based technologies for production automation

Extending light-based technologies to control the factory of the future requires precise methods for determining component positioning during assembly and confirming the quality of finished products. As a result of EMRP research, systems have been developed that will make exact lab based interferometry measurements more accessible to industrial users. These systems will enable greater positioning accuracy across the entire range of product assembly, from the very largest of components such as aircraft wings or wind turbine blades to the smallest electronics used on silicon wafers.

Proof-of-concept prototypes based on laser tracking and other optical technologies capable of measuring distances of tens of metres with micrometre precision have been developed, fully characterised, and trialled in an industrial environment provided by Airbus as a result of EMRP research. The IP developed has been protected by five patents, with two of the prototypes adopted by companies for commercialisation.

Accurate positioning on the nanoscale is essential in the semiconductor industry. A new laser light source, which has sufficient power to provide the multiple interferometry light beams required for size constrained silicon wafer production environments, is now available as a result of EMRP research. This is being incorporated into a prototype wafer production system that will help facilitate EU independence in electronics manufacturing.



Ensuring electric products are compatible

All electrical devices, from wind turbines to hairdryers, must comply with the EU's Electromagnetic Compatibility (EMC) directive. To meet this, products must undergo electromagnetic emission and immunity testing in lab assessments for portable items or onsite for installed equipment. Testing performed by accredited labs to international standards should generate consistent results. However, reliable methods are needed for establishing that this is the case.

EMRP research developed instrumentation that enables EMC immunity testing in lab based set-ups to be easily compared, by mimicking devices undergoing assessment and recording the testing parameters used. Being able to reliably compare the performance of accredited labs is key for ensuring measurement harmonisation across Europe.

Support for clean room production

To create small features, semiconductors, photovoltaic devices, and nanotechnologies all rely on chemical processes performed in cleanroom production facilities. However, traces of chemical contamination in the air can damage subsequent production stages resulting in faulty parts and rejected batches. EMRP research developed advanced optical instruments for determining traces of the most critical airborne contaminants, and created the reference materials required to accurately calibrate them. These instruments enable reliable contamination detection at the parts-per-billion (ppb) level and are suitable for cleanroom use. The knowledge gained from the project has contributed to revisions of ISO standards on the preparation of calibration gas mixtures using dynamic generation methods. Improving cleanroom air quality will help to increase production efficiency, therefore supporting advanced manufacturing in European industries.



Ensuring the EU is at the forefront of industrial innovation

Modern commerce relies heavily on silicon-based technologies, supported by reliable timekeeping, to ensure smooth data communication via satellite systems. Future proofing operations, as transmission speeds increase and components shrink, will depend on cutting-edge innovation.

Understanding the properties of silicon replacement materials requires new atomic scale measurement techniques. EMRP research has supported the creation of world leading capabilities in this area by upgrading existing facilities at the XMaS beamline in Grenoble and also at the synchrotron radiation source at PTB's Berlin Institute. These are enabling fundamental material property research for quantum communications and, in collaboration with the US Government, next generation radar. Recent advances also contributed to IBM's decision to create an IBM Watson for a cyber security unit in Switzerland.

Europe is world leading in atomic clock technologies, but maintaining self-sufficiency will be important for the reliable operation of the Galileo satellite system. EMRP research has supported upgrades to atomic clock prototypes, with improvements in performance confirmed by comparison to NMI time standards. Optical atomic clocks have potential to further increase industrial timekeeping precision, but the technology still needs some development. As a result of EMRP research, the feasibility of constructing an optical clock from commercially available components, with lower power requirements than current assemblies, has been demonstrated – an important step in this technology's development.



Ensuring mobile phone mast safety

Today, mobile phones have become the most used form of real-time communication. As usage varies through the day, so does the signal power radiating from network base stations. For the safety of workers and the public, this non-ionising radiation must remain below pre-set levels regulated by European legislation. EMRP research has developed greater calibration accuracy for the instruments used to measure mast power by simulating transmissions in the lab using signal generators traceable to SI units. Ensuring communication masts operate within prescribed power limits, as network capacity increases, is essential to allay growing fears over our exposure to non-ionising radiation.

Second EMRP Industrial Innovation theme projects



Pooling expertise of

17 NMIs
and
18 DIs from
19 European countries



plus the NMI from
New Zealand



businesses



204 presentations
at workshops
and seminars, reaching
an audience of
11,280
people



at a glance

135

articles
in peer-reviewed
journals



training courses
delivered to over

800
people

422

presentations at
conferences



132

contributions
to

57

technical
committees and
working groups
of standards
organisations

Supported the
development of improved
instrumentation with
projected sales of

€17.4 M

47

contributions to draft standards
and published standards

Supporting next generation ICT

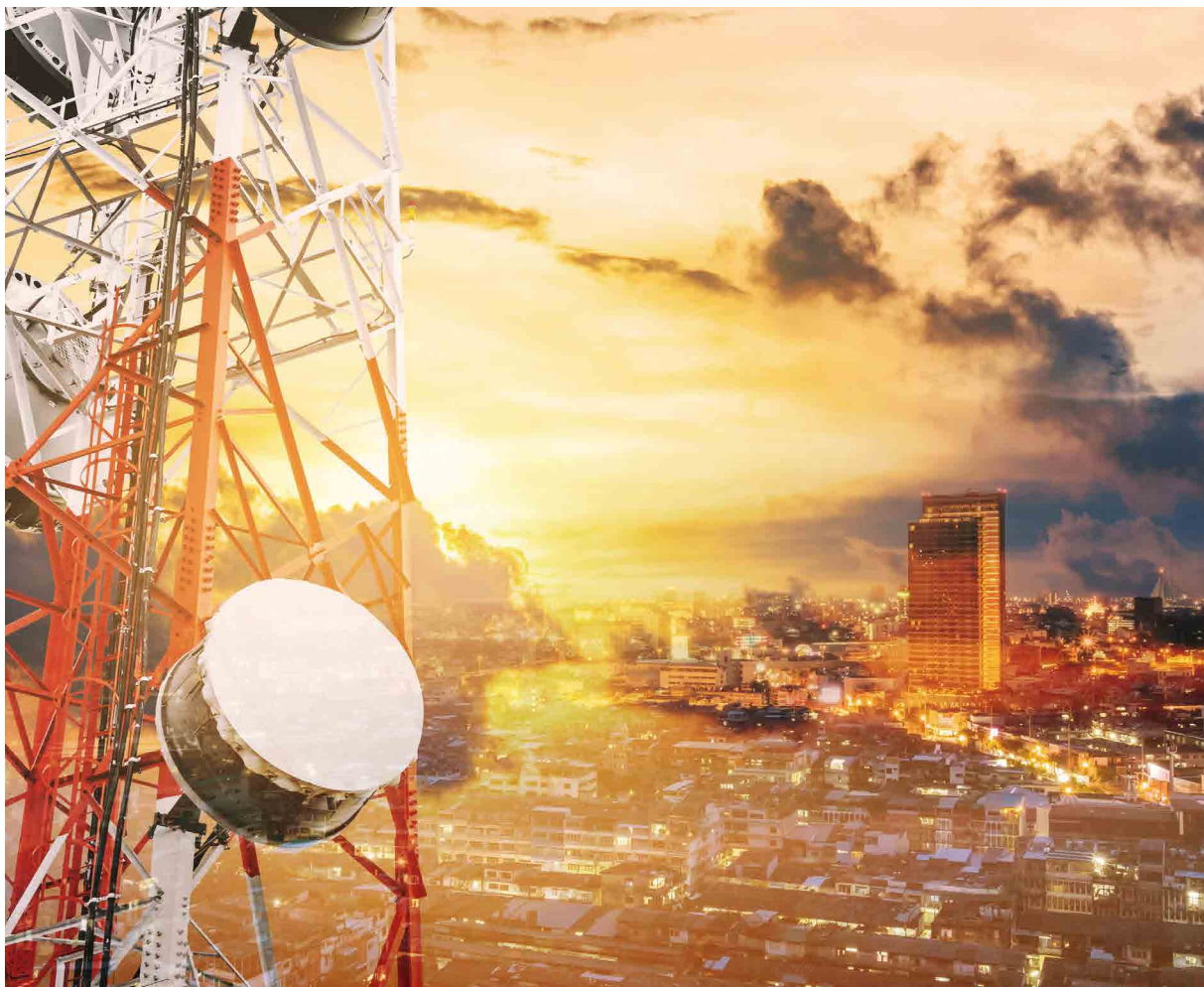
Measurement challenges

Almost every aspect of modern life is dependent on a secure and reliable communication network, from multimillion euro banking transactions to the transmission of vital patient information in emergency medical care. The current system, based on satellite, fibre, and mobile communications, is reaching capacity and must expand to cope with increasing demands. Technical innovation coupled with a rigorous measurement infrastructure is essential for ensuring that Europe remains at the forefront of telecommunication developments.

Replacing silicon technologies in next generation electronics requires the development of precise analytical methods to reliably characterise materials, such as graphene, on an atomic scale. The anticipated benefits resulting from component miniaturisation and increased operating speed also depends on improvements to data transmission synchronisation. Atomic timekeeping, used for this purpose, needs to improve its ruggedness and reliability if it is going to be operated outside closely controlled environments. As 4G transmission speeds increase to 5G and beyond, measurement capability must also develop to ensure components meet specifications and perform as anticipated in new communications systems designed to meet our ever increasing demands.

EMRP research has supported projects that address the development of:

- Advanced analytical techniques for accurately measuring nanoscale material properties, to support the innovation in electronics.
- Improved traceability for 4G and 5G communication networks and the components used in them.



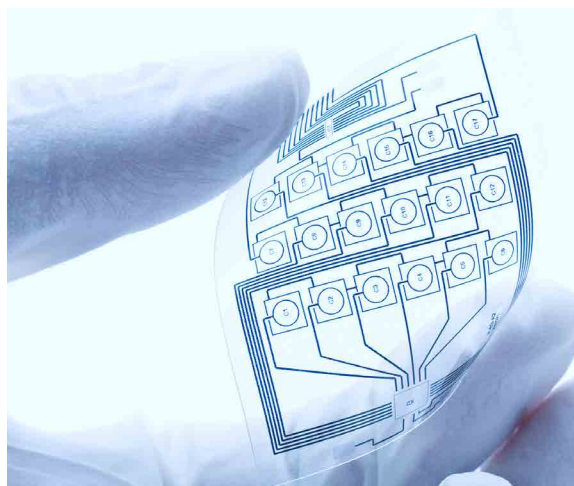
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Key technical achievements

Characterising new materials for next generation electronics

Europe's electronics industry, worth hundreds of billions of euros, must innovate to remain competitive as silicon wafers reach their physical limits. Next generation devices will require faster processing speeds, and miniaturised components based on novel materials operating on far smaller scales than current technologies.

