European Metrology Research Programme

Article 169

RTD/B1/2009/EMRP

Impact of the EMRP

(Version 2.0 - Analysis on data available at the end of July 2019)

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Executive Summary

The 400 M€ European Metrology Research Programme (EMRP) was established in 2009 by twenty-two participating countries and the European Union, utilising Article 169 (now Article 185) of the European Treaties. EURAMET - the European Association of National Metrology Institutes – was set up in 2007 as the body responsible for the implementation of the EMRP. The core activity of the EMRP was to fund multi-partner transnational joint research projects to advance metrology and its applications.

In view of the concentrated capacities in metrology, the core part of the EMRP was executed by National Metrology Institutes and Designated Institutes identified by the participating States. The joint research projects were supplemented by three Researcher grant schemes: Researcher Excellence Grants aimed at broadening metrological expertise in the programme, which were exclusively available to the wider non NMI/DI research community. Researcher Mobility Grants which encouraged transnational mobility within the programme participants but also provided an opportunity for European countries not participating directly in the Programme to engage in capacity building of their metrology research capability. Finally, Early Stage Researcher Mobility Grants provided the next generation of metrology researchers from the participating NMIs and DIs with the opportunity to gain transnational experience.

The programme is now complete. In total, 119 Joint Research Projects (JRPs) were contracted worth almost 368 M€. Over 39.6 M€ was contracted through the associated Researcher Grants. This represents 2116 funded years of effort in the JRPs, 497 funded years in Researcher Grants and 123 years of effort from the unfunded partners.

Overall, 48 Countries participated in the programme in some form. 91 industrial companies were unfunded partners, 308 academic and research organisations were hosts to the researcher grants. 211 Small and Medium Enterprises and 146 Large Enterprises were associated with the projects as collaborators.

The projects reported over 2465 peer-reviewed publications, 1206 inputs to standards committees, 5259 conference presentations and posters, 1152 training activities, 59 patents and 2452 other dissemination activities.

The projects made contributions to the sustainability of Europe’s energy supplies by enabling measurements that allow biofuels to be used alongside more traditional fuels, making powerplants more efficient, modernising the electricity grids, and giving consumers confidence in new lighting sources. They also addressed high priority environmental and industrial needs.

The EMRP was an excellent example of European Joint Programming - pooling national research efforts in order to make better use of Europe's precious public R&D resources to tackle common European challenges more effectively. The first stage of the call selected research areas where the stakeholder need was clear, and the metrology community had the appropriate resources to make a significant impact. The second stage was a competition where the best proposals (in terms of scientific excellence and potential impact) were chosen by independent referees. The result was collaborative European projects where critical mass was brought to bear on clear objectives, with agreed project plans and enhanced stakeholder engagement. All the participants abided by the European level independent evaluation, clearly demonstrating the true “European Research Area” nature of the EMRP.

Details of the completed projects are available from the EURAMET website www.euramet.org.

Effectiveness

The programme delivered against all of its operational and specific objectives.

Specific objectives - contributing to the ERA / creating a Metrology Research Area

Leveraging and consolidating metrology funding in Europe

The programme achieved a significant level of coordination of national public metrology research programmes. 23 European countries participated in EMRP, leveraging national funding of 219.24 M€ – 10 % above the target of 200 M€ – for EMRP activities.

The programme enabled widespread collaboration in metrology research, not only among the traditional metrology institutes (the NMIs and DIs) but also with the academic, industrial and public sector communities.

The Commission and national funding supported 119 joint research projects with 957 participations from the metrology community (i.e. NMIs and DIs) and 1157 participations from a further 916 organisations the academic, industrial and public sector communities.

Scientific integration

The programme was designed and governed by the participating countries at a number of levels to support scientific integration of metrology research across Europe:

The programme was guided by a common research agenda developed by the European metrology community under the precursor ERA-NET programme iMERA.

The programme was designed around themes focused on grand societal challenges (energy, environment, health, industry) as well as supporting important developments in the international systems of units (the SI).

Call scopes were developed by the EMRP Committee of representatives from 23 countriesin line with the common research agenda;

A two-stage call process brought the European metrology community together, along with the academic community and measurement research end-users, to develop and deliver collaborative research projects;

Project selection was based on an assessment, by the EMRP committee, of alignment with strategic requirements (stage 1) and independent expert review (stage 2). The Interim Evaluation of EMRP and the annual independent observers' reports confirm that this process was independent and robust.

All participating countries could (in most cases, did) participate in all levels of the programme, including and project design and governance.

Projects were conducted by consortia of NMIs, DIs, academics, industrial and other organisations. This significantly increased the level of collaboration enabling the flow of ideas, knowledge and people and sharing of metrology research facilities.

Management integration

EURAMET implemented a dedicated and centralised governance and management processes for the programme from the outset, made up of the EMRP Committee, a EMRP Programme Manager and a dedicated Management and Support Unit (MSU). The delivery of the programme was monitored and reviewed in various ways (annual reports, audits, Interim Evaluation) The Interim Evaluation found the programme processes to be of high quality, transparent and in line with the Commission's requirements.

Financial integration

The programme managed 200 M€ of EU funding and coordinated 19 M€ of national metrology research funds using a common approach to financial rules. From its initiation the programme adopted a model contract and financial approach based on the FP7 model. Guidelines and templates were provided to support project partners who were new to this approach, helping them to cost projects and ensure finances were reported consistently and in accordance with the financial rules.

Specific objective - delivering scientific, economic and social impact

Scientific excellence and impact

The EMRP programme provided a structured process of research collaboration among European metrology institutes (NMIs and DIs). Prior to EMRP (and its predecessor ERA-NET iMERA+) research collaboration was rather ad-hoc, based on goodwill and existing relationships between individual institutes and researchers. A key benefit of the programme was not only the ability to coordinate resources and skills but the opportunity to align research timescales. An important example of this was the coordination of the European research contribution to the redefinition of the international system of units (the SI) in May 2019. EMRP projects under the first SI call became a focal point for European redefinition activity and, for some projects, an international focal point. The pooling of research expertise and the alignment of critical experiments and measurement comparisons not only enhanced Europe's scientific contribution but also led to a more coordinated European position in the redefinition decision.

EMRP researchers have published 2465 papers in peer-reviewed journals. Bibliographic analysis shows that the publications were above world averages in terms of citations, impact factor and highly cited papers and have been increasing over the period from 2008 to 2015 (i.e. before and during EMRP). In addition, the level of international co-authorship of peer-reviewed papers increased from 32 % to 47 %.

Economic impact

Accurate traceable measurement, reliable, robust internationally-recognised, underpins world trade. Metrology research ensures that international measurement systems are fit for the future and supports the introduction of innovative product and services through the accurate validation of new technologies and ideas. The pathways and timescales for economic impact are not always direct or immediate. Nevertheless, EURAMET has collected evidence of early impact - that is the adoption of EMRP project outputs by measurement users. Early adopters of metrology research are often (but not solely) the instrumentation sector and the accredited laboratory sector who make use the new NMI/DI capabilities or adopt the improved measurement techniques to develop their own new products and services. These sectors are an important bridge to measurement end-users in other business sectors and public sector agencies, who use improved measurement capabilities to develop their new products and/or improve processes.

EURAMET conducted surveys of industrial participants in EMRP projects and developed impact case studies. These demonstrated an economic impact in terms of actual and projected sales of innovative products (as quoted and/or estimated by the early adopters) influenced by the programme of 1627 M€. Of this figure, the early adopters estimate that 352.8 M€ is directly attributable to the programme. This figure covers the industrial participants that participated in projects in all EMRP calls. In addition, the new products sold will contribute to economic benefits for many of the end-users. EURAMET has identified and published 141 case studies demonstrating economic impact.

Examples include:

Social impact

Three of the programme's themes Energy, Environment and Health were explicitly focused on Europe's key societal challenges such as environmental protection, healthcare, food safety and public security. Research in these three themes addressed the requirements for accurate data and appropriate instrumentation to improve the ability to identify, quantify and better understand these issues, and to design and implement effective solutions and/or appropriate regulation. Many of the projects were directly focused on European regulation supporting issues such as water and air quality, safety of healthcare products and radiation protection. 51 projects (43 % of the total) supported regulation.

As for economic impact, the pathways and timescales for social impact are not always direct or immediate but EURAMET identified and developed 62 case studies of impact in these three themes. These case studies provide examples of the adoption of project outputs by the measurement users and demonstrate that the route to longer-term impact has commenced. Examples include:

- New flow and temperature instrumentation that has been demonstrated to improve efficiency in traditional power plants, leading to reduced carbon emissions and providing financial benefits
- Supporting the introduction of energy efficient lighting in the Italian tunnel network, improving safety and reducing both costs and energy use
- The development and trial of practical reference standards to improve the robustness of roadside emissions monitoring
- Contributing measurement methods and standards to the European Space Agency's (ESA) next generation Earth observation satellites
- Developing accurate validation of molecular methods to identify and quantify infectious diseases

Meeting our Operational Objectives

Participation from European metrology institutes

There was extensive participation from across Europe in EMRP research activities. 23 countries were formal EMRP participating states (19 EU Member States and 4 non-EU) plus the JRC. A further 21 countries (including five EU Member States) participated in projects as unfunded partners or collaborators. Collaborative research projects involved between 4 and 18 NMI /DI partners.

Extensive participation from the scientific community and metrology end-users

There were 1147 participations in EMRP projects from 916 organisations outside the NMI /DI community. 50 % (570) of participations were from universities and public research organisations and 41 % (474) from industry.

The academic and public research community largely participated in the programme via the Researcher Grant mechanism, while industrial participation was largely in the form of unfunded partners or collaboration via a Non-Disclosure Agreement (NDA) with project partners.

Considerable international participation

There were 140 participants in EMRP research projects by non-European researchers from the NMI/DI, academic and industrial communities either as unfunded partners or collaborators, including NMIs/ DIs from 14 countries (Argentina, Australia, Brazil, Canada, China, Egypt, Japan, Republic of Korea, Mexico, New Zealand, Russian Federation, Taiwan, Thailand, United States).

Researcher Mobility

384 mobility grants supported the transfer of staff between institutions to facilitate learning and the development of personal and institutional networks. These grants were taken up in particular by developing NMIs/DIs (60 % of grants were from this group) enabling their researchers to spend time in the more developed NMIs and DIs (97 % of mobility grant destinations were from this group).

Capacity building

Seven of the EMRP participating countries were EU new member states and two were accession /pre-accession states. A further three new member states participated in the programme, two of which formally joined the successor EMPIR programme. Developing metrology institutes were able to increase the research skills of their metrologists via participation in projects and mobility grants. Most were able to increase their research activities where formerly they focused on maintaining national measurement standards and providing calibration services. For example: CMI, the NMI in the Czech Republic, was able to develop critical mass in research in key areas and create a community of research-focused metrologists. IMBiH, the NMI in Bosnia and Herzegovina, progressed from mobility grants, to collaborative projects, to being a coordinator of a project under EMPIR.

Supporting European standardisation and regulation

The design of the programme around key societal challenges ensured strong alignment of the research to European regulation. Metrology research enabled more robust and reliable measurements to support compliance with, and monitoring the implementation of, European regulation. 51 of the 119 projects funded had direct relevance to regulation including, for example, the Renewable Energy Directive, the Water Framework Directive, Air Quality Directive and the in-vitro diagnostic devices regulation (a full list is provided in section 4.3).

Project teams also made 1223 contributions to 310 unique standards committees. Many of these standards committees directly supported regulation, at EU and international level. Others supported the characterisation of innovative technologies, products and processes to facilitate their market adoption.

Extensive dissemination of research results

Project teams have undertaken wide-ranging dissemination activities to share the research outputs with the metrology, scientific and end-user communities in the public and private sectors. Dissemination activities included:

- 2537 peer-reviewed papers
- 5368 conferences presentations and posters
- 1186 training activities
- 2519 communications and dissemination activities (exhibitions, newsletters, trade press, etc)
- 59 patent applications

Efficiency

The programme objectives and impacts were delivered efficiently. The costs of administering the programme were less than 16 M€. This represents 3.8 % of the total 419 M€ programme budget.

European value-added

Metrology is both a national and international endeavour. In some countries the requirement to hold national measurement standards to support the economy and society is enshrined in law and the international system of metrology ensures that primary measurement standards and the measurements they support are comparable and accepted across the world. However, the requirements for research to ensure measurements are fit for the future are increasing. Meeting ever-growing demands for new measurement standards in emerging areas of technology whilst still meeting the expectations of existing sectors and users places increasing demands on national metrology research budgets, with most countries having similar demands. Conducting research at

European level via EMRP has enabled national metrology institutes to pool resources and knowledge and reduce duplication in order to reach critical mass in key areas.

1 Introduction

This report represents EURAMET’s view of the Impact of the EMRP based on the data available at the end of July 2019. It is based on the evidence EURAMET presented to the ex-post evaluation but has been updated with information received in the following 3 years. It presents data against the programme’s specific and operational objectives as defined in Part 5 of the Annex to the General Agreement (GA) and summarises the evidence against the evaluation criteria of effectiveness, efficiency and European Value-added.

EMRP commenced in 2009 as an Article 169 TEC initiative, later transitioning to an Article 185 TFEU initiative. The programme held annual calls for joint research projects from 2009 to 2013, with projects in the last call finishing in 2017. The programme was preceded by two ERA-NET projects (MERA and iMERA+) that assessed the potential for joint working in metrology research; defined common research areas and piloted an initial joint research call.

2 EMRP objectives

The ex-ante impact assessment set out a set of nested general, specific and operational objectives for EMRP (Figure 1). The general objectives reflected the objectives of FP7 and the Lisbon agenda, and the specific and operational objectives were designed to ensure EMRP would contribute to these wider goals.

The EMRP specific objectives S1.1, 1.2 and 1.3 contributed to the creation of the European Research Area (general objectives G1.2 and G1.3): the coordination of metrology research in Europe; aiming to reducing fragmentation and duplication; and removing barriers not just among the national metrology organisations but also with the wider research community, fostering inter-disciplinarity and the latest research in new and emerging technologies.

Specific objective 1.4 explicitly focused on the impact of the metrology research directly aligned to the Lisbon objectives in three areas: scientific excellence, economic growth and addressing societal challenges (contributing to general objectives G1.1 and G1.4).

Figure 1 General, specific and operational objectives for EMRP

EMRP GENERAL OBJECTIVES	
Over-arching objective: The general policy objectives of the initiative is to enhance the EU's capacity to achieve its high-level policy goals and respond to the major challenges it faces in the coming years:	
G1.1	To contribute to the achievement of the objectives of the revised Lisbon Strategy, focussing on four priority areas: (1) concern for citizens, (2) concern for the environment, (3) a more competitive economy, and (4) knowledge and innovation
G1.2	In particular to invest more and better in knowledge for growth and jobs (and to take steps towards the so called "fifth freedom" – the free movement of knowledge within ERA)
G1.3	To contribute to the realisation of the European Research Area (ERA) by implementing a genuine “European Metrology Research Area” (MERA).
G1.4	To help Europe respond more effectively to key societal challenges such as environmental protection, health care, food safety, or public security through research striving for scientific excellence in human potential and institutional resources

EMRP SPECIFIC OBJECTIVES
Over-arching objective: In order to contribute to achieving the general European policy objectives, it will be necessary to improve the efficiency and effectiveness of public metrology research programming in Europe in areas where it is facing major societal challenges

EMRP SPECIFIC OBJECTIVES	
S1.1	Structuring the ERA through coordinating and partly integrating national public metrology research programmes to provide solutions to important European societal challenges
S1.2	Improve the efficiency of Europe's fragmented public metrology research approach
S1.3	To remove barriers between national metrology research programmes and to foster sustainable cross-border cooperation e.g. through mobility of young researchers, scientists and academic staff and to open up the national programmes to inter-disciplinary cooperation with researchers and scientists from other fields in particular relating to new and emerging technologies.
S1.4	To increase the impact of these programmes, both S&T impacts (scientific excellence, pooling of resources, data and expertise, achievement of critical mass, facilitating programme optimisation) and economic and societal impacts.

EMRP OPERATIONAL OBJECTIVES	
O1.1	Cross-border public research programme coordination and integration
O1.2	Address the grand challenges (e.g. climate change) and areas with pressing metrology needs (e.g. new and emerging technologies like for example nano- biotech- healthcare- metrology)
O1.3	Enable some "new" MS or candidate countries to build metrology research capacity
O1.4	Open access to unique research infrastructures and facilities
O1.5	Increase generic collaboration between national metrology research programmes with the relevant science community at European level
O1.6	Modernisation in the programming of national and European research priorities
O1.7	Foster mobility of "early-stage" researchers from National Metrology Institutes and Designated Institutes
O1.8	Europe should speak with one voice to strengthen its influence at global level
O1.9	Metrology research has to become a supporting activity for government regulation
O1.10	Support to industry and economic growth through up-front public metrology research

3 Indicators: specific objectives

This section provides data and evidence against the indicators set for the programme's specific objectives as presented in Figure 2 below.

Figure 2 Specific objectives and indicators

EMRP SPECIFIC OBJECTIVES		INDICATORS
Over-arching objective: In order to contribute to achieving the general European policy objectives, it will be necessary to improve the efficiency and effectiveness of public metrology research programming in Europe in areas where it is facing major societal challenges		
S1.1	Structuring the ERA through coordinating and partly integrating national public metrology research programmes to provide solutions to important European societal challenges	**Leveraging investments and co-funding of EMRP by the participating States** • National funding committed and effectively spent on EMRP: the target is EUR 200 million spent by the participating

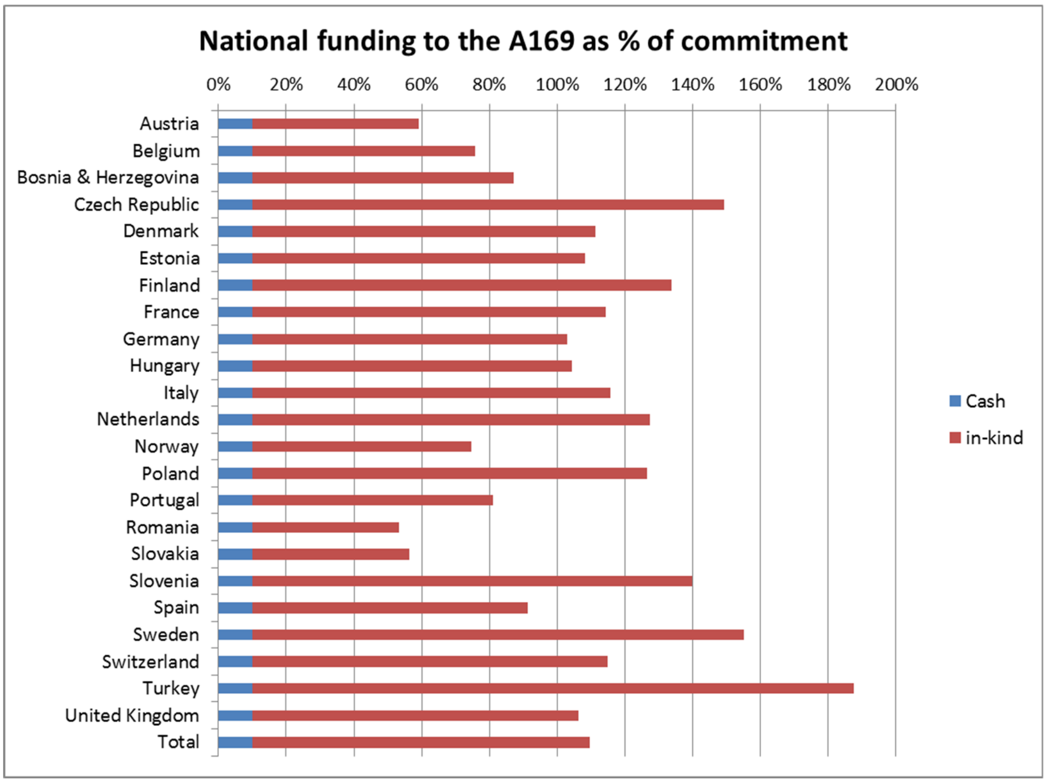
EMRP SPECIFIC OBJECTIVES		INDICATORS
S1.2	Improve the efficiency of Europe's fragmented public metrology research approach	States; identification of the use of the reserve funding capability. **Programme efficiency** • The time required between the closure of the call for EMRP proposals or for researcher grants and the date where information on the outcome of the evaluation is sent to the applicants.
S1.3	To remove barriers between national metrology research programmes and to foster sustainable cross-border cooperation e.g. through mobility of young researchers, scientists and academic staff and to open up the national programmes to inter-disciplinary cooperation with researchers and scientists from other fields in particular relating to new and emerging technologies.	**Progress towards the integration of national programmes** *Scientific integration* • Common definition of research topics following the EMRP and involving third parties through the call for potential research topics; • Effectively working central evaluation with independent experts, and central selection decision. *Management integration* • The dedicated implementation structure is in place and is effectively implementing EMRP; • The use of a common contract (model grant agreement per category of activity) linking all the fund recipients to EURAMET. *Financial integration* • The projects selected at central level are effectively co-funded by the participating States from their national earmarked budget and the reserve funding capability, according to the order in the ranking list; • The Community contribution is allocated to the projects according to the order of the ranking list; • Progress towards more financial integration through the use of harmonised financial rules (e.g. eligibility of costs, funding rates, ex-post verification).
S1.4	To increase the impact of these programmes, both S&T impacts (scientific excellence, pooling of resources, data and expertise, achievement of critical mass, facilitating programme optimisation) and economic and societal impacts.	*No indicators set but relevant data is provided in this report*

3.1 Leveraging investments and co-funding of EMRP by the participating States (S1.1)

Figure 3: Specific Objectives - Indicator 1

INDICATOR 1	National funding committed and effectively spent on EMRP: the target is EUR 200 million spent by the participating States; identification of the use of the reserve funding capability
Data / Evidence	
The total national funding committed to EMRP was **219.236 M€**. The target commitment was 200 M€ and therefore 19.236 M€ of reserve funding was allocated. Figure 4 presents the national target and actual commitment and Figure 4 presents the same data as a chart illustrating the cash and in-kind contributions.	

Figure 4: National commitments to EMRP – cash and in-kind



Source: EMRP 2018 Annual Report

Figure 5: National commitments to EMRP

	Initial national commitment	Actual national commitment
	k€	k€
Austria	840	495
Belgium	840	637
Bosnia & Herzegovina	100	87
Czech Republic	4,295	6,414
Denmark	2,235	2,486
Estonia	420	454
Finland	8,033	10,748
France	19,014	21,742
Germany	71,473	73,609
Hungary	840	875
Italy	14,081	16,279
Netherlands	10,827	13,772
Norway	1,397	1,044
Poland	420	532
Portugal	840	681
Romania	840	448
Slovakia	2,526	1,423
Slovenia	1,257	1,760
Spain	4,475	4,085
Sweden	2,389	3,704
Switzerland	6,424	7,370
Turkey	1,588	2,978
United Kingdom	44,845	47,611
Total	**200,000**	**219,236**

Source: EMRP 2015 Annual Report

3.2 Programme efficiency (S1.2)

Figure 6: Specific Objectives - Indicator 2

INDICATOR 2	The time required between the closure of the call for EMRP proposals or for researcher grants and the date where information on the outcome of the evaluation is sent to the applicants
Data / Evidence	

The time between call close and the announcement of the outcome to the applicants varied year to year. Between the 2010 and 2013 Calls the average time was 55 days. The timescale of the first call was particularly short as the programme was given approval to commence later than expected. It was possible to achieve this because the call was very small (covering only one theme and 9 funded projects) compared to later calls (that covered two or three themes and ~20-30 funded projects per year).

Year	Stage 2 close	Stage 2 preliminary results	Days required
2009	02/11/2009	27/11/2009	25
2010	11/10/2010	29/11/2010	49
2011	03/10/2011	28/11/2011	56
2012	01/10/2012	28/11/2012	58
2013	01/10/2013	25/11/2013	55

For Researcher Grants, the time between call close and the communication of results to the applicant was planned to be one month, and this was met in the majority of cases, but as the individual consortia were responsible for the final selection, there were times that this took longer.

3.3 Progress towards the integration of national programmes (S1.3)

3.3.1 Scientific integration

Figure 7: Specific Objectives - Indicator 3a

INDICATOR 3a	Common definition of research topics following the EMRP and involving third parties through the call for potential research topics
Data / Evidence	

National commitment of EMRP member states to a common definition of research

At the national level, metrology programme owners supported the common definition of research topics at the European level by relinquishing control over a large proportion of their national programmes (219 M€ - which is a significant proportion of national funding for metrology research) and allowing the research topics to be defined via the processes of the EMRP.

Common research agenda

Before the Programme started there was considerable work in the precursor ERA-NET projects (MERA, iMERA) to define common areas of interest that would be suitable to define call areas under EMRP (and the pilot call under iMERA+). Detailed roadmaps were developed and one of the iMERA outputs was further refined to become a published “outline” to define the priorities for the Programme.

At the end of the EMRP this process was repeated resulting in the publication of EURAMET’s Strategic Research Agenda (http://www.euramet.org/research-innovation/sra-survey/) that informs the research conducted under EMPIR.

Themed calls

A key element of the common research agenda in the EMRP Outline and the subsequent EURAMET Strategic Research Agenda was a thematic structure with a strong focus on metrology to address the grand challenges rather than the traditional metrology approach of themes based on technical areas and/ or SI units. EMRP calls were designed around the themes (referred to as TPs (Targeted Programme) in EMRP) and the call scopes were based on the EMRP Outline. The programme was strongly focused on the grand challenges with five of the seven themes (and 78 % of the funding) focused on the **Environment, Health, Energy, Industry, New Technologies** themes.

Common definition research topics via the call process

The greatest integration of the national metrology programmes comes through the construction of the Selected Research Topics (SRT) and the proposals in response to those. Over the life of the programme nearly half the total metrology research in the EMRP member states is funded through the Programme. This provides a great focus for the scientists working in the National Metrology Institutes - to see their work funded they need to engage in collaboration across Europe.

The process started long before a call was announced. Each Technical Committee (TC) in EURAMET met at least annually to discuss plans for future EMRP calls. Contact Persons from each member state discuss their future plans, stakeholder needs in their countries, and outline work they would like to do to address those needs. Where a consensus emerged in a TC that a need was significant enough to be best addressed collaboratively and it was in line with the call scope then interested parties refined the idea and submitted a Potential Research Topic (PRT) when the call was announced. Where the need was best addressed nationally then it was left for individual national responses. To ensure PRTs were focused on the needs of industry, public services and policy-makers and engaged with the wider research base, there was strong encouragement from the EMRP Committee to develop PRTs with those outside the NMI/DI community with measurement users. For example, in the 2011 call, 153 PRTs were submitted written by a total of 1069 co-authors, 29 % of whom were from outside the NMI/DI community.

At the next stage, the submitted PRTs were prioritised and converted into SRTs by the EMRP Committee to become the basis of a competitive process for research proposals. The EMRP Committee undertook a higher level of research integration by bringing a more strategic view of both national capabilities and priorities and stakeholder needs and potential benefits. The committee constructed SRTs designed to bring about change in the metrology community, requiring different technical areas to cooperate to achieve an objective where this would not happen naturally due to organisational boundaries, or requiring the active engagement of industry, regulators or standards bodies throughout a project where the technical community would prefer merely to present the final results.

In addition, by setting the indicative budgets by theme the EMRP Committee took a joint strategic view on priorities for metrology research across Europe. In 2010, for example, following the decision on the SRTs, the Committee took the view that a greater need had been identified in the Industry TP than in the Environment TP and moved 3 M€ from Environment to Industry. In 2011 a similar decision was initially made to move budget from SI to Health. These decisions are not about individual projects but strategic direction and feed through to national programmes and resource allocations within the NMIs.

Although national programme owners had given control over a large proportion of their national programmes to EMRP, they had influence over the national response to the research topics identified (in the SRTs) by the EMRP Committee. As proposals were developed in response to the SRTs they could choose how to spread their resources across the proposals being prepared. In theory they could withdraw from a bid at the end of that process, although this was rare as it would cause some damage to the relationship with their partners and affect other proposals. But once the proposal was submitted they relinquished control and the result was in the hands of the independent referees. In general, half the proposals were funded with scoring based on scientific excellence, relevance, potential impact, and quality.

Research projects of critical mass

The relatively large size of the funded JRPs (typically 3 M€) reduced fragmentation and duplication. Critical mass was brought to bear on clear objectives, with agreed project plans and enhanced stakeholder engagement. What could have been 20 independent research teams working on a smaller scale in a similar research area and with enhanced stakeholder engagement.

Figure 8: Specific Objectives - Indicator 3b

INDICATOR 3b	Effectively working central evaluation with independent experts, and central selection decision
Data / Evidence	

The call was transparent with all processes, procedures and documents publicly available on the website managed by the EURAMET Management and Support Unit (MSU).

The MSU managed a review conference for each call where independent experts reviewed and scored each proposal received. An Independent Observer was appointed by the Commission to review and report on the review conference process.

The Independent Observers were satisfied and complementary. For example, the Independent Observer at the Review Conference for the last EMRP call in 2013 stated:

"*The main conclusions that I can draw from attendance at the 2013 EMRP Review Conference and related documents are:*

- *The selection of the Referees and design of the evaluation processes leading to the Single Ranked List was carried out in accordance and compliance with the rules established in the Decision and General Agreement*
- *The Review Conference was organised in a highly professional and transparent manner*
- *The Single Ranked List for each of the two Targeted Programme was approved by all of the Referees and has subsequently been accepted by the EURAMET EMRP Committee*

One of the most impressive features of the EMRP is the culture of continuous improvement. Further refinements had clearly been implemented for the 2013 Call, including some that were derived from consideration of 2012 recommendations."

3.3.2 Management integration

Figure 9: Specific Objectives - Indicator 3c

INDICATOR 3c	The dedicated implementation structure is in place and is effectively implementing EMRP
Data / Evidence	

Programme level

EURAMET implemented governance and management processes at the start of EMRP. These processes provided an integrated approach to governing the strategic direction of the programme, selecting research projects to be undertaken and managing the programme's funding. As a significant proportion of national metrology research funds were coordinated via the programme this represented a significant level of management coordination of metrology research in Europe.