Piezoelectric materials have unique properties. When physical forces induce strain, their atomic structure changes – altering their electrical properties. This makes them an ideal candidate for future nanoscale electronic switches. Realising the potential of new materials requires the development of well-characterised measurement techniques to accurately determine their properties.



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The EMRP project **Novel electronic devices based on control of strain at the nanoscale** developed advanced analytical techniques for accurately measuring how strain introduces changes in atomic structure. This will support future research into nanoscale piezoelectric materials for next generation electronics.

The project:

- **Upgraded a facility at the Grenoble XMaS beamline by combining X-rays and lasers for characterising strain at the atomic level.** This allows simultaneous measurements of voltage, current, movement, and atomic position changes using X-ray diffraction, making it possible to compare structural changes caused by strain on the nanoscale.
- **Demonstrated the measurement of nanoscale stress and strain using infrared optical microscopy and Raman spectroscopy** by monitoring interference band changes and relating these to the applied stress.
- **Demonstrated and improved Digital Image Correlation (DIC) approaches** used to visualise how piezoelectric samples behave under stress, and developed open source software for data analysis.
- **Developed theoretical modelling capabilities for predicting how materials change due to strain,** based on atomic interactions.

The introduction of next generation microelectronics based on novel materials relies on robust characterisation of their properties on the atomic scale. New measurement techniques must be developed and validated that are suitable for use on a smaller scale than those used today. This project has created world leading European capabilities in characterising materials that are important for next generation electronics, based on improved experimental facilities at the XMaS beamline, operated by the University of Liverpool, and PTB's synchrotron radiation source. This is evidenced by interest from the US Government in new collaborative research for future radar and quantum communications, as well as IBM's decision to move a computer research unit to Switzerland.

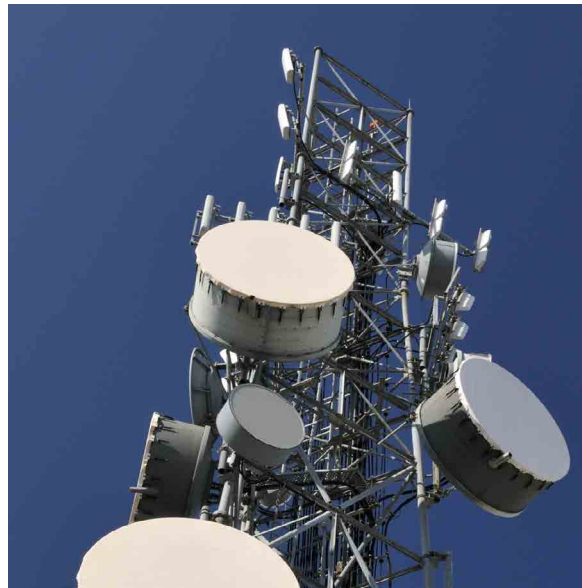
Research in this area continues in the EMPIR ADVENT project which aims to continue to extend the measurement tools for characterising piezoelectric materials. Longer term, the developments from these new measurement technology projects will stimulate innovation in the electronics industry, ensuring strong European participation in the growth of the nanotechnology market.

<p>More information is available at</p>	<p>IND54: Novel electronic devices based on control of strain at the nanoscale (Nanostrain) http://www.euramet.org/project-IND54 Follow on EMPIR project 16ENG06 Metrology for advanced energy-saving technology in next-generation electronics applications (ADVENT)</p>	
<p>Contact</p>	<p>Mark Stewart (NPL)</p>	<p>mark.stewart@npl.co.uk</p>

Measurements for 5G communication technologies

Satellite, fibre, and mobile communication networks are an essential part of modern life, with data transmission demand expanding at 40 % per year. To cope, the data carrying capacity of communication networks must expand. One cost effective solution would be to increase the existing system's capacity and speed. As 4G networks upgrade to 5G and beyond, reliably achieving faster data processing requires greater measurement accuracy of transmission speeds and signal reception characteristics.

The EMRP project **Metrology for optical and RF communication systems** addressed fundamental challenges to improve the reliability of measurements for characterising communication components by increasing the accuracy of instrument calibrations. This supports the development and testing of very high bandwidth telecommunication products, suitable for extending the current systems data carrying capacity at a reasonable cost.



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The project:

- **Developed algorithms to improve calibration and real-time measurements made using oscilloscopes** to ensure that communication system components can demonstrate that their performance meets specifications.
- **Established a new calibration method for telecom RF receivers** using the industry standard Long-Term Evolution wireless protocol. This new SI-traceability enables reliable measurements of mobile phone mast power, as user connections fluctuate throughout the day.
- **Developed a new electro-optic field sensor and improved methods for characterising RF quiet zones** during antenna power transmission testing at compact test set-ups. This reduces the need for complex corrections to instrument responses caused by sheltered areas or Quiet Zones, where transmission power measurements are reduced by shielding effects.
- **Developed Measurement Best Practice Guidance for the reliable characterisation of components for 4G and future 5G communication networks.**

Expanding the data carrying capability of communication systems already at capacity requires innovation in data transmission methods and the measurement infrastructure that underpins it. This project developed new European calibration and testing facilities to enable communication system suppliers to reliably demonstrate that component performance matches specifications - an essential requirement in determining overall system speeds.

The project increased interactions between NMI and European industrial stakeholders, such as that between LNE and Dassault for avionic and space antenna testing. The development of a novel device that simulates instrumentation under test also now enables accredited testing labs to demonstrate that calibration set-ups meet communication industry standards.

More information is available at	IND51: Metrology for optical and RF communication systems (MORSE) http://www.euramet.org/project-IND51	
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Compact, high-performance timing

Precise timing is essential for synchronising telecommunication networks and power transmission grids, timestamping financial services, and enabling satellite navigation. The accuracy of atomic clock technologies – where time measurement is based on the frequency of electronic transitions in atoms – is increasing, and optical atomic clocks have become the most accurate timing instruments ever created. But for wider use in industry and commerce, atomic clocks need to be more compact and easier to operate, whilst also offering increased accuracy and reliability. Development and extension of new clock technologies, such as Rubidium (Rb) vapour-cell clocks operating at microwave frequencies, are needed if industrial requirements for reliability, low power consumption, and good frequency stability are to be met.



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The EMRP project **Compact and high-performing microwave clocks for industrial applications**

investigated emerging clock technologies and designs with the potential to provide compact, highly accurate time and frequency references for next generation satellite navigation systems.

The project:

- **Compared the performance of prototype atomic clocks** to select the best clocks for further development. A pulsed optical pumping (POP) Rb-clock, the RUBICLOCK/HORACE clock based on cooled caesium (Cs) atoms, and a pulsed Cs coherent population trapping (CPT) clock were selected for further development.
- **Developed a simplified POP clock** with a more compact vapour cell and laser system that makes the clock frequency very stable.
- **Redesigned and developed an improved version of the RUBICLOCK** based on laser-based optical cooling, simplified optical components, and a redesigned microwave cavity that provides greater frequency stability than previously possible.
- **Assembled and characterised an innovative CPT clock prototype** using industrial components with smaller volume and lower power requirements than previously possible. The prototype demonstrated good frequency stability over an extended measurement time (100 seconds), whilst performance limitations were being identified.

The production of commercial atomic clocks for industry that can achieve comparable performance to the hyper accurate NMI clocks used for maintaining the international time standard has been brought nearer to fruition as a result of this project.

A significant project outcome has been the development of different prototype atomic clock technologies towards future commercialisation. This has been made possible by an intensive and extensive collaboration between leading European atomic clock experts, from National Measurement Institutes (NMIs), to academia. Joint research has improved key clock component design, assembly, and testing. The project has generated a better understanding and greater control of the small physical changes that are key to achieving atomic clock stability and precise timekeeping.

The RUBICLOCK prototype has been commercialised by French company Muquans, whilst another prototype POP clock is undergoing further development as a potential candidate for use in the next generation of Galileo satellites – the European Global Navigation Satellite System. This system will provide Europe with independent and secure telecommunications. Improved time and frequency standards are also critical for greater synchronisation and timekeeping in business and commerce.

More information is available at	IND55 Compact and high-performing microwave clocks for industrial applications (Mclocks) http://www.euramet.org/project-IND55
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Supporting light technology innovation in manufacturing

Measurement challenges

As industrial automation advances, enhancing the competitiveness of European industries worth billions of euros requires innovation. Light-based technologies could transform manufacturing and production processes, and so create increased prosperity. From controlling and monitoring movements of robotic machine tools making intricate parts to determining the quality of finished products, light has the potential to revolutionise manufacturing processes.

To accelerate these innovations, new ways to monitor and correct manufacturing procedures using in-line measurements with instantaneous feedback for adjustments are needed. Light-based technologies could provide the tools needed to make this change. Interferometry, a lab-based measurement technique using light, has great potential for applications in diverse industrial settings from manufacturing miniscule electronic circuits to the precision positioning of aircraft wings. However, research is needed to make this highly accurate technique available to industrial users. Increasing the quality of European products and generating new on-machine or in-line measurement capabilities will enhance the competitiveness of many highly regarded European industries.

EMRP research has supported projects that address production accuracy by improving:

- Measurements for accurate positioning in 3D, used in the electronics, aerospace, and automotive industries
- Measurement precision for assembling large components that are important in the aerospace and energy industries
- Better links between multi-sensor measurements of micro-parts used in the automotive, medical, and telecommunications industries
- Measurements for complex visual effects used in the automotive, printing, and cosmetic industries



Key technical achievements

Accurate positioning in three dimensions

Electronics, aerospace, and automotive products worth billions of euros to the EU economy, all depend on precision engineering – an area where Europe has a world leading capability. As components shrink in size, maintaining this global standing requires increased measurement accuracy and improved quality control. Having confidence that machine tools working in 3D, or with six degrees of freedom (6DoF), are following precise pre-set movements to form components with micro-sized features is essential. Accelerating quality assessments based on measurements made by surface scanning probes, and more rapid confirmation that machine tools are reliably following pre-set specifications will increase precision engineering productivity and help European industries to remain competitive.



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The EMRP project **Metrology for movement and positioning in six degrees of freedom** has

increased the accuracy of determining machine tool or positioning stage micro-movements, and developed ways to increase the usability of rapid and extensive scanning probe microscopy measurements.

The project developed:

- **A mobile, easy-to-use measurement system that can characterise the motion of precision machine tools** by detecting changes to light interference patterns generated from nanoscale movements of the machine tool.
- **A powerful semiconductor laser system suitable for providing multiple light beams for 3D dimension measurements**, using interferometry. This has potential to be used for precise nanoscale measurements, where high laser output power and advanced frequency tuneability are required for industrial applications.
- **A calibration measurement strategy for manufacturing or microscopy stages that make sub-micrometre movements**. The strategy is based on performing numerous measurements along a single axis, and fewer measurements on other axes.
- **Strategies to decrease the effects of tip wear and instrument drift during extended or rapid scanning of surface features using atomic force microscopy**. A good practice guide has been issued to promote measurement comparability and reliability.