EURAMET put in place an EMRP Committee, Programme Manager and dedicated Management and Support Unit (MSU) to govern and manage the EMRP. All EMRP processes were governed by the EMRP Committee and delivered via the Programme Manager and the MSU. The delivery of the programme was monitored and reviewed in various ways and no significant problems or issues arose:

- All EMRP annual reports submitted to the Commission have been be accepted.
- The Interim Evaluation found the EMRP processes to be of high quality and transparent and in line with the Commission's requirements "*The Panel was most impressed by the quality and efficiency of the governance and operational systems that had been established by EURAMET, the EMRP Committee and the operational management units in Germany and the UK. These are all in accordance with the General Agreement.*" and concluded that "*EMRP is a well managed joint European research programme that has already achieved a relatively high level of scientific, management and financial integration*. "The Commission reiterated this in a press release on the Programme that stated "*EMRP is a well managed and progressively more and more integrated European programme. It has transformed a specialised*

INDICATOR 3c	The dedicated implementation structure is in place and is effectively implementing EMRP

and fragmented community into a successful public-public partnership confirming the advantages of the European Research Area."[1]

Project level

While the management culture and processes at individual NMIs/DIs are highly varied, the programme has developed a common understanding of suitable project management practices for research projects. EURAMET had a poor history of delivering collaborative (self-funded) projects to time and this needed to change to ensure the delivery of EMRP projects with defined timescales and budgets. Initially this required considerable direction from the Programme Manager and MSU through the implementation of prescriptive EMRP templates for the project plans and reporting. As the programme progressed, the level of detail required in the project plans and reports has been continuously reduced as the community needs less supervision from EURAMET. Under EMPIR, the successor programme, the guidance to project coordinators is much less prescriptive. Project coordinators and partners are advised to plan at a level of detail appropriate to the size of the project and only maintain documentation within the consortium as necessary, and they report less frequently and in less detail to EURAMET. This progress has only been possible because of systematic training of potential coordinators over the years both from EURAMET and in individual partner organisations. EURAMET held training events for those considering PRT submissions, potential coordinators, project support providers (concentrating on technical reporting) and financial support staff (concentrating on financial reporting and the financial rules).

The final step of management integration occurred in the EURAMET ex-post audit process. This consisted of both a financial audit based on EC practices from FP7 and a technical audit assessing "the scientific/technical management and control systems relating to the proper execution of the JRP and the JRP-Contract". This later part included:

- the degree of fulfilment of the JRP-Protocol
- the resources planned and utilised in relation to the achieved progress, particularly regarding the principles of economy, efficiency and effectiveness
- the management procedures and methods of the project
- the plan for the use and dissemination of Foreground IP
- the auditee's contribution and integration within the project
- the claimed potential impact in scientific, technological, economic, competitive and social terms

Figure 10: Specific Objectives - Indicator 3d

INDICATOR 3d	The use of a common contract (model grant agreement per category of activity) linking all the fund recipients to EURAMET
Data / Evidence	
The same model contract was used for all joint research projects. Similarly, there was a standard model contract for each type of Researcher Grant (one each for: Researcher Excellence Grant, Researcher Mobility Grant and Early Stage Researcher Mobility Grant).	

[1] The Interim Evaluation report is publicly available at: https://ec.europa.eu/research/evaluations/pdf/archive/other_reports_studies_and_documents/mtr_report_final.pdf

3.3.3 Financial integration

Figure 11: Specific Objectives - Indicators 3e & 3f

INDICATOR 3e	The projects selected at central level are effectively co-funded by the participating States from their national earmarked budget and the reserve funding capability, according to the order in the ranking list
INDICATOR 3f	The Community contribution is allocated to the projects according to the order of the ranking list
Data / Evidence	
The proposed joint research projects were scored and ranked (against the standard FP7 criteria) by independent experts at a Review Conference. Projects were then formally selected for funding by the EMRP Committee according to the order in the ranked lists. The funded projects are listed on the EURAMET website: http://www.euramet.org/research-innovation/emrp/emrp-calls-and-projects/ Once selected for funding, the projects were co-funded by the Commission allocation to EMRP and the national programmes' commitment to EMRP. The national commitment is demonstrated by the commitment data in Figure 5.	

Figure 12: Specific Objectives - Indicator 3g

INDICATOR 3g	Progress towards more financial integration through the use of harmonised financial rules (e.g. eligibility of costs, funding rates, ex-post verification)
Data / Evidence	
The programme manages EU funding and coordinates national metrology research funds using a common approach to financial rules. From the start the programme adopted a model contract and financial process based on FP7 rules. There were no national deviations beyond those allowed in FP7. EURAMET did publish its own Financial Guidelines but these were not deviations from FP7, merely specific advice tailored to the contract rather than other options in the FP7 generic documents that were not relevant to this programme. Guidelines and templates were provided to support project partners to cost projects at the outset and to ensure finances were reported consistently and in accordance with the financial rules. The final step of financial harmonisation occurred in the EURAMET ex-post audit process as described under **Specific indicator 3c.** The audits identified a number of common observations in the EMRP community that were fairly similar to those found across FP7 projects such as: inconsistency among professional auditors; some organisations underestimating overhead rates; a general view that organisations and their auditors found the FP7 guidelines insufficiently clear, and in some places contradictory, leading to confusion on, and different interpretations of, the financial rules. The Full Economic Cost (FEC) model required under FP7 was implemented in EMRP. As project costing methods and financial management processes varied greatly among the NMI/DI institutions, the move to the FEC approach was a significant change for many NMIs/DIs.	

3.4 Scientific, economic and social impact (S1.4)

Figure 13: Specific Objectives – indicator 4a

INDICATOR 4a	Scientific impact
Data / Evidence	

Scientific excellence

The programme focused on research excellence - project selection was a competitive process based on external peer review.

2537 papers were published across a range of journals, reflecting the breadth of the research. out of them 752 peer-reviewed papers were published in conference proceedings and 32 contributions made to books.

In addition, the annual number of scientific publications from the European metrology community increased as a result of EMRP (figure below) and there were early indicators from a bibliometric analysis to suggest that citation scores and journal impact factors increased compared to international comparator metrology institutes. The figure also shows that the level of international co-authorship with other NMIs and academics, particularly among EURAMET countries, increased. From the overall 2537 peer reviewed publications 840 are co-authored by several institutions and 434 of them are co-authored of NMIs of more than one country.

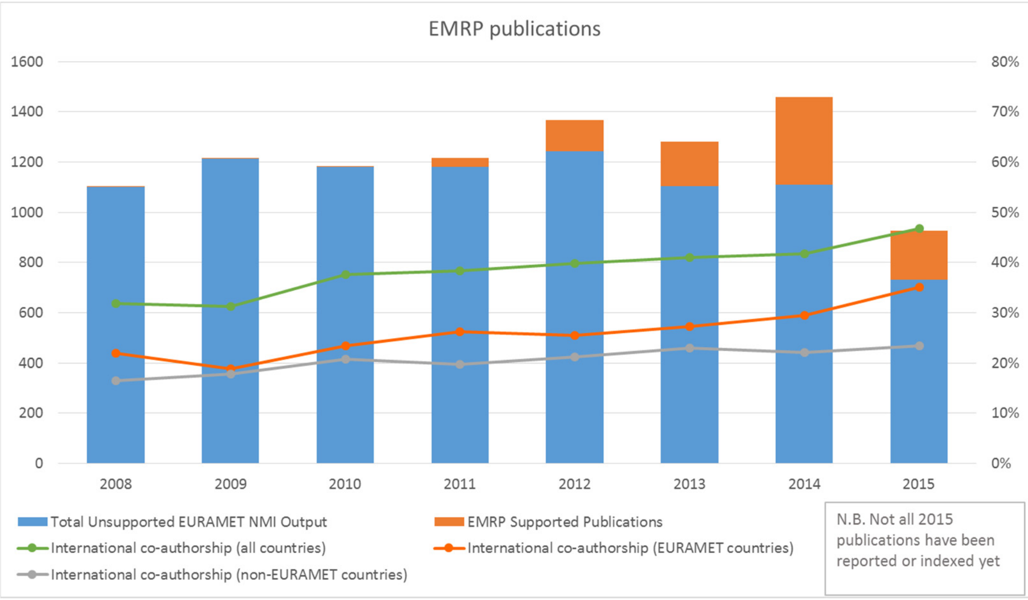


Figure 14 bibliographic study on EMRP publication, done in 2015.

Based on a bibliographic study done in 2015 we could identify that in 2014 publications resulting from EMRP supported research were 33 % of total publications (see figure above).

Pooling of resources / critical mass

EMRP enabled the pooling and coordination of resources across European metrology institutes. Prior to the Commission supported programmes, research collaboration was rather ad-hoc, based on goodwill and relationships between individual institutes and researchers. A key benefit of the programme was not only the ability to coordinate resources and skills but also the ability to align research timescales. For example, EMRP played an important role in the European contribution to the redefinition of the international system of units (the SI). The first call for projects under the SI Theme was predominantly focused on research supporting the redefinition.

The redefinition was a major milestone for the international metrology community - nothing on this scale had ever been undertaken before. The comparison of data from metrology experiments in different laboratories was essential to establishing the new SI definitions and agreeing methodologies for realising primary standards. EMRP provided a focal point and project management structure to the European contribution to an international endeavour. It enabled the world-class European NMIs to work collaboratively to share skills, undertake key experiments and share results in a coordinated manner, and make a more coordinated European contribution to the international decision processes required to agree the details of the redefinition.

The EMRP projects were highly visible internationally with NMIs outside Europe joining the projects as unfunded partners or collaborators.

The EMRP collaborations led to the start of longer-term coordination activities in European metrology research. This was a considerable achievement for the NMI and DI community in Europe. Networks of centre of excellence were investigated as a part of several EMRP projects in a number of areas:

- MATHMET: the European Centre for Mathematics and Statistics in Metrology
- Metrology for Smart Grids
- Metrology for Earth Observation

These discussions resulted in European Metrology networks, approved and launched by EURAMET, as shown on the website: https://www.euramet.org/european-metrology-networks/.

Impact on the scientific community

The EMRP research community collaborated widely with the academic and public research community. The Researcher Excellence Grant (REG) mechanism was the main instrument that supported formal collaboration, but academic groups also joined projects as formal unfunded partners and as collaborators (signing a Non-Disclosure Agreement with the project team to be able to access the research and it outputs while it was in progress). While REGs were primarily designed to ensure that metrology research could draw on the best available scientific inputs from the academic and public research community, they also enabled a two-way flow of expertise, knowledge and skills that continues to have an impact on academic research. Examples include:

- The outputs of an industry project addressing accurate metrology of large volume objects (such as aircraft) were used to assess the alignment of accelerator systems at CERN and had wider applications in other large research facilities such as European Synchrotron Radiation Facility and ITER.
- An industry project focused the metrology of magnetic materials for electronics led to the development of an instrument that is was used to assess the magnetic cleanliness of ESA's LISA Pathfinder mission. This mission was designed to test the concept of gravitational wave detection and pave the way for future more extensive missions.
- The outputs of an industry project investigating dielectric properties of materials was used in graphene research at Imperial Collage and in a method for label-free detection of tumours.
- The accurate spectroscopic data arising from an environment project was used by a research group at University College, London to support theoretical modelling of molecular line spectra for atmospheric gases. These were then used in predictive modelling of atmospheric gas concentrations in the Earth's atmosphere for climate change studies.

There were 384 participations in EMRP projects via the REG mechanism from 146 academic and public research organisations across Europe (these are listed along with all the REGs in Annex A). Over the period 2008 to 2015 co-authorship of publications between NMIs and academic organisations increased from 47 % to 68 %.

Figure 15: Specific Objectives – indicator 4b

INDICATOR 4b	Economic impact
Data / Evidence	

Metrology research's contribution to economic impact:

Accurate measurement supports economic impact in two ways:

- **Supporting trade**. Measurements traceable to national metrology standards ensure that measurements are the same in any location and at any time. This gives confidence throughout supply chains, across borders and to consumers that products and components are what they say they are and perform as specified.

- **Supporting innovation.** Accurate measurements enable the performance of novel products, techniques and processes to be tested and validated, so supporting business growth and productivity improvements.

Metrology research improves the accuracy of measurement at the highest level, extends accurate measurement to new technical areas or measurement ranges, and develops new and improved measurement techniques and instrumentation. These new capabilities flow to first-tier measurement users in industry in a number of ways: via improved calibration services at NMIs/DIs and at commercial accredited calibration and test laboratories; via improved performance of commercial measurement and test instrumentation; and by direct sharing of knowledge and skills with a wide range of sectors (manufacturing sectors in particular).

Therefore, the early adopters of metrology research are often (but not solely) the instrumentation sector and the accredited laboratory sector who make use of the new NMI/DI capabilities or adopt the improved measurement techniques to develop their own new products and services. These sectors are an important bridge to measurement for end-users in, for example, the automotive, aerospace, oil and gas sectors and public sector agencies, who use improved measurement capabilities to develop new products and/or improve processes.

In addition, NMIs and DIs interact directly with sophisticated measurement end-users during research activities - developing measurement techniques to solve industrial problems and sharing knowledge and skills.

Finally, improved measurement contributes to economic impact via the indirect economic effects of addressing social challenges such as improved health and a better environment.

The EMRP strongly encouraged industrial participation in the research projects. Industry engaged directly with projects as either 'unfunded partners' where they made a direct contribution to the projects or as 'collaborators' where they signed a Non-Disclosure Agreement with the project team to be able to access the research and it outputs while it was in progress.

In total, there were 745 industrial participations from 653 organisations in the EMRP projects.

Industrial participation	No. of participations	No. of unique organisations
Unfunded partners	92	76
Collaborators	653	585

In addition, projects shared their research outputs with a much larger group of organisations via their extensive communication and diffusion activities (see **Indicator 10d**).

Early impacts of EMRP research

The MSU collected evidence of 'early impact'. By this we mean, the examples of the early adoption (relatively soon after projects are completed) of project outputs by measurement users in the public and private sector. This early adoption demonstrates that the route to impact has started and therefore that longer-term impact is much more likely to occur.

Timescales for economic impact from metrology research vary, depending on the nature of the research undertaken and the measurement user group. Highly industrial focused metrology research can result in innovation within the instrumentation sector, for example, relatively quickly. Impact case studies and a survey of industrial participants in the EMRP projects funded in the first three calls (2009-2011) found that early adopters of project outputs were the companies (mostly instrumentation manufacturers) who participated in research projects. As a result of their participation, they were able to develop and/or validate innovative products or utilise new measurement methodologies soon after the projects ended. Survey respondents and case study companies provided data on early sales achieved to date and projected sales for the next 10 years. In total the EMRP projects in the first three calls:

- **Influenced total sales of innovative products of 1627 M€**
- **Of which 352.8 M€ was attributable to the EMRP supported research**
- These figures cover the industrial participants that participated in projects in all EMRP calls.
- Over longer-time periods these innovative products go on to provide economic benefits for their end-users.

(The 'influenced' figure is the total value of actual and projected sales of the innovative products whose development was influenced by the EMRP research. The 'attributed' figure is the portion of the 'influenced' figure that the company estimated to be directly related to the EMRP research. For example, if the product could not have been developed at all without the EMRP research the 'influenced' and 'attributed' figure would be the same. If the product was developed more quickly as result of the EMRP research the company might estimate a 10 % attribution to the research.)

The **Industry theme** was strongly focused on meeting industrial measurement needs. 30 research projects addressed a wide range of industrial measurement needs and this theme was the largest contributor to the impact figure presented above.

A number of examples of early impact from the Industry theme are presented below (more examples are provided in Annex C). These include examples focused on impact for instrumentation and process equipment manufacturers, as well as end-users and the adoption of project outputs to support the development of emerging technologies (such as quantum technologies). Case studies of early adoption of the research outputs are provided on the EURAMET website and summarised in the Industry Impact Report (covering the completed projects in the first Industry theme call).[2]

1. Instrumentation innovation – gas analysis

INFICON, a Swiss manufacturer of instruments for gas analysis, used the new NMI vacuum metrology system to demonstrate that its innovative gauge for dynamic pressure responded twenty times faster than the previous model. This offered opportunities to their customers in the semiconductor sector to reduce the processing time for manufacturing steps conducted in vacuums.

2. Instrumentation innovation – automation equipment

Tetra, a manufacturer of automation and robotic equipment, developed a novel optical sensor for a high-performance friction test system at a metrology institute. This sensor has since been used to improve their own high-end positioning system making it one of the best on the market and supporting new sales.

3. Instrumentation innovation – fluxgate sensors

Bartington Instruments, a manufacturer of high-performance fluxgate sensors, used the new metrology facilities for magnetic measurements to validate the performance of its sensors across a wide temperature range. These sensors have been used to prepare navigational instruments for the European Space Agency's (ESA) Solar Orbiter mission, scheduled for launch in 2018.

4. Instrumentation innovation – dynamic pressure sensors

Kistler Instruments AG, a leading manufacturer of dynamic pressure sensors was one of the first users of a new calibration facility designed to test the performance of pressure sensors under dynamically changing pressure conditions. They are proposing to use the new facility to support the development of new prototype sensors that be able to perform effectively under extreme conditions in automotive R&D. This supported the development of engines with higher efficiency and reduced emissions.

5. Accurate analytical measurements for innovative materials

Advanced analytical instrumentation based on a range of atomic and spectroscopic effects offer the ability to understand and assess the characteristics and performance of a wide range of innovative materials. These instruments are used in a wide range of sectors – such as electronics, optoelectronics, aerospace, medical devices – where the chemical and physical structure of surfaces and thin films is critical to the functionality and performance of devices and components. Establishing traceability for these instruments increases their value to product and process innovation as it provides reliable quantitative assessments of material structure and performance. EMRP project teams developed reference materials and transfer standards for a range of analytical instrumentation that were then used by instrumentation manufacturers to validate their products, provide traceability to their customers and support instrument R&D. Examples include:

Bruker Nano Analytics has used certified reference materials to improve its Energy Dispersive X-Ray Spectroscopy (EDS) instruments that support innovation in catalysts for car exhaust systems and coatings for faster and more durable microelectronics. Kratos Analytical, manufacturer of high-value x-ray photoelectron spectroscopy (XPS) instrumentation, has used reference materials to improve the performance of their XPS instruments for innovation in biomaterials, polymers, catalysts.

[2] https://www.euramet.org/metrology-for-societys-challenges/metrology-for-industry/

6. Better heat-treatment process control

ALOtec, a German provider of materials processing services to the manufacturing sector, improved the performance of its laser-hardening process. Laser hardening is a heat-treatment technique and precise temperature monitoring is required to control the process to ensure high-quality products and minimal waste.

Working with the EMRP project High temperature metrology for industrial applications (>1000 °C), ALOtec tested the portable 'fixed-point' temperature device developed in the project on its laser-hardening system, demonstrating its suitability as an in-situ calibration tool to correct the thermometers that control the process. Testing revealed that the device could correct for large deviations from the ideal processing temperature, where a deviation of 10 °C above or below the required temperature can cause faulty parts. The information gained enabled ALOtec to optimise its laser-hardening process and provide an improved service to its customers in the machine building, automotive and power generation sectors and mould and tool making industries.

7. Supporting development of for fuel-efficient vehicles

Improvements in the accuracy of pressure measurements at the highest metrological levels helped the automotive industry to design and manufacture the next generation diesel engines. To meet consumer demands and comply with emissions regulation, engines needed to be more fuel efficient. A key element in fuel efficiency is the use of higher pressures in the fuel injection process. EMRP research developed improved metrology in high pressure and dynamic pressures that supported European engine research and development. Working closely with the automotive and instrumentation sectors, the metrology community helped to ensure the measurement instrumentation for high-pressure manufacturing processes and in-line process control equipment was developed. HBM, for example, used the facility to calibrate one of its high-pressure sensors, P3MB Blue Line Top Class transducer©, creating a highly accurate in-house standard which allowed them to calibrate all the sensors it sells and provide reliable high pressure measurement services to its customers who develop high pressure technologies. Maximator used the facility to verify its autofrettage systems, which use high pressure to strengthen materials. This provided assurance to its automotive customers that its systems met the pressures required for industrial strengthening processes for new, lower emissions diesel engines. This helped those customers meet new EU emissions standards and so remain competitive.

8. Advancing quantum communications

Toshiba used the results of an EMRP project in the first public demonstration of a prototype communications system secured using Quantum Key Distribution (QKD). QKD, which shares encryption keys using single photons, offers a level of security beyond that possible with classical communication techniques.

The measurement capabilities developed as part of the EMRP project Metrology for industrial quantum communication technologies were used to characterise Toshiba's laser system, a crucial element in the prototype communications system. After this performance validation, Toshiba had confidence in the laser's use as a single-photon transmitter, and it was used as part of the first public demonstration of a QKD system using commercially-available components on a standard fibre optic network.

The success of this demonstration, conducted at BT in the UK, provided validation of this next-generation communications technology and was an important step towards the widespread implementation of QKD networks for secure data transmission.

9. Building trust in quantum technologies

Micro Photon Devices (MPD), a research establishment of Microgate Srl, a leading producer of professional timing systems used the new detector characterisation facility developed within the EMRP project Metrology for industrial quantum communication technologies to improve the accuracy of its single-photon counters specifications.

Single-photon detectors are the key components underpinning many new and emerging photonic technologies. MPD produced single-photon counters based on these detectors, specifically designed and optimised for applications requiring low-noise and low-power measurements, such as space-earth communications or atmospheric sensing. Precise characterisation at the new facility gives MPD's customers in the research and development sector greater confidence in the performance of its detectors.

Reliable specifications for the components underpinning quantum communications build end-user confidence and accelerate the introduction of next-generation quantum technologies.

10. High-performance thin film technologies

Plasma Quest, a developer of thin film materials and deposition technology for customers in the electronics industry, developed a new, cost-effective production technique for the high-performance barrier layers used to protect advanced thin-film products.

Plasma Quest used a new facility established by an EMRP project to test the effect of different production techniques on the quality of barrier layers in thin films. This enabled the company to successfully demonstrate a new technique enabling high-volume production of barrier layers unhampered by dust in the production environment.

The ability to create effective barrier layers without the expense of maintaining clean room conditions significantly reduces production costs without any reduction in product performance, supporting the development of durable thin film devices, reducing costs and opening new markets. Plasma Quest received enquiries from several manufacturers of mobile phone screens looking to implement the new technique.

Figure 16: Specific Objectives – indicator 4c

INDICATOR 4c	Social impact
Data / Evidence	

Metrology research's contribution to social impact:

Accurate measurement underpins society's ability to address grand challenges in a number of ways. It provides the ability to accurately and effectively identify and quantify problems and monitor the progress and effectiveness of actions taken to solve or mitigate those problems. For example:

- Accurate measurements enable the quantification of pollutants in air, water and soil to identify where action is needed and support relevant policy-making. Accurate measurement also enables public agencies to monitor the effectiveness of policies and enforce regulation aiming to reduce emissions;
- Accurate measurements underpin the accuracy of diagnostic tests in healthcare and ensure that therapies and treatment are safe and effective e.g. accurate measurement of dose delivered during radiotherapy;
- Robust measurements assess the performance of new technologies and instrumentation required to address social challenges e.g. assessing the performance of low carbon technologies, sustainable fuels, or emissions monitoring instrumentation.

Metrology research contributes to solving societal challenges in a number of related ways:

- It improves the accuracy (and therefore the robustness and comparability) of measurement data used to make decisions about the environment, healthcare provision, etc;
- It contributes knowledge on robust measurement methods to regulatory and standardisation organisations;
- It supports innovation in the development of appropriate measurement instrumentation to enable effective and efficient implementation of regulation.

Early impacts of EMRP research

The link between metrology research and quantifiable social impact is complex. Accurate measurement is one aspect of the many and diverse social processes required to bring about change. Furthermore, the timescales between metrology research and quantifiable social impact are often long – 5 to 10 years and longer in some cases. Nevertheless, the EMRP research in the Energy, Environment and Health themes (in particular) was focused on very practical problems and a wide range of research outputs have already been adopted by standards developing organisations (CEN, ISO, etc), instrumentation manufacturers and end-users.

As the data reported against **Operational Indicator 9b** demonstrates, the EMRP research community engaged widely with the standards developing organisations: making 1223 contributions to 310 unique standards committees resulting in contributions to 126 published or draft standards. In addition, **Operational Indicator 9a** shows that at least 51 projects have direct references to regulations in the description of their research.

The MSU collected evidence of 'early impact'. By this we mean, the examples of the early adoption (relatively soon after projects are completed) of project outputs by measurement users in the public and private sector. This early adoption demonstrates that the route to impact has started and therefore that longer-term impact is much more likely to occur.

The **Energy theme** had a strong focus on research to support the Commission's Renewable Energy Directive, developing improved measurement accuracy and techniques to characterise renewable energy sources and low carbon technologies and support modernisation of the electricity infrastructure. Case studies of early adoption of the research outputs are provided on the EURAMET website and summarised in the Energy Impact Report (covering the completed projects in the first Energy theme call).[3] The case study summaries are also provided in Annex C.

Examples of early impact include:

1. Enabling implementation of smart grids

Smart grids that proactively manage highly variable supply and demand of electricity were a key component in the energy infrastructure needed to meet Europe's target of 20 % of energy consumption from renewable sources by 2020. As smart grids are managed by radically different instrumentation and control processes to traditional grids, they require the development of an appropriate measurement infrastructure. Phasor measurement units (PMUs) are the 'life-support monitor' for the smart grids of the future. Installed throughout the grid, PMUs assess and compare the power signals across the network, enabling grid operators to monitor and control these complex systems. EMRP research developed calibration equipment, software and processes that enabled PMUs to be validated against traceable measurement standards for the first time in Europe. Tests of PMUs in operational grids in Greece and Sweden resulted in best practice guidelines for PMU use, which were incorporated into a revision of the relevant IEEE Standard used by the industry and supported the development of PMUs and commercial equipment to calibrate PMUs. The best practice guide also supported a pilot a 'smart energy cluster' on the outskirts of Dublin, which linked small-scale renewable energy generators with local consumers through a smart grid.

2. Improved efficiency of power plants - reducing CO_2 emissions

Increased efficiency of existing fossil fuel and nuclear power plants is part of the solution to reduced CO_2 emissions and will also lower the cost of energy for consumers. EMRP research developed better methods for temperature and flow measurements to support process control in power plants. KROHNE, a leading manufacturer and supplier of industrial process instrumentation, used the new methods to demonstrate the accuracy of an innovative ultrasonic flow meter that can also simultaneously measure temperature. A trial of the new flowmeter in a nuclear power plant against existing measurement methods indicated that deployment of the flowmeter across the plant would lead to operational efficiencies - of the order of 60 MW, equivalent to the electricity required to power 10000 extra homes. This represented a significant improvement in plant efficiency and given Europe's dependence on large-scale power plants for the foreseeable future, an important contribution to the efforts to reduce Europe's carbon footprint.

3. Implementing low energy lighting in the transport network

The EU committed to cutting its greenhouse gas emissions by at least 20 % by 2020 compared to 1990 levels and to improving energy efficiency by 20 %. With 14 % of the EU's total electricity consumption used for lighting, more efficient lighting technologies could make a significant contribution towards meeting these targets. Solid state lighting (SSL), which uses LEDs as the light source, is the most energy-efficient lighting technology available and offers good quality light and visual performance and is an ideal candidate for safe and efficient road lighting. However, our eyes work very differently under the low light (or mesopic) conditions experienced in road tunnels and many other important lighting applications and standards were needed to improve the accuracy of light intensity measurements in these conditions. EMRP research developed a novel mesopic luminance meter and accompanying low light measurement method. Project researchers worked with Autostrade per l'Italia to study Italian highway tunnels with LED lighting and determine safety critical design parameters. The outputs contributed to an Italian standard to support the safe introduction of LED lighting into Italian road tunnels. It enabled a significant reduction in the consumption of electrical power for tunnel lighting. LEDs operating at the new safe lighting levels identified within the project contributed a further 33 % saving in electricity consumption. With LED lighting introduced into approximately 95 % of Italy's

[3] https://www.euramet.org/metrology-for-societys-challenges/metrology-for-energy/

1500 km of highway road tunnel network, this standard led to safer roads with significantly reduced power consumption and associated CO_2 emissions.

The **Environment theme** was focused on measurement research to improve our understanding and assessment of climate change and ensuring a safe and clean environment by improving measurements to support environmental regulation in areas such as air and water quality. Case studies of early adoption of the research outputs are provided on the EURAMET website and summarised in the Environment Impact Report (covering the completed projects in the first Environment theme call).[4] The case study summaries are also provided in Annex C.

Examples of early impact include:

1. **Enabling compliance with the European Water Framework Directive (WFD)**

The WFD specifies very low permitted levels of pollutants that present a significant risk to or via the aquatic environment. Toxic pollutants such as tributyltin (TBT), polybrominated diphenylether (PBDE) and selected polycyclic aromatic hydrocarbons (PAH) are particularly harmful as they are liable to accumulate in the food chain and endanger a wide range of living organisms. However, the primary measurement methods did not exist to support compliance with the low levels permitted by the WFD. EMRP research developed validated primary reference methods (traceable to the SI units) and reference materials for the analysis of these pollutants in real-world water samples at the low levels required. These methods allow the robustness of measurements made in public and commercial labs to be validated and enable regulators to have confidence in assessments of water quality. The methods are deployed in a number of European regions and have enabled the CEN Technical Committee on Water Analysis to develop standards on the analysis of TBT, PBDE and PAH.

2. **Improved roadside pollution monitoring**

Improving air quality requires accurate measurements of pollutants at the low concentrations permitted by European regulation. EMRP research developed preparation methods for calibration gases for SO_2, NO and NO_2 at or near the limit values of the regulation and a practical portable NO_2 generator for cost-effective calibration of air quality sensors in the field. The NO_2 generator has been used by the City of Zürich Health and Environment Department to calibrate its installed air quality sensors, enabling it to evaluate its pollution reduction strategy and maintain its lead in reducing city centre pollution.

3. **Enabling compliance with the European regulation on vehicle emissions**

Particulates are classified as carcinogenic by the World Health Organisation and each generation of the European emissions regulation reduces the levels permitted in vehicle exhausts. Euro 6, the latest version of the regulation, introduces a limit on particle number as well as particle mass. EMRP research developed a new validated aerosol for calibrating the condensation particle counters used to type-test and certify new engines and ensured its uptake through incorporation of measurement best practice in the relevant ISO standard. The new facilities at NMIs have enabled two companies to validate and/or improve instrumentation used to assess automotive exhausts and therefore enable compliance with the tighter regulation and contribute to reduced harmful emissions.

4. **Improved data for Essential Climate Variables**

EMRP research has made significant developments towards the goal of an 'NMI in space' that will calibrate and validate the climate data from Earth observation satellites. The metrology community worked closely with the European Space Agency and climate scientists to develop and test high-level metrology instrumentation for the space environment. The instrument, a primary radiometer, is capable of a radiometric accuracy of 0.3 %, a factor of 10 improvement on previous traceability methods. The instrument is the key component of the planned TRUTHS mission (Traceable Radiometry Underpinning Terrestrial- and Helio- Studies) that will establish an NMI in space.

The **Health theme** focused on measurement research to improve the diagnosis and treatment of health conditions via both improved accuracy of chemical and biological analyses and more effective therapeutic methods and technologies. Case studies of early adoption of the research outputs are provided on the

[4] https://www.euramet.org/metrology-for-societys-challenges/metrology-for-environment/

EURAMET website and summarised in the Health Impact Report[5]. The case study summaries are also provided in Annex C.

Examples of early impact include:

1. Enabling the introduction of next generation MRI scanners

Next generation MRI scanners with improved image resolution enable clinicians to make more accurate and effective diagnoses. These scanners, already in use as research tools, work at higher magnetic field strengths and the safety of both patients and healthcare professionals must be demonstrated before the new scanner can be adopted in clinical practice. EMRP research developed tools and techniques to accurately assess patient and operator exposure in the higher magnetic fields. The project outputs contributed to international guidelines from International Commission on Non-Ionising Radiation Protection (ICNIRP) as well as international and national standards, all of which are essential to the type-approval of MRI scanners. The project also worked closely with European MRI manufacturers enabling them to assess their products effectively and ensure compliance with the relevant standards and regulation. This supports both a faster market introduction of innovative products and ensures the most effective technology is available to patients.

2. More effective therapeutic ultrasound

High intensity therapeutic ultrasound (HITU) is able to destroy cells with minimal damage to surrounding tissue and has been approved by some countries to treat a range of specific medical conditions such as prostate and liver cancer. However, there was no metrological infrastructure in place to accurately assess the dose given to patients and ensure they are treated effectively (not given too low a dose) and treated safely (not given too high a dose) and this uncertainty creates risks for patients and hinders wider uptake of the technique. Accurate dose measurements are also essential to creating robust personalised treatment plans for individual patients. EMRP research (building on research started under EMRP's precursor programme - iMERA+) developed a metrological infrastructure HITU that enables consistent and robust measurements of ultrasound dose and contributed to the key international standards that support the implementation of the European Medical Device Regulation in this technological area and is also referred to by the US Food and Drug Administration. The project team has also supported European manufacturers developing HITU equipment via new calibration services and consultancy, ensuring they can provide equipment and components that will comply with regulation and provide effective treatment.

3. Enabling effective diagnosis and management of infectious diseases

Infectious diseases account for over 20 % of human deaths globally and 25 % of all morbidity. Accurate and rapid methods to diagnose and manage infectious diseases are critical to protect public health. Infectious pathogens can be present in samples at very low levels and accurate and consistent assessment methods are needed to identify and quantify pathogens. Molecular methods such as digital PCR and nucleic acid sequencing (NGR), offer the potential to establish the highest-order metrological methods as well as improve the identification and quantification of pathogens in clinical practice. Traceability to international systems of measurement is in its infancy in the biological realm and EMRP research developed highly accurate methods that are moving towards SI traceability and used them to evaluate new and emerging molecular approaches for the surveillance and monitoring of infectious diseases. The higher-order methods will support the development of reference materials used to assure the quality of analyses made in end-user laboratories and so support robust and effective identification and monitoring of infectious diseases.

4. Improving medical implants

Implantable medical devices improve quality of life for millions of people, but the rates of complication, infection and device failure are unacceptably high. Novel materials, surfaces and antibacterial and drug-releasing coatings can improve the biocompatibility of implants, reducing infections and complications. These require accurate assessment of physical and chemical surface features at the molecular level to support product development and quality assurance during manufacture. EMRP research developed analytical tools to validate the near-surface chemistry of implantable medical devices. It advanced the traceability of the highest-order measurement techniques (complex, expensive and slow methods conducted in a vacuum) and assessed and improved 'ambient' methods suitable for the manufacturing environment. The project team worked with both implant manufacturers and academic researchers to assess failure mechanisms and identify sources of contamination on a production line.

[5] https://www.euramet.org/metrology-for-societys-challenges/metrology-for-health/

4 Indicators: operational objectives

This section provides data and evidence against the indicators set for the **programme's operational objectives** as presented in Figure 17 below.

Figure 17 Operational objectives and indicators

EMRP OPERATIONAL OBJECTIVES		INDICATORS
O1.1	Cross-border public research programme coordination and integration.	Number of Member States involved in EMRP and national programmes actively coordinated
O1.2	Address the grand challenges (e.g. climate change) and areas with pressing metrology needs (e.g. new and emerging technologies like for example nano- biotech- healthcare- metrology).	Number of research projects which build on the specific strength of NMI and DI and their infrastructures and their impact on primary standards
O1.3	Enable some "new" MS or candidate countries to build metrology research capacity.	Number of new Member States building up metrology capacities Increase in metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development
O1.4	Open access to unique research infrastructures and facilities	Number of research infrastructures jointly used in RTD projects
O1.5	Increase generic collaboration between national metrology research programmes with the relevant science community at European level.	Number of research organizations (not being NMI of DI) involved in EMRP projects Level of participation in the programme by outside researchers and research institutions Total PhDs trained in metrology
O1.6	Modernisation in the programming of national and European research priorities.	List of advanced technologies employed in the developments of primary standards can and should be transferred to new and challenging research activities
O1.7	Foster mobility of "early-stage" researchers from National Metrology Institutes and Designated Institutes	Number of mobility grants implemented
O1.8	Europe should speak with one voice to strengthen its influence at global level	Number of generic cooperation activities with non-European research actors
O1.9	Metrology research has to become a supporting activity for government regulation.	Number of EMRP projects with direct references to regulation Number of presentations at standardisation technical committees or working groups
O1.10	Support to industry and economic growth through up-front public metrology research.	Number of publications, patents granted, presentations at congresses, dissemination activities Number and quality of training activities
	ADDITIONAL INDICATOR (specified in Annex to the General Agreement)	Total number of metrology researchers involved in EMRP projects by age, class and seniority level

4.1 Cross-border public research programme (O1.1)

Figure 18: Operational Objectives - Indicator 1

INDICATOR 1	Number of Member States involved in EMRP and national programmes actively coordinated
Data / Evidence	

23 national metrology research programmes were actively coordinated via EMRP. Each country had formally made a commitment to participate in EMRP as specified in the EMRP Decision (No 912/2009/EC) of the European Parliament and Council.

These 23 countries were the EMRP '*participating states'* and were 19 EU Member States plus four non-EU European states and the EU Joint Research Centre (JRC):

EU Member States participating in EMRP		**Non-EU Member States participating in EMRP**
Austria	Netherlands	Bosnia and Herzegovina*
Belgium	Poland	Norway
Czech Republic	Portugal	Switzerland
Denmark	Romania	Turkey
Estonia	Slovakia	
Finland	Slovenia	
France	Spain	
Germany	Sweden	
Hungary	United Kingdom	
Italy		

* Bosnia and Herzegovina joined the programme in 2013

Additional information

In addition to the participating states, organisations from five other EU Member States and 16 non-EU countries have formally participated in EMRP projects as unfunded partners in JRPs and/or funded partners via EMRP researcher grants:

EU: Bulgaria, Croatia, Greece, Ireland, Latvia
Other Europe: Liechtenstein, Montenegro, Serbia

Rest of the world: Australia, Brazil, Canada, China, India, Japan, Republic of Korea, Mexico, New Zealand, Russian Federation, Taiwan-Province of China, Ukraine, United States.

4.2 Address grand challenges (O1.2)

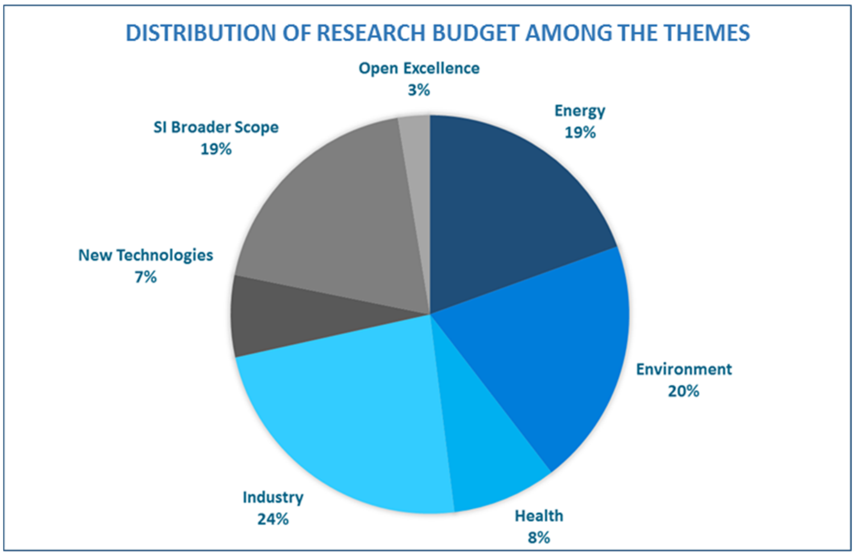
Figure 19: Operational Objectives - Indicator 2

INDICATOR 2	Number of research projects which build on the specific strength of NMI and DI and their infrastructures and their impact on primary standards
Data / Evidence	

All 119 EMRP projects were designed to build on the specific strengths of NMIs and DIs. The projects supported improved and developed this expertise to ensure that the European metrology infrastructure provides traceability to primary standards in areas important to the European economy and society.

Projects addressed both the accuracy of the underpinning SI units and metrology to address the grand challenges.

- The SI Broader scope theme (TPs: SIB1 & SIB2) was specifically focused on the coordinated development of primary standards of the SI units at the highest level – contributing to the international effort to redefine the SI units (SIB1) and extending traceability of measurements to SI units into new areas (SIB2). 24 projects were supported under the two calls in this theme.
- The projects in the grand challenges themes: **Environment, Health, Energy, Industry, New Technologies** took a coordinated approach to developing improved traceability to primary standards, establishing traceability where it did not previously exist or made traceability to primary standards more accessible. 78 % of the programme budget was allocated to research focused on the grand challenges:



4.1 Building capacity in New Member States (O1.3)

Figure 20: Operational Objectives - Indicator 3a

INDICATOR 3a	Number of New Member States building up metrology capacities
Data / Evidence	

Seven of the EMRP participating states were New Member States. These seven countries participated in joint research projects funded under EMRP enabling them to collaborate in metrology research projects with more experienced Member States to develop their metrology capabilities:

EU New Member States participating in EMRP
Czech Republic
Estonia
Hungary
Poland
Romania
Slovakia
Slovenia

Three additional New Member States also participated in EMRP projects via Researcher Grants: Bulgaria, Croatia, Latvia. During the later stages of EMRP, Bulgaria and Croatia (and accession state, Serbia) made the decision to be full participating members of the successor programme (EMPIR) demonstrating their commitment to European metrology research and their desire and capacity to participate in joint research projects.

New Member States (and accession states) made considerable use of researcher mobility grants (as reported under **Indicator 7**). The majority of the recipients of mobility grants (60 %) were from New Member States and accession states.

Figure 21: Operational Objectives - Indicator 3b

INDICATOR 3b	Increase in metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development
Data / Evidence	
Participation in EMRP processes and projects enabled countries in new member states and accession /pre-accession states with developing NMIs and DIs to increase and improve their metrology capacities and their research skills. Six capacity building case studies are provided below.	

Czech Republic

Overview

The Czech Metrology Institute, CMI, is the cornerstone of the national metrology system in the Czech Republic responsible for legal metrology, maintenance of national measurement standards and the provision of calibration services to end-users. CMI is an independent public organisation, reporting to the Ministry of Trade and Industry.

The EMRP and EMPIR programmes have played a central role in increasing the scale and quality of the metrology research undertaken at CMI. Prior to EMRP and EMPIR the activities of CMI were focused predominantly on the maintenance of Czech national metrology standards and the delivery of calibration services to Czech industry, with research only representing approximately 20 % of CMI's activities. The EU funding from EMRP leveraged additional matched funding from the Czech government research, increasing research to approximately 40 % of CMI's activities. This new funding has enabled CMI to establish a critical mass of research activities and has supported strategic investments in research staff and facilities. As a result, there is now a community of research-focused metrologists at CMI with at least one full-time person dedicated to research in each technical department. This would not have been possible without the EMRP support, in terms of both funding and access to the expertise of the wider NMI community made possible by the programme.

CMI has focused its participation strategically, targeting the Industry, Energy, Environment and New Technologies themes of the programmes (as well as the SI theme) as these align most closely with their goals and the needs of Czech industry and society.

Capacity building impact

The research collaboration and researcher mobility activities significantly increased the skills and knowledge base enabling CMI to develop high quality primary national facilities in technical areas where traditionally Czech national standards were traceable to the national standards in other countries. These skills enabled CMI to offer a wider range of R&D problem-solving skills to Czech industry over and above the more straightforward calibration services. Collaboration also enabled CMI to deepen its relationships with the European NMI community and establish formal agreements to access national standards and services in other countries to meet user needs where it makes sense to do so. New national capabilities and facilities, developed in part via EMRP, include:

- a step-change in its capabilities in time and length metrology, developing an optical clock to create services to support precision manufacturing, electronics, defence, security. Working with the European NMI community via EMRP enabled CMI to learn from their experience and 'jump a stage' in the development in atomic clocks.
- the development of an electrical resistance standard based on graphene (and the Quantum Hall Effect) resulting in a more cost-effective primary standard, enabling CMI to provide increased accuracy to the electronics sector in the Czech Republic.
- a new laboratory to assess thermal protection materials at high temperatures that is not only widely used by industry in the Czech Republic but also by businesses in neighbouring countries.

- increased ability to support high-tech industries such as semi-conductors and nanotechnology bthrough new complex analytical instrumentation to characterise surfaces and materials at the micro and nano-scale.
- a low magnetic measurements laboratory to meet demand from Czech industry for lower uncertainties and calibrations matched to local magnetic conditions. Customers of the service include automotive, geology and surveying and the military.

The new skills and facilities developed via the EMRP and EMPIR programmes enables CMI to better support Czech industry and society. While CMI had a long tradition of providing calibration services to industry its new capabilities are enabling it to provide more complex R&D problem-solving services for businesses in, for example, the automotive, instrumentation and electronics sectors, so supporting product and process innovation. Examples include:

- The knowledge gained in making accurate temperature measurements in the real-world conditions of power plants has been used by a Czech manufacturer to design temperature sensors that can operate in high vibration environments.
- Improved facilities in high pressure and dimensional measurements are supporting automotive manufacturers and their suppliers in the Czech Republic.
- The new facilities to assess materials at the micro and nano-scale have been used to support the innovation processes of a range of companies developing new and improved products that include new hard-wearing coating for car headlights and the surfaces of novel coloured solar–cells.
- CMI contributed to the development of a tabletop Terahertz spectrometer that has the potential to be commercialised to offer a smaller and most-effective device for security applications.

Turkey

Overview

Turkey committed approximately 1.6 M€ at the start of EMRP, a relatively small share compared to its peers in EURAMET. By the end of the programme, however, the value of Turkey's contribution via participation in 37 JRPs, was 2.8 M€, which can be viewed as an indicator that the Turkish National Metrology Institute (TUBITAK UME), considers EMRP to be a success.

TÜBİTAK UME is a young, medium-sized NMI with capabilities that expanded rapidly from the mid-1990s into the early 2000s through significant investments made by the Turkish government and the implementation of two successive World Bank funded projects. Before the iMERA+ programme (the precursor programme to EMRP) its main focus was on building up capability for primary level calibration and measurement services to cover the unmet needs of the rapidly expanding and industrialising Turkish economy. What little research activity did exist consisted mostly of efforts to resolve measurement problems encountered by industrial customers and public agencies, to set up primary level standards similar to those available in other NMIs, and smaller scale applied research projects undertaken within the technical committees of EUROMET. In preparation for participation in iMERA+ and EMRP, TÜBİTAK UME's designation was changed from "service facility" to a "research and development institution" by its governing body, signalling a reorientation of priorities and allowing engagement in large scale, externally funded R&D.

Capacity building impact

TÜBİTAK UME's participation in EMRP projects was broad based and fairly well distributed across the themes. However, there was a somewhat higher concentration of projects in Energy (9) and SI Broader Scope (11). The first was a reflection of a national priority given to the issues of energy security and diversification and electrical grid improvements, and the second, of TÜBİTAK UME's concern with keeping abreast of developments pertaining to technical implications of the expected redefinition of some SI units and efforts to establish traceability in emerging areas of measurement so as to ensure that it will maintain and improve its ability to provide primary level services in these areas.

In general, TÜBİTAK UME's engagement in EMRP delivered a number of important benefits. First and foremost, it allowed the institute to engage in state-of-the-art research and access knowledge at the cutting edge of metrology, bringing its knowledge base closer to that of the top tier of metrology institutions in Europe than would have otherwise been possible. In parallel, TÜBİTAK UME's researchers gained significant experience working in high level research in collaboration with other researchers across Europe, some of whom were among the best in their fields, contributing to a general elevation in personnel skill sets and knowledge and an enhancement in the quality of their scientific output. Furthermore, participation in EMRP projects was instrumental in transforming TÜBİTAK UME's stance vis-a-vis stakeholders. Whereas it was once primarily reactive to stakeholder demands, seeking to build capacity to meet fully materialised and urgent needs, it became able to build capabilities that anticipate demands for metrology services expected to emerge in the future and stimulate the adoption of more advanced technologies in the economy.

Examples of the capabilities gained by TÜBİTAK UME through specific EMRP projects and their benefits to stakeholders include:

- Participation in the SIB64 METefnet (Metrology for Moisture in Materials) allowed TÜBİTAK UME to develop high-level skills in measurement of moisture in materials, which is particularly important to agricultural concerns and was a demand that TÜBİTAK UME could not previously meet. Calibration and measurement services in the area were initiated in 2017.
- Through SIB10 Noted (Novel Techniques for Traceable Temperature Dissemination), TÜBİTAK UME developed capabilities in the production and characterisation of reference thermocouples.
- The SIB01 InK (Implementing the New Kelvin) project allowed TÜBİTAK UME to expand the range of its temperature measurements and calibration capability into high temperatures (>1000 °C), which is important for a number of industries
- As a result of IND12 Vacuum (Vacuum Metrology for Production Environments), a dynamic vacuum system, a gas mixture preparation system and a set-up for the secondary calibration of leak standards, used for the characterisation of quadrapole mass spectrometers (QMS) were gained by the Vacuum Laboratory of TÜBİTAK UME. New services were initiated in the calibration of leak standards, for which customers were previously referred to other NMIs in Europe.
- Work undertaken within the SIB56 SoundPWR (Realisation, dissemination and application of the unit watt in airborne sound) project resulted in the realisation of a primary level reference standard for sound power in the Acoustics Laboratory, now used to offer services to industry. New methods developed within the project eliminated the need for measurements of sound power to take place in purpose-built environments, reducing the cost of such measurements.
- Expertise and experience gained through participation in various projects within the Health theme catalysed the establishment of a Medical Metrology Laboratory at TÜBİTAK UME, addressing a significant deficit in the metrology infrastructure in Turkey.
- As the coordinator of SIB58 Angles (Angle Metrology), TÜBİTAK UME became one the leading institutes in angle measurements, significantly reducing uncertainties and extending the range of angle measurements that can be performed at the nano-radian scale. Skills and knowledge gained have been used in joint projects with stakeholders.
- Participation in ENG04 Smartgrid (Metrology for Smart Electrical Grids) resulted in the development of much needed standards for power quality measurement parameters as well as methods for the calibration of instruments that measure power quality. New skills and services led to the implementation of a project to enhance the calibration capabilities and measurement infrastructure of the national electric distribution company, ultimately contributing to greater electrical grid stability.
- Through HLT03 DUTy (Dosimetry for Ultrasound Therapy), TÜBİTAK UME became one of four institutes in Europe with the necessary metrological infrastructure to characterise high intensity focused ultrasound (HIFU) systems that have widespread medical applications.

Bosnia and Herzegovina

Overview

As a relatively young country, Bosnia and Herzegovina has a young and developing national metrology system. The Institute of Metrology of Bosnia and Herzegovina (IMBiH) was legally established in 2004 and became operational in 2007. It is an independent administrative organisation directly responsible to the Council of Ministers of Bosnia and Herzegovina. IMBiH is responsible for establishing and maintaining the whole metrology system in Bosnia and Herzegovina including scientific, industrial and legal metrology. This includes: developing, declaring and maintaining the base of national standards of legal units and ensuring their traceability to the International Standards of the SI system; prescribing metrological requirements for standards, reference materials and measuring instruments, recognising standards as national standards, performing conformity assessment including the pattern evaluation and pattern approvals of measuring instruments. IMBiH maintains two laboratories and currently has 53 employees.

As a young NMI in a country that is a potential candidate country for EU membership, IMBiH has accessed a range of support mechanisms to assist its development. For example, EU IPA (Instrument for Pre-Accession Assistance) funding has enabled labs to be equipped in the field of chemical, electrical, thermal and mechanical quantities and a calibration lab in ionising radiation to be established. IMBiH achieved associate membership of EURAMET in 2005 and full membership since 2009, with representation on ten of EURAMET's 12 Technical Committees.

Capacity building impact

EMRP provided IMBiH with the opportunity to develop the metrology research skills of its staff as well as improve their metrology skills more generally, complementing the equipment acquired via other support mechanisms. Bosnia and Herzegovina became the 23rd participating country in EMRP towards the end of the programme in 2013. Prior to that it had participated in seven researcher mobility grants. This enabled the IMBiH and its staff to engage with the programme and gain first-hand experience in more developed NMIs in Germany, the UK, Italy, the Netherlands and Turkey. On joining the programme in 2013 IMBiH became a partner in four research projects – three in the Energy theme and one in the Environment theme.

Key capacity building achievements resulting from EMRP include:

- IMBiH participation in researcher mobility grants (including early-stage researchers) enabled knowledge transfer and ensured sustainability of cooperation between IMBiH and other NMIs. The opportunity to work on these projects as mobility grant researchers helped gain experience and knowledge for the career development of IMBiH scientists and prepared the ground for participation in EMRP research projects. IMBiH's participation in collaborative research projects continues - to date it is a partner in six EMPIR projects. A key achievement being that an IMBiH ESRMG/RMG researcher (under EMRP) has gained necessary experience to be able to coordinate an EMPIR research project (15RPT03 HUMEA - Expansion of European research capabilities in humidity measurement). This was the first time that an EMRP or EMPIR project has been instigated and led by an NMI from an emerging country
- Institute staff have further confirmed their competences through publication of papers in peer reviewed journals and other technical magazines.
- IMBiH increased its entries in the BIPM Calibration and Measurement capabilities (CMC) database – the key database that demonstrates the equivalence of national metrology systems worldwide. Methods on primary and secondary level of calibration were developed in IMBiH in different fields; laboratories implemented a quality management system according to international standard for metrology: EN ISO/IEC 17025 and IMBiH took part in different inter-comparisons to support their CMCs in relevant fields.
- IMBiH designs its research and laboratory development activities to address the needs of environmental agencies, the electronics, automotive, pharmaceutical and medical device sectors, secondary calibration laboratories, manufacturers of sensors and accreditation institutes at the national level. The improved CMCs and research capabilities are helping to improve the quality of calibration laboratories, with ultimate beneficiaries being the companies and public agencies that use the calibration services. For example:
    - Validated calibration procedures and associated uncertainty formulations developed by the projects are directly used by calibration laboratories in Bosnia and Herzegovina in order to ensure traceability of measurements. Measurement results are reported with the associated measurement uncertainty, which enabling a transparent comparison of measurement results and issue of valid calibration certificates. This has a large impact on calibration laboratories;
    - Testing capabilities of the Laboratory for Chemistry have been improved by publishing CMCs and has enabled further development of chemistry department in the field of reference measurements and assignment of reference values for proficiency testing (PT) samples. The Laboratory for chemistry is active in the field of development of reference methods for testing impurities in gas matrices in accordance with European normative documents.
    - Benefit to the industrial companies that rely on such calibration services; workshops at the national level will be held to share the project's outputs and engage with the target user communities.

Poland

Overview

The national metrology institute, the Central Office of Measures (GUM) is the NMI in Poland. It was established on the basis of the Decree on Measures of February 8, 1919 and the President of GUM the central authority of the state administration in matters of measurement and hallmarking, reporting to the Minister of Economy. In addition, there are two designated institutes in Poland - the Institute of Low Temperature and Structure Research of the Polish Academy of Sciences (INTiBS) and the Laboratory of Radioactivity Standards, located at the Radioisotope Centre (RC) POLATOM, the National Centre for Nuclear Research.

Capacity building impact

Poland's metrology system has a relatively small research activity and therefore its EMRP participation was focused on areas of most importance to the country – in the SI theme to develop Poland's metrology system and in the Industry and Environmental themes. GUM, as the NMI, was the most frequent participant in EMRP activities, plus additional participation from public or academic research groups such as the Polish National Centre for Nuclear Research.

Key capacity building achievements resulting from EMRP include:

- New metrological services in the Laboratory of the Electricity Department at GUM in contactless measurements of the electrical properties of materials for applications in electronics and electrical products.
- Establishment of a direct traceability route for AC resistance and a measurement system for small values of resistance at acoustic frequencies.
- The extension of scope for GUM's force measurements. This resulted in a collaboration with a producer of force transducers.
- GUM made important contributions to the Large Volume Metrology project (focused in particular on the aerospace industry), in refractive index of air measurements and preparation of a 50m interferometer for a testing campaign.
- Improved research skills and measurement capabilities in angle measurements and temperature and humidity measurements.

Estonia

Overview

AS Metrosert is the NMI in Estonia, responsible for the majority of national standards. It is supported by a designated institute, the Testing Centre of the University of Tartu. The national metrology system of Estonia is described in the Estonian Metrology Act and was established in 2004. Estonia was a founding member of both EMRP and its precursor programme iMERA+. The EMRP funding supports research activities (mainly researcher time) and as such has complemented EU Structural Funds that have supported the acquisition of equipment and facilities for metrology.

Capacity building impact

As a very small country with a small NMI, Estonia's participation was focused on the unique technical skills and needs of the country. Their participation in research projects was primarily focused on radiometry/ optics/ quantum optics (three projects plus a project under iMERA+), plus practical industrial dimensional measurements, measurements of biofuels and measurement of ocean parameters.

Key capacity building achievements resulting from EMRP include:

- Development of metrology capabilities in radiometry (e.g. in low photon flux measurements, low photocurrent measurements, fibre-optic measurements) including the development of new services for industrial users in electrical and optical measurements, plus skills in silicon technologies and semi-conductor physics. The capabilities and skills gained by the NMI are important for supporting Estonian industry in precision mechanics and optoelectronics and enabling Estonian industry and service providers to meet the recommendations of ITU (International Telecommunication Union).
- The research collaboration in in-process dimensional measurement has significantly increased the skills and knowledge base in industrial dimensional measurements generally, including 3D

measurements of workpieces in laboratory conditions and in the workshop environment; accurate assessment of machine tools and their measurement capabilities; and the influences of environmental conditions in workshop environment. These new capacities enable better understanding of cost-effective production of accurate workpieces and the provision of better NMI (AS Metrosert) measurement services for industry.

Slovenia

Overview

Although the current metrology system in Slovenia is fairly young, it is based in a long history of regulation related to weights and measures, and Slovenia has been an active participating country in the EU-supported metrology research activities since their inception in 2002 – from the ERA-NETs (MERA, iMERA and IMERA+) all the way through to the EMRP and EMPIR programmes. As one of the smallest countries in the programmes their financial contribution is small, nevertheless Slovenian metrology institutes have participated in 23 joint research projects and five researcher grants.

Slovenia's participation had a strong focus on projects in the Environment and Industry themes to support Slovenian industry and develop its expertise in a range of environmental measurements. Projects have also addressed smart grids for future energy supply and managing radioactive materials. Slovenia also participated in projects developing the SI system and widening SI traceability at the highest level to ensure it can meet future needs for accurate measurement.

Capacity building impact

Slovenia has a distributed metrology system making best use of metrology expertise in a number of institutes and universities across the country and many of them participated in EMRP.

Key capacity building achievements resulting from EMRP include:

- The Slovenian Institute of Quality and Metrology participated in a range of projects in the Energy, Industry and SI themes, developing new skills and measurement capabilities in power quality for smart grids, EMC assessment, the assessment of the performance of dielectric materials and assessments of complex waveforms. Together these are supporting Slovenian industry, such as the instrumentation sector and public utilities.
- The Department of Biotechnology and Systems Biology at the National Institute for Biology significantly increased its skills and knowledge in quantitative PCR and digital PCR to support diagnostics of human pathogens. This not only led to many high-quality publications but will also support improved public health. This work brought together research funding and PCR equipment acquired via European Structural funding (ESIF).
- The Environmental Sciences and Low and Medium Energy Physics group at the Jozef Stefan Institute contributed to projects in the Environment theme, developing skills and new calibration capabilities for trace elements in air, water, soil and food to support implementation of the Air and Water Quality Directives in Slovenia plus traceable measurements for radioactive quantities to support the management of nuclear waste (the latter brought together research funding and PCR equipment acquired via European Structural funding).
- The Faculty of Electrical Engineering / Laboratory of Metrology and Quality at the University of Ljubljana developed and improved their facilities for the calibration of meteorological moisture sensors that support improved understanding of the atmosphere and measurements of Essential Climate Variables.
- The Faculty of Mechanical Engineering / Laboratory for Production Measurement and the Institute of Metals and Technology / Laboratory of Pressure Metrology improved and extended their capabilities in a range of dimensional and mechanical measurements that underpin the calibration chain for a wide range of manufacturing sectors.

4.2 Open access to research infrastructures (O1.4)

Figure 22: Operational Objectives - Indicator 4

INDICATOR 4	Number of research infrastructures jointly used in RTD projects
Data / Evidence	
The metrology infrastructure in each country is a research infrastructure – the NMIs and DIs in each country provide both specialist facilities and expertise to conduct metrology research and deliver metrology services to measurement users. Therefore, each participation of an NMI or DI in a joint research project constitutes a sharing of research infrastructures. This amounts to 957 research infrastructures jointly used across the 119 EMRP projects. In addition, the researcher mobility grants supported a very direct method of sharing of research infrastructures by enabling the movement of researchers between the national research infrastructures. There were 73 research mobility grants each involving shared use of metrology facilities for joint research (see **Operational indicator 7**).	

4.3 Increase cooperation between NMI/DIs and science community (O1.5)

Figure 23: Operational Objectives - Indicator 5a

INDICATOR 5a	Number of research organisations (not being NMI of DI) involved in EMRP projects
INDICATOR 5b	Level of participation in the programme by outside researchers and research institutions
Data / Evidence	
In addition to participation from NMI and DIs, there were 1147 participations in EMRP projects from 916 organisations. 50 % (570) of participations were from universities and public research organisations and 41 % (474) from industry. They participated as: • Unfunded project partners - i.e. full project partners providing a defined contribution to the projects • Grant recipients - providing additional funded contributions to projects • Collaborators - signing a Non-disclosure Agreement with the projects to enable them to contribute to the project and network with project partners The data is illustrated in the figure below. Industrial participation was largely in the form of collaboration via a Non-disclosure Agreement or as unfunded partners. University and public research organisations participated via the Researcher Grant mechanisms or as collaborators. A list of participants is provided in Annex A.	