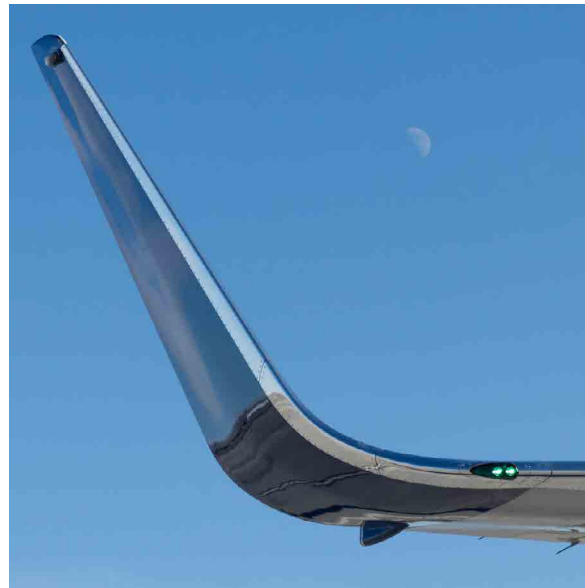
Traceable nanometre measurements of position, angle, and straightness are essential in many areas of industry and science. Examples include the highly precise positioning stages used in semiconductor manufacture by photolithography, and samples undergoing analysis using electron microscopy. As a result of this project, new calibration services have been introduced for instruments used to determine the position of machine tools that inspect nanoscale samples through to larger industrial parts. A 10-50 fold improvement in measurements for positioning accuracy in both small and large 3D systems with simultaneously large, linear, and angular motions has also been achieved. This will improve high-end manufacturing efficiency, raise quality, and reduce defects in cutting-edge products such as semiconductors and automotive parts, whilst also accelerating inspection. Improved efficiency in precision manufacturing and quality control across Europe is essential for securing technological leadership and sustainable economic growth.

More information is available at	IND58: 6DoF Metrology for movement and positioning in six degrees of freedom (6DoF) http://www.euramet.org/project-IND58	
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Precision for assembling large components

Assembling large structures, such as large aircraft wings or wind turbines, relies on accurately manufacturing and aligning constituent parts with precision to tenths of a micrometre. To achieve first time right assembly, component mismatches created by sagging or small temperature variations in vast assembly halls need mitigation. For example, misalignments in aircraft wing assembly can require the addition of several hundred kilograms of shim, effecting the planes fuel economy throughout its life.

In industry laser trackers are used for measuring dimensions and controlling positioning of large components using light based interferometry. This technique offers nanometre precision in well controlled labs but in industrial workshops temperature gradients and air turbulence seriously degrade its performance.



© arosoft

The EMRP project **Large volume metrology**

in industry (LVM) developed measurement concepts based on interferometry techniques, for new cost-effective and precise Large Volume Metrology tools, and derived strategies to compensate for measurement errors associated with industrial conditions.

The project:

- **Established three approaches to compensate** for refractive index effects in optical measurements due to environmental variations (temperature, humidity etc.) in real industrial environments.
- **Developed proof-of concept prototypes and novel systems based on laser tracking and other optical technologies**, capable of measuring distances of the order of 40-50 metres with micrometre precision.
- **Validated the performance of these systems at NMI calibration facilities** under very stable conditions to ensure measurement traceability in more rigorous testing.
- **Assessed the performance of these new systems** at the 50-metre tape bench facility at GUM, which was upgraded with additional temperature, pressure, and humidity sensors to enable provision of conditions similar to those in industrial environments.
- **Demonstrated the performance of the new systems under industrial conditions** at the Airbus industrial research facility in Filton, UK.

Industries manufacturing and assembling large components need new measurement systems to bridge the accuracy gap between expensive laser tracking and other cheaper methods. By stimulating innovation in optical measurement techniques, this project has initiated new end-user collaborations, redirected existing research, generated best measurement practice, and provided valuable training to the LVM community. Five patents have been submitted relating to project outcomes and these form the basis for potential industrial exploitation: two measurement systems (InPlanT and FSI) are being developed further, and a third (compensated tracking interferometer) is the subject of commercial discussions. Outputs from this EMRP project are contributing to the UK national project *The Light Controlled Factory*, which is further researching the enabling role of optical metrology in factories of the future. A multimillion Euro investment at Airbus in Filton, UK to develop measurement capability will use results from the project. A new calibration service using the tracking interferometer is also being established for large component measuring machines.

The follow-on EMPIR project *Large Volume Metrology Applications* (LAVA) enables the continuation of developments to the methods established in this project towards commercialisation and greater industrial uptake.

More information is available at	IND53: Large Volume Metrology in Industry (LUMINAR) http://www.euramet.org/project-IND53 Follow on project 17IND 03 Large Volume Metrology Applications (LAVA)	
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Multi-sensor measurement for innovation

Micro-parts with complex geometries are increasingly used in the automotive, medical, and telecommunications industries. Products, such as micro-gears, fuel injection systems, or drug delivery mechanisms all rely on accurate and reliable 3D measurements. Micro-coordinate measurement machines (CMMs) are used to measure components with small features using tactile probes or optical sensors. X-ray computed tomography (CT) systems are beginning to provide dimensional measurements of the complete geometry including inaccessible features, but these often lack traceability. Combining and analysing data from different sensors, such as CT, optical devices, and tactile probes, also presents a challenge in terms of reconciling coordinate systems and producing consistent data sets.



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The EMRP project **Multi-sensor metrology for microparts in innovative industrial products** developed a consistent and reliable 3D measurement framework using data from multi-sensor inputs.

The project:

- **Demonstrated that diamond-coated CMM probes are more durable and accurate for industrial tactile measurements** of very fine structures, in comparison to conventional ruby probes.
- **Developed and validated a series of reference materials with complex shapes**, enabling increased accuracy for optical and CT measurements in industry.
- **Evaluated task-specific multi-sensor measurement uncertainties** using three industrial reference standards, and developed and improved virtual models to simulate micro-coordinate measurement uncertainties.
- **Provided insights on the effects of linking the different coordinate systems** used for making measurements of the same part (tactile, optical, and CT), and determined improved approaches to reduce measurement uncertainties.
- **Developed a simulation method to identify systematic errors in CT measurements of micro-parts**, resulting in a 50% increase in dimensional accuracy.

Essential micro-parts, whether micro-gears in insulin pumps or lens implants used to restore sight after cataract surgery, must meet micrometre tolerances. This project has improved the accuracy of industrial measurements by improving CMM probes, combining different sensors and measurement techniques, and providing better traceability through use of reference standards. European manufacturers of intricate micro-parts can now benefit from greater accuracy in CMM probe calibrations, which will contribute to improved quality and competitiveness in many industrial sectors. Overall, the project has delivered greater measurement reliability to support increased penetration of the global precision engineering market by European micro-part and microsystem manufacturers. A follow on EMPIR project *Advanced Computed Tomography for dimensional and surface measurements in industry* (AdvanCT) will build on the EMRP project developments to promote SI traceability and greater industrial uptake of CT measurements for complete geometry determination including inaccessible features.

<p>More information is available at</p>	<p>IND59 Multi-sensor metrology for microparts in innovative industrial products (Microparts) http://www.euramet.org/project-IND59 Follow on project 17IND08 Advanced Computed Tomography for dimensional and surface measurements in industry AdvanCT</p>	
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Measuring complex visual effects reliably

The European automotive industry has a turnover of 900 billion euro – nearly 7 % of the EU's GDP – with highly competitive car manufacturers vying to attract customers with stunning visual effects. Similar effects are used in printing and cosmetics, where colour, texture, gloss and sparkle drive sales. These complex surface finishes include particles and flakes to produce unique effects that depend on lighting conditions.

Instrumentation for quantifying visual effects and complex surface finishes is replacing expert inspections, providing greater consistency and efficiency in product quality control. Robust measurement methods and well-characterised reference standards are needed to improve links between human perception of complex visual effects and measurements made using instrumentation.



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The EMRP **Project Multidimensional reflectometry for industry**, increased the accuracy of Bidirectional Reflectance Distribution Function (BRDF) measurements, used to determine quantitatively how light interacts with surfaces, and developed standards and statistical models to match measurements to our perception of complex visual effects.

The project:

- **Increased the accuracy of BRDF measurements to a resolution comparable with that of the human eye**, enabling accurate optical characterisation of complex surface finishes.
- **Developed a faster method to assess visual effects using BRDF** by identifying significant measurement orientations and applying new data analysis, reducing the time and complexity of measurements without sacrificing accuracy.
- **Constructed light booths for testing samples' sparkle, iridescence and gloss** under different lighting conditions, augmenting the understanding of human visual perception. This has the potential to increase the use of instrumentation in quality assurance measurements.
- **Developed a method and reference materials for measuring sparkle** as a first step towards measurement standardisation and a future international documentary standard for sparkle effects.
- **Developed new approaches for the evaluation of measurement uncertainties in CIELAB colour space**. The CIELAB colour space mathematically and uniquely describes all perceivable colours.

This project has increased the accuracy of instrument measurements for complex surface finishes and developed better statistical models and simulations to improve links between measurements results and our perception of complex optical effects. Project collaboration has created a unified European approach to measuring complex surface effects where each institute brings its own ethos and expertise, avoiding duplication and competition. New reference materials now provide increased SI traceability. Optical measurement calibration capabilities have been extended as a result of this project, and now cover the spectrum from the infrared to the ultraviolet. These provide improved SI traceability for instruments used in climate change studies, as well as those used for characterising materials used in solar energy cells.

A follow on EMPIR project *Bidirectional reflectance definitions* (BiRD) is building on XDRreflect developments and is investigating increased standardisation for BRDF, sparkle, and gloss measurements and data formats. This new project aims to further improve quality assurance for complex optical effects important for the highly competitive EU industries that generate large volumes of export sales.

More information is available at	IND52: Multidimensional reflectometry for industry (xDRreflect) http://www.euramet.org/project-IND52 Follow on project 16NORM08 Bidirectional reflectance definitions	
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Supporting high quality products

Measurement challenges

Ensuring that industries generating billions of euros for the European economy are competitive in global markets relies on manufacturing quality products. The electrical and precision engineering sectors are examples of where European commercial success has been achieved through the creation of desirable products supported by extensive quality testing. This relies on rigorous measurements to ensure parts match specification, and often involves monitoring for chemical contamination either on the product itself or in the production environment.

However, maintaining a competitive edge should not come at the expense of the environment. Europe has set demanding CO₂ emission targets and aims to reduce other forms of pollution, such as plastic waste. By developing new materials and improved monitoring techniques, there is potential to increase industrial competitiveness whilst also achieving these goals.