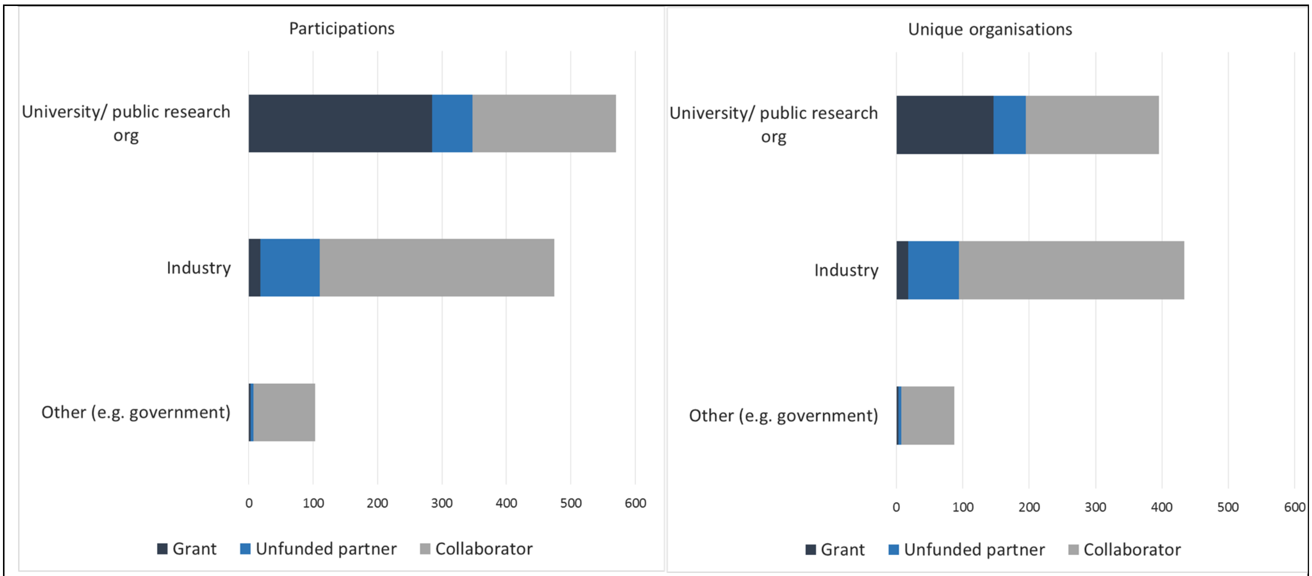


Figure 24: Operational Objectives - Indicator 5c

INDICATOR 5c	Number of PhDs trained in metrology
Data / Evidence	
40 PhDs in metrology have been published.	

4.4 Modernisation in programming (O1.6)

Figure 25: Operational Objectives - Indicator 9

INDICATOR 6	List of advanced technologies employed in the developments of primary standards which can and should be transferred to new and challenging research activities
Data / Evidence	

Metrology research makes use of advanced technologies to develop next generation techniques for realising primary measurement standards and, in the process of developing primary measurement standards, advances technologies, tools and techniques that may be applied to challenging research activities. Examples from EMRP projects include:

Graphene

An EMRP project investigated the use of graphene as a practical quantum resistance standard. Graphene characterisation methods were enhanced by the project and are already being used in various laboratories where graphene films are grown for research or for applications development (e.g. in the field of electronics). The ultimate goal of a graphene-based quantum resistance standard will not only improve primary electrical standards but will also enable accurate assessment of resistance in academic and industrial R&D.

Single photon technologies

A number of EMRP projects have been developing single photon sources and detectors to improve the primary standards for the measurement of light (radiant power, etc.) but also to ensure that such devices can be accurately characterised for use in quantum cryptography and quantum computing.

Single electron technologies

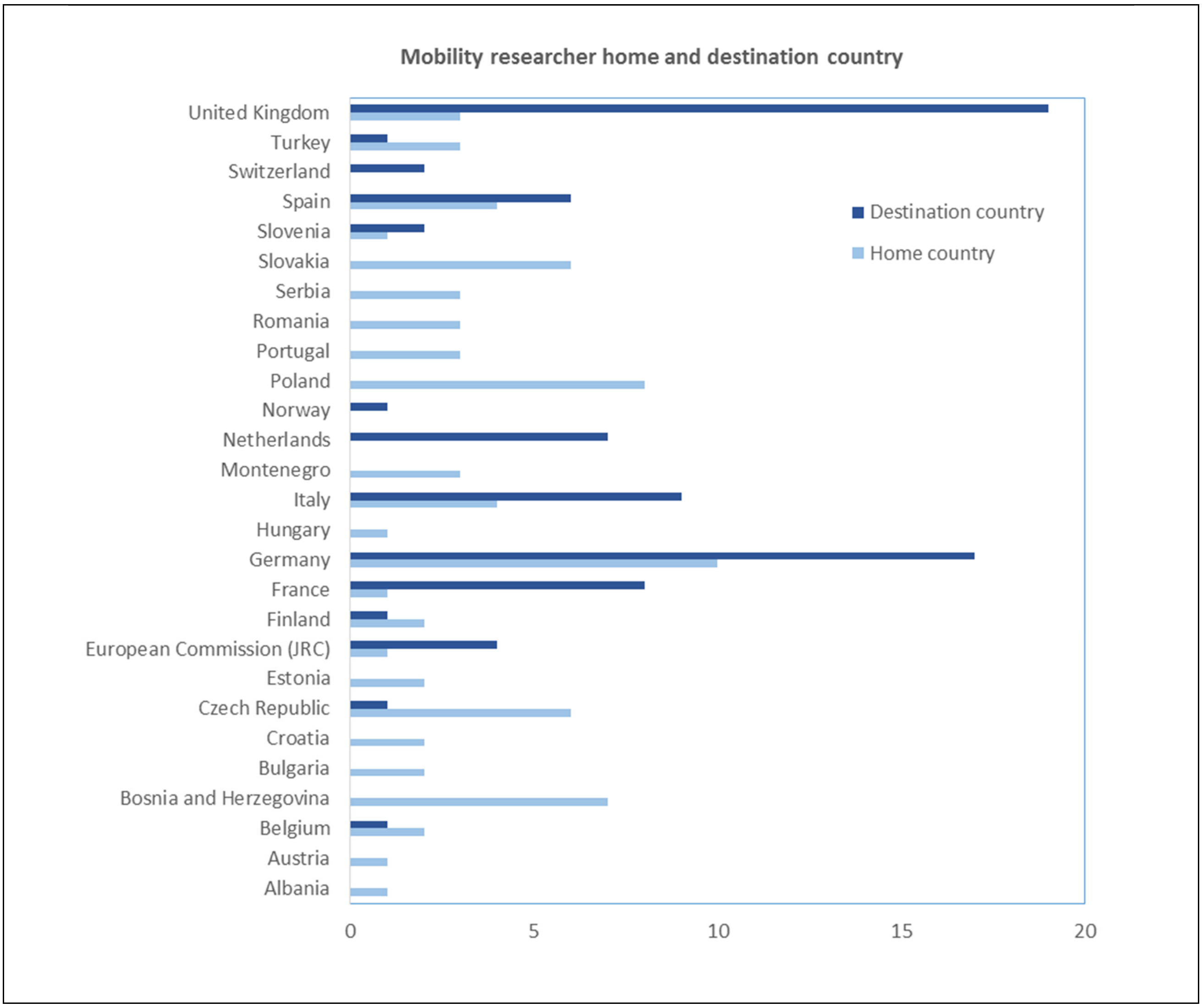
A project developed state-of-the-art Single Electron Transport (SET) devices - known as SET pumps – to support future realisation of the SI unit the ampere. These pumps move a single electron at a time and offer the opportunity to investigate fundamental electronic phenomena and develop applications such as single-electron-based information processors and highly sensitive scanning probes.

Atomic and optical clocks The metrology community has been at the forefront of the development of atomic and optical clocks for accurate time measurement. EMRP projects not only advanced the development of practical atomic clocks for wider industrial and space applications but advanced the ion-trap technologies and techniques for future optical clocks. The ion-trap techniques have applications in quantum physics and quantum information and communications research. **Large volume metrology** An EMRP project developed state-of-the-art techniques and instrumentation of the accurate dimensional measurement of large objects such as aircraft and spacecraft during manufacture. The techniques have wider applicability to large-scale research facilities that require accurate alignment of components and systems such as CERN (the project team is already working with CERN), European Synchrotron Radiation Facility and ITER. **Advanced spectroscopic techniques** A number of EMRP projects improved the accuracy of high-performance spectroscopic techniques such as energy dispersive X-ray spectroscopy (EDS), X-ray photoelectron spectroscopy (XPS) atomic force microscopy (AFM), secondary ion mass spectrometry (SIMS), etc. These have wide application in materials research (in particular) with more accurate techniques enabling the research base to make better quantitative assessments of new materials.

4.1 Mobility (O1.7)

Figure 26: Specific Objectives - Indicator 7

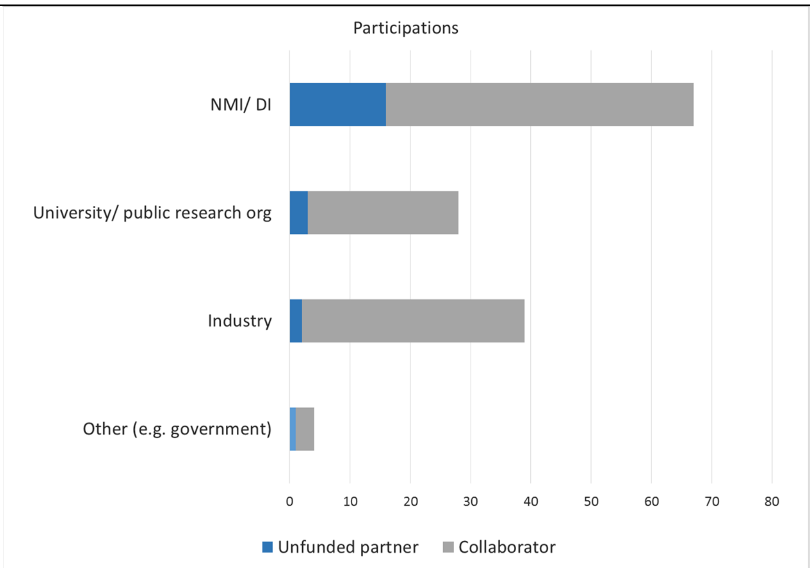
INDICATOR 7	Number of mobility grants implemented
Data / Evidence	
384 mobility grants were implemented. These enabled researchers to spend time at other institutions. 30 % of the mobility grants were for early stage researchers. The home and destination countries are shown in the chart below illustrating the use of mobility grants for capacity building. 60 % of the home countries of mobility grant recipients were in New Member States and accession states, while 82 % of the destination NMI and DIs were in the larger most experienced NMIs and DIs in Germany, UK, France, Netherlands, Italy and Spain. Lists of the mobility grant recipients are provided in Annex B.	

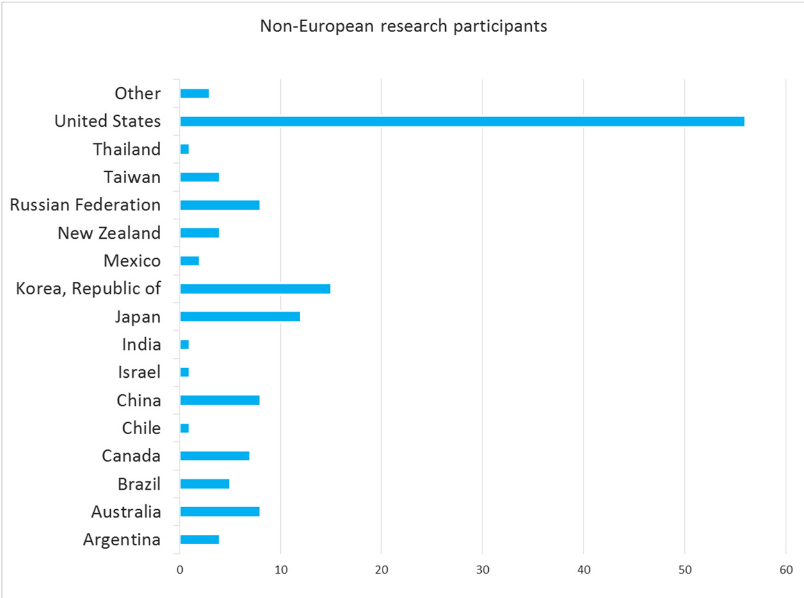


4.2 Strengthen European influence (O1.8)

Figure 27: Operational Objectives - Indicator 8

INDICATOR 8	Number of generic cooperation activities with non-European research actors
Data / Evidence	
There was significant participation from non-European research actors in the programme. There were 140 participations in EMRP projects by non-European research actors from the NMI/DI, academic and industrial communities either as unfunded partners or collaborators, illustrated in the chart below. The most frequent non-European actors were the NMI /DI community, with participation from NMIs/ DIs in 14 countries participated in EMRP projects (Argentina, Australia, Brazil, Canada, China, Egypt, Japan, Republic of Korea, Mexico, New Zealand, Russian Federation, Taiwan, Thailand, United States). No generic cooperation activities with non-European research actors were established but as the second chart below shows, there was significant levels of interaction with NMI in the USA (NIST) and other important NMIs in Japan, Korea and China. The EMRP projects addressing the research for the forthcoming redefinition of the SI have played an important focal point for international activity, bringing together the European expertise and international NMIs via the unfunded partner and collaborator mechanisms.	





4.3 Supporting regulation (O1.9)

Figure 28: Operational Objectives - Indicator 9a

INDICATOR 9a	Number of EMRP projects with direct references to regulation
Data / Evidence	
The EMRP Energy, Environment and Health themes had a strong focus on regulation with many projects addressing regulatory issues. A number of projects in other themes (such as Industry and SI Broader scope) also addressed regulation. In total 43 projects (out of the 119 funded) had a direct reference to regulation (see Figure 29).	
Additional information	
<u>Energy theme</u> The Energy theme was predominantly focused on metrology to support Europe's climate and energy targets. Twelve projects made a direct reference to the Renewable Energy Directive (2009/28/EC). The directive set a target that at least 20 % of Europe's total energy needs fulfilled by renewables by 2020. The projects focused on:	

- Accurate measurement techniques needed to characterise and quantify renewable fuels to support their development and trade
- Accurate measurement techniques required for the smart grids and high voltage transmission systems being developed to ensure electricity generated from renewable sources could be managed and distributed safely and cost-effectively.

Three Energy projects also supported the development of low carbon technologies to support Europe's target for increased energy efficiency (Energy Efficiency Directive 2012/27/EU).

- Two projects focused on the accurate measurements required to characterise and assess on low energy lighting (LED, OLEDs, etc), supporting both the Energy Efficiency Directive and the Eco-design Directive (2009/125/EC)

  One project addressed the measurements required to characterise and assess energy harvesting technologies to reduce energy use and potentially reduce use of small batteries, supporting both the Energy Efficiency Directive and the Batteries Directive (2008/98S/EC)

Two projects on liquid natural gas (LNG) also supported the EU Directive concerning common rules for the internal market in natural gas (2003/55/EC), the Measuring Instruments Directive (2014/32/EU) and the Sulphur Directive (2012/33/EU (amendment on Directive 1999/32/EC)) that regulates sulphur emissions from ships.

SUPPORTING EUROPE'S ENERGY POLICY

In 2009 and 2013, EURAMET launched calls for projects in this area with an aim to establish the measurement infrastructure necessary to support Europe's sustainable energy goals. Focus was placed on technologies that enable greatly reduced greenhouse gas emissions, while also ensuring the security of Europe's energy supply.

RENEWABLE ENERGY

The increased use of energy from renewable sources was a key feature of European energy policy. The **Renewable Energy Directive (2009/28/EC)** set a target of at least 20 % of Europe's total energy needs to be fulfilled with renewables by 2020 including at least 10 % of transport fuels from renewable sources by the same date.

Thirteen EMRP projects supported the Renewable Energy Directive (2009/28/EC). Three among these focused on the development of measurement infrastructures required for biogas, liquid biofuels and LNG to ensure they could be traded fairly and efficiently and be incorporated safely into existing distribution networks and infrastructures and supporting the development of the **Internal Market in Natural Gas (2009/73/EC).**

ENG01 - Characterisation of energy gases - This project put in place the necessary metrology infrastructure to enable the "inter-changeability" of energy gases so that gaseous fuels from non-conventional sources could access grids across the EU.

ENG09 - Metrology for biofuels - This project addressed the need for internationally-accepted methods and certified reference materials to improve the accurate measurement of biofuels from different geographical regions. It developed a measurement infrastructure that not only provided reliable data but could rapidly adapt to different types and origins of biofuels. It also made considerable progress towards European and International harmonisation of the measurement methods of biofuels and their blends with fossil fuels.

ENG03 -Metrology for liquefied natural gas – this project enabled natural gas trading between countries not served by pipelines.

These projects also supported the **Measuring Instruments Directive (2014/32/EU)** and the **Sulphur Directive (2012/33/EU** (amending Directive 1999/32/EC)) that regulated the sulphur content of marine fuels.

IMPROVING ENERGY EFFICIENCY

Seven projects supported the development of low carbon technologies to achieve Europe's target for increased energy efficiency and support the EU Internal Market in Electricity. **(Energy Efficiency Directive 2012/27/EU and 2009/72/EC**

Four EMRP projects focused on the measurements required to help improve the efficiency of existing power plants, support the development of next generation nuclear plants and HVDC connections, and manage smart grids: ENG06 Metrology for Improved Power Plant Efficiency; ENG04 Metrology for Smart Electrical Grids; ENG07 Metrology for High Voltage Direct Current and ENG08 Metrology for New Generation Nuclear Power Plants.

ENG07: Metrology for High Voltage Direct Current (HVDC)
High Voltage Direct Current (HVDC) energy transmission is crucial for a successful uptake of renewable energy sources in the grid. This project provided improvements to the existing the metrology infrastructure to support HVDC, at the proposed 800 kV working level, to ensure that HVDC can be reliably measured for grid protection or billing purposes.

Four projects also supported the **Eco-design Directive**: ENG02, ENG05, ENG62, IND62

ENG02 Metrology for Energy Harvesting

Harvesting energy from waste heat, movement and vibration can provide energy at the point of use for a wide range of portable electronic devices, decreasing the demand for energy from the grid and batteries. It also offers opportunities for increasing the efficiency of vehicles via recycling energy lost to heat.

ENG05 Metrology for Solid State Lighting extended NMI capabilities in the measurement of incandescent and fluorescent lighting to solid-state lighting (i.e. LEDs), providing more accurate measurements of electrical, optical and visual performance required for the design, manufacture and quality control of solid-state lighting devices. One-fifth of global electricity consumption is for lighting and a considerable reduction in energy consumption could be obtained by replacing conventional lighting products with low energy technologies such as LEDs.

EU Emissions Trading Scheme
EU Directive 2003/87/EC on the EU's Emissions Trading scheme was directly referred to in two projects, ENG07 Metrology for High Voltage Direct Current (HVDC) and ENG01 on the characterisation of energy gases:

ENG01 on the characterisation of energy gases. The advances made through the project in composition determination made it easier to analyse refinery gases and syngases with a wide composition range, allowing more reliable measurement of compliance with the Emission Trading Scheme. The project also addressed the need arising from Scheme for accurate measurements of the carbon content of alternative fuel gases, such as refinery gas and syngas that principally arise as by-products of coke and petroleum production.

Environment theme

Ten projects in the Environment theme focus on the measurements required to robustly analyse and quantify pollutants and other hazardous substances to support air and water quality regulation and therefore directly refer to the:

- Water Framework Directive (WFD-2000/60/EC) and the related directives: the Drinking Water Directive (98/83/EC); the Directive on Technical Specifications for Chemical Analysis and Monitoring of Water Status (2009/90/EC); Directive on environmental quality standards in the field of water policy (2008/105/CE) and Directive relating to restrictions on the marketing and use of certain dangerous substances and preparations (organostannic compounds) (2002/62/EC)
- Ambient air quality and cleaner air for Europe Directive (2008/50/EC) and related directives such as Directive relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (2004/107/EC)
- The Euro series of emissions regulations for type-approval of motor vehicles and engines: for light duty vehicles (cars and vans) (No 715/2007) and for heavy duty vehicles (No 595/2009) and related directives on regular emissions testing
- Industrial Emissions Directive (IED) (2010/75/EU) that sets out limits on the emissions from a range of industrial processes.
- Directive on national emission ceilings for certain atmospheric pollutants (NEC) (2001/81/EC) regulates ammonia emissions in the Member States
- Directives focused on reducing mercury in the environment: Restriction of Hazardous Substances RoHS) in Electrical and Electronic Equipment Directive (2002/95/EC) and the Directive relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (2004/107/EC)

In terms of broader environmental challenge climate change, a project focused on issues related to the measurement of environmental parameters to assess climate change addressing the INSPIRE Directive (2007/2/EC) – to establish an Infrastructure for Spatial Information in the European Community for the purposes of EU environmental policies and policies.

Three environment projects addressed measurements related to radioactivity. Two projects addressed measurements of radioactive waste during the decommissioning of nuclear power plants, addressing Directive 96/29/EURATOM laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation and related IAEA Safety Standards Series. The third project addressed measurements for a radiological early-warning systems in Europe.

Health theme

Seven projects in the Health theme addressed the provision of accurate measurements to support the implementation of Directives focused on the use of medical procedures and devices. Accurate measurement ensure that healthcare tools and processes are effective and that safety standards are meaningful. Five projects addressed:

- Medical Device Directive (93/42/EEC) and related directives that cover the conformity assessment of all medical equipment used to diagnose, prevent, monitor and treat medical conditions.
- In-vitro Diagnostics (IVD) Directive (98/79/EC) that regulates devices and accessories used to perform tests on samples for diagnostic, prevention and health monitoring purposes
- Directive on medicinal products for human use (2001/83/EC) and its related directives – that regulate medicinal products such as pharmaceuticals, and the Directive on processing, storage and distribution of human blood and blood components (2002/98/EC)

Two projects in the Health theme addressed the requirements for accurate measurements of ionising radiation to ensure patient safety covered by Directive 97/43/EURATOM health protection on individuals against the dangers of ionising radiation in relation to medical exposure.

A further project addressed the safety of healthcare workers regarding the electromagnetic radiation of MRI scanners as covered by the Physical Agents Directive (2004/40/EC). In this case the issue was accurate measurements to support both healthcare workers and ensure the effectiveness of the MRI as a diagnostic tool.

A project addressed the effects of non-audible sound on humans and potential extensions to the coverage of environmental noise directives: Directive on the assessment and management of environmental noise (2002/49/EC) and Directive on minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (2003/10/EC).

ENVIRONMENTAL PROTECTION

Ten projects in the Environment theme focussed on the measurements required to robustly analyse and quantify pollutants and other hazardous substances to support air and water quality regulation and therefore directly refer to the:

- **Water Framework Directive (WFD-2000/60/EC)** and the related directives: the Drinking Water Directive (98/83/EC); the Directive on Technical Specifications for Chemical Analysis and Monitoring of Water Status (2009/90/EC); Directive on environmental quality standards in the field of water policy (2008/105/CE) and Directive relating to restrictions on the marketing and use of certain dangerous substances and preparations (organostannic compounds) (2002/62/EC)
- **Air Quality Directive (2008/50/EC)** and related directives such as Directive relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (2004/107/EC)
- **Regulation (EU) 305/2011 (amends 89/106/EEC) on VOCs in Construction products**
- **The 6th Environmental Action Programme (2002/1600/EC)**
- **Marine Strategy Framework Directive (2008/56/EC)**
- **The Euro series of emissions regulations for type-approval of motor vehicles and engines:** amended by Commission Regulation (EU) 2018/1832) for light duty vehicles (cars and vans) and for heavy duty vehicles and related directives on regular emissions testing
- **Industrial Emissions Directive (IED) (2010/75/EU)** that sets out limits on the emissions from a range of industrial processes.
- **Directive on national emission ceilings for certain atmospheric pollutants (NEC) (2001/81/EC**) regulates ammonia emissions in the Member States
- **Habitats Directive (92/43/EEC)** which ensures the conservation of rare, threatened or endemic animal and plant species
- Directives focused on reducing mercury in the environment: **Restriction of Hazardous Substances RoHS) in Electrical and Electronic Equipment Directive (2002/95/EC)**

ENV05 OCEAN - Metrology for ocean salinity and acidity

This project aimed to meet the objectives of the European Marine Strategy Framework Directive (MSFD 20089) to have measurement techniques in place to monitor the Ocean's status. The project outcomes delivered the required metrological basis for simplified sensor calibration on sea and helped establish links to European and worldwide monitoring projects.

The project results represent important steps towards an integrated European ocean observation infrastructure based on robust metrology, indispensable for measuring small changes in long-term oceanographic data series. It also developed a reliable database to advance deep sea research - important not only for climate forecasting but also for sustainable economic use of the ocean.

Two projects focussed on metrology for Earth Observation and climate change, and will directly benefit the EU's Copernicus programme (Europe's satellite system for monitoring the Earth for environment and security), as well as informing the INSPIRE Directive (2007/2/EC) – to establish an Infrastructure for Spatial Information in the European Community for the purposes of EU environmental policies. In addition, this has led to an enduring partnership between NMIs and key stakeholders, forming the foundations of a European centre of excellence: the European Metrology Network for Climate and Ocean Observation.

NUCLEAR SAFETY
Six projects addressed measurements related to the decommissioning of nuclear facilities and radioactive waste management, directly related to the three EURATOM directives: **2011/70/EURATOM; 2014/87/EURATOM and 2013/59/EURATOM (repealing Directive 96/29/EURATOM)** laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation and related IAEA Safety Standards Series.

IMPROVING CITIZEN'S HEALTH
Five projects in the EMRP programme have enabled instrument manufacturers, clinicians and researchers to comply with the requirements of **Regulation (EU) 2017/746 on *in vitro diagnostic medical devices* that repeals Directive 98/79/EC**.

HLT04 Metrology for the characterisation of biomolecular interfaces for diagnostic devices developed new reference materials and biomarker analysis techniques to aid instrument manufacturers and researchers in the development of better IVDs for a broad range of medical conditions, while HLT05 Metrology for metalloproteins developed primary reference methods to provide traceability to measurement standards for many different types of previously uncharacterised metalloproteins to establish compliance with the Regulation.

HLT08 Metrology for monitoring infectious diseases, antimicrobial resistance, and harmful micro-organisms successfully developed highly accurate SI traceable methods to support the quantification of bacteria in clinical samples and generated reference materials for use in External Quality Assessment schemes. The research outputs are particularly important for supporting the proposed new network of Reference Laboratories for Class D (infectious pathogens) In Vitro Diagnostic devices (IVDs).

A further project as part of the SI broader scope initiative, SIB09 Primary standards for challenging elements developed procedures and methods for realising SI traceable solution standards for four industrially important elements: Magnesium (Mg), Aluminium (Al), Zinc (Zn), Rhodium (Rh) and Molybdenum (Mo), to enable accurate measurements for instruments such as the in vitro diagnostic devices Regulation and the Water Framework Directive.

The results from the project SIB54 Traceability for biologically relevant molecules and entities enabled the demonstration of SI traceability through counting for nucleic acid and cell measurements. This underpins the development of reference materials, supports compliance with the IVD Regulation, and with international standards such as ISO 17511.

MEDICAL DEVICES DIRECTIVE
The EMRP project HLT03 Dosimetry for Ultrasound Therapy developed the basis for High Intensity Focused Ultrasound (HIFU) dose determination and the heating effects induced using validated modelling methods and phantoms to replicate the body during treatment. This contributed to part of a series of standards under the European Medical Devices Directive.

IND56 Chemical metrology tools to support the manufacture of advanced biomaterials in the medical device industry developed a suite of new tools for European NMIs to support medical device characterisation as well as tools and techniques suitable for research and industrial use. The project's outputs were disseminated widely to the metrology community; high-level users of precision instrumentation in research environments; regulators and medical device manufacturers.

NON-IONISING RADIATION
Two projects HLT06 Metrology for next-generation safety standards and equipment in MRI, and NEW07 Microwave and terahertz metrology for homeland security related directly to the **Physical Agents Directive**

2013/35/EC, which repeals 2004/40/EC regarding the exposure of workers to electro-magnetic fields, including the safety of clinicians performing tasks near operating MRI machines.

HLT06 Metrology for next-generation safety standards and equipment in MRI developed an assessment procedure to provide hospitals with a strategy for evaluating the safety of staff actions when planning new surgical procedures. This enables hospitals and staff to have greater confidence when identifying critical situations which may exceed safety limits and permits the early introduction of strategies to reduce debilitating "motion-induced" sensations, in an important step towards the safe performance of new MRI guided surgical procedures.

NEW07 Microwave and terahertz metrology for homeland security developed robust calibration methods and a validated modelling approach that has shown that terahertz radiation is safe for use in security surveillance. The techniques developed during this project can also be used to demonstrate compliance with the Physical Agents Directive, as well as for other applicable national and international guidelines, such as that of the International Commission on Non-Ionising Radiation Protection (ICNIRP).

A project addressed the effects of non-audible sound on humans and potential extensions to the coverage of environmental noise directives: **Directive on the assessment and management of environmental noise (2002/49/EC) and Directive on minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (2003/10/EC).**

Figure 29: List of projects and related directives*

Renewable Energy Directive (2009/28/EC)	
Renewable Energy Directive (2009/28/EC); Emissions Trading Directive (2003/87/EC)	
ENG01 GAS	Characterisation of Energy Gases
ENG02 Harvesting	Metrology for Energy Harvesting
ENG03 LNG	Metrology for Liquefied Natural Gas (LNG)
ENG04 SmartGrid	Metrology for Smart Electrical Grids
ENG07 HVDC	Metrology for High Voltage Direct Current
ENG09 Biofuels	Metrology for Biofuels
ENG52 SmartGrid II	Measurement tools for Smart Grid stability and quality
ENG53 ThinErgy	Traceable characterisation of thin-film materials for energy applications
ENG54 Biogas	Metrology for biogas
ENG55 PhotoClass	Towards an energy-based parameter for photovoltaic classification
ENG56 DriveTrain	Traceable measurement of drive train components for renewable energy systems
ENG61 FutureGrid	Non-conventional voltage and current sensors for future power grids
ENG63 GridSens	Sensor network metrology for the determination of electrical grid

Energy Efficiency Directive 2012/27/EU) **Eco-design Directive (2009/125/EC)**	**Batteries Directive (2008/98S/EC)** **Waste Directive (2008/98/EC)**
ENG02 Harvesting	Metrology for Energy Harvesting
ENG04 SmartGrid	Metrology for Smart Electrical Grids
ENG05 Lighting	Metrology for Solid State Lighting
ENG06 PowerPlants	Metrology for improved power plant efficiency
ENG52 SmartGrid II	Measurement tools for Smart Grid stability and quality
ENG62 MESaIL	Metrology for efficient and safe innovative lighting

IND04	MetroMetal	Ionising radiation metrology for the metallurgical industry
Directive concerning common rules for the internal market in natural gas (2003/55/EC) Measuring Instruments Directive (2014/32/EU) Sulphur Directive (2012/33/EU (amendment on Directive 1999/32/EC))		
ENG03	LNG	Metrology for Liquefied Natural Gas
ENG54	Biogas	Metrology for biogas
ENG60	LNG II	Metrological support for LNG custody transfer and transport fuel applications
Water Framework Directive (WFD-2000/60/EC) and associated directives		
ENV08	WFD	Traceable measurements for monitoring critical pollutants under the European Water Framework Directive (WFD-2000/60/EC)
ENV05	Ocean	Metrology for ocean salinity and acidity
ENV51	MeTra	Traceability for mercury measurements
Ambient air quality and cleaner air for Europe Directive (2008/50/EC) The Euro series of emissions regulations for type-approval of motor vehicles and engines		
ENV01	MACPoll	Metrology for Chemical Pollutants in Air
ENV02	PartEmission	Emerging requirements for measuring pollutants from automotive exhaust emissions
ENV52	HIGHGAS	Metrology for high-impact greenhouse gases
ENV56	KEY-VOCs	Metrology for VOC indicators in air pollution and climate change
INSPIRE Directive (2007/2/EC)		
ENV04	MetEOC	European metrology for earth observation and climate
ENV53	MetEOC2	Metrology for earth observation and climate
Directive 96/29/EURATOM		
ENV09	MetroRWM	Metrology for Radioactive Waste Management
ENV54	MetroDecom	Metrology for decommissioning nuclear facilities
ENV57	MetroERM	Metrology for radiological early warning networks in Europe
HLT09	MetrExtRT	Metrology for radiotherapy using complex radiation fields
HLT11	MetroMRT	Metrology for molecular radiotherapy
IND04	MetroMetal	Ionising radiation metrology for the metallurgical industry
Industrial Emissions Directive (IED) (2010/75/EU)		
ENV60	IMPRESS	Metrology to underpin future regulation of industrial emissions
ENV51	MeTra	Traceability for mercury measurements
Directive on national emission ceilings for certain atmospheric pollutants (NEC) (2001/81/EC)		
ENV55	MetNH3	Metrology for ammonia in ambient air

ENV52 HIGHGAS	Metrology for high-impact greenhouse gases
Hazardous Substances RoHS) in Electrical and Electronic Equipment Directive (2002/95/EC) Directive relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (2004/107/EC)	
ENV51 MeTra	Traceability for mercury measurements
Medical Device Directive (93/42/EEC)	
HLT03 DUTy	Dosimetry for ultrasound therapy
IND56 Q-AIMDS	Chemical metrology tools to support the manufacture of advanced biomaterials in the medical device industry
In-vitro Diagnostics (IVD) Directive (98/79/EC)	
HLT04 BioSurf	Metrology for the characterisation of biomolecular interfaces for diagnostic devices
HLT05 Metallomics	Metrology for metalloproteins
HLT08 INFECT-MET	Metrology for monitoring infectious diseases, antimicrobial resistance, and harmful micro-organisms
SIB54 Bio-SITrace	Traceability for biologically relevant molecules and entities
Directive on medicinal products for human use (2001/83/EC) Directive on processing, storage and distribution of human blood and blood components (2002/98/EC)	
HLT10 BiOrigin	Metrology for biomolecular origin of disease
Physical Agents Directive (2004/40/EC)	
HLT06 MRI safety	Metrology for next-generation safety standards and equipment in MRI
Directive on the assessment and management of environmental noise (2002/49/EC) Directive on minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (2003/10/EC)	
HL01 Ears	Metrology for a universal ear simulator and the perception of non-audible sound
EMC Directive (2004/108/EC)	
IND60 EMC	Improved EMC test methods in industrial environments
Construction products regulation (Regulation (EU) No 305/2011)	
SIB52 Thermo	Metrology for thermal protection materials

*Some projects are listed under more than one category of regulation

Figure 30: Operational Objectives - Indicator 9b

INDICATOR 9b	Number of presentations at standardisation technical committees or working groups
Data / Evidence	
1206 contributions were made to 534 unique standards committees, this resulted in contributions to 126 published and draft standards.	

Many of the technical committees were working on standards linked to the effective implementation of the regulations reported under **Operational Indicator 9a**. Such standards specify measurement methods to be deployed in the field or commercial calibration and test laboratories that provide measurements to assess, for example, air and water quality.

4.4 Supporting industry through up front public metrology research (O1.10)

Figure 31: Operational Objectives - Indicator 10a

INDICATOR 10a	Number of scientific publications
Data / Evidence	
2465 papers were published. In addition, 607 papers were published in conference proceedings and 33 contributions made to books.	

Figure 32: Operational Objectives - Indicator 10b

INDICATOR 10b	Number of presentations at congresses
Data / Evidence	
5259 contributions were made at conferences - 3394 presentations and 1521 posters.	

Figure 33: Operational Objectives - Indicator 10c

INDICATOR 10c	Number of patents granted
Data / Evidence	
36 patent applications were made.	

Figure 34: Operational Objectives - Indicator 10d

INDICATOR 10d	Number and quality of activities related to metrology communication and diffusion
Data / Evidence	

2155 activities have been undertaken to communicate and diffuse the outputs of EMRP projects. In the majority of cases (89 %) the target audience was measurement users in the industrial, public sector and academic communities. The remainder (11 %) were targeted at the general public.

These included a wide range of activities:

Dissemination activities	Number
Presentation at seminar/workshop etc.	711
Website	238
JRP event / workshop / seminar	209
Article published in trade / professional press	136
Article published in the popular press	98
Exhibition	89
Newsletter, flyer, leaflets	119
Press release	84
Media interview	53
Communication with the public/public report	73
Video /film	12
Email lists, social networking, etc.	22

Other	311
TOTAL	**2155**

Audience size: the dissemination activities are estimated to have reached a total audience of 653,000[6]

Figure 35: Operational Objectives - Indicator 10e

INDICATOR 10e	Number and quality of training activities
Data / Evidence	

1020 training activities were undertaken. Of these:

- 463 were focused on training for the NMI/DI community
- 557 were focused in training of users of metrology

The training took a wide range of formats, appropriate to the audiences being targeted:

	Audience	
Type of training	**Measurement users**	**NMI/DI community**
One-to-one training	42	172
Training course/workshop for external	448	248
Interactive online training course/tool	17	7
Written training material for external (online/paper)	23	28
Other	27	8
TOTAL	**557**	**463**

A further 35 PhDs (see Operational indicator 5c) and 25 Masters students were trained in metrology.

It is estimated that the training activities reached the following audiences.

Measurement user community: an estimated 7,400 people from the measurement user community were trained in small group sessions and workshops (with an estimated total number of training days of 9,400).

NMI/DI community: 3,100 people in the NMI/DI community were trained (with an estimated total number of training days of 8,500).[7]

The total number of training days is larger for training the NMI/DI community as the training tends to be more intensive such as training visiting guest workers.

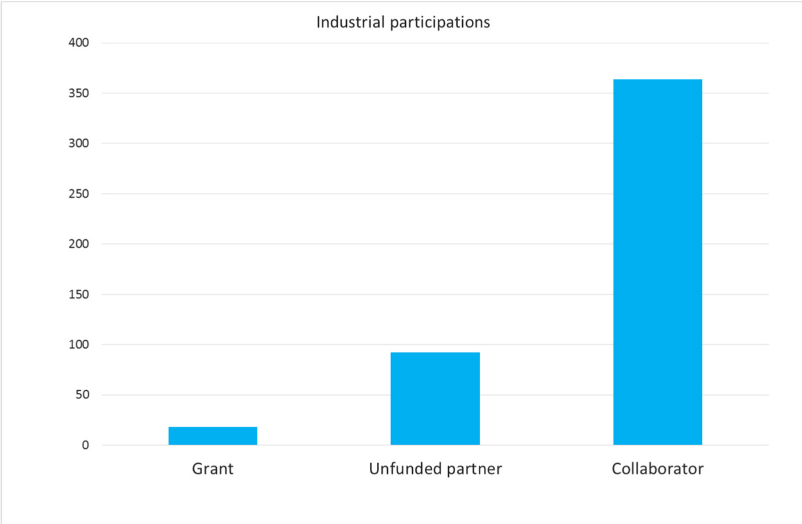
Specific Objectives - Indicator 10e

INDICATOR 10e	Number of industrial participants
Data / Evidence	

[6] Project partners report estimated audience size in ranges (e.g. 50-100, 101-200 people), therefore the total number is an estimate. The estimate does not represent unique numbers of people as people may be targeted by more than one dissemination activity.

[7] Project partners report numbers of attendees at training events in ranges (e.g. 5-10, 11-25 people), therefore the total number is an estimate. The estimate does not represent unique numbers of people as people attending more than one training event will be counted each time they attend.

As reported under **Operational indicator 5a**, there was significant participation by industry. There were 474 participations from 434 organisations.[8] The majority (77 %) participated as collaborators, signing a Non-Disclosure Agreement with the project partners enabling them (with conditions) to engage with the project team and access results. A smaller number made formal contributions to the projects as unfunded partners or via Researcher Grants.



5 Effectiveness, Efficiency and European value-added

5.1 Effectiveness

The programme has delivered against all of its operational and specific objectives.

Contributing to the ERA / creating a Metrology Research Areas

S1.1 Structuring the ERA through coordinating and partly integrating national public metrology research programmes to provide solutions to European societal challenges

S1.2 Improve the efficiency of Europe's fragmented public metrology research approach

S1.3 To remove barriers between national metrology research programmes and to foster sustainable cross-border cooperation e.g. through mobility of young researchers, scientists and academic staff and to open up the national programmes to inter-disciplinary cooperation with researchers and scientists from other fields in particular relating to new and emerging technologies.

Levering and consolidating metrology funding in Europe

The programme achieved a significant level of coordination of national public metrology research programmes. 23 European countries participated in EMRP, leveraging national funding of 219.236 M€ – 10 % above the target of 200 M€ – for EMRP activities.

The programme enabled widespread collaboration in metrology research, not only among the traditional metrology institutes (the NMIs and DIs) but also with the academic, industrial and public sector communities. The Commission and national funding supported 119 joint research projects with 957 participations from the

[8] The actual number of unique organisations is likely to be lower than this due to the way that company names are reported by project partners (particularly for collaborators), where the same company and/or their subsidiaries can be reported under slightly different names.

metrology community (i.e. NMIs and DIs) and 1157 participations from a further 916 organisations the academic, industrial and public sector communities.

Scientific integration

The programme was designed and governed by the participating countries at a number of levels to support scientific integration of metrology research across Europe:

- The programme was guided by a common research agenda developed by the European metrology community under the precursor ERA-NET programme iMERA+
- The programme was designed around themes focused on grand societal challenges (energy, environment, health, industry) as well as supporting important developments in the international systems of units (the SI).
- Call scopes were developed by the EMRP Committee supported by the new themed Task Groups established by EURAMET
- A two-stage call process brought the European metrology community together, along with the academic community and measurement research end-users, to develop and deliver collaborative research projects.
- Project selection was based on an assessment, by the EMRP committee, of alignment with strategic requirements (stage 1) and independent expert review (stage 2). The Interim Evaluation of EMRP and the annual independent observers' reports confirm that this process was independent and robust.

All participating countries could (in most cases, did) participate in all levels of programme and project design and governance.

Projects were conducted by collaborations of NMIs, DIs, academics, industrial and other organisations significantly increasing the level of networking and enabling the flow of ideas, knowledge and people and sharing of metrology research facilities.

Management integration

EURAMET implemented a dedicated and centralised governance and management processes for the programme from the outset, made up of the EMRP Committee, an EMRP Programme Manager and a dedicated Management and Support Unit (MSU). The delivery of the programme was monitored and reviewed in various ways (annual reports, audits, Interim Evaluation, etc) and no significant problems or issues arose. The Interim Evaluation found the programme processes to be high quality and transparent and in line with the Commission's requirements.

Financial integration

The programme managed 200 M€ of EU funding and coordinated 219 M€ of national metrology research funds using a common approach to financial rules. From the very beginning the programme adopted a model contract and financial approach based on the FP7 model. Guidelines and templates were provided to support project partners who were new to this approach, helping them to cost projects and ensure finances were reported consistently and in accordance with the financial rules.

Delivering economic and social impact

S1.4 To increase the impact of these programmes, both S&T impacts (scientific excellence, pooling of resources, data and expertise, achievement of critical mass, facilitating programme optimisation) and economic and societal impacts.

Scientific excellence and impact

The EMRP programme provided a structured process of research collaboration among European metrology institutes (NMIs and DIs). Prior to EMRP (and its predecessor ERA-NET iMERA+) research collaboration was rather ad-hoc, based on goodwill and relationships between individual institutes and researchers. A key benefit of the programme was not only the ability to coordinate resources and skills but the ability to align research timescales. An important example of this being the coordination of European research contribution to the redefinition of the international system of units (the SI). EMRP projects under the first SI call became a focal point for European redefinition activity and, for some projects, an international focal point. The pooling of research expertise and the alignment of critical experiments and measurement comparisons enhanced the European contribution scientifically but also in terms of creating a more coordinated European position in the redefinition decision.

EMRP researchers have published 2465 papers in peer-reviewed journals. Bibliographic analysis shows that the publications are above world averages in terms of citations, impact factor and highly cited papers and have increased over the period from 2008 to 2015 (i.e. before and during EMRP). In addition, the level of international co-authorship of peer-reviewed papers increased from 32 % to 47 %.

Economic impact

Accurate traceable measurement, reliable and robust worldwide, underpins trade. Metrology research ensures the international measurement systems are fit for the future and supports the introduction of innovative product and services through the accurate validation of new technologies and ideas. The pathways and timescales for economic impact are not always direct or immediate and will sometimes show their benefit years after completion. Nevertheless, EURAMET collected evidence of early impact from all projects - that is the adoption of EMRP project outputs by measurement users. Early adopters of metrology research are often (but not solely) the instrumentation sector and the accredited laboratory sector who make use the new NMI/DI capabilities or adopt the improved measurement techniques to develop their own new products and services. These sectors are an important bridge to measurement end-users in other businesses sectors and public sector agencies, who use improved measurement capabilities to develop their new products and/or improve processes.

EURAMET conducted surveys of industrial participants in EMRP projects and developed impact case studies. These demonstrated an economic impact in terms of actual and projected sales of innovative products influenced by the programme of 1673 M€. Of this figure 352.8 M€ is directly attributable to the programme. This figure covers the industrial participants that participated in projects of all EMRP calls. In addition, the new products sold will contribute to economic benefits for many of the end-users. EURAMET has identified and published 141 case studies demonstrating economic impact.

Social impact

Three of the programme's themes were explicitly focused on social impact via the grand challenges Energy, Environment and Health. Research in these themes addressed the requirements for accurate data and appropriate instrumentation to improve the ability to identify, quantify and better understanding problems, and to design and implementation effective solutions and/or appropriate regulation. Many of the projects in these themes were directly focused on European regulation supporting issues such as water and air quality, safety of healthcare products and radiation protection. 43 projects (36 % of the total) supported regulation.

As for economic impact, the pathways and timescales for impact are not always direct or immediate but EURAMET identified and developed several dozens of case studies of social impact. These case studies provide examples of the adoption of project outputs by the measurement users and demonstrate that the route to longer-term impact has commenced. Examples include:

- New flow and temperature instrumentation that has been demonstrated to improve efficiency in traditional power plants, leading to reduced carbon emissions and providing financial benefits
- Supporting the introduction of energy efficient lighting in the Italian tunnel network, improving safety and reducing both costs and energy use
- The development and trial of practical reference standards to improve the robustness of roadside emissions monitoring, so protecting human health
- Contributing measurement methods and standards to ESA's next generation Earth observation satellites
- Developing accurate validation of molecular methods to identify and quantify infectious diseases

5.2 Efficiency

The programme objectives and impacts have been delivered efficiently. The costs of administering the programme were less than 16 M€. This represents 3.8 % of the total 419 M€ programme budget.

5.3 European value added

Metrology is both a national and international endeavour. In some countries the requirement to hold national measurement standards to support the economy and society is enshrined in law and the international system of metrology ensures that primary measurement standards and the measurements they support are comparable and accepted across the world. However, the requirements for research to ensure measurements are fit for the future are increasing. Meeting ever-growing demands for new measurement standards in emerging areas of technology whilst still meeting the expectations of existing sectors and users, places increasing demands on national metrology research budgets, with most countries showing similar demands. Conducting research at European level via EMRP has enabled national metrology institutes to pool resources and knowledge and reduce duplication and reach critical mass in key areas.

6 Annex A: Non-NMI/DI project participants

6.1 Researcher Grants

There were 306 participations by 146 organisations in researcher grants.

Figure 36: Researcher grants

Project	Organisation	Country	Organisation type
ENG01	Politecnico di Torino	Italy	University/ public research org
ENG03	Ruhr-Universitaet Bochum	Germany	University/ public research org
ENG04	Aristotelio Panepistimio Thessalonikis	Greece	University/ public research org
ENG04	University of Strathclyde	United Kingdom	University/ public research org
ENG05	University of Surrey	United Kingdom	University/ public research org
ENG05	University of Surrey	United Kingdom	University/ public research org
ENG05	Technische Universiteit Delft	Netherlands	University/ public research org
ENG06	Technische Universitaet Graz	Austria	University/ public research org
ENG07	Technische Universitaet Braunschweig	Germany	University/ public research org
ENG08	The Chancellor, Masters and Scholars of the University of Cambridge	United Kingdom	University/ public research org
ENG09	Universidad de Oviedo	Spain	University/ public research org
ENG09	Universitaet Rostock	Germany	University/ public research org
ENG09	Universitaet Rostock	Germany	University/ public research org
ENG51	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
ENG51	Centre National de la Recherche Scientifique	France	University/ public research org
ENG51	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
ENG52	Technische Universiteit Eindhoven	Netherlands	University/ public research org
ENG52	École Polytechnique Federale de Lausanne	Switzerland	University/ public research org
ENG52	University of Strathclyde	United Kingdom	University/ public research org
ENG53	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
ENG53	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH	Germany	University/ public research org
ENG53	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
ENG54	Institut national de l'environnement industriel et des risques ineris	France	University/ public research org
ENG54	Fundación General de la Universidad de Valladolid	Spain	University/ public research org
ENG54	Helsingin Yliopisto	Finland	University/ public research org
ENG55	Loughborough University	United Kingdom	University/ public research org
ENG55	Institut für Solarenergieforschung GmbH	Germany	Industry
ENG55	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
ENG56	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
ENG56	Cardiff University	United Kingdom	University/ public research org
ENG56	Rheinisch-Westfälische Technische Hochschule Aachen	Germany	University/ public research org
ENG57	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
ENG58	University of Leeds	United Kingdom	University/ public research org
ENG58	University of Leeds	United Kingdom	University/ public research org
ENG58	Cranfield University	United Kingdom	University/ public research org
ENG59	International Research Institute Of Stavanger AS	Norway	University/ public research org
ENG59	Faculdade de Ciências e Tecnologia Universidade Nova de Lisboa	Portugal	University/ public research org
ENG60	Ruhr-Universitaet Bochum	Germany	University/ public research org

Project	Organisation	Country	Organisation type
ENG60	Ruhr-Universitaet Bochum	Germany	University/ public research org
ENG60	Technische Universitaet Braunschweig	Germany	University/ public research org
ENG61	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
ENG61	Technische Universitaet Dresden	Germany	University/ public research org
ENG61	University of Strathclyde	United Kingdom	University/ public research org
ENG62	Technische Universiteit Delft	Netherlands	University/ public research org
ENG62	Technische Universitaet Braunschweig	Germany	University/ public research org
ENG62	Institut National de la Sante et de la Recherche Medicale (INSERM)	France	University/ public research org
ENG63	Technische Universiteit Delft	Netherlands	University/ public research org
ENG63	Technische Universiteit Eindhoven	Netherlands	University/ public research org
ENG63	University of Strathclyde	United Kingdom	University/ public research org
ENV01	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
ENV01	Agencia Estatal Consejo Superior de Investigaciones Cientificas	Spain	University/ public research org
ENV01	Helsingin Yliopisto	Finland	University/ public research org
ENV02	Leibniz Institut fuer Troposphaerenforschung e.V.	Germany	University/ public research org
ENV03	Medizinische Universität Innsbruck	Austria	University/ public research org
ENV03	The University of Manchester	United Kingdom	University/ public research org
ENV03	The University of Manchester	United Kingdom	University/ public research org
ENV03	Health Protection Agency HPA	United Kingdom	Other (e.g. government)
ENV04	Universitaet Zuerich	Switzerland	University/ public research org
ENV04	Universitaet Zuerich	Switzerland	University/ public research org
ENV04	ZiNIR Ltd	United Kingdom	Industry
ENV04	Maanmittauslaitos	Finland	University/ public research org
ENV05	University of Plymouth	United Kingdom	University/ public research org
ENV05	Fundacao da Faculdade de Ciencias da Universidade de Lisboa	Portugal	University/ public research org
ENV06	Stichting Katholieke Universiteit	Netherlands	University/ public research org
ENV07	Aarhus Universitet	Denmark	University/ public research org
ENV07	Karlsruher Institut fuer Technologie	Germany	University/ public research org
ENV07	Universitat Rovira i Virgili	Spain	University/ public research org
ENV07	EV-K2-CNR	Italy	University/ public research org
ENV07	Consiglio Nazionale delle Ricerche	Italy	University/ public research org
ENV08	Universidad de Oviedo	Spain	University/ public research org
ENV08	Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung GmbH	Germany	University/ public research org
ENV09	NUVIA a.s.	Czech Republic	Industry
ENV51	Universidad de Oviedo	Spain	University/ public research org
ENV51	Centre National de la Recherche Scientifique	France	University/ public research org
ENV51	Consiglio Nazionale delle Ricerche	Italy	University/ public research org
ENV52	Stichting Katholieke Universiteit	Netherlands	University/ public research org
ENV52	Eidgenoessische Materialpruefungs- und Forschungsanstalt	Switzerland	University/ public research org
ENV53	Universitaet Zuerich	Switzerland	University/ public research org
ENV53	Humboldt-Universität zu Berlin	Germany	University/ public research org
ENV53	Maanmittauslaitos	Finland	University/ public research org
ENV54	NUVIA a.s.	Czech Republic	Industry
ENV55	Natural Environment Research Council	United Kingdom	University/ public research org

Project	Organisation	Country	Organisation type
ENV55	Helsingin Yliopisto	Finland	University/ public research org
ENV56	Politecnico di Torino	Italy	University/ public research org
ENV56	Universität des Saarlandes	Germany	University/ public research org
ENV56	Deutscher Wetterdienst	Germany	Other (e.g. government)
ENV57	Universitat Politècnica de Catalunya	Spain	University/ public research org
ENV57	Aristotelio Panepistimio Thessalonikis	Greece	University/ public research org
ENV57	NUVIA a.s.	Czech Republic	Industry
ENV58	Università degli Studi di Genova	Italy	University/ public research org
ENV58	Seconda Università degli Studi di Napoli	Italy	University/ public research org
ENV58	Universitat Politècnica de Catalunya	Spain	University/ public research org
ENV59	Universitaet Bremen	Germany	University/ public research org
ENV59	Universidad de la Laguna	Spain	University/ public research org
ENV59	Aristotelio Panepistimio Thessalonikis	Greece	University/ public research org
ENV60	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
ENV60	Technische Universiteit Delft	Netherlands	University/ public research org
ENV60	DCMR Milieudienst Rijnmond	Netherlands	Other (e.g. government)
EXL01	Oesterreichische Akademie der Wissenschaften	Austria	University/ public research org
EXL01	Gottfried Wilhelm Leibniz Universität Hannover	Germany	University/ public research org
EXL01	Crystalline Mirror Solutions GmbH	Austria	Industry
EXL01	Institut d'optique théorique et appliquée IOTA - SupOptique	France	University/ public research org
EXL02	Friedrich-Alexander-Universität Erlangen - Nürnberg	Germany	University/ public research org
EXL02	Universität des Saarlandes	Germany	University/ public research org
EXL02	Danmarks Tekniske Universitet	Denmark	University/ public research org
EXL02	Danmarks Tekniske Universitet	Denmark	University/ public research org
EXL02	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
EXL03	Royal Holloway and Bedford New College	United Kingdom	University/ public research org
EXL03	Royal Holloway and Bedford New College	United Kingdom	University/ public research org
EXL03	Lancaster University	United Kingdom	University/ public research org
EXL03	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
EXL04	The Chancellor, Masters and Scholars of the University of Cambridge	United Kingdom	University/ public research org
EXL04	Universitaet Bielefeld	Germany	University/ public research org
EXL04	Laboratorio Iberico Internacional De Nanotecnologia	Portugal	University/ public research org
EXL04	Laboratorio Iberico Internacional De Nanotecnologia	Portugal	University/ public research org
EXL04	Fyzikální ústav AV ČR, v.v.i.	Czech Republic	University/ public research org
HLT01	University College London	United Kingdom	University/ public research org
HLT01	Max Planck Gesellschaft Zur Foerderung Der Wissenschaften E.V.	Germany	University/ public research org
HLT02	Research Centre for Natural Sciences, Hungarian Academy of Sciences	Hungary	University/ public research org
HLT02	AMC Medical Research B.V.	Netherlands	University/ public research org
HLT02	AMC Medical Research B.V.	Netherlands	University/ public research org
HLT03	University College London	United Kingdom	University/ public research org
HLT03	Institute of Cancer Research - Royal Cancer Hospital	United Kingdom	University/ public research org
HLT03	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
HLT04	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
HLT04	The University of Nottingham	United Kingdom	University/ public research org

Project	Organisation	Country	Organisation type
HLT04	Charite - Universitaetsmedizin Berlin	Germany	University/ public research org
HLT04	Technische Universität Berlin	Germany	University/ public research org
HLT05	The University Court of the University of Aberdeen	United Kingdom	University/ public research org
HLT05	Loughborough University	United Kingdom	University/ public research org
HLT05	Universitaet fuer Bodenkultur Wien	Austria	University/ public research org
HLT05	Deutsches Krebsforschungszentrum	Germany	University/ public research org
HLT06	King's College London	United Kingdom	University/ public research org
HLT07	Fachhochschule Lübeck	Germany	University/ public research org
HLT07	Universitair Medisch Centrum Utrecht	Netherlands	University/ public research org
HLT07	Universitair Medisch Centrum Utrecht	Netherlands	University/ public research org
HLT08	Charite - Universitaetsmedizin Berlin	Germany	University/ public research org
HLT08	University College London	United Kingdom	University/ public research org
HLT08	Bolnisnica Golnik Klinicni oddelek za pljucne bolezni in alergijo	Slovenia	University/ public research org
HLT09	Université d'Auvergne Clermont-Ferrand 1	France	University/ public research org
HLT09	Università degli Studi di Roma Tor Vergata	Italy	University/ public research org
HLT10	Charite - Universitaetsmedizin Berlin	Germany	University/ public research org
HLT10	The Chancellor, Masters and Scholars of the University of Oxford	United Kingdom	University/ public research org
HLT10	The University of Edinburgh	United Kingdom	University/ public research org
HLT10	Freie Universitaet Berlin	Germany	University/ public research org
HLT10	Robert Koch-Institut	Germany	University/ public research org
HLT11	Velindre National Health Service Trust	United Kingdom	University/ public research org
HLT11	Institute of Cancer Research - Royal Cancer Hospital	United Kingdom	University/ public research org
HLT11	Institut National de la Sante et de la Recherche Medicale (INSERM)	France	University/ public research org
IND01	Bayerisches Zentrum für Angewandte Energieforschung ZAE e.V.	Germany	University/ public research org
IND01	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
IND02	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
IND02	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
IND02	Eidgenössische Technische Hochschule Zürich	Switzerland	University/ public research org
IND02	Eidgenössische Technische Hochschule Zürich	Switzerland	University/ public research org
IND04	NUVIA a.s.	Czech Republic	Industry
IND05	Koc University	Turkey	University/ public research org
IND05	Queen Mary University of London	United Kingdom	University/ public research org
IND05	Schwarzer Norbert	Germany	University/ public research org
IND06	Politecnico di Milano	Italy	University/ public research org
IND06	Oulun Yliopisto	Finland	University/ public research org
IND06	ID Quantique SA	Switzerland	Industry
IND07	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
IND07	Technische Universiteit Delft	Netherlands	University/ public research org
IND07	Technische Universität Berlin	Germany	University/ public research org
IND07	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH	Germany	University/ public research org
IND07	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
IND08	Universitaet Bielefeld	Germany	University/ public research org
IND08	HITACHI Europe Limited	United Kingdom	Industry

Project	Organisation	Country	Organisation type
IND10	Universitaet Stuttgart	Germany	University/ public research org
IND10	Technische Universitaet Ilmenau	Germany	University/ public research org
IND10	XPRESS Precision Engineering B.V.	Netherlands	Industry
IND10	Mahr GmbH	Germany	industry
IND10	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
IND11	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
IND11	University of Southampton	United Kingdom	University/ public research org
IND12	Karlsruher Institut fuer Technologie	Germany	University/ public research org
IND12	Università degli Studi di Genova	Italy	University/ public research org
IND12	Panepistimio Thessalias	Greece	University/ public research org
IND13	Technische Universitaet Ilmenau	Germany	University/ public research org
IND14	The University Court of the University of St Andrews	United Kingdom	University/ public research org
IND15	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
IND16	Technische Universiteit Delft	Netherlands	University/ public research org
IND16	National Instruments Belgium NV	Belgium	Industry
IND17	Technische Universiteit Delft	Netherlands	University/ public research org
IND17	Itä-Suomen yliopisto	Finland	University/ public research org
IND17	JCMwave GmbH	Germany	Industry
IND17	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH	Germany	University/ public research org
IND51	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
IND51	Technische Universiteit Delft	Netherlands	University/ public research org
IND51	Universite de Rennes I	France	University/ public research org
IND52	Katholieke Universiteit Leuven	Belgium	University/ public research org
IND52	Universidad de Alicante	Spain	University/ public research org
IND52	Innventia AB	Sweden	Industry
IND53	Karlsruher Institut fuer Technologie	Germany	University/ public research org
IND53	University College London	United Kingdom	University/ public research org
IND53	University of Bath	United Kingdom	University/ public research org
IND54	The University of Edinburgh	United Kingdom	University/ public research org
IND54	The University of Liverpool	United Kingdom	University/ public research org
IND54	Centre National de la Recherche Scientifique	France	University/ public research org
IND55	Universite de Neuchatel	Switzerland	University/ public research org
IND56	The University of Nottingham	United Kingdom	University/ public research org
IND56	Gottfried Wilhelm Leibniz Universität Hannover	Germany	University/ public research org
IND56	Westfaelische Wilhelms-Universitaet Muenster	Germany	University/ public research org
IND56	Robert Koch-Institut	Germany	University/ public research org
IND57	Universitaet fuer Bodenkultur Wien	Austria	University/ public research org
IND57	Statni ustav radiacni ochrany v.v.i.	Czech Republic	University/ public research org
IND57	Glowny Instytut Gornictwa	Poland	Industry
IND58	University of Bristol	United Kingdom	University/ public research org
IND58	Technische Universitaet Ilmenau	Germany	University/ public research org
IND58	Technische Universitaet Ilmenau	Germany	University/ public research org
IND58	Ústav přístrojové techniky AV ČR, v.v.i.	Czech Republic	University/ public research org
IND59	The University of Nottingham	United Kingdom	University/ public research org
IND59	Friedrich-Alexander-Universität Erlangen - Nürnberg	Germany	University/ public research org