A robust measurement infrastructure with rigorous links to SI units is a key element in delivering production quality from researching new materials, to delivering components meeting specifications, to ensuring that the finished product is fit for purpose. EMRP research has supported:

- Improved test methods for demonstrating compliance with the EMC Directive – essential for electrical engineering production quality
- Improved cleanroom chemical contamination monitoring – essential for semiconductor, photovoltaic, and nanotechnology production quality
- Improved in-process calibrations for installed measurement devices – essential for increasing efficiency in precision production processes
- Improved high temperature erosion testing and facilities – essential for increasing turbine efficiency and reducing CO₂ emissions in energy production
- Improved chemical analysis of surfaces and layers – essential for quality and safety in medical implant production
- Improved analyses for naturally occurring radioactive materials in feedstocks – essential for worker safety in a variety of production processes.



Key technical achievements

Ensuring electromagnetic compatibility

The EU is responsible for 21% of the world's electrical engineering production, supplying essential components for industrial sectors, from consumer electronics to electric transportation and power generation. The electromagnetic compatibility (EMC) Directive sets the European standard that ensures electrical equipment neither produces nor suffers from electromagnetic interference. To meet this directive, products must undergo electromagnetic emission and immunity testing either in lab assessments or, for installed equipment, on-site. New compatibility testing approaches needed to enable manufacturers to reliably demonstrate compliance with the EMC Directive.



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The EMPR project, **Improved EMC test methods in industrial environments** developed equipment and methods for achieving greater accuracy in EMC compliance test measurements, both in the lab and for electrical installations in industrial settings.

The project:

- **Improved the accuracy of EMC testing in industry** using newly developed and improved test methods, and established greater links to laboratory test methods.
- **Developed a fast and easy to use EMC emission testing method for large fixed electrical installations** using an oscilloscope and time-domain data analysis software. A comparison against existing test methods confirmed its accuracy, enabling its use to confirm EMC Directive compliance.
- **Developed reference devices for demonstrating that labs accredited for EMC testing are performing testing that complies with the directive.** The devices record test signals for later interrogation, allowing labs to confirm ISO 17025 compliance for the first time.
- **Developed special calibration adapters for Line Impedance Stabilization Network (LISN) calibrations.** These isolate the devices undergoing testing from mains electrical interference, enabling greater accuracy when determining any interference conducted to the electricity supply via mains cables.

This project developed new cost-effective methods to simplify and speed-up EMC testing, supporting continued European competitiveness. Project developments will help electronics manufacturers to reliably evaluate new products during the design stage, potentially accelerating their commercialisation and boosting the competitiveness of European industry.

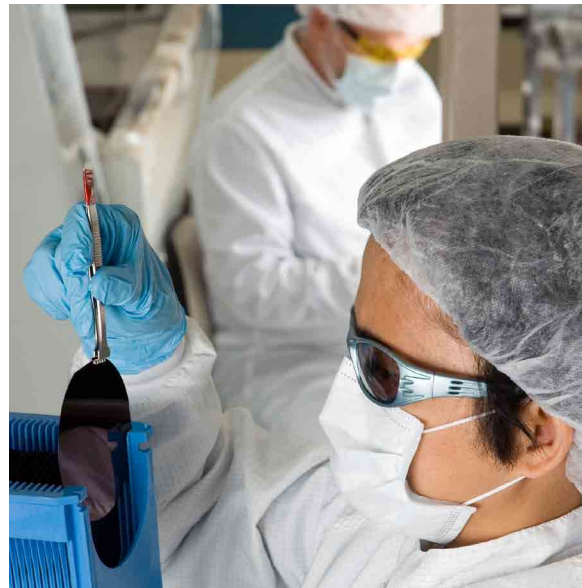
As a result of project participation, Turkey and two new EU member states, the Czech Republic and Slovenia, were able to improve their EMC Directive testing capabilities, and improved their links with other NMIs. A key aspect of the project was developing EMC testing methods and introducing them via on-site demonstrations to industrial users. This project developed EMC testing methods and promoted their uptake via on-site demonstrations to industrial users such as Mecalux during trials at a large warehouse storage facility and trackside to Alstom for electric train EMC compliance. The project's LISN calibration adapter, and oscilloscope and time-domain emission testing method have both been taken up by the International Electrotechnical Commission, who are responsible for EMC testing normative standards. The adapter has created impetus for a new IEC international standards working group, which will enable greater measurement harmonisation for conducted EMC testing, whilst the time-domain method has been incorporated into the issued standard IEC 62920 Annex B.

More information is available at	IIND60: Improved EMC test methods in industrial environments (EMC) http://www.euramet.org/project-IIND60
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Monitoring for cleanroom air quality

Semiconductors, photovoltaic devices, and nanotechnologies are all advanced technologies that rely on cleanroom production facilities. The European semiconductor market alone is valued at 286 billion euro and employs over 600,000 people. Staying competitive relies on optimising production processes, where small changes have huge financial implications.

Cleanroom production involves chemical processes that create small features and interfaces, but if these chemicals leave traces of contamination in the air this can damage subsequent production stages, leading to faulty parts and rejected batches. Optimal production requires strict air quality control to accurately and rapidly detect traces of process contamination from key airborne molecular contaminants such as ammonia and hydrogen fluoride.



The EMRP project **Metrology for airborne molecular contamination in manufacturing environments** developed advanced optical instruments for measuring trace amounts of the most critical airborne contaminants, and reference materials to accurately calibrate them. The instruments enable reliable contaminant detection at the parts-per-billion (ppb) level and are suitable for cleanroom use.

The project developed:

- **Spectrometry instruments** for reliably and rapidly detecting ammonia and hydrogen fluoride at ppb levels in cleanroom air.
- **A prototype NICE-OHMS spectrometer**; an advanced, analytical instrument with sub-ppb detection capabilities for cleanroom contaminants.
- **A method for extending gas chromatography** for the monitoring of airborne molecular contamination at trace levels.
- **New dynamic reference standards for selected contaminants** present at trace levels in cleanrooms, to improve monitoring instrument calibration.
- **Best practice guidance on achieving accurate air contamination monitoring**, based on determining the most appropriate usage of monitors and investigating materials used in system pipework to ensure reliable sampling.

As a result of this project, industries reliant on the rapid identification of trace contamination in air can now have greater confidence in installed monitoring systems. The knowledge gained from the project has contributed to revisions of ISO standards on the preparation and calibration of gas mixtures using dynamic generation methods, and the NICE-OHMS spectrometer is being licensed for further commercialisation. Other project developments are being incorporated into new airborne contamination monitoring products by the manufacturers Optoseven Oy and HC Photonics.

The project's advanced air monitoring technology for detecting trace contamination in cleanrooms is now available for industrial use and has the potential to significantly reduce costs whilst increasing the speed of contamination detection. Improving cleanroom air quality will help to increase production efficiency by decreasing yield losses. This will help advanced European manufacturing industries such as electronics by aiding their competitiveness in the global market place.

<p>More information is available at</p>	<p>IND63: Metrology for airborne molecular contamination in manufacturing environments (MetAMC) http://www.euramet.org/project-IND63 Follow on project 17IND09 Metrology for airborne molecular contamination in manufacturing environments II (MetAMCII)</p>	
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On machine in-process dimension measurement

Europe is the world's largest producer and exporter of precision engineering production tools, such as cutting and milling machines. Millions of jobs in automotive and aeronautical manufacturing rely on these machines to reliably fabricate the complex components which underpin sophisticated products. The early identification of faulty components has the potential to increase productivity by 20%.

Many of the production machines incorporate measurement systems to confirm that components meet specification before they leave the machine. These measurement systems need periodic re-calibration, where carefully controlled environments are used to eliminate the significant errors associated with shop floor temperature variations. Installed methods for confirming system performance on the machine itself would make measurements of complex shaped components more reliable and increase the early identification of parts nearing specification limits.



The EMRP project **Traceable in-process dimensional measurement** developed new reference materials and procedures for accurate, in-process calibration of installed measurement devices.

The project developed:

- **Temperature stable reference materials with well characterised and complex geometries** to simulate the intricate shapes of precision components to provide in situ measurement system calibrations.
- **A portable climate simulation chamber**, which can house a medium-size dimensional measuring machine, enabling evaluations of how changing temperature affects performance and measurement accuracy.
- **Validated procedures for determining machine tool positioning uncertainties** using the new reference standards, as well as developing methods for making temperature-dependent error corrections to minimise measurement uncertainties.
- **Five best practice guides**, which form the basis of a training course for industrial users on how to make measurements and determine factors that contribute to measurements uncertainty.

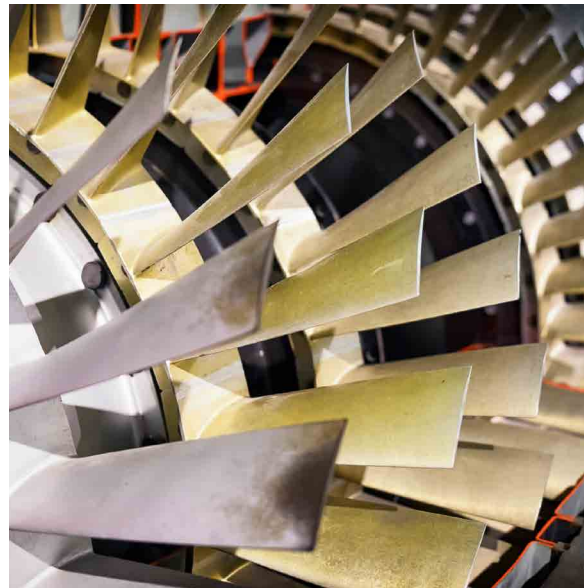
Spotting components that are nearing the edges of tolerance during the manufacturing process, and taking corrective action, relies on the ability to make continually accurate measurements. This in turn requires that instrument calibrations remain true and reliable, and that corrections matching environmental operating conditions are available for use. This project has given industry the tools and techniques needed to perform *in situ* calibrations of dimensional measurements, and verify that complex parts produced by machine tools meet specification. Companies in Finland and Slovenia have already benefited from project developments, giving improved accuracy for their manufacturing process measurements. Project procedures and investigations have also fed into new documentary ISO standards on geometric production tolerances, helping to improve dimensional measurements practices across Europe.

Robust on-machine measurement techniques will lead to more reliable and accurate measurements, enhancing machine productivity and reducing energy consumption by 30 %. Higher quality products and lower manufacturing costs will both help increase the competitiveness of European industry.

More information is available at	IND62: Traceable in-process dimensional measurement (TIM) http://www.euramet.org/project-IND62	
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Improving high temperature turbine efficiency

Erosion damage to power generation turbine blades costs 200 million euro per year in lost performance, outages, and repairs. This is caused by particles colliding at high speed and at high temperatures with the turbine's blades, eroding their leading edges and reducing efficiency. The same effect occurs in aircraft engines where ingestion of dust, sand, and other particles can erode components. Concerns over the effects of ingesting volcanic dust particles grounded aircraft following the 2010 Icelandic eruption of Eyjafjallajökull, costing the airline industry an estimated 1.3 billion euro.