Project	Organisation	Country	Organisation type
IND59	Loughborough University	United Kingdom	University/ public research org
IND60	Universitat Politècnica de Catalunya	Spain	University/ public research org
IND60	Universiteit Twente	Netherlands	University/ public research org
IND61	Cranfield University	United Kingdom	University/ public research org
IND61	Ricerca sul Sistema Energetico – RSE S.p.A.	Italy	University/ public research org
IND62	Karlsruher Institut fuer Technologie	Germany	University/ public research org
IND62	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
IND63	Politecnico di Torino	Italy	University/ public research org
IND63	The Chancellor, Masters and Scholars of the University of Oxford	United Kingdom	University/ public research org
IND63	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
NEW01	Interuniversitair Micro-Electronicacentrum IMEC VZW	Belgium	University/ public research org
NEW01	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
NEW01	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
NEW02	Eidgenössische Technische Hochschule Zürich	Switzerland	University/ public research org
NEW02	King's College London	United Kingdom	University/ public research org
NEW02	King's College London	United Kingdom	University/ public research org
NEW03	Heriot-Watt University	United Kingdom	University/ public research org
NEW03	Universitaet Hamburg	Germany	University/ public research org
NEW03	Research Centre for Natural Sciences, Hungarian Academy of Sciences	Hungary	University/ public research org
NEW04	Università degli Studi di Torino	Italy	University/ public research org
NEW05	Technische Universitaet Dresden	Germany	University/ public research org
NEW05	Technische Universitaet Chemnitz	Germany	University/ public research org
NEW05	Helsingin Yliopisto	Finland	University/ public research org
NEW06	Westsächsische Hochschule Zwickau	Germany	University/ public research org
NEW06	The University of Huddersfield	United Kingdom	University/ public research org
NEW06	Ostfalia Hochschule fur angewandte Wissenschaften Hochschule Braunschweig Wolfenbuttel	Germany	University/ public research org
NEW06	University of York	United Kingdom	University/ public research org
NEW07	Technische Universität Berlin	Germany	University/ public research org
NEW07	Philipps-Universität Marburg	Germany	University/ public research org
NEW07	Philipps-Universität Marburg	Germany	University/ public research org
NEW07	Centre National de la Recherche Scientifique	France	University/ public research org
NEW08	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
NEW08	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
NEW08	Royal Holloway and Bedford New College	United Kingdom	University/ public research org
NEW08	Helsingin Yliopisto	Finland	University/ public research org
NEW09	University of Leeds	United Kingdom	University/ public research org
NEW09	Cranfield University	United Kingdom	University/ public research org
NEW09	aixACCT Systems GmbH	Germany	Industry
SIB01	Royal Holloway and Bedford New College	United Kingdom	University/ public research org
SIB01	Seconda Università degli Studi di Napoli	Italy	University/ public research org
SIB01	Seconda Università degli Studi di Napoli	Italy	University/ public research org
SIB01	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
SIB02	Akademia Gorniczo-Hutnicza im. Stanislawa Staszica w Krakowie	Poland	University/ public research org
SIB02	University of Southampton	United Kingdom	University/ public research org

Project	Organisation	Country	Organisation type
SIB02	Consiglio Nazionale delle Ricerche	Italy	University/ public research org
SIB03	Leibniz-Institut für Oberflächenmodifizierung	Germany	University/ public research org
SIB03	Leibniz-Institut für Oberflächenmodifizierung	Germany	University/ public research org
SIB03	Universita Degli Studi Di Cagliari	Italy	University/ public research org
SIB04	Universitaet Siegen	Germany	University/ public research org
SIB04	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
SIB04	University of Sussex	United Kingdom	University/ public research org
SIB04	LZH Laserzentrum Hannover e.V.	Germany	industry
SIB05	Technische Universitaet Ilmenau	Germany	University/ public research org
SIB06	Klinikum rechts der Isar der Technischen Universitat Munchen	Germany	University/ public research org
SIB06	Istituto Nazionale di Fisica Nucleare	Italy	University/ public research org
SIB06	Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento	Portugal	University/ public research org
SIB07	The Chancellor, Masters and Scholars of the University of Cambridge	United Kingdom	University/ public research org
SIB07	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
SIB07	Latvijas Universitate	Latvia	University/ public research org
SIB07	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
SIB08	Technische Universiteit Delft	Netherlands	University/ public research org
SIB08	Università degli Studi di Torino	Italy	University/ public research org
SIB08	BIAS Bremer Institut für angewandte Strahltechnik GmbH	Germany	Industry
SIB09	Universiteit Gent	Belgium	University/ public research org
SIB09	Leibniz-Institut fuer Festkoerper- und Werkstoffforschung Dresden e.V.	Germany	University/ public research org
SIB10	Politecnico di Torino	Italy	University/ public research org
SIB51	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
SIB51	Linköpings universitet	Sweden	University/ public research org
SIB51	Universitaet Bielefeld	Germany	University/ public research org
SIB53	Politechnika Slaska	Poland	University/ public research org
SIB53	Uniwersytet Zielonogorski	Poland	University/ public research org
SIB55	Gottfried Wilhelm Leibniz Universität Hannover	Germany	University/ public research org
SIB56	Politecnico di Torino	Italy	University/ public research org
SIB56	Bundesanstalt fuer Arbeitsschutz und Arbeitsmedizin	Germany	University/ public research org
SIB57	Tallinna Tehnikaulikool	Estonia	University/ public research org
SIB57	Universitetet I Oslo	Norway	University/ public research org
SIB57	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
SIB58	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH	Germany	University/ public research org
SIB59	Høgskolen i Sørøst-Norge	Norway	University/ public research org
SIB60	Technische Universiteit Delft	Netherlands	University/ public research org
SIB60	Gottfried Wilhelm Leibniz Universität Hannover	Germany	University/ public research org
SIB60	Rheinische Friedrich-Wilhelms-Universitaet Bonn	Germany	University/ public research org
SIB60	Technische Universitaet Braunschweig	Germany	University/ public research org
SIB61	Universita Degli Studi del Piemonte Orientale Amedeo Avogadro	Italy	University/ public research org
SIB61	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
SIB61	Fyzikální ústav AV ČR, v.v.i.	Czech Republic	University/ public research org
SIB62	University of Leeds	United Kingdom	University/ public research org

Project	Organisation	Country	Organisation type
SIB62	Katholieke Universiteit Leuven	Belgium	University/ public research org
SIB62	České Vysoké Učení Technické v Praze	Czech Republic	University/ public research org
SIB62	Forschungsverbund Berlin e.V.	Germany	University/ public research org
SIB64	Oulun Yliopisto	Finland	University/ public research org
SIB64	Università degli Studi di Cassino e del Lazio Meridionale	Italy	University/ public research org

6.2 Unfunded Partners

There were 158 participations by 129 organisations as unfunded partners.

Figure 37: Unfunded Partners

Project	Organisation	Country	Organisation type
ENG01	E + E Elektronik	Austria	Industry
ENG03	Elengy SA	France	Industry
ENG03	E.ON Ruhrgas AG	Germany	Industry
ENG03	Enagas SA	Spain	Industry
ENG04	Technische Universitaet Braunschweig	Germany	University/ public research org
ENG04	Technische Universitaet Clausthal	Germany	University/ public research org
ENG05	Universite Paul Sabatier Toulouse III	France	University/ public research org
ENG05	Technische Universitaet Ilmenau	Germany	University/ public research org
ENG05	Centro per la Conservazione ed il Restauro dei Beni Culturali "LA VENARIA REALE"	Italy	University/ public research org
ENG07	Trench France SAS	France	Industry
ENG51	Keysight Technologies GmbH	Austria	Industry
ENG51	AZUR SPACE Solar Power GmbH	Germany	Industry
ENG51	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
ENG52	Seconda Università degli Studi di Napoli	Italy	University/ public research org
ENG52	Slovenská technická univerzita v Bratislave	Slovakia	University/ public research org
ENG53	PANalytical B.V.	Netherlands	Industry
ENG54	HC Photonics Corporation Limited	Taiwan, Province of China	Industry
ENG55	Scuola Universitaria Professionale della Svizzera Italiana (SUPSI)	Switzerland	University/ public research org
ENG55	TÜV Rheinland Energie und Umwelt GmbH	Germany	Industry
ENG56	Mitutoyo CTL Germany GmbH	Germany	Industry
ENG56	Carl Zeiss Industielle Messtechnik GmbH	Germany	Industry
ENG56	MDM Metrosoft S.r.l.	Italy	Industry
ENG56	Hexagon Metrology GmbH	Germany	Industry
ENG58	KEMA Nederland BV	Netherlands	Industry
ENG58	Shell Global Solutions International B.V.	Netherlands	Industry
ENG58	Industrial Tomography Systems Plc	United Kingdom	Industry
ENG59	Shell Global Solutions International B.V.	Netherlands	Industry
ENG60	Shell Global Solutions International B.V.	Netherlands	Industry
ENG60	Oil & Gas Measurement Limited	United Kingdom	Industry
ENG62	OSRAM GmbH	Germany	Industry
ENG63	Technische Universitaet Clausthal	Germany	University/ public research org
ENG63	Fundacion Circe Centro de investigacion de recursos y consumos energeticos	Spain	University/ public research org
ENV03	CMS Ing. Dr. Schreder GmbH	Austria	Industry
ENV03	Kipp & Zonen BV	Netherlands	Industry
ENV04	Bergische Universitaet Wuppertal	Germany	University/ public research org
ENV04	Deutsches Zentrum fuer Luft- und Raumfahrt eV	Germany	Industry
ENV04	Forschungszentrum Juelich GmbH	Germany	Industry
ENV04	Maanmittauslaitos	Finland	University/ public research org
ENV07	Uniwersytet Wroclawski	Poland	University/ public research org
ENV07	Aarhus Universitet	Denmark	University/ public research org
ENV07	Chalmers tekniska hoegskola AB	Sweden	University/ public research org

Project	Organisation	Country	Organisation type
ENV08	Istituto Superiore per la Protezione e la Ricerca Ambientale	Italy	University/ public research org
ENV53	Bergische Universitaet Wuppertal	Germany	University/ public research org
ENV53	University College London	United Kingdom	University/ public research org
ENV53	Science and Technology Facilities Council	United Kingdom	University/ public research org
ENV53	Deutsches Zentrum fuer Luft- und Raumfahrt eV	Germany	Industry
ENV53	Forschungszentrum Juelich GmbH	Germany	Industry
ENV53	Maanmittauslaitos	Finland	University/ public research org
ENV54	Agence nationale pour la gestion des dechets radioactifs	France	Other (e.g. government)
ENV54	NUVIA a.s.	Czech Republic	Industry
ENV54	Electricite de France S.A	France	Industry
ENV57	Institut de Radioprotection et de Surete Nucleaire	France	University/ public research org
ENV57	Bundesamt fuer Strahlenschutz	Germany	Other (e.g. government)
ENV58	Service hydrographique et océanographique de la Marine	France	Other (e.g. government)
ENV59	Kipp & Zonen BV	Netherlands	Industry
EXL02	The University System of Maryland Foundation, Inc.	United States	University/ public research org
HLT02	Academisch Medisch Centrum bij de Universiteit van Amsterdam	Netherlands	Industry
HLT03	Hochschule Merseburg	Germany	University/ public research org
HLT03	M V Lomonosov Moscow State University	Russian Federation	University/ public research org
HLT03	Institute of Cancer Research - Royal Cancer Hospital	United Kingdom	University/ public research org
HLT03	Agencia Estatal Consejo Superior de Investigaciones Cientificas	Spain	University/ public research org
HLT11	Lunds Universitet	Sweden	University/ public research org
HLT11	University College London	United Kingdom	University/ public research org
HLT11	The Christie NHS Foundation Trust	United Kingdom	University/ public research org
HLT11	Velindre National Health Service Trust	United Kingdom	University/ public research org
HLT11	Istituti Fisioterapici Ospitalieri	Italy	University/ public research org
HLT11	Istituto Superiore di Sanità	Italy	University/ public research org
HLT11	Azienda Unità Sanitaria Locale Latina	Italy	University/ public research org
HLT11	Institute of Cancer Research - Royal Cancer Hospital	United Kingdom	University/ public research org
IND01	Endress + Hauser Wetzer GmbH Co KG	Germany	Industry
IND01	GDF Suez	France	Industry
IND01	Meggitt (UK) Limited	United Kingdom	Industry
IND01	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
IND02	Keysight Technologies GmbH	Austria	Industry
IND03	Technische Universitaet Clausthal	Germany	University/ public research org
IND05	CSM Instruments	Switzerland	Industry
IND05	NGF EUROPE Limited	United Kingdom	Industry
IND05	Schwarzer Norbert	Germany	University/ public research org
IND06	AIT Austrian Institute of Technology GmbH	Austria	University/ public research org
IND06	ID Quantique SA	Switzerland	Industry
IND07	PANalytical B.V.	Netherlands	Industry
IND07	Solarprint Limited	Ireland	Industry
IND07	TOTAL S.A.	France	Industry
IND10	Technische Universitaet Ilmenau	Germany	University/ public research org
IND10	XPRESS Precision Engineering B.V.	Netherlands	Industry

Project	Organisation	Country	Organisation type
IND10	IBS Precision Engineering bv	Netherlands	Industry
IND10	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek TNO	Netherlands	Industry
IND10	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
IND11	Friedrich-Alexander-Universität Erlangen - Nürnberg	Germany	University/ public research org
IND11	Alicona Imaging GmbH	Austria	Industry
IND11	Teknologian tutkimuskeskus VTT	Finland	University/ public research org
IND12	Danfoss A/S	Denmark	Industry
IND12	INFICON GmbH	Germany	Industry
IND12	INFICON AG	Liechtenstein	Industry
IND12	Lazzero Tecnologie Srl	Italy	Industry
IND12	VACOM Vakuum Komponenten & Messtechnik GmbH	Germany	Industry
IND13	Ecole Nationale Superieure de Mecanique et d'Aerotechnique	France	University/ public research org
IND13	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
IND14	Keysight Technologies Deutschland GmbH	Germany	Industry
IND14	Componentes Hibridos y Laseres de Fibra Optica S.L.	Spain	Industry
IND15	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
IND15	ION-TOF Technologies GmbH	Germany	Industry
IND15	Kratos Analytical Limited	United Kingdom	Industry
IND15	Scienion AG	Germany	Industry
IND15	Specs Surface Nano Analysis GmbH	Germany	Industry
IND15	FOCUS GmbH Geräte zur Elektronenspektroskopie und Oberflächenanalytik	Germany	Industry
IND16	Agilent Technologies UK Limited	United Kingdom	Industry
IND17	Nanocomp Oy Ltd	Finland	Industry
IND51	Keysight Technologies Deutschland GmbH	Germany	Industry
IND51	Dassault Aviation SA	France	Industry
IND53	The University of Sheffield	United Kingdom	University/ public research org
IND53	SIOS Meßtechnik GmbH	Germany	Industry
IND53	Airbus Operations Limited	United Kingdom	Industry
IND54	The University of Liverpool	United Kingdom	University/ public research org
IND55	Muquans	France	Industry
IND56	Medtronic Bakken Research Center B.V.	Netherlands	industry
IND56	Smith & Nephew Medical Limited	United Kingdom	Industry
IND59	Science and Technology Facilities Council	United Kingdom	University/ public research org
IND59	XPRESS Precision Engineering B.V.	Netherlands	Industry
IND59	IBS Precision Engineering bv	Netherlands	Industry
IND59	LEGO System A/S	Denmark	Industry
IND59	Novo Nordisk A/S	Denmark	Industry
IND59	Robert Bosch GmbH	Germany	Industry
IND62	Fundacion Tekniker	Spain	University/ public research org
IND62	Universidad de Zaragoza	Spain	University/ public research org
IND62	Magnicon GmbH	Germany	Industry
IND62	Daimler AG	Germany	Industry
IND62	EMO - Orodjarna d.o.o.	Slovenia	industry
IND62	Gorenje Orodjarna, d.o.o., Velenje, Partizanska 12	Slovenia	industry

Project	Organisation	Country	Organisation type
IND62	VEPLAS Velenjska Plastika d.d.	Slovenia	Industry
IND62	RollResearch International Oy	Finland	Industry
IND63	HC Photonics Corporation Limited	Taiwan, Province of China	Industry
NEW01	ION-TOF Technologies GmbH	Germany	Industry
NEW02	Naturwissenschaftliches und Medizinisches Institut an der Universitaet Tuebingen	Germany	University/ public research org
NEW02	Indian Institute of Science	India	University/ public research org
NEW06	Hexagon Metrology PTS GmbH	Germany	Industry
NEW06	Mitutoyo CTL Germany GmbH	Germany	Industry
NEW06	Werth Messtechnik GmbH	Germany	Industry
NEW06	Carl Zeiss Industielle Messtechnik GmbH	Germany	Industry
NEW07	ROHDE & SCHWARZ GmbH & Co. Kommanditgesellschaft	Germany	Industry
NEW07	Sensor- und Lasertechnik - Dr. Werner Bohmeyer	Germany	Industry
NEW08	Magnicon GmbH	Germany	Industry
NEW08	Helsingin Yliopisto	Finland	University/ public research org
NEW09	aixACCT Systems GmbH	Germany	Industry
SIB01	Universidad De Valladolid	Spain	University/ public research org
SIB02	CESNET, Zajmove Sdruzeni Pravnickych OSOB	Czech Republic	University/ public research org
SIB03	Leibniz-Institut für Oberflächenmodifizierung	Germany	University/ public research org
SIB03	National Institute of Advanced Industrial Science and Technology	Japan	University/ public research org
SIB06	Politecnico di Milano	Italy	University/ public research org
SIB09	General Secretariat of Information Systems, Hellenic Ministry of Finance	Greece	Other (e.g. government)
SIB10	Universidad De Cantabria	Spain	University/ public research org
SIB53	esz AG calibration & metrology	Germany	Industry
SIB58	Fundacion Tekniker	Spain	University/ public research org
SIB58	Möller-Wedel Optical GmbH	Germany	Industry
SIB58	Fagor Automation S Coop Ltda	Spain	Industry
SIB58	National Institute of Advanced Industrial Science and Technology	Japan	University/ public research org
SIB62	ROHDE & SCHWARZ GmbH & Co. Kommanditgesellschaft	Germany	Industry
SIB62	Keysight Technologies Belgium BVBA	Belgium	Industry

6.3 Collaborators

There were 683 participations by 620 organisations as collaborators.

Figure 38: Collaborators

Project	Organisation	Country	Organisation type
ENG01	NET4GAS	Czech Republic	Industry
ENG01	Transgaz	Romania	Industry
ENG01	Enagas	Spain	Industry
ENG01	Michell Instruments	United Kingdom	Industry
ENG01	Valdemingómez Technological Park (VTP)	Spain	Industry
ENG01	MBW Calibrations	Switzerland	Industry
ENG01	University of Valladolid	Spain	University /public research org
ENG01	Technical University of Darmstadt	Germany	University /public research org
ENG02	VTT Technical Research Centre of Finland	Finland	Industry
ENG02	Aalto University	Finland	University /public research org
ENG04	Vestas	Denmark	Industry
ENG04	SEPS a.s.	Slovakia	Industry
ENG04	Aidon Oy	Finland	Industry
ENG04	Stenbakken	United States	Industry
ENG04	Mitox Oy	Finland	Industry
ENG04	University of Zaragoza and Foundation CIRCE	Spain	University /public research org
ENG07	ABB High Voltage Cables	Sweden	Industry
ENG07	Schniewindt Gmbh & Co. KG	Germany	Industry
ENG07	Aalto University	Finland	University /public research org
ENG08	CAEN S.p.A.	Italy	Industry
ENG09	Strathclyde University	United Kingdom	University /public research org
ENG51	InPact	France	Industry
ENG51	Scientec	France	Industry
ENG51	Isofoton SA	Spain	Industry
ENG51	Instytut Technologii Materia?ów Elektronicznych	Poland	Industry
ENG51	Naps Systems OY	Finland	Industry
ENG51	Politécnica – Instituto de Energia Solar	Spain	University /public research org
ENG51	University of Jaen	Spain	University /public research org
ENG51	University of Malaga	Spain	University /public research org
ENG51	Instituto de Sistema Fotovoltaicos de Concentracion	Spain	University /public research org
ENG52	FTM - Fabbrica Trasformatori di misura	Italy	Industry
ENG52	Centre for renewable energy sources and saving	Greece	Other (e.g. government)
ENG52	Università di Padova	Italy	University /public research org
ENG52	University of Thrace	Greece	University /public research org
ENG53	Merck Chemicals Ltd.	United Kingdom	Industry
ENG53	LINSEIS Messgeräte GmbH	Germany	Industry
ENG53	von Ardenne	Germany	Industry
ENG53	Semimetrics Ltd.	United Kingdom	Industry
ENG53	Accurion GmbH	Germany	Industry
ENG53	SENTECH Instruments GmbH	Germany	Industry
ENG53	NMI - National Microelectronics Institute	United Kingdom	Other (e.g. government)
ENG53	EMPA	Switzerland	University /public research org

Project	Organisation	Country	Organisation type
ENG54	Gasum	Finland	Industry
ENG55	Logica E.M. S.A.	Portugal	Industry
ENG55	IKS Photovoltaik GmbH	Germany	Industry
ENG55	Naps Systems Oy	Finland	Industry
ENG55	PV-Engineering GmbH	Germany	Industry
ENG55	solarklima e. K. - Solar-Sachverständigenbüro	Germany	Industry
ENG55	WAVELABS Solar Metrology Systems GmbH	Germany	Industry
ENG56	Rolls-Royce	United Kingdom	Industry
ENG56	ZF Services UK Ltd.	United Kingdom	Industry
ENG56	Schaeffler Technologies AG & Co. KG	Germany	Industry
ENG56	The Timken Company	United States	Industry
ENG56	Allen Gearing Solutions	United Kingdom	Industry
ENG56	Contact Gearing	United Kingdom	Industry
ENG56	Fred Olsen Renewables	United Kingdom	Industry
ENG56	Ludwig Nano Präzision GmbH	Germany	Industry
ENG56	Finnish Wind Power Association	Finland	Other (e.g. government)
ENG56	United Kingdom Accredidation Service	United Kingdom	Other (e.g. government)
ENG56	British Gear Asslociation	United Kingdom	Other (e.g. government)
ENG56	Verband Deutscher Maschinen- und Anlagenbau e.V.	Germany	Other (e.g. government)
ENG56	Verein Deutscher Ingenieure e.V.	Germany	Other (e.g. government)
ENG58	OneSubsea	Norway	Industry
ENG58	Atout Process	United Kingdom	Industry
ENG59	Statoil ASA	Norway	Industry
ENG59	British Petrol Exp Op Co Ltd	United Kingdom	Industry
ENG59	M-I Swaco	Norway	Industry
ENG59	Thermo Electron (Karlsruhe) GmbH	Germany	Industry
ENG59	Brookfield Engineering Laboratories, Inc.	United States	Industry
ENG59	Anton Paar GmbH	Austria	Industry
ENG59	IFP Energies nouvelles	France	University /public research org
ENG59	The Swedish Institute for Food and Biotechnology	Sweden	University /public research org
ENG59	Centro de Ciências Moleculares e Materiais	Portugal	University /public research org
ENG59	Faculty of Sciences and Technology - Centre for Research in Materials	Portugal	University /public research org
ENG60	GE Sensing	United Kingdom	Industry
ENG60	Emerson MM	Netherlands	Industry
ENG60	Enagas	Spain	Industry
ENG60	Gasunie	Netherlands	Industry
ENG60	Kaiser optical systems	United States	Industry
ENG60	Kongsberg	Norway	Industry
ENG60	Krohne	Netherlands	Industry
ENG60	Mustang Sampling	United States	Industry
ENG60	National Grid (UK)	United Kingdom	Industry
ENG60	Gasnaturalfenosa	Spain	Industry
ENG60	E&H	Switzerland	Industry
ENG60	Cameron Caldon	United Kingdom	Industry
ENG60	E.on Ruhrgas	Germany	Industry

Project	Organisation	Country	Organisation type
ENG63	Sakarya Elektrik (SEDAȘ)	Turkey	Industry
ENV01	Air Liquide	United States	Industry
ENV01	Air Products	United Kingdom	Industry
ENV01	Alphasense	United Kingdom	Industry
ENV01	Praxair	Belgium	Industry
ENV01	Saes Pure Gas	United States	Industry
ENV01	Linde AG, Linde Gas Division	Germany	Industry
ENV01	Airgas Inc.	United States	Industry
ENV01	CAIRPOL	France	Industry
ENV01	IM2NP	France	Industry
ENV01	Sensirion	Switzerland	Industry
ENV01	Unitec	Italy	Industry
ENV01	Picarro	United States	Industry
ENV01	Takachiho	Japan	Industry
ENV01	SilcoTek	United States	Industry
ENV01	TigerOptics	United States	Industry
ENV01	LNI Schmidlin	Switzerland	Industry
ENV01	Environics	United States	Industry
ENV01	Gradko International	United Kingdom	Industry
ENV01	SIAD	Italy	Industry
ENV01	IngenierosAsesores	Spain	Industry
ENV01	Aalto University	Finland	University /public research org
ENV01	University of Barcelona	Spain	University /public research org
ENV02	Robert Bosch GmbH	Germany	Industry
ENV02	Pegasor Oy Ltd.	Finland	Industry
ENV02	Matter Aerosol AG - Testo	Switzerland	Industry
ENV02	TSI GmbH	Germany	Industry
ENV02	MAHA GmbH & Co. KG.	Germany	Industry
ENV03	EKO Instruments Europe B.V.	Netherlands	Industry
ENV03	World Meteorological Organisation (WMO)	Other	Other (e.g. government)
ENV03	ARPA Valle D'Aosta	Italy	Other (e.g. government)
ENV03	Deutscher Wetterdienst (DWD)	Germany	University /public research org
ENV03	Aristotele University of Thessaloniki	Greece	University /public research org
ENV04	Surrey Satellite Technologies Ltd (SSTL)	United Kingdom	Industry
ENV04	Karlsruhe Institute of Technology (KIT)	Germany	University /public research org
ENV04	MET Office: An Executive Agency of the Ministry of Defence (MET office)	United Kingdom	Other (e.g. government)
ENV04	Rutherford Appleton Laboratory (RAL)	United Kingdom	University /public research org
ENV05	SCOR	Other	University /public research org
ENV05	IAPSO	Other	University /public research org
ENV05	IUPAC	Other	University /public research org
ENV05	IAPWS	Other	University /public research org
ENV05	Instituto Hidrografico	Portugal	University /public research org
ENV05	Ifremer	France	University /public research org
ENV05	IOW (Leibniz Institute of Baltic sea research)	Germany	University /public research org
ENV05	MARUM	Germany	University /public research org
ENV05	GEOMAR	Germany	University /public research org

Project	Organisation	Country	Organisation type
ENV05	University of British Columbia/ Joint Committee on seawater	Canada	University /public research org
ENV05	Leibniz Universität Hannover	Germany	University /public research org
ENV05	SCRIPPS	United States	University /public research org
ENV07	Spanish Meteorology Agency	Spain	Other (e.g. government)
ENV07	ISTI	Other	Other (e.g. government)
ENV07	GRUAN	Other	Other (e.g. government)
ENV07	Climate Consulting	Italy	Other (e.g. government)
ENV07	Royal Meteorological Institute of Belgium	Belgium	Other (e.g. government)
ENV07	ARPA Valle d'Aosta	Italy	Other (e.g. government)
ENV07	ARPAS - Sardegna	Italy	Other (e.g. government)
ENV07	ARPA Lombardia	Italy	Other (e.g. government)
ENV07	Società Meteorologica Italiana	Italy	Other (e.g. government)
ENV07	Slovenia Environment Agency	Slovenia	Other (e.g. government)
ENV07	CERIS-CNR	Italy	University /public research org
ENV07	EVK2CNR	Italy	University /public research org
ENV07	Turkish State Meteorological Service	Turkey	University /public research org
ENV07	Finnish Meteorological Institute	Finland	University /public research org
ENV07	MetOffice	United Kingdom	University /public research org
ENV07	Consiglio Nazionale delle Ricerche-CNR / Istituto per le Macchine agricole e Movimento Terra, IMAMOTER	Italy	University /public research org
ENV07	Osservatorio di Milano Duomo	Italy	University /public research org
ENV07	Istituto di Scienze dell'Atmosfera e del Clima – Consiglio Nazionale delle Ricerche (ISAC-CNR)	Italy	University /public research org
ENV07	C3	Spain	University /public research org
ENV07	Uni of Reading	United Kingdom	University /public research org
ENV07	National Centre for Atmospheric Science (NCAS) School of Earth and Environment	United Kingdom	University /public research org
ENV07	Università Cattolica del Sacro Cuore - Facoltà Agraria	Italy	University /public research org
ENV07	Dipartimento di Scienze della Terra – Università degli Studi di Torino	Italy	University /public research org
ENV07	Università degli Studi di Torino, Dip. Fisica Generale	Italy	University /public research org
ENV07	Earth Temperature Network- University of Edinburgh	United Kingdom	University /public research org
ENV08	Universidad de Oviedo	Spain	University /public research org
ENV09	Eckert&Ziegler Nuclitec GmbH	Germany	Industry
ENV09	Sellafield plc	United Kingdom	Industry
ENV09	Sellafield plc	United Kingdom	Industry
ENV09	Sellafield plc	United Kingdom	Industry
ENV09	Sellafield plc	United Kingdom	Industry
ENV09	Sellafield plc	United Kingdom	Industry
ENV09	VUHZ, a.s.	Czech Republic	Industry
ENV09	Research Centre Rez Ltd	Czech Republic	Industry
ENV09	Research Centre Rez Ltd	Czech Republic	University /public research org
ENV09	UJV Rez a.s.	Czech Republic	University /public research org
ENV09	Faculty of Nuclear Science and Physical Engineering	Czech Republic	University /public research org
ENV52	VICI AG International	Switzerland	Industry
ENV52	SAES Getters	Italy	Industry