Innovative erosion-resistant materials could lead to in-service turbine efficiency improvements of up to 10 %. Testing these materials under representative conditions using high speed and high temperature particles is key to their successful development. However, few facilities exist that are able to conduct testing with the necessary precision and control.

Replicating in-service conditions and reliably measuring erosion requires new and upgraded test facilities.

The EMRP project **Metrology to enable high temperature erosion testing** developed measurement capabilities for in situ measurements to improve existing facilities and underpin a new NMI-based high temperature solid particle erosion test facility capable of operating to 900 °C.

The project:

- **Investigated parameters that affect erosion measurements** such as volume, flow, speed, and temperature, enabling better matching of in-service conditions during testing.
- **Characterised the shape and size of particles** in erosion tests using measurement techniques such as optical microscopy and X-ray Computed Tomography, to ensure test conditions can be better matched to those experienced in-service
- **Developed new imaging technology for accurately measuring particle speeds** during testing using a laser and CCD camera.
- **Incorporated developments into a new NMI facility** which can reliably demonstrate the matching of test to in-service particle speeds, and incorporated in situ measurements enabling testing times to be reduced from five days to only a few hours.
- **Developed and validated a predictive model for standard computers** which simulates the effects of the vast numbers of individual particles used in erosion studies. This can rapidly and accurately relate test data to in-service component performance.

Engineers working to improve turbine efficiency, whether for power generation or aircraft fuel economy, require turbine material performance to be demonstrated through extensive testing. This project has enabled a step change in the capability for measuring erosion caused by high temperature particles, and for understanding and predicting the wear created. Project developments have been combined into a new facility that reduces erosion testing times by ~90 %.

Developers of innovative industrial materials that must demonstrate erosion resistance can now quickly identify optimal characteristics and gather accurate data on in situ performance. A UK company is using project knowledge to create more cost-effective erosion testing to validate their high temperature turbine coatings. Danish SME, Pyro Optic, successfully markets the particle speed measurement system to academia and industry. Improvements in predicting erosion material properties will deliver greater efficiency and durability to turbines, engines, and other components with engineered surfaces operating in harsh environments. This will save money, reduce emissions, and improve safety.

More information is available at	IND61: Metrology to enable high temperature erosion testing (Metrosion) http://www.euramet.org/project-IND61	
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Chemical tools support medical industry

Europe creates medical devices worth in excess of 200 billion euro annually, and is a major global supplier of millions of replacement hip joints, cardiovascular stents, and pacemakers, which can vastly improve the quality of life for patients. Ensuring devices are free from manufacturing contamination and optimising the complex drug coatings used to prevent infection or rejection are important for patient wellbeing. Implant manufacturers need improved analytical methods that are easy to use and have robust links to SI units to ensure the quality, efficacy, and safety of the devices they supply.

The EMRP project **Chemical metrology tools to support the manufacture of advanced biomaterials in the medical device industry** developed new high-vacuum analytical tools for accurately characterising thin films and surface implants coatings. The project also investigated optical techniques, such as vibrational spectroscopy, for potential application in surgical implant manufacturing environments.



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The project:

- **Developed reference materials simulating layers and coatings important for medical implants** and characterised them using XPS and other well established analysis techniques that have robust traceability to SI units
- **Used the characterised reference materials to calibrate high-vacuum measurement techniques**, such as Time of Flight Secondary Ion Mass spectroscopy (ToF SIMS), for analysing medical implant materials and layers
- **Validated technique performance by analysing accurately known ‘real world’ materials** to demonstrate reliable chemical depth profiling of drug layers that are used to improve patient outcomes
- **Investigated the feasibility of non-vacuum analysis techniques such Raman spectroscopy for near production line quality assurance**, using contaminants on surfaces lining hip replacement joints
- **Developed a guide to aid the selection of the most appropriate high-vacuum or ambient surface chemistry analysis techniques** depending on specific measurement requirements. This provides users with the necessary advice to facilitate their analysis selection in a complex measurement area.

By providing a suite of advanced analytical techniques, validated using appropriate reference materials derived from real medicines, this project has had both an immediate and lasting impact on the global competitiveness of the European medical implant industry. The project’s analytical techniques have enabled the development of new medical devices, such as urinary catheters with novel coatings, prostheses with improved performance, and improved assessments of implant corrosion. Smith and Nephew, a global supplier of medical implants, used the project’s ToF SIMS methods to rapidly and categorically confirm a production batch was not contaminated; resulting in a swift resumption of production that avoided significant down-time costs. Another global supplier, B. Braun, is using the same technique to optimise drug implant coatings for the next generation of stents. Work continues to address the challenge of detecting low-level contamination on implants in the follow-on EMPIR project 15HLT01 Quantitative measurement and imaging of drug-uptake by bacteria with antimicrobial resistance (MetBadBugs).

<p>More information is available at</p>	<p>IND56 Chemical metrology tools to support the manufacture of advanced biomaterials in the medical device industry (Q-AMIDS) http://www.euramet.org/project-IND56 Follow on project 15HLT01 Quantitative measurement and imaging of drug-uptake by bacteria with antimicrobial resistance (MetBadBugs)</p>	
<p>Contact</p>	<p>Fiona Moriarty, NPL</p>	<p>Fiona Moriarty, NPL</p>

Processing materials with natural radioactivity

Naturally Occurring Radioactive Materials (NORM) are present in the mineral feedstocks used by a wide range of industries, from fertiliser and pigment production to house brick manufacture and water treatment. NORM does not usually pose a significant hazard to workers or the public, but in some industrial processes radioactive content may become concentrated. In such cases, additional precautions are required for handling products or waste streams. Ensuring the safety of workers, or those using NORM, requires accurate, reliable, and efficient measurements of radioactivity both in industrial processes and in NORM products.

The EMRP project **Metrology for processing materials with high natural radioactivity** developed new and more accurate assay methods for measuring radioactivity in raw materials and waste streams, generated new NORM reference materials, and established innovative insitu methods for radioactive contamination monitoring.



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The project:

- **Improved laboratory methods** for automating the preparation of NORM samples for analysis based on techniques used in the mining industry.
- **Evaluated the performance of innovative pixel detectors, and developed new monitoring instrumentation** including an alpha spectrometer enabled for relaying responses for quick on-site analysis.
- **Devised an easy to follow method for determining the NORM radioactive fingerprint associated with the lead-210 radionuclide**, an indicator for the presence of other NORM radionuclides in feedstocks, reducing assay complexity and costs.
- **Conducted a comparison exercise using well-characterised reference materials**, enabling labs that routinely measure NORM materials by gamma spectrometry to demonstrate measurement competence.
- **Developed e-learning training materials** for project managers and scientific staff in NORM- industries.

A long-lasting achievement from the project has been the establishment of a new NORM measurement infrastructure and increased accuracy in radioactive analysis at many newly joined EU member states National Measurement Institutes (NMIs). This collaborative project has improved end-user measuring systems and methods, in particular for in-situ use, and provided innovative, well-characterised radiation monitoring instrumentation for raw material selection across a wide range of European industries. Accurately determining a material's radioactive content, whether from raw feedstocks or NORM waste streams, helps demonstrate compliance with the European Construction Products Directive requirements, the European Directive on radioactivity in drinking water, and the EU's Basic Safety Standards. Better compliance with these directives boosts public safety, helps to eliminate technical trade barriers, and reduces the potential for trade disputes between EU.

More information is available at	IND57 Metrology for processing materials with high natural radioactivity (MetroNORM) http://www.euramet.org/project-IND57 Follow on project 16ENV10 Metrology for radon monitoring (MetroRADON)
Contact	Franz Josef Maringer (BEV/PTP) Franz Josef Maringer (BEV/PTP)

Focus on impact

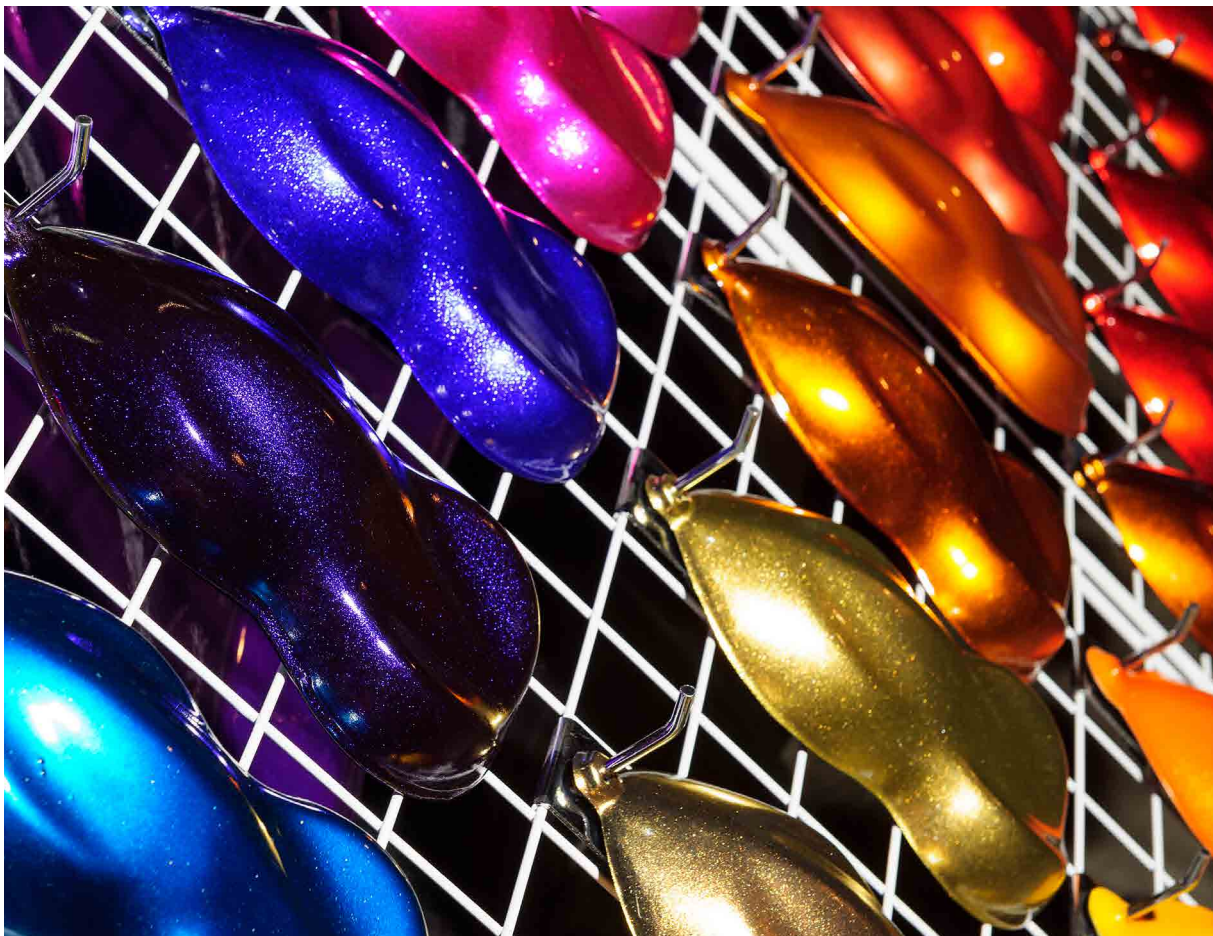
All EMRP projects engage widely with the user communities who can benefit from their research. The measurement capabilities developed in the second EMRP Industrial Innovation theme support improved manufacturing productivity, for example, by the early recognition of production lines deviating from stringent specifications. Other theme outcomes assist with meeting the EU's goals of independence in silicon wafer production and the provision of an alternative global satellite navigation system to GPS. Product quality and regulatory compliance have been addressed with impact examples highlighting improved measurement rigor for EMC Directive compliance and more fuel efficient coatings for power turbines that will assist with meeting the EU's CO₂ reduction targets.

Measuring sparkle

The EMRP Project, **Multidimensional reflectometry for industry**, characterised sparkle paint samples and used these to evaluate the performance of measurement instruments. This enabled X-Rite, a provider of instrumentation for industrial R&D and production line pigment assessments, to confirm that their instruments are reliably determining sparkle effects.

The project also identified the most significant illumination angles for assessing sparkle and used these in light booths that compare instrument based measurements to our perception of surface effects. Through using a project validated light booth, Audi discovered a mismatch between instrument results fed into perception models and visual expert panels assessing the same paint samples.

This has added to growing industrial concern over the reliability of sparkle effect measurements, which is now being addressed by a new working group set up by the international standards organisation for optical measurements, the CIE.

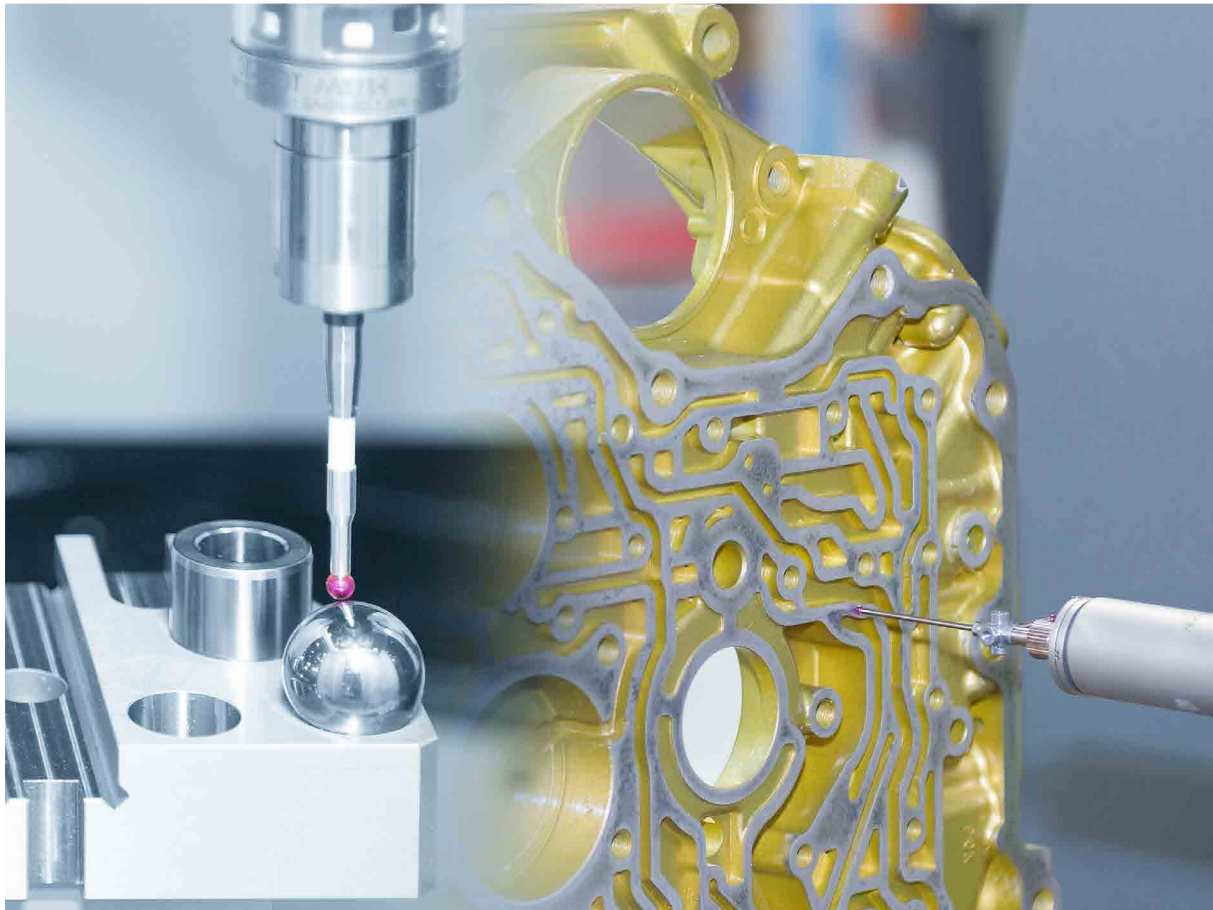


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Ensuring precision component quality

The EMRP Project, **Metrology for movement and positioning in six degrees of freedom**, upgraded an existing one-dimensional light based laboratory measurement technique to make it suitable for industrial 3D positioning applications. This technique uses reflective targets on moving objects to precisely establish exact tool movements on a nanometre scale.

Mpro GmbH, a start-up company developing precision measurement instrumentation, is using the project's 3D measurement technology for the vital positioning accuracy in its prototype micro coordinate measurement machine. By adding a feedback system to instigate tool positioning corrections in real time, MPro hopes to enable full production and quality control automation. This innovation has potential for introducing greater efficiency in industries important for growing Europe's economy.



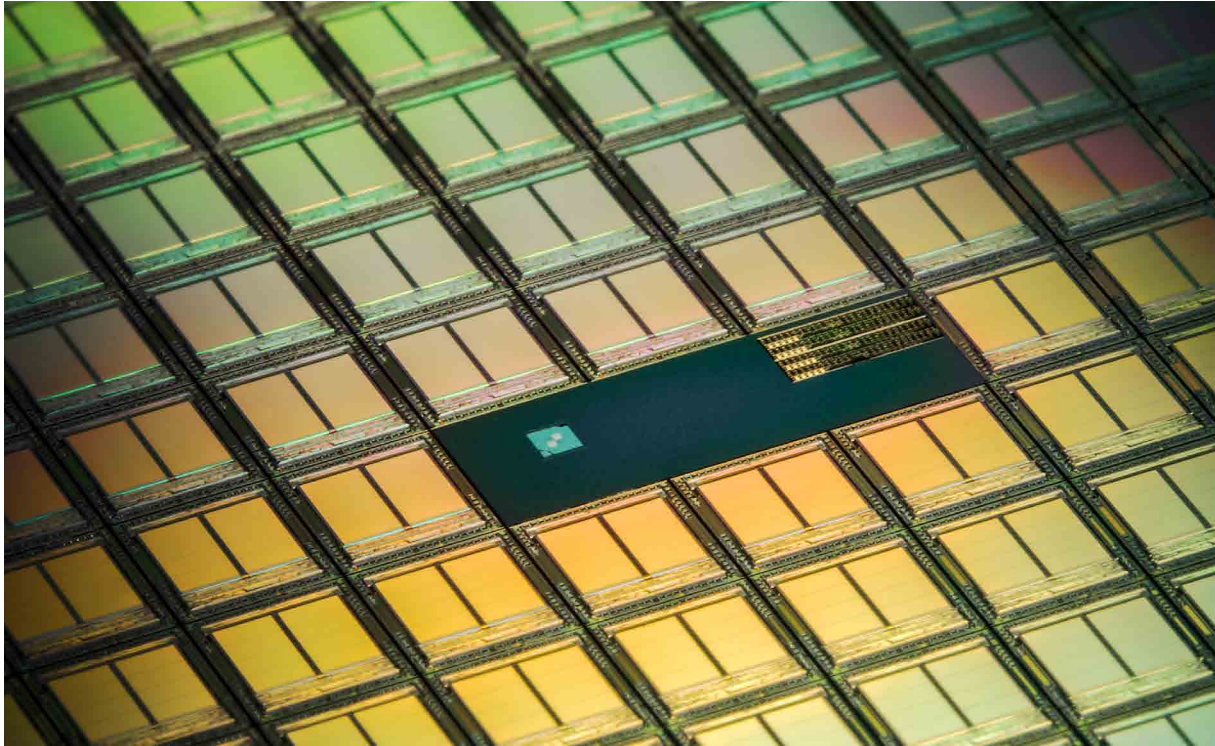
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Precise measurements for microparts

The Swiss watch industry, worth 16 billion euro per year, is centred on the quality of precision micro-mechanisms, similar manufacturing techniques are also used in the automotive and medical device industries. Improved performance often relies on shrinking component sizes and this introduces requirements for greater dimension accuracy.

The EMRP Project, **Multi-sensor metrology for microparts in innovative industrial products**, developed smaller probes for traceable tactile measurements and improved links between other measuring techniques to reduce discrepancies.

Nivarox, manufactures many of the microparts used in Swatch watch mechanisms, and was one of the first to have a complex 'gold standard' component verified using new measurement capabilities developed in the project. This is used now during quality assurance measurements, and provides robust confirmation that Nivarox's own tactile and optical measurement systems are operating correctly. European precision engineering companies have a global reputation for quality, extending our measurement capability as micro-mechanisms shrink is essential for new product innovations and continuing product quality.



© jamesbenet

Precision positioning for electronics

Europe aims to capture 20% of the global silicon wafer production market, with an estimated value of 11.5 billion euro by 2025, as uses in new smart devices and automotive electronics expand. To do so, innovative manufacturing techniques for producing the next generation of larger silicon wafers with increased numbers of electronic circuits must be developed.

The EMRP Project, **Metrology for movement and positioning in six degrees of freedom**, developed and characterised an infra-red laser, which is 10 times more powerful than those currently used in measurement applications. This increased power allows a single laser light to be split into multiple beams of sufficient intensity for simultaneously determining nanoscale movements in 3D.

TESCAN, a Czech company manufacturing scanning electron microscopes and advanced analysis instrumentation, is upgrading the project's laser technology to make it suitable for use in the prototype silicon wafer manufacturing system under development. Increasing precision for 3D nano-positioning is essential for next generation electronics production, where very small components require careful assembly into multiple circuits on a single silicon wafer

Nanoscale surface mapping

Nano-technologies using multifunctional materials such as semiconductors and photonics increasingly rely on measurements of very small features. Atomic Force Microscopy (AFM) is a technique that could allow manufacturers to benefit from the highest levels of accuracy in their processes quality assurance. But long scan times due to the high number of data points required causes both tip wear and instrument drift compromising accuracy.