Project	Organisation	Country	Organisation type
ENV52	Lni Schmidlin	Switzerland	Industry
ENV52	Fine Metrology S.R.L.S.	Italy	Industry
ENV52	RHUL	United Kingdom	University /public research org
ENV53	University of Miami	United States	Industry
ENV53	Surrey Satellite Technology Ltd	United Kingdom	Industry
ENV53	Alexander Cede	Austria	Other (e.g. government)
ENV53	Institute for Environment and Sustainability	Italy	University /public research org
ENV53	National Aeronautical and Space Administration	United States	University /public research org
ENV53	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	France	University /public research org
ENV53	Laboratoire d'Océanographie de Villefranche	France	University /public research org
ENV53	Tartu Observatory	Estonia	University /public research org
ENV53	Centre National d'Etudes Spatiales (CNES)	France	University /public research org
ENV53	University of Southampton	United Kingdom	University /public research org
ENV53	UNIVERSITÉ PIERRE ET MARIE CURIE	France	University /public research org
ENV53	University of Leicester	United Kingdom	University /public research org
ENV53	University of Reading	United Kingdom	University /public research org
ENV53	Chinese Academy of Sciences	China	University /public research org
ENV53	Oxford University	United Kingdom	University /public research org
ENV54	CEA-LIST	France	Industry
ENV54	EDU	Czech Republic	Industry
ENV54	Sellafield	United Kingdom	Industry
ENV54	Canberra	France	Industry
ENV54	LLWR	United Kingdom	Industry
ENV54	Canberra	France	Industry
ENV54	Sogin	Italy	Industry
ENV54	Nucleco	Italy	Industry
ENV54	LabLogic Systems Ltd	United Kingdom	Industry
ENV54	UB	Romania	University /public research org
ENV54	FJFI	Czech Republic	University /public research org
ENV55	Tiger Optics	United States	Industry
ENV55	VICI International	Switzerland	Industry
ENV55	Picarro Inc.	United States	Industry
ENV55	LNI Schmidlin SA	Switzerland	Industry
ENV55	AERODYNE Research	United States	Industry
ENV55	Green Grass - Atmospheric Environment Expert Ltd.	Hungary	Industry
ENV55	SilcoTek GmbH	Germany	Industry
ENV55	Los Gatos Research	United States	Industry
ENV55	Gradko Environmental	United Kingdom	Industry
ENV55	Owlstone Ltd.	United Kingdom	Industry
ENV55	LSE Monitors BV, Groningen	Netherlands	Industry
ENV55	Takachiho Chemical industrial Co., Ltd.	Japan	Industry
ENV55	fine metrology S.r.l.s	Italy	Industry
ENV55	ECOPHYSICS AG	Switzerland	Industry
ENV55	SAES Getters	Italy	Industry
ENV55	Staatliches Gewerbeaufsichtsamt Hildesheim	Germany	Other (e.g. government)

Project	Organisation	Country	Organisation type
ENV55	Fondazione Salvatore Magueri	Italy	University /public research org
ENV55	INRA	France	University /public research org
ENV55	National Research Council - Institute for Agricultural and Forest Systems in the Mediterranean	Italy	University /public research org
ENV55	University of Wuppertal, Physical Chemsitry	Germany	University /public research org
ENV56	Restek	Germany	Industry
ENV56	Linde	Germany	Industry
ENV56	Air Products	Belgium	Industry
ENV56	Air Liquide	United States	Industry
ENV56	SAES	United States	Industry
ENV56	Takachiho	Japan	Industry
ENV56	Silco Tek	United States	Industry
ENV56	FINE Metrology	Italy	Industry
ENV56	Nano Sense	France	Industry
ENV56	Recordum	Austria	Industry
ENV56	Ion Science	Italy	Industry
ENV56	Aeroqual	New Zealand	Industry
ENV56	Gradko	United Kingdom	Industry
ENV56	Markes International	United Kingdom	Industry
ENV56	Entegris	United States	Industry
ENV56	Bentekk	Germany	Industry
ENV56	Schmidlin	Switzerland	Industry
ENV56	CNR-IMM	Italy	University /public research org
ENV56	Department of Physics, Chemistry and Biology at Linköping University	Sweden	University /public research org
ENV57	Saphymo	Germany	Industry
ENV57	LUBW	Germany	Other (e.g. government)
ENV57	Czech Technical University Prague - Faculty of Nuclear Science and Physical Engineering	Czech Republic	University /public research org
ENV58	CAL Power S.R.L.	Italy	Industry
ENV58	AEMET	Spain	Other (e.g. government)
ENV58	Climate Consulting	Italy	Other (e.g. government)
ENV58	ARPA Piemonte	Italy	Other (e.g. government)
ENV58	ARPA Valle d'Aosta	Italy	Other (e.g. government)
ENV58	ARPAS - Sardegna	Italy	Other (e.g. government)
ENV58	ARPA Lombardia	Italy	Other (e.g. government)
ENV58	Slovenia Environment Agency	Slovenia	Other (e.g. government)
ENV58	Società Meteorologica Italiana	Italy	Other (e.g. government)
ENV58	Royal Meteorological Institute of Belgium	Belgium	Other (e.g. government)
ENV58	Osservatorio di Milano Duomo	Italy	Other (e.g. government)
ENV58	ISTI	United States	Other (e.g. government)
ENV58	Slovak Hydrometeorological Institute	Slovakia	Other (e.g. government)
ENV58	GRUAN	Germany	Other (e.g. government)
ENV58	Italian Air Force	Italy	Other (e.g. government)
ENV58	CERIS-CNR	Italy	University /public research org
ENV58	Istituto per le Macchine agricole e Movimento Terra, , Consiglio Nazionale delle Ricerche, IMAMOTER-CNR	Italy	University /public research org

Project	Organisation	Country	Organisation type
ENV58	Istituto di Scienze dell'Atmosfera e del Clima – Consiglio Nazionale delle Ricerche (ISAC-CNR)	Italy	University /public research org
ENV58	LMD/CNRS, Ecole Polytechnique	France	University /public research org
ENV58	Università Cattolica del Sacro Cuore - Facoltà Agraria	Italy	University /public research org
ENV58	Dipartimento di Scienze della Terra – Università degli Studi di Torino	Italy	University /public research org
ENV58	National Centre for Atmospheric Science (NCAS) School of Earth and Environment	United Kingdom	University /public research org
ENV58	Università degli Studi di Torino, Dip. Fisica Generale	Italy	University /public research org
ENV58	Earth Temperature Network- University of Edinburgh	United Kingdom	University /public research org
ENV59	Arctic Research Center (FMI)	Finland	University /public research org
ENV59	Deutscher Wetterdienst (DWD)	Germany	University /public research org
ENV59	Deutscher Wetterdienst (DWD)	Germany	University /public research org
ENV59	National Oceanic and Atmospheric Administration	United States	University /public research org
ENV59	Czech Hydrometeorological Institute	Czech Republic	University /public research org
ENV59	Agencia Estatal de Meteorologia (AEMET)	Spain	University /public research org
ENV59	Medical University Insbruck	Austria	University /public research org
ENV59	CNRS (Centre National de Research schientifique), UPMC&PSL Research University	France	University /public research org
ENV60	Quantitech Ltd	United Kingdom	Industry
ENV60	Gasmet	Finland	Industry
ENV60	EON New Build and technology Ltd	United Kingdom	Industry
ENV60	Hessisches Landesamt für Umwelt und Geologie	Germany	Other (e.g. government)
EXL02	University of Wurzburg	Germany	University /public research org
EXL02	Terchnical University of Berlin	Germany	University /public research org
EXL04	University of Naples "Federico II"	Italy	University /public research org
EXL04	Hamburg University	Germany	University /public research org
EXL04	Halle-Wittenberg University	Germany	University /public research org
EXL04	TU München	Germany	University /public research org
HLT01	Acoustic Metrology Limited	United Kingdom	Industry
HLT01	Otodynamics Ltd.	United Kingdom	Industry
HLT01	Guymark UK	United Kingdom	Industry
HLT01	HNO Klinik Regensburg	Germany	Other (e.g. government)
HLT01	Marmara University	Turkey	University /public research org
HLT01	Warsaw University of Technology	Poland	University /public research org
HLT01	Royal Liverpool University Hospital	United Kingdom	University /public research org
HLT01	Institute of Technical Acoustics	Germany	University /public research org
HLT01	Royal Free Hampstead NHS Trust	United Kingdom	University /public research org
HLT02	John Radcliffe Hospital	United Kingdom	Other (e.g. government)
HLT02	John Radcliffe Hospital	United Kingdom	Other (e.g. government)
HLT02	Helmholtz-Zentrum Berlin	Germany	University /public research org
HLT03	US Food and Drugs Administration	United States	Other (e.g. government)
HLT04	LGC	United Kingdom	Industry
HLT04	Scienion	Germany	Industry
HLT04	Plasmore	Italy	Industry
HLT04	Orion Diagnostica	Finland	Industry
HLT04	JRC, IHCP, EC	Other	Other (e.g. government)

Project	Organisation	Country	Organisation type
HLT04	CIN2 CSIC	Spain	Other (e.g. government)
HLT04	Nanotechnology Industries Assocation (NIA)	United Kingdom	Other (e.g. government)
HLT04	International Iberian Nanotechnology Lab (INL)	Portugal	University /public research org
HLT04	NESAC/BIO	United States	University /public research org
HLT04	University of Utah	United States	University /public research org
HLT04	Materials & Surface Science Institute, University of Limerick	Ireland	University /public research org
HLT04	Charité	Germany	University /public research org
HLT04	University of Nottingham	United Kingdom	University /public research org
HLT04	Lausitz University	Germany	University /public research org
HLT05	Aqura	Germany	Industry
HLT05	Instand e.V.	Germany	Other (e.g. government)
HLT05	Instand e.V.	Germany	Other (e.g. government)
HLT06	University Medical Centre of Utrecht	Netherlands	Other (e.g. government)
HLT06	STUK (Radiation and Nuclear Safety Authority)	Finland	Other (e.g. government)
HLT06	Bundesamt für Strahlenschutz (Radiation Safety Authority)	Germany	Other (e.g. government)
HLT06	Deutsches Krebsforschungszentrum (DKFZ)	Germany	University /public research org
HLT06	Politecnico di Torino	Italy	University /public research org
HLT07	B.braun	Netherlands	Industry
HLT07	B.braun	Portugal	Industry
HLT07	Bronkhorst High-Tech	Netherlands	Industry
HLT08	University Clinic of Respiratory and Allergic Diseases	Slovenia	University /public research org
HLT09	Carl Zeiss Meditec AG	Germany	Industry
HLT09	PTW - Freiburg Germany	Germany	Industry
HLT09	IBA	Germany	Industry
HLT09	Tampere University Hospital	Finland	Other (e.g. government)
HLT09	Helsinki University Central Hospital	Finland	Other (e.g. government)
HLT09	UK S-H, campus Kiel	Germany	University /public research org
HLT09	University degli studi di Roma "Tor vergata"	Italy	University /public research org
HLT09	Czech Technical University in Prague	Czech Republic	University /public research org
HLT10	IBM	United Kingdom	Industry
HLT11	Royal Surrey County Hospital	United Kingdom	Other (e.g. government)
HLT11	University Hospital Southampton	United Kingdom	Other (e.g. government)
HLT11	S. Maria Nuova Hospital (ASMN-IRCCS)	Italy	Other (e.g. government)
HLT11	Nuclear Medicine Royal Victoria Hospital	United Kingdom	Other (e.g. government)
HLT11	Belfast Hospitals	United Kingdom	Other (e.g. government)
HLT11	VUMC	Netherlands	Other (e.g. government)
HLT11	Gurutzeta-Cruces Hospital	Spain	Other (e.g. government)
HLT11	Fakultni nemocnice v Motole	Czech Republic	Other (e.g. government)
HLT11	Nemocnice Na Homolce	Czech Republic	Other (e.g. government)
HLT11	Sant' Andrea Hospital (SAH)	Italy	Other (e.g. government)
HLT11	"Theagenion" Cancer Hospital (TCH)	Greece	Other (e.g. government)
HLT11	University Hospital of Wuerzburg	Germany	Other (e.g. government)
HLT11	Hospital Beaujon	France	Other (e.g. government)
HLT11	ASMN-IRCCS	Italy	Other (e.g. government)
HLT11	Royal Surrey County Hospital	United Kingdom	Other (e.g. government)

Project	Organisation	Country	Organisation type
HLT11	Physics Department St Lukes Hospital	Ireland	Other (e.g. government)
HLT11	Philips GmbH Innovative Technologies, Research Laboratories	Germany	Industry
HLT11	Eckert and Ziegler Nuclitec	Germany	Industry
HLT11	GE Medical Systems	Israel	Industry
HLT11	Sirtex Technology Pty Ltd	Australia	Industry
HLT11	Radioisotope Service Belfast Health & Social Care Trust	Ireland	Other (e.g. government)
HLT11	Erasmus MC	Netherlands	Other (e.g. government)
HLT11	Erasmus MC	Netherlands	Other (e.g. government)
HLT11	Erasmus MC	Netherlands	Other (e.g. government)
HLT11	National Center for Nuclear Research	Poland	University /public research org
HLT11	IMSERM UMR	France	University /public research org
HLT11	(ICRNA) Institut Regional du Cancer Nantes-Atlantique	France	University /public research org
HLT11	John Hopkins University	United States	University /public research org
HLT11	University of Ulm	Germany	University /public research org
HLT11	University of Potsdam	Germany	University /public research org
HLT11	Department of Physics, Nanoscience Center, University of Jyväskylä	Finland	University /public research org
IND01	Johnson Matthey	United Kingdom	Industry
IND01	Sisecam	Turkey	Industry
IND01	Erdemir	Turkey	Industry
IND01	Vitkovice	Czech Republic	Industry
IND01	Safina	Czech Republic	Industry
IND01	ZPA Nova Paka	Czech Republic	Industry
IND01	Omega	United Kingdom	Industry
IND01	Fraunhofer Institute	Germany	University /public research org
IND02	Emerson & Cuming Microwave Products N.V.	Belgium	Industry
IND02	Powerwave UK Ltd	United Kingdom	Industry
IND02	Rohde & Schwarz GmbH & Co. KG	Germany	Industry
IND02	Schlumberger Cambridge Research Ltd	United Kingdom	Industry
IND02	Infineon Technologies AG	Germany	Industry
IND02	Cyclops Technologies Ltd.	United Kingdom	Industry
IND02	Jožef Stefan Institute	Slovenia	University /public research org
IND02	Instytut Technologii Materia?ow Elektronicznych	Poland	University /public research org
IND02	University of Birmingham	United Kingdom	University /public research org
IND02	Warsaw University of Technology,	Poland	University /public research org
IND02	University of Nottingham	United Kingdom	University /public research org
IND02	University of Nova Gorica, Materials Research Laboratory	Slovenia	University /public research org
IND03	MAXIMATOR GmbH	Germany	Industry
IND03	WIKA Alexander Wiegand SE & Co. KG	Germany	Industry
IND03	PREMATLAK, a.s.	Slovakia	Industry
IND03	Hottinger Baldwin Messtechnik GmbH	Germany	Industry
IND03	PREMATLAK, a.s.	Slovakia	Industry
IND03	MAXIMATOR GmbH	Germany	Industry
IND03	WIKA Alexander Wiegand SE & Co. KG	Germany	Industry
IND03	Uhde High Pressure Technologies GmbH	Germany	Industry

Project	Organisation	Country	Organisation type
IND03	Uhde High Pressure Technologies GmbH	Germany	Industry
IND03	Hottinger Baldwin Messtechnik GmbH	Germany	Industry
IND03	High Pressure & Force Metrology and Consultancy, Global technologically tubular testing	Netherlands	Other (e.g. government)
IND03	High Pressure & Force Metrology and Consultancy, Global technologically tubular testing	Netherlands	Other (e.g. government)
IND03	Commissariat à l'énergie atomique et aux énergies alternatives	France	University /public research org
IND03	Commissariat à l'énergie atomique et aux énergies alternatives	France	University /public research org
IND04	Acroni d.o.o, Slovenia	Slovenia	Industry
IND04	Arcelor Mittal Galati SA	Romania	Industry
IND04	U.S. Steel Košice - Labortest s.r.o	Slovakia	Industry
IND04	SN Seixal-Siderurgia Nacional, SA,	Portugal	Industry
IND04	Strore Steel d.o.o	Slovenia	Industry
IND04	UNESID (Unión de Empresas Siderúrgicas)	Spain	Other (e.g. government)
IND05	NGFE	United Kingdom	Industry
IND05	Anton Parr	Switzerland	Industry
IND05	SDS Ltd	United Kingdom	Industry
IND06	Polytechnic of Milan	Italy	University /public research org
IND06	Polytechnic of Milan	Italy	University /public research org
IND07	Plasma Quest Limited	United Kingdom	Industry
IND07	Accurion GmbH	Germany	Industry
IND07	Laboratorio "Materials and Devices for Microelectronics"	Italy	University /public research org
IND07	Rochester Institute of Technology	United States	University /public research org
IND08	Sensitec	Germany	Industry
IND08	NXP	Germany	Industry
IND08	Bartington Instruments Limited	United Kingdom	Industry
IND08	Innovent	Germany	University /public research org
IND08	RAL	United Kingdom	University /public research org
IND08	Ghent University	Belgium	University /public research org
IND08	Czech Technical University in Prague	Czech Republic	University /public research org
IND10	Mahr GmbH, Carl Zeiss Promenade 10, 07745 Jena	Germany	Industry
IND10	asphericon GmbH, Stockholmer Str. 9, 07747 Jena	Germany	Industry
IND11	KP Technology	United Kingdom	Industry
IND11	Hardide	United Kingdom	Industry
IND11	Teer Coatings	United Kingdom	Industry
IND11	Wallwork Heat Treatment Ltd	United Kingdom	Industry
IND11	University of Aarhus	Denmark	University /public research org
IND11	ICB UMR5209 - Optique en champ proche (OCP), Université de Bourgogne	France	University /public research org
IND12	Philips Medical Systems GmbH	Germany	Industry
IND12	Visteon-Autopal Services s.r.o.	Czech Republic	Industry
IND12	miCos GmbH	Germany	Industry
IND12	Reuter Technologie GmbH	Germany	Industry
IND12	Cinquepascal	Italy	Industry
IND12	Karlruhe Institute of Technology (KIT)	Germany	University /public research org
IND12	Labor für Vakuumtechnik, Technische Hochschule Mittelhessen	Germany	University /public research org

Project	Organisation	Country	Organisation type
IND12	Russian Academy of Sciences Dorodnicyn Computing Center	Russian Federation	University /public research org
IND13	Magnicon GmbH	Germany	Industry
IND13	SIOS GmbH	Germany	Industry
IND13	TNO Science and Industry	Netherlands	University /public research org
IND14	EXFO	Canada	Industry
IND14	Diamond SA	Switzerland	Industry
IND14	EADS-SODERN	France	Industry
IND14	Astrium GmbH	Germany	Industry
IND14	Airbus España S. L.	Spain	Industry
IND14	Menlo Systems GmbH	Germany	Industry
IND14	NKT Photonics A/S	Denmark	Industry
IND14	Kayser-Threde GmbH	Germany	Industry
IND14	Oclaro Technology Limited	United Kingdom	Industry
IND14	IDIL Fibres optiques S.A.S.	France	Industry
IND14	FOCUS S.L.	Spain	Industry
IND14	Opticsvalley	France	Other (e.g. government)
IND14	European Space Agency	Netherlands	Other (e.g. government)
IND14	Direction Generale de l'Armement	France	Other (e.g. government)
IND14	Swiss National Committee of IEC and Cenelec	Switzerland	Other (e.g. government)
IND14	BSI British Standards	United Kingdom	Other (e.g. government)
IND15	Mettler-Toledo (Schweiz) GmbH	Switzerland	Industry
IND15	SÜD-CHEMIE AG	Germany	Industry
IND15	Thales Alenia Space SpA	Italy	Industry
IND15	AstraZeneca	United Kingdom	Industry
IND15	W. C. Heraeus GmbH	Germany	Industry
IND15	Bruker Nano	Germany	Industry
IND15	Tascon GmbH	Germany	Industry
IND15	Innopsys	France	Industry
IND15	Cambridge Display Technology	United Kingdom	Industry
IND15	Insplorion AB	Sweden	Industry
IND15	Thermo Fisher Scientific s.p.a.	Italy	Industry
IND15	Catal International	Other	University /public research org
IND15	Competence Center for Catalysis at Chalmers University of Technology KCK	Sweden	University /public research org
IND15	University of Nottingham	United Kingdom	University /public research org
IND16	Anritsu	United States	Industry
IND16	Astrium Satellites	Germany	Industry
IND16	Rohde & Schwarz GmbH & Co. KG	Germany	Industry
IND16	Jan Verspecht b.v.b.a.	Belgium	Industry
IND16	esz AG calibration & Metrology	Germany	Industry
IND16	Cambridge Wireless	United Kingdom	University /public research org
IND16	Institut für Nachrichtentechnik	Germany	University /public research org
IND16	Institut für Hochfrequenztechnik	Germany	University /public research org
IND51	Keysight UK	United Kingdom	Industry
IND51	WiCO	China	Industry
IND51	Quintel	United Kingdom	Industry

Project	Organisation	Country	Organisation type
IND51	Keysight DK	Denmark	Industry
IND51	U2T Photonics QG	Germany	Industry
IND51	NEC/Mobile VCE/ICT KTN	United Kingdom	Other (e.g. government)
IND51	ESA	Netherlands	University /public research org
IND51	European Telecommunications Standards Institute	France	Other (e.g. government)
IND51	ETH Zürich	Switzerland	University /public research org
IND52	Konica Minolta	Germany	Industry
IND52	Merck KgaA	Germany	Industry
IND52	Escolab nv	Belgium	Industry
IND52	Fogra Forschungsgesellschaft Druck e.V.	Germany	Industry
IND52	Eldim	France	Industry
IND52	TQC	Netherlands	Industry
IND52	Munksjö	France	Industry
IND52	NUBIOLA	Spain	Industry
IND52	St Gobain Recherche	France	Industry
IND52	TechnoTeam Bildverarbeitung GmbH	Germany	Industry
IND52	Rhopoint Instruments Ltd	United Kingdom	Industry
IND52	AUDI AG	Germany	Industry
IND52	Cramer Forschungsinstitut	Germany	Industry
IND52	Lucideon	United Kingdom	Industry
IND52	2C	France	Industry
IND52	Deutsche farbwissenschaftliche Gesellschaft e.V.	Germany	Other (e.g. government)
IND52	PPG IBERICA SA	Spain	Other (e.g. government)
IND53	University of Strathclyde	United Kingdom	University /public research org
IND54	IBM	United States	Industry
IND54	Universite de Picardie Jules Verne	France	University /public research org
IND54	Wisconsin-Madison University	United States	University /public research org
IND55	Selex-ES	Italy	Industry
IND55	Spectratime	Switzerland	Industry
IND56	Sorin Group Italia s.r.l., Italy	Italy	Industry
IND57	IRSN – Institut de Radioprotection et de Sûreté Nucléaire	France	University /public research org
IND57	VÚHŽ a.s.	Czech Republic	University /public research org
IND58	Physik Instrumente (PI) GmbH & Co.	Germany	Industry
IND58	TESCAN Brno, s.r.o	Czech Republic	Industry
IND58	Ferrovac GmbH	Switzerland	Industry
IND58	Mecartex SA	Switzerland	Industry
IND58	Queensgate Instruments	United Kingdom	Industry
IND58	Sios Meßtechnik GmbH	Germany	Industry
IND58	California Nano Systems Institute	United States	University /public research org
IND58	Fraunhofer-Institut für Angewandte Optik und Feinmechanik IOF	Germany	University /public research org
IND59	Mitutoyo Research Center Europe	Netherlands	Industry
IND59	ZygoLOT GmbH	Germany	Industry
IND59	Werth Messtechnik GmbH	Germany	Industry
IND59	SARIX SA	Switzerland	Industry
IND59	Alicona Imaging GmbH	Austria	Industry

Project	Organisation	Country	Organisation type
IND59	TU Ilmenau	Germany	University /public research org
IND59	National Taiwan University	Taiwan	University /public research org
IND59	IMT, TU Braunschweig	Germany	University /public research org
IND61	Rolls Royce	United Kingdom	Industry
IND61	EPRI	United States	Industry
IND61	Tecvac	United Kingdom	Industry
IND61	E.ON New Build & Technology	United Kingdom	Industry
IND61	Alstom Power	United Kingdom	Industry
IND61	Alstom Power	United Kingdom	Industry
IND61	Doosan Babcock	United Kingdom	Industry
IND61	Turbomet	United States	Industry
IND61	Laser Cladding	United Kingdom	Industry
IND61	CNR-ITC, Italy	Italy	Industry
IND61	Monitor Coatings	United Kingdom	Industry
IND61	University Southampton, UK	United Kingdom	University /public research org
IND62	Hexagon Metrology, S.A.	Spain	Industry
IND62	AIRBUS	United Kingdom	Industry
IND62	Rolls-Royce	United Kingdom	Industry
IND62	Mitutoyo ?esko, s.r.o.	Czech republic	Industry
IND62	Dassault Aviation	France	Industry
IND62	GEOMNIA	France	Industry
IND62	C.D. Measurement Ltd.	United Kingdom	Industry
IND62	Zkušebna VUOS, s.r.o.	Czech republic	Industry
IND62	TOPMES, m??icí stroje, v.o.s.	Czech republic	Industry
IND62	SolidVision	Czech republic	Industry
IND62	AlwaiD s.r.o.	Czech republic	Industry
IND62	Advance Manufaturing Technologies	Spain	Industry
IND62	Valmet Oyj (former Metso Oyj)	Finland	Industry
IND62	Verein Deutscher Werkzeugmaschinenfabriken	Germany	Other (e.g. government)
IND62	University Research Laboratory in Automated Production (LURPA)	France	University /public research org
IND63	Murata Electronics Oy	Finland	Industry
IND63	VTT	Finland	University /public research org
NEW01	Samsung Electronics Co. Ltd	Korea, Republic of	Industry
NEW01	CNR-IMM	Italy	University /public research org
NEW01	Dipartimento di Scienze dell'Ambiente e della Vita (DISAV)	Italy	University /public research org
NEW02	Gloucester Hospitals NHS Trust	United Kingdom	Other (e.g. government)
NEW02	Renishaw	United Kingdom	Industry
NEW02	WITec GmbH	Germany	Industry
NEW02	Nanotechnology Industries Association (NIA)	Belgium	Other (e.g. government)
NEW04	SCA Hygiene Products AB	Sweden	Industry
NEW04	CEA: Commissariat à l’énergie atomique et aux energies alternatives	France	Other (e.g. government)
NEW04	IMEKO TC21: Mathematical Tools for Measurement	Other	University /public research org
NEW04	NAFEMS: The International Association for the Engineering Analysis Community	Other	University /public research org
NEW04	PUCC: Pontificia Universidad Catolica de Chile	Chile	University /public research org

Project	Organisation	Country	Organisation type
NEW04	CUNY: Columbia University New York	United States	University /public research org
NEW05	CSM Instruments	Switzerland	Industry
NEW05	SiMetrics GmbH	Germany	Industry
NEW05	Particular GmbH	Germany	Industry
NEW05	Institute for Technical Chemistry, University Essen Duisburg	Germany	Industry
NEW05	Quantum Wise A/S	Denmark	Industry
NEW05	Koc University	Turkey	University /public research org
new06	Rolls-Royce	United Kingdom	Industry
new06	Airbus UK	United Kingdom	Industry
new06	Build IT	Canada	Industry
new06	IMEKO TC 21	Hungary	Other (e.g. government)
NEW07	QMC Instruments Ltd.	United Kingdom	Industry
NEW07	"Department of Metrology Standardization and Certification, Siberian State Academy of Geodesy (SSAG)"	Russian Federation	Other (e.g. government)
NEW07	Leibnitz Universität Hannover, Institut für Grundlagen der Elektrotechnik und Messtechnik	Germany	University /public research org
NEW07	"Institut für Elektromagnetische Verträglichkeit (IEMV), Technische Universität Braunschweig)"	Germany	University /public research org
NEW07	University of Würzburg, Department of Toxicology	Germany	University /public research org
NEW07	Institut für Nachrichtentechnik (IfN), Technische Universität Braunschweig	Germany	University /public research org
NEW08	Crystec	Germany	Industry
SIB01	Oxford Instruments	United Kingdom	Industry
SIB01	Aalto	Finland	University /public research org
SIB01	University of Cantabria	Spain	University /public research org
SIB01	University of Delaware	United States	University /public research org
SIB01	Chinese Academy of Sciences	China	University /public research org
SIB02	Institute for Experimental Physics, Heinrich-Heine-Universität	Germany	University /public research org
SIB03	Mettler-Toledo	Switzerland	Industry
SIB03	Bureau International des Poids et Mesures	France	Other (e.g. government)
SIB03	Centre for Nuclear Applications Australian Nuclear Science and Technology Organisation	Australia	University /public research org
SIB03	Centre européen de recherche nucléaire	Switzerland	University /public research org
SIB03	University of Turin	Italy	University /public research org
SIB03	Cagliary University, department of physics	Italy	University /public research org
SIB03	Cagliary University, department of physics	Italy	University /public research org
SIB03	Ecole Polytechnique de Lausanne, Laboratoire de Systèmes Robotiques	Switzerland	University /public research org
SIB04	Institute of Laser Physics, Siberian Branch of the Russian Academy of Sciences	Russian Federation	University /public research org
SIB04	Institute of Geodesy, Leibniz Universität Hannover	Germany	University /public research org
SIB04	York university and University of Ottawa	Canada	University /public research org
SIB05	Troemner Inc	United States	Industry
SIB05	Mettler Toledo	Switzerland	Industry
SIB05	Haefner	Germany	Industry
SIB06	Royal Surrey County Hospital (RSCH)	United Kingdom	Other (e.g. government)
SIB06	Universitätsklinikum Hamburg-Eppendorf (UKE)	Germany	Other (e.g. government)
SIB06	Helmholtz-Zentrum für Gesundheit und Umwelt (HZM)	Germany	University /public research org
SIB06	Loma Linda University Medical Center (LLU)	United States	University /public research org