The EMRP project, **Metrology for movement and positioning in six degrees of freedom**, developed freely available software that enables users to preselect where the AFM probe goes, allowing a faster adaptive scanning approach. This helps reduce tip wear and instrument drift, and therefore improves measurement accuracy.

NenoVision sro, a University of Brno spinout, markets the Litescope, an AFM accessory for scanning electron microscopes that extends the instruments capabilities to include mechanical, electrical and magnetic material properties. The Litescope, includes the project's software, bringing more rapid and adaptive AFM scanning to researchers as a first step towards greater uptake of AFM as a tool for determining product quality.

Keeping cleanrooms clean

Precise and rapid air quality monitoring for chemical traces released into cleanrooms is essential for efficiently manufacturing complex components, such as electronic circuits on silicon wafers. Currently laser based monitors are used to detect individual chemicals at part per billion concentrations in cleanroom air. These require periodic recalibration to confirm their performance at close to operating conditions.

The EMRP project **Metrology for airborne molecular contamination in manufacturing environments** developed new low concentration reference gas mixtures and improved the facilities used for cleanroom monitor calibrations.

An early user of these upgraded facilities was Optoseven Oy, a manufacturer of gas and liquid analyser systems. They confirmed the performance of an innovative cleanroom monitor prototype based on detecting small ultrasonic chemical fingerprints produced by laser excited atoms. This new technology makes it possible for a single monitor to rapidly detect several cleanroom contaminants simultaneously. As a result of prototype testing, Optoseven is now confidently promoting their new product to the Asian semiconductor manufacturers responsible for the majority of global semiconductor production.



© Freezingtime

Innovation for cleanroom monitoring

Complex manufacturing processes, such as those used to make semiconductors and high power LEDs, rely on cleanroom production facilities where air quality is monitored using laser technologies. With cleanroom space at a premium, more compact contamination monitors able to detect chemicals, such as ammonia or hydrochloric acid at parts per billion levels in air, are needed to ensure production efficiency.

The EMRP project **Metrology for airborne molecular contamination in manufacturing environments** designed a compact laser system which can be tuned to the specific absorption wavelengths of individual cleanroom contaminants, allowing accurate detection of chemical traces in cleanroom air.

As a result of interaction with the project team, HC Photonics, an SME specialising in laser wavelength conversion technologies, improved their understanding of laser design. This has enabled them to develop an innovative compact tuneable laser, which is significantly cheaper than existing infra-red light sources. Applications for this new laser include cleanroom air monitoring for multiple contaminants, environmental air pollution sensing and fibre optic communications.



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Mobile phone mast safety

From e-banking to social media, mobile communications are an essential part of modern life. As networks expand to meet rising demand, safety concerns over nonionising radiation emitted by mobile phone base stations need to be addressed. Confirming transmission power does not exceed regulatory limits can be challenging as the radiated signal strength is dependent on network usage, and therefore continuously varies throughout the day. Methods are needed for rigorously monitoring the radio frequency transmissions onsite, using industry standard hand-held probes.

The EMRP project **Metrology for optical and RF communication systems** developed a calibration setup for hand-held RF probes and a statistical method for calculating the maximum transmission power, based on network connection signals broadcast at constant power.

NED-TECH GmbH, a Swiss company providing transmission measurement services, was one of the first to use the project's calibration setup and statistical approach. This has enabled NED-TECH to reliably measure emitted radiation from base stations. In strengthening the demonstration of mobile network station compliance with environmental regulations, the public can now be more confident that exposure to any non-ionising radiation emitted stays within safe limits.

Atomic clocks for satellites

Navigation, from phone-based maps to shipping routes, depends on global positioning satellites and their onboard atomic clocks. Several bulky clocks are installed in each satellite to provide reliable time keeping but this redundancy significantly increases launch costs. Galileo, Europe's satellite positioning system, is spurring atomic clock innovations as smaller, more robust clocks are needed for future satellite and industrial uses.

The EMRP project, **Compact and high-performing microwave clocks for industrial applications** improved a prototype atomic clock based on pulsed optical pumping (POP) by simplifying components and upgrading electronics, to generate a more compact prototype better suited for space-based applications.

Leonardo, a global high-tech company in Aerospace, Defence and Security, is further developing the POP clock prototype to make it a viable candidate for next generation Galileo 2 satellites by exploring ways to make it lighter, and more robust for space use whilst reducing complexity. More compact clocks will provide European telecommunications, navigation and commerce with accurate and reliable frequency and synchronisation tools so removing reliance on external suppliers for vital systems components.

Transportable atomic clocks

Banks and internet companies increasingly rely on remote atomic clocks to provide accurate time and date stamps for processing high frequency transactions and sending information. The most accurate NMI atomic clocks need to operate under strictly controlled conditions maintained by experts, making them unsuitable for use on-site by non-specialist staff. Simpler more compact atomic clocks are being developed for industrial uses, but ensuring performance requires overcoming small yet significant manufacturing size variations.

The EMRP project **Compact and high-performing microwave clocks for industrial applications**, made design changes to a clock prototype and improved understanding of how to make adjustments to tune the clocks frequency, thereby compensating for dimensional variations from the manufacturing process. Muquans, a spin-out company from the Institut d'Optique and Observatoire de Paris, has upgraded the project's prototype and this has now been launched as the Muclock. Operating with comparable accuracy to NMI clocks without the size or requirements for closely controlled environmental conditions and expert interventions, the Muclock is one of the first to provide reliable on-site atomic timekeeping to commercial users.



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Measuring lens implants accurately

Reducing micropart size allows new functionality in smaller spaces, but confirming the accuracy of tiny dimensions is extremely challenging. One area where this is critical is in measuring the eye's curvature to inform selection of the lens implants used to restore sight during cataract surgery.

The EMRP Project, **Multi-sensor metrology for microparts in innovative industrial products**, increased the accuracy with which complex tiny shapes can be measured, upgraded links between different measurement techniques and introduced improved measurement services for reliably characterising complex reference objects.

Haag-Streit, manufacturer of instrumentation for eye care professionals, was one of the first to use the project's improved characterisation service and had a complex meniscus-shaped reference standard accurately assessed. This was then used to confirm the performance of a new instrument for measuring the eye's curvature. The instrument takes these results and using an on-board lens implant database generates a short list to assist surgeons in achieving the best possible vision outcomes for patients undergoing cataract surgery.

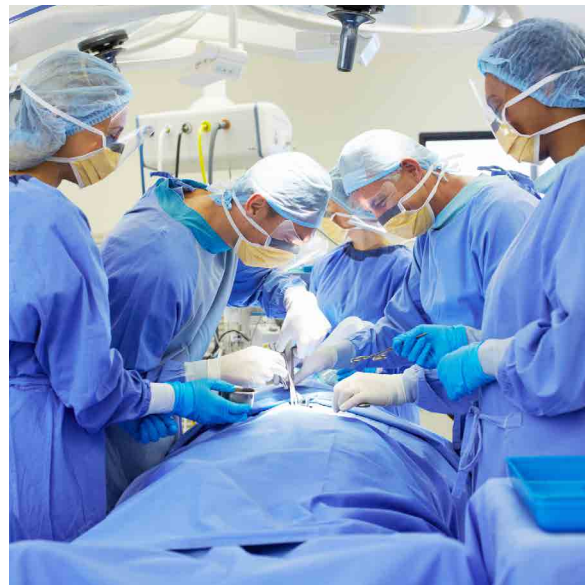


Ensuring medical implant safety

Manufacturing complex layered structures, for example semiconductors, and drug delivery mechanisms on medical implants, relies on chemical interactions to deliver functionality. Advanced analysis methods confirm chemical layer performance at all stages of the production process from research through to confirming the quality of products. Greater accuracy for surface chemical analyses is needed to ensure they work as expected and, in the case of medical devices, is essential for patient safety.

The EMRP Project, **Chemical metrology tools to support the manufacture of advanced biomaterials in the medical device industry**, investigated high vacuum techniques, such as Time of Flight Secondary Ion Mass Spectrometry (ToF SIMS) for characterising chemical layers used in medical implant manufacture. The project characterised materials used in medical implants and used these to confirm the techniques accuracy and increase its links to SI units.

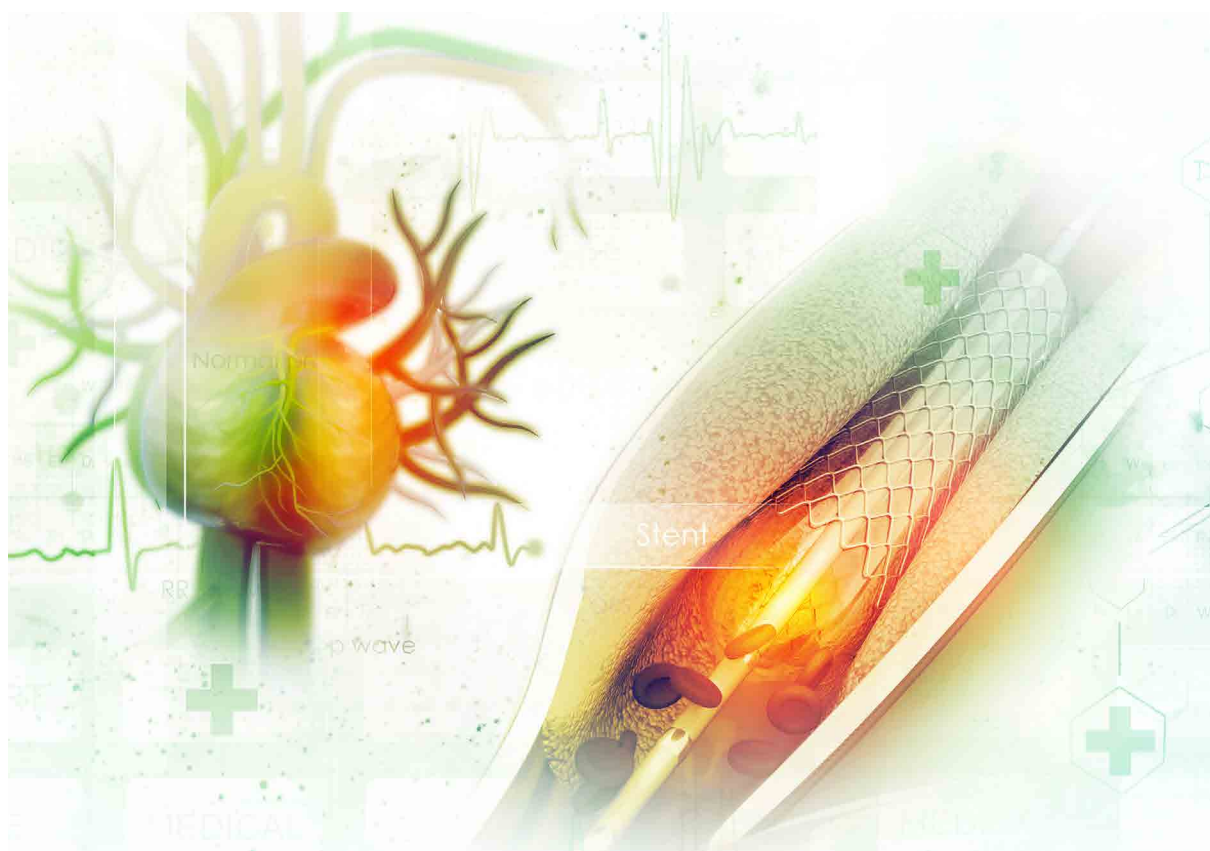
Global manufacturers of medical products, Smith and Nephew, using the project's ToF SIMS measurement methods were able to rapidly resolve a manufacturing concern – had production line equipment been exposed to a potential contaminant? Smith and Nephew were able to unequivocally demonstrate that their procedure had been rigorously followed, so avoiding production line re-fit with its potential tens of millions of euros cost. Accurate high temperature properties will lead to greater uptake of piezoelectric materials into advanced devices and sensors, bringing new and improved functionality to innovative new technologies.



Precision for complex drug layers

Manufacturing complex layered structures, for example drug delivery mechanisms on medical implants, relies on chemical interactions to deliver functionality. Complex layers are used in long-term medical implants, but to optimise patient outcomes greater accuracy for analysis methods is needed.

The EMRP project **Chemical metrology tools to support the manufacture of advanced biomaterials in the medical device industry**, investigated the use of a range of high vacuum techniques including Time of Flight Secondary Ion Mass Spectrometry (ToF SIMS) for characterising drug layers used in medical devices such as stents used to widen blocked arteries. The project's technique has been adopted by B. Braun, a worldwide supplier of healthcare products, as a research tool for investigating how drug concentrations coatings vary with depth. This powerful new measurement capability opens the door for companies, like B. Braun, to tailor drug delivery from medical implants to an individual patient's specific clinical needs. The technique has the potential to boost European competitiveness in the global medical device market estimated to be worth 70 billion euro to the EU economy annually.



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X-ray measurement smooths insulin flow

Ensuring the quality of microparts, especially those with inaccessible dimensions like drug delivery systems is challenging. X-ray Computed Tomography (CT), commonly used in medical imaging, is one technique with potential to accurately access internal dimensions but requires better characterisation to minimise errors and uncertainty.

The EMRP Project, **Multi-sensor metrology for microparts in innovative industrial products**, investigated the use of X-ray CT measurements and developed better links to existing measurement techniques. The project developed new reference samples for use across industry including the development of insulin needles for diabetics.

In Europe, some 60 million diabetics must inject insulin several times a day using single use needles. Smaller needles can reduce the pain of injections. Healthcare company NovoNordisk are now using a 'gold standard' reference needle characterised in the project to design new smaller needles and verify the performance of their own CT machines. A follow-on EMPIR project will support FDA approval for use of CT measurements in mass production of needles.



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Coatings for gas turbines to increase efficiency

Harsh operating conditions in gas fired power plants, create small particles in the air stream that wear away turbine blades, costing the power industry 200 million euro per year in lost efficiency or down time. Coatings protect blades against negative effects of high temperature exposure and make them more energy efficient but their erosion resistance is a concern; therefore having confidence in performance relies also on rigorous erosion testing under installed conditions.

The EMRP Project, **Metrology to enable high temperature erosion testing**, investigated testing parameters such as particle speeds and material removal rates, and developed new instrumentation to improve predictions of how materials will perform in-service.

Pyro Optic, a small university spin-out specialising in precise imaging measurements, validated its technology for determining particle speeds, in a collaboration with the project team. LED lighting and a digital camera to capture particle trajectories, coupled with millisecond data processing, enables the Pyro Optic system to rapidly reset for new analyses. This technology has potential for applications in gas discharge cleaning systems or flowing liquids in bio- and life- science research where determining particle or droplet motion are important.

Ansaldo Energia, is looking forward to using the project's upgraded test facilities and believes that greater confidence that coating testing closely matches their specification will enable more accurate selection of higher performing new barrier coatings. Ansaldo Energia's power turbines generate 33,400 MWh of electricity worldwide and they are actively developing improved coatings to further increase their turbines efficiency. Accurately setting test conditions and producing reliable results is key for predicting a coating's in-service performance. Confidently introducing new materials for turbine blades is important for improving power plant efficiency and reducing CO2 emissions per generated MWh.

Precision in paper production

Paper production contributes 12 billion euro to Finland's economy. Manufacturers rely on smooth rollers to turn paper pulp into sheets but over time scratches and dents develop that must be removed by re-grinding to ensure product quality. Measurement probes are used to confirm surface smoothness and these require periodic offsite recalibration.

The EMRP project **Traceable in-process dimensional measurement** developed a calibration reference disk for confirming probe performance on roller regrinding machines and developed training materials based on measurement best practices. These methods have recently been incorporated into a revised ISO standard.

Staff at RollResearch, a Finnish manufacturer of high-tech roller measuring and regrinding control systems, were some of the first to receive project developed measurement training. This expertise forms the basis for a new in-situ recalibration service for customers using RollResearch's four-point roller measuring system. Improving the efficiency of roller maintenance enables RollResearch's global clients to stay ahead in the highly competitive paper production market.



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Mains adapter boosts competitiveness

The European electrical industry produces 700 billion euros of goods annually and has a reputation for high quality, reliable products. Maintaining excellence requires rigorous product compliance to the EU's electromagnetic compatibility (EMC) Directive, which relies on a laboratory accreditation scheme to ensure testing quality and result comparability. The directive demands that all electrical items undergo testing to confirm that they do not compromise the performance of other products via their electricity supply mains leads, but demonstrating a laboratory's test set-up does not affect its results is challenging.

The EMRP Project, **Improved EMC test methods in industrial environments**, investigated the requirements for mains isolation test devices and developed an adapter to improve conductive EMC testing reliability.

Trescal, a Danish accredited lab with customers across Europe, is an early user of the project's new mains adapter for customer EMC compliance testing. As a result Trescal and its customers have increased confidence in the accuracy of the results produced. Greater robustness in EMC testing helps support the competitiveness of a vital EU industry in a global market where quality is key.



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Confirming labs meet the EU EMC Directive

All electrical devices, from wind turbines to hairdryers, must comply with the EU's Electromagnetic Compatibility (EMC) directive. This requires that any electric powered item should not cause interference that might damage or compromise the performance of other devices nearby, and simultaneously, that it should show a certain degree of immunity to the electromagnetic radiation of nearby devices. EMC testing is performed by accredited labs in accordance with international testing standards. However, few standardised methods exist to easily evaluate the performance and the testing capabilities of EMC accredited laboratories.

The EMRP project **Improved EMC test methods in industrial environments** developed a device that simulates an electrical product undergoing EMC immunity testing, and records test parameters for subsequent evaluation. The device was circulated between the project partners and Swiss EMC accredited labs to confirm their testing capabilities. Future use by other accreditation authorities across Europe is now planned to support greater harmonisation of EMC testing across Europe.

This type of inter-laboratory exercise helps confirm that testing is performed to international standards, enabling identification of underperforming labs. Remedial action will therefore be possible, leading to overall measurement capability improvements.

On-site radioactive contamination surveying

Radioactive contamination, typically associated with nuclear incidents, can also occur on construction sites in areas of high natural radioactivity. Radon gas released from ground excavations can lead to detectable building site contamination. To ensure public and worker safety, reliably identifying contamination from any source can require accurate detection of alpha particle emissions.

The project Metrology for processing materials with high natural radioactivity developed alpha emitting reference materials to simulate radon decay products and used these to validate the performance of a number of instruments including an advanced hand-held alpha emitting contamination detector prototype, the 'Adonis probe'. Developed at STUK, the Finnish DI, the probe uses the VASIKKA spectrometry software system to relay contamination data for remote expert analysis, potentially independently from GPS. The sensitivity of the Adonis system was confirmed using radon induced contamination at a metro construction site during the project.

Reliably identifying hazardous alpha contamination during routine or emergency area surveys is essential to ensure that critical decisions on contamination mitigation can be quickly made.



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Meeting the EU's Radiation Safety Directive

Many groundwater sources, including the removal of water from coal mines prone to flooding, accumulate sediments that can contain high levels of Naturally Occurring Radioactive Materials (NORM). European mine operators must comply with the EU's Radiation Protection Directive that requires that radioactive hazards are identified and mitigated to keep both workers and the public safe. In Poland, where 70 million tonnes of coal are produced per year, new national regulations also require sediments to be monitored for the lead isotope, Pb-210, a significant contributor to the radiation dose caused by the total NORM content. However, accurately determining levels of Pb-210 is challenging.

The EMPR project **Metrology for processing materials with high natural radioactivity** used sediment samples provided by Poland's Central Mining Institute to produce well-characterised reference materials. Using these, the project developed a procedure for accurately measuring the presence of lead isotope Pb-210 and subsequently accurately determining NORM content.

As a result, Polish mine operators can now confidently determine NORM content in coal mine sediments and more reliably demonstrate compliance with the new regulations and the EU Directive, increasing coal miner and public safety.

Further information

More detailed information on outputs from the EMRP projects and the contact details for each project can be found at:

<https://www.euramet.org/research-innovation/emrp/emrp-calls-and-projects/emrp-call-2012-industry-si-broader-scope-open-excellence/>

Other projects in the EMRP Industry theme can be found at:

<https://www.euramet.org/emrp-industry-environment-2010>

Other projects in the EMPIR Industry theme can be found at:

<https://www.euramet.org/research-innovation/research-empir/empir-calls-and-projects/>

Europe's National Measurement Institutes working together

The majority of European countries have a National Metrology Institute (NMI) that ensures national measurement standards are consistent and comparable to international standards. They also investigate new and improved ways to measure, in response to changing demands.

While traditional metrology stakeholders in manufacturing demand ever-increasing scope and greater accuracy, there is also a greater demand for accurate measurement in support of food safety, clinical medicine, and environmental quality, alongside a need to support emerging areas such as biotechnology and nanotechnology. This requires resources beyond the scope of most national metrology systems and therefore it makes sense for NMIs to significantly increase their level of collaboration. The European Association of National Metrology Institutes (EURAMET) is the body that coordinates collaborative activities in Europe.

EURAMET has implemented the European Metrology Research Programme (EMRP), a project programme organised by 23 NMIs and supported by the European Union, with a value of over €400 million. The EMRP facilitates the formation of joint research projects between different NMIs and other organisations, including businesses, industries, and universities.



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