Project	Organisation	Country	Organisation type
SIB06	Clatterbridge Centre for Oncology (CCO)	United Kingdom	University /public research org
SIB06	Centre for Medical Radiation Physics (CMRP), University of Wollongong	Australia	University /public research org
SIB06	Centre for Medical Radiation Physics (CMRP), University of Wollongong	Australia	University /public research org
SIB06	University of Ontario Institute of Technology (UOIT)	Canada	University /public research org
SIB06	Deutsches Krebsforschungszentrum (DKFZ)	Germany	University /public research org
SIB06	Klinikum rechts d. Isar, Technical University Munich (TUM)	Germany	University /public research org
SIB06	University of Pavia	Italy	University /public research org
SIB06	Ion Beam Centre (IBC), University of Surrey	United Kingdom	University /public research org
SIB06	Università Degli Studi di Padova (UPD)	Italy	University /public research org
SIB06	Universitá Degli Studi di Palermo (UNIPA)	Italy	University /public research org
SIB06	Heavy Ion Laboratory (HIL) of the University of Warsaw	Poland	University /public research org
SIB06	Nuclear Physics Institute (NPI), Czech Academy of Science	Czech Republic	University /public research org
SIB07	Aalto University	Finland	University /public research org
SIB08	ASML	Netherlands	Industry
SIB08	IBS Precision Engineering B. V.	Netherlands	Industry
SIB08	Queensgate	United Kingdom	Industry
SIB08	Optocraft	Germany	Industry
SIB08	SIOS	Germany	Industry
SIB08	Vrije Universiteit Amsterdam	Netherlands	University /public research org
SIB08	TU Delft	Netherlands	University /public research org
SIB10	Optris GmbH	Germany	Industry
SIB10	Heitronics Infrarot Messtechnik GmbH	Germany	Industry
SIB10	DIAS Infrared GmbH	Germany	Industry
SIB10	Isotech	United Kingdom	Industry
SIB10	Sensortherm GmbH	Germany	Industry
SIB51	Fluke Calibration	United States	Industry
SIB51	TransMIT GmbH	Germany	Industry
SIB51	Magnicon GmbH	Germany	Industry
SIB51	esz AG calibration & metrology	Germany	Industry
SIB51	Aalto ubiversity	Finland	University /public research org
SIB51	Chalmers tekniska hoegskola AB	Sweden	University /public research org
SIB52	Rolls-Royce plc	United Kingdom	Industry
SIB52	Isover Saint-Gobain CRIR	France	Industry
SIB52	FIW	Germany	Other (e.g. government)
SIB53	Analog devices	Spain	Industry
SIB55	TimeTech GmbH	Germany	Industry
SIB55	Observatoire Royal de Belgique	Belgium	University /public research org
SIB55	Laboratoire Souterrain de Modane	France	University /public research org
SIB55	DIATI-POLITO (Politecnico di Torino)	Italy	University /public research org
SIB57	Cogenda	Other	Other (e.g. government)
SIB57	Aalto University	Finland	University /public research org
SIB59	The Universidad de Málaga (ISIS - DTE - UMA)	Spain	University /public research org
SIB60	Onsala Space Observatory (OSO)	Sweden	University /public research org

Project	Organisation	Country	Organisation type
SIB60	Korea Advanced Institute of Science and Technology (KAIST)	Korea, Republic of	University /public research org
SIB60	Universität der Bundeswehr	Germany	University /public research org
SIB60	Frankfurt University of Science (FRA-UAS)	Germany	University /public research org
SIB61	Polytec GmBh	Germany	Industry
SIB61	STS Nanotechnology	Germany	Industry
SIB61	SiMetrics GmbH	Germany	Industry
SIB61	Omicron Nano Technology GmbH	Germany	Industry
SIB61	NanoWorld Service GmbH	Germany	Industry
SIB61	Sensofar Tech SL	Spain	Industry
SIB61	Physik Instrumente GbmH & Co KG (PI)	Germany	Industry
SIB61	SPECS Surface Nano Analysis GmbH	Germany	Industry
SIB61	Image Metrology A/S	Denmark	Industry
SIB61	MEMC Electronic Materials SpA	Italy	Industry
SIB62	Polar Instruments	United Kingdom	Industry
SIB63	HBM	Germany	Industry
SIB63	GTM	Germany	Industry
SIB63	IBMB	Germany	Other (e.g. government)
SIB64	Valmet Automation Inc.	Finland	Industry
SIB64	Metrohm	Finland	Industry
SIB64	Raute Oyj Mecano Business Unit	Finland	Industry
SIB64	Henkel Slovenija d.o.o.	Slovenia	Industry
SIB64	Seltek Ltd	Turkey	Industry
SIB64	Intertek Pharmaceutical Services Manchester, ITS Testing Services, Ltd	United Kingdom	Industry
SIB64	TBD Biodiscovery	Estonia	Industry
SIB64	Domel d.o.o.	Slovenia	Industry
SIB64	Universidad Politécnica de Cartagena	Spain	University /public research org

7 Annex B: Mobility grants

There were 79 mobility grants. 56 Researcher Mobility Grants (RMG) and 23 Early Stage Researcher Mobility Grants (ESRMG).

Figure 39: Mobility grants

Project	Type of grant	Organisation	Country	Organisation type
ENG01	RMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
ENG04	ESRMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
ENG05	ESRMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
ENG05	ESRMG	Istituto Nazionale di Ricerca Metrologica	Italy	NMI / DI
ENG07	RMG	Turkiye Bilimsel ve Teknolojik Arastirma Kurumu	Turkey	NMI / DI
ENG08	RMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
ENG08	RMG	Institutul National de Cercetare-Dezvoltare pentru Fizica si Inginerie Nucleara "Horia Hulubei"	Romania	University / Public research org
ENG09	RMG	Laboratoire national de métrologie et d'essais	France	NMI / DI
ENG09	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
ENG52	ESRMG	General Directorate of Metrology	Albania	NMI / DI
ENG54	RMG	Fundación General de la Universidad de Valladolid	Spain	University / Public research org
ENG55	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
ENG55	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
ENG55	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
ENG55	RMG	Loughborough University	United Kingdom	University / Public research org
ENG55	RMG	JRC - Joint Research Centre - European Commission	European Commission	University / Public research org
ENG55	RMG	Loughborough University	United Kingdom	University / Public research org
ENG56	RMG	Ministarstvo ekonomije	Montenegro	NMI / DI
ENG59	RMG	Instituto Português da Qualidade, I.P.	Portugal	NMI / DI
ENG59	RMG	Instituto Português da Qualidade, I.P.	Portugal	NMI / DI
ENG60	RMG	Cesky Metrologicky Institut	Czech Republic	NMI / DI
ENV01	ESRMG	Ministarstvo privrede Direkcija za mere i dragocene metale	Serbia	NMI / DI
ENV01	RMG	Turkiye Bilimsel ve Teknolojik Arastirma Kurumu	Turkey	NMI / DI
ENV07	RMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
ENV08	RMG	Bulgarian Institute of Metrology	Bulgaria	NMI / DI
ENV53	ESRMG	Aalto-korkeakoulusäätiö sr	Finland	University / Public research org
ENV58	RMG	Sveuciliste U Zagrebu, Fakultet Strojarstva I Brodogradnje	Croatia	University / Public research org
ENV58	RMG	Instytut Niskich Temperatur i Badan Strukturalnych im. Wlodzimierza Trzebiatowskiego Polskiej Akademii Nauk	Poland	University / Public research org
ENV58	RMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
ENV58	RMG	Ministarstvo ekonomije	Montenegro	NMI / DI
EXL02	RMG	Tallinna Tehnikaulikool	Estonia	University / Public research org
EXL04	ESRMG	Istituto Nazionale di Ricerca Metrologica	Italy	NMI / DI
EXL04	RMG	Istituto Nazionale di Ricerca Metrologica	Italy	NMI / DI
EXL04	RMG	NPL Management Limited	United Kingdom	NMI / DI
EXL04	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI

Project	Type of grant	Organisation	Country	Organisation type
HLT02	RMG	Helsingin Yliopisto	Finland	University / Public research org
HLT06	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
IND01	ESRMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
IND01	ESRMG	Cesky Metrologicky Institut	Czech Republic	NMI / DI
IND04	ESRMG	Institutul National de Cercetare-Dezvoltare pentru Fizica si Inginerie Nucleara "Horia Hulubei"	Romania	University / Public research org
IND04	ESRMG	Centro de investigaciones energeticas, medioambientales y tecnologicas	Spain	University / Public research org
IND04	ESRMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
IND07	RMG	Institut za fiziku	Croatia	University / Public research org
IND08	ESRMG	Cesky Metrologicky Institut	Czech Republic	NMI / DI
IND15	ESRMG	Bundesanstalt fuer Materialforschung und -pruefung	Germany	University / Public research org
IND57	ESRMG	Physikalisch-Technischer Pruefdienst des Bundesamt fuer Eich- und Vermessungswesen	Austria	NMI / DI
NEW01	RMG	Interuniversitair Micro-Electronicacentrum IMEC VZW	Belgium	University / Public research org
NEW02	RMG	Istituto Nazionale di Ricerca Metrologica	Italy	NMI / DI
NEW03	RMG	Research Centre for Natural Sciences, Hungarian Academy of Sciences	Hungary	University / Public research org
NEW06	ESRMG	Central Office of Measures	Poland	NMI / DI
NEW07	RMG	Cesky Metrologicky Institut	Czech Republic	NMI / DI
NEW07	RMG	Philipps-Universität Marburg	Germany	University / Public research org
NEW07	RMG	Philipps-Universität Marburg	Germany	University / Public research org
SIB01	ESRMG	Centro Español de Metrología	Spain	NMI / DI
SIB02	ESRMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
SIB04	RMG	Institute of Solid State Physics Bulgarian Academy of Sciences	Bulgaria	University / Public research org
SIB05	RMG	Ministrstvo za gospodarski razvoj in tehnologijo	Slovenia	NMI / DI
SIB05	RMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
SIB05	RMG	Instituto Português da Qualidade, I.P.	Portugal	NMI / DI
SIB06	ESRMG	Studiecentrum voor Kernenergie, Centre d'Etude de l'Energie Nucléaire, Fondation d'Utilité Publique	Belgium	University / Public research org
SIB06	ESRMG	Narodowe Centrum Badań Jądrowych	Poland	Other (e.g. government)
SIB10	ESRMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
SIB10	ESRMG	Central Office of Measures	Poland	NMI / DI
SIB10	RMG	Central Office of Measures	Poland	NMI / DI
SIB10	RMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
SIB10	RMG	Instytut Niskich Temperatur i Badan Strukturalnych im. Wlodzimierza Trzebiatowskiego Polskiej Akademii Nauk	Poland	University / Public research org
SIB10	RMG	Central Office of Measures	Poland	NMI / DI
SIB10	RMG	Ministarstvo privrede Direkcija za mere i dragocene metale	Serbia	NMI / DI
SIB10	RMG	Ministarstvo privrede Direkcija za mere i dragocene metale	Serbia	NMI / DI
SIB10	RMG	Ministarstvo ekonomije	Montenegro	NMI / DI
SIB10	RMG	Biroul Roman de Metrologie Legala	Romania	NMI / DI

Project	Type of grant	Organisation	Country	Organisation type
SIB10	RMG	Instytut Niskich Temperatur i Badan Strukturalnych im. Wlodzimierza Trzebiatowskiego Polskiej Akademii Nauk	Poland	University / Public research org
SIB55	RMG	Cesky Metrologicky Institut	Czech Republic	NMI / DI
SIB56	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
SIB57	ESRMG	Agencia Estatal Consejo Superior de Investigaciones Cientificas	Spain	University / Public research org
SIB57	RMG	Tallinna Tehnikaulikool	Estonia	University / Public research org
SIB59	RMG	Turkiye Bilimsel ve Teknolojik Arastirma Kurumu	Turkey	NMI / DI
SIB60	RMG	Ústav přístrojové techniky AV ČR, v.v.i.	Czech Republic	University / Public research org
SIB60	RMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI

8 Annex C: EMRP Good News Stories

EURAMET published many Good News Stories over the life of the programme, a summary is below:

Total	**191**
Project highlight/Dissemination	**54**
Project highlight/Uptake	**31**
Project highlight/Technological advance	**30**
Project highlight/Standardisation	**7**
Published Material	**5**
MSU-Call Process/Events	**22**
International Day	**14**
General EURAMET	**28**

Some example Good News Stories that concentrate on outstanding collaboration among NMIs/Dis are reproduced below:

EMRP project accomplished 12 joint publications

Spintronics is the science behind the magnetic technology that, for example, reads (and writes) data on the hard disk in your laptop. Recently spintronic research has investigated the potential of manipulating individual magnetic elements (domain walls) and combining spintronics with thermo-electricity in a new field named 'spin-caloritronics'.

Spin-caloritronics focuses on the interaction of electron spins and heat currents. New effects have been observed such as the spin-Seebeck effect (SSE), which enables the efficient generation of spin currents driven by thermal gradients and could lead to novel device applications. However, measurements are affected by the specific test conditions and this has resulted in published SSE material parameters being the subject of intense scientific debate.

To move this research area forwards to useful commercial devices requires the development of a robust underpinning metrological infrastructure. The EURAMET European Metrology Research Programme project 'Spintronics and spin-caloritronics in magnetic nanosystems' (SpinCal) characterised domain wall devices and developed reliable measurements both for those devices and for spin caloritonics in magnetic nanosystems. The project included both basic research and enabling metrology to develop and characterise several magnetic nanodevices. These were then used to generate an understanding of the interplay of electron spin and thermal gradients within these devices. The project results were disseminated to the wider scientific and technical community through a dozen joint scientific publications.

Long-standing collaboration

The SpinCal project built on a long-standing collaboration between National Metrology Institutes (NMIs), including PTB (Germany), NPL (UK) and INRIM (Italy), in the field of nano-scale magnetic metrology. The collaboration started with iMERA-Plus (Implementing Metrology in the European Research Area) projects, the first phase of the European Metrology Research Programme, that were initially launched in 2007.

"This built the basis for a trusting and very successful continuing collaboration," says Dr Hans Werner Schumacher from PTB and coordinator of the SpinCal project and helped the joint authorship process.

Such collaboration was an essential element to make progress. Research departments in NMIs in the field of magnetic nanosystems are usually relatively small compared to other metrology fields. Therefore, collaboration between the institutes brought many advantages, no competitive elements, and hence many joint publications. "We really needed each other," comments Dr Schumacher.

The mixture of complementary competences led to a successful division of work. Each of the NMIs was able to advance the project with its specific individual contribution: PTB, for example, provided the cleanroom, while other NMIs provided a range of different measurement methods. "In this collaborative and trusting environment joint publications developed almost automatically," explains Dr Schumacher.

The results of the SpinCal project reached far beyond what could have been achieved through the activities of a single partner. This is demonstrated by the large number of joint scientific publications that have been published or submitted for publication during the course of the project including in high impact factor publications such as Nature Communications and Physical Review Letters.

In addition, some 66 presentations at international meetings and conferences were made with invited presentations at Spin-Caloritronics VII in Utrecht and at the European Magnetic Sensors and Actuators Conference in Turin.

Added value

For all groups involved in the project, the joint publications have brought an added value. “From my point of view joint publications are very important. They can lead to new research approaches for follow-on EMPIR projects, but also they are very helpful for gaining additional funding through applications outside the European Metrology Research Programmes,” explains Dr Schumacher.

In addition, NMI metrologists at early stages in their careers and the academic partners involved in the project initiated many of the successful joint publications.

One of the key aims of the project was to take the first steps towards European and international standardisation by establishing metrology infrastructure for spintronics and spin-caloritronics. The project has enabled the metrology infrastructure to be put into place for characterising domain wall devices. This includes best practice for SSE measurements that has been developed and published in an open access journal publication supporting ongoing research into these materials and underpinning quantitative materials research.

In the long term, the fundamental research carried out within the SpinCal project will enable European industrial stakeholders to develop more energy efficient ICT devices (such as low power magnetic logic and storage devices) and more sensitive diagnostic tools for biosensing and manipulation of individual biomolecules. These new developments will also be based on the publications which have submitted and published by the project.

Taking the measure of Smart Grids - EMRP project authored [22 / 24] joint publications

The electricity grid is the backbone of our modern society guaranteeing high quality power and a high level of security of supply. The recent increase in decentralised energy supply, due to the growth of renewable energy sources, has meant that the grid must become ‘smarter’. Smart grids must be able to handle bi-directional energy flows, respond flexibly to rapidly changing supply and demand, and cope with voltage distortions.

The European Metrology research Programme project ‘Metrology for smart electrical grids’ made significant advances in creating a metrology infrastructure for monitoring the stability and quality of supply in smart electrical grids that had a significant impact in their rapid and effective development and implementation. This in turn has been a key enabling factor for the widespread integration of renewable power and more efficient uses of energy in Europe.

“Joint papers are always the result of good joint work,” says Dr Gert Rietveld, Chief Metrologist at VSL, the Netherlands Metrological Institute, and coordinator of the project. “And this project involved a lot of good cooperative work.”

22 partner institutions from 17 countries were involved and all had a huge interest in the subject as it was a new area with a considerable potential impact. “Everyone wanted to be involved in every aspect of the project,” says Dr Rietveld, “But each partner was only involved in one of the four work packages. This ensured that efforts were focused.”

Teamwork is the key

Teamwork was key. “Many of the elements in the project were new to everyone, so new capabilities needed to be developed and this involved lots of interaction between partners. This was the basis for the high number of joint publications and conference proceedings,” says Dr Rietveld.

The project developed tools for designing metrological strategies for cost effective optimised measurement and control of smart grids. The projects algorithms for modelling, simulation and network analysis of smart grids now enable operators to develop effective measurement strategies, optimal sensor placement plans and cryptographic infrastructures to ensure grid security.

The project also established a measurement framework for reliable and accurate Phasor Measurement Units (PMUs) that are a key tool for monitoring stability of smart grids. A suite of devices was developed to provide traceable measurements and practical methods to assess stability.

Significant new insights were also obtained on the effect of renewable energy sources on power quality through an on-site campaign in locations across Europe. This work has enabled grid operators to predict the impact of planned large-scale installations and make provisions for network reinforcements to mitigate any potential detrimental effects they may have on power quality or network reliability.

The project also established traceable on-site energy measurement systems that ensure fair energy trading by supporting cost-effective implementation of accurate smart metering for grid operators and consumers.

Utility collaboration

The project worked closely with utility companies, grid operators and instrumentation manufacturers and the on-site measurement campaigns deepened relationships with the industrial community. This was a key element of the success of the project highlighting requirements for grid monitoring and control and underlining the requirements and practical limitations for real-time metrology in the field.

"In many ways the biggest successes for the project came from the opportunities to directly access the grid and make 'real' measurements in the context of the issues that the utilities face on a daily basis," explains Dr Rietveld.

"All partners realised that they were facing similar problems and realised that the measurement infrastructure was not adequate to the task, so it was both helpful and necessary for everyone to work closely together," he states. And the success of the cooperation was reflected in the high number of joint publications.

"In addition, many of the partners had already worked together on previous, more laboratory-orientated, problems, so people knew each other already and could recognise each other's capabilities," Dr Rietveld concludes. "These personal links were already in place and paved the way for the SmartGrid success."

Three follow-on projects from SmartGrid were undertaken within EMPIR (European Metrology Programme for Innovation and Research): Measurement tools for Smart Grid stability and quality (SmartGrid II); Sensor network metrology for the determination of electrical grid characteristics (Gridsens); and Non-conventional voltage and current sensors for future power grids (FutureGrids).

A European Metrology Network on Smart Electricity Grids has also been established, which ensures long-term collaboration between metrology experts in this field and commercial stakeholders.

MetroMetal helps harmonise radiation measurement - EMRP project accomplished 11 joint publications

Annually, more than 500 steel production sites across 23 EU Member States produce some 200 million tonnes of steel. Over 40% of this material is produced by recycling scrap metal. The steel mills must use radiation detection portals to test the scrap material for the presence of radioactive sources. If these detection portals fail, then radioactive contamination of steel and steel by-products is possible. Clearly, ensuring the reliability and performance of these detection systems is important to guarantee the quality and safety of the steel recycling process and its products.

Although such episodes are rare, recent incidents have demonstrated that these risks are still relatively common across Europe and that as well as monitoring scrap materials before melting, additional measurements are needed after melting to ensure and certify the absence of radioactive contamination in steel, slag and fumes dust.

Consistent approach

Prior to the project, surveillance in the European steel industry was carried out by a number of different detection systems, primarily using scintillator/gamma detection systems. However, these systems vary in their technical approach, resulting in different measurements, which made it difficult to compare detection results. This lack of consistency could then lead to trade disputes over contamination levels and/or radioactive contamination of steel products.

To improve radiation detection capabilities the EURAMET European Metrology Research Programme project 'Ionising Radiation Metrology for the Metallurgical Industry' (MetroMetal) analysed the available gamma detection systems and recommended best methods and alternative prototype devices for monitoring radioactivity. Three prototype spectrometric devices for the measurement of activity in cast steel, fume dust and slag samples were developed, two of which were tested at end-user facilities in Europe. In addition, SI traceable reference standards made of typical materials encountered in steel mills were produced and characterised to support better industrial measurements.

In addition, there were no standard methods for measuring radioactivity at all stages (i.e. scrap loads, metal products, slag and fume dust) of the melting process or relevant reference materials for the validation of measurement devices and methods.

The project has successfully set the basis for establishing common standards for radioactivity monitoring in steel mills and the reliable certification for non-radioactivity of steel and steel by-products in the industry.

An ongoing issue

The issue tackled by MetroMetal is a common, and ongoing, problem for the European steel industry. “The issue is a critical problem for European industry, and this is understood by all stakeholders and actors in the sector. The number of joint reports flowing from the project demonstrated its importance and the common interest in Europe in this field,” comments Dr Eduardo García-Toraño, President of the International Committee for Radionuclide Metrology, who is based at the CIEMAT laboratories in Madrid.

Dr García-Toraño was coordinator of the MetroMetal project and led 13 partners in the collaboration. “Several published papers included contributions from all of the partners,” he notes.

Like many fruitful collaborations, the success of the project and its joint publications reflect a long-term effort. “Most of the partners in the project had worked together previously over a number of years,” explains Dr García-Toraño. “There has been a long tradition of cooperation, with some collaborations extending back as far as the 1960s!”

“In addition, the work required in this field is difficult to tackle in a single laboratory,” he continues. “Within the project the various work packages were interrelated and this meant that it was important for project partners to follow each other’s progress.”

An example is the characterisation of reference material. “This required at least four comparisons between laboratory results and naturally led to joint publications,” states Dr García-Toraño.

The collaboration was very positive throughout. “All the project meetings attracted at least 20 people, which showed the serious interest of the partners,” concludes Dr García-Toraño. “And the results of the work have been taken very seriously and appreciated around the world.”

MIQC takes the measure of quantum technologies - EMRP project accomplished 12 joint publications

With ever increasing amounts of sensitive data being stored, transferred and accessed over computer networks, ensuring the security of information is a significant challenge. Quantum communication technologies, such as quantum key distribution (QKD), can help increase security. QKD involves the generation of secret random cryptographic keys between two parties that communicate over an open quantum channel. Cryptographic keys are at the heart of encrypted communication and transaction technologies, such as blockchain technology. These keys are vital for realising secure communication between the two parties; the use of quantum keys radically increases the level of security.

Disruptive technology

QKD has supported the development of quantum information science and is likely to be a disruptive technology in the information management industry with the potential to displace established technologies, shake up business models and create new ways of working. With its significant long-term security perspective, QKD will be an important building block for developing dependable, secure communication networks.

The focus of the EURAMET European Metrology Research Programme project ‘Metrology for Industrial Quantum Communication Technologies’ (MIQC) was the development of techniques and facilities for traceable characterisation of single-photon components of QKD systems. QKD technology can address the need for improved data security in, for example, banking, commerce, government, and the transmission of personal data such as medical records. However, a lack of validation and standardisation remains a barrier to a wider market take-up of this technology, in which Europe is currently a world-leader, and addressing this falls within the remit of National Measurement Institutes (NMIs).

The main challenge was the identification of the physical system parameters critical to quantum communication and the development of appropriate metrics and measurement techniques for their quantification. The MIQC project put in place a series of measurement systems that characterise the properties of individual particles of light, as well as ‘Quantum Key Distribution’ technologies. This has laid the foundations for a pan-European measurement infrastructure capable of validating the performance of QKD systems that will support the development of next-generation secure communications systems and quantum networks driving new services in the fields of e-government, e-commerce, e-health, transmission of biometric data, intelligent transport systems and many other areas. The project provided important metrological expertise to support an industry-led, real-world demonstration of ‘Quantum Key Distribution’ that has made the technology a more attractive commercial proposition and should accelerate its commercial deployment.

New skills

The MIQC project required the combination of expertise and resources from a range of European NMIs to provide the measurement framework needed for characterising QKD systems and led to a significant number of joint publications.

“For me, the key to achieving so many joint publications was that this topic of quantum keys was brand new for all involved,” says Dr Maria Luisa Rastello from the Italian NMI INRIM, who coordinated the project.

“The subject was totally different from our previous experience and therefore no NMI had specific skills already,” she continues. “However, the consortium partners knew each other very well from previous collaborative work and trusted each other.” This made it easy to assign tasks between the partners as all participating NMI were at the same level.

This also enabled the consortium to build a coherent ‘single voice’ for the viewpoint of European metrology in the subject area through joint publications in articles, conference proceedings and other communications.

“The emerging subject area of quantum technologies required a single voice from metrology to ensure coherent progress in a fast-moving field,” says Dr Rastello. “And it was also very useful for achieving high visibility in other initiatives such as the Quantum Technologies Flagship.” This is a large-scale, long-term research initiative supported by the European Commission that brings together research institutions, industry and public funders to consolidate and expand European scientific leadership and excellence in this field. The flagship aims to place Europe at the forefront of the new quantum revolution, bringing transformative advances to science, industry and society.

“The MIQC project helped build a single voice for quantum metrology and has laid the foundation for an immense future in this area,” concludes Dr Rastello. “From the original project other initiatives have sprung up including proposals for further work in quantum photonics, EURAMET work on quantum technologies in clocks and the MIQC project planted the seed for the formation of a European Metrology Network on Quantum Technologies.”

A direct follow-on project from MIQC was undertaken within EMPIR (European Metrology Programme for Innovation and Research): Optical metrology for quantum enhanced secure telecommunication (MIQC2).

New definition of the Kilogram

The seven elements of the International System of Units (SI) are the fundamental basis upon which all other measurement units are derived. They must be defined accurately, and the definitions must be accessible, to ensure that measurements made throughout the world are consistent and reliable. The seven base units underpin all scientific and industrial measurements and increases in the accuracy of their definition support the development of innovative products and services.

Unlike the other SI base units, until recently, the SI base unit of mass, the kilogram, was defined as the mass of the International Prototype Kilogram (IPK), a platinum-iridium cylinder kept in Paris. This definition was not capable of supporting future increases in accuracy and had limited accessibility.

New definition

In 2018 the method used to define the kilogram changed. A kilogram was redefined as a ratio to the Planck constant (*h*), a fundamental physical constant, rather than by using a physical ‘model’ object. This redefinition will support future scientific and industrial innovation.

However, the new definition required a very accurate determination of the Planck constant. The focus of the EURAMET European Metrology Research Programme project ‘Realisation of the awaited definition of the kilogram’ (kNOW) was to refine and improve two approaches to the determination of the Planck constant, to increase the accuracy to which the constant can be stated, to ensure the results from the two approaches were consistent with each other, and ultimately, to ensure that they could be used for the redefinition of the kilogram.

Two approaches

One approach to determine the Planck constant uses a Kibble balance: a device that is essentially like a conventional weighing balance but with a mass on one side and a current carrying coil of wire within a magnetic field on the other. The electromagnetic force required to balance the mass allows the determination of *h* in terms of quantum electrical units. The alternative approach is to relate the Avogadro constant (N_A), the number of atoms in one mole of a substance, to the Planck constant by counting atoms that form a silicon sphere.

Both approaches are extremely technically challenging, and the kNOW project sought to address inconsistencies between the two approaches and bring a practical realisation of the definition of the kilogram by bringing the methods into more precise agreement. The success of the project enabled the European metrology community to make a significant contribution to improved determinations of the Planck and Avogadro constants, eliminate differences between their results and take an essential step towards the redefinition of the kilogram.

An indispensable element of this was joint publication. “Joint publication is the essential collaborative work,” states Dr Giovanni Mana of INRIM, the project coordinator. “And joint thinking and joint work were at the heart of solving the problems and challenges in this project.”

The kNOW project was a large coordinated effort with a range of different research teams working on different problems but relying on constant contact between the partners in order to progress.

“Counting silicon atoms and building and operating Kibble Balances involve completely different fields of science, different skills and expertise,” says Dr Mana. “This was a great strength for the project that required both sharing of knowledge and close collaboration.”

The partners in the project had built up a deep knowledge of the two approaches to determining the constants, but the kNOW project was the first to merge and collaborate results for the two approaches.

“Efficiently merging the various contributions, one with the other was essential to realising the full value of the work,” says Dr Mana. “There were different views on the same problem, simultaneously, that required close comparison of approaches but ultimately yielded new and valuable insights.”

The project was fortunate to build on existing collaborations between European National Measurement Institutes (NMIs), but there was also a need for other expert input. “Due to the complexity of the problem we needed to access different faces with different expertise – to look outside the usual faces – and bring in other competencies from outside the NMIs,” says Dr Mana.

“In many ways joint publications can be seen as the final defining step of a project process,” concludes Dr Mana. “The final value of the project mission was realised through the joint publications that were achieved.”

9 Annex D: Bibliographic indicators

Bibliometric indicators

The bibliometric analysis was conducted by Science-Metrix. Below are their definitions of the indicators used.

Average of relative citations (ARC)

The average of relative citations (ARC) is an indicator of the average scientific impact of papers produced by a given entity (e.g., a country, an institution) relative to the world average (i.e., the expected number of citations). The number of citations received by each publication is counted for the year in which it was published and all subsequent years (i.e., citation windows of variable length).[9] To account for different citation patterns across scientific subfields and document types (e.g., there are more citations in biomedical research than in mathematics, and reviews include more references and are more cited than articles), as well as to account for differences in the age of publications (i.e., older papers have accumulated citations over a longer period), each publication's citation count is divided by the average citation count of all publications (in Scopus) of the corresponding document type that were published the same year in the same subfield. In this way, one arrives at a relative citation count (RC). The ARC of a given entity is the average of the RCs of the papers belonging to it. An ARC value above 1 means that a given entity is cited more frequently than the world average, while a value below 1 means that its publications receive, on average, fewer citations than the world average.

Citations distribution chart (CDC) and citation distribution index (CDI)

The citation distribution chart (CDC) is a tool that facilitates a simple but nuanced visual inspection of an entity's research impact relative to worldwide performance. To prepare these charts, Science-Metrix divides all publications in a given research area into 10 groups of equal size, or “deciles”, based on their RC scores.10 The

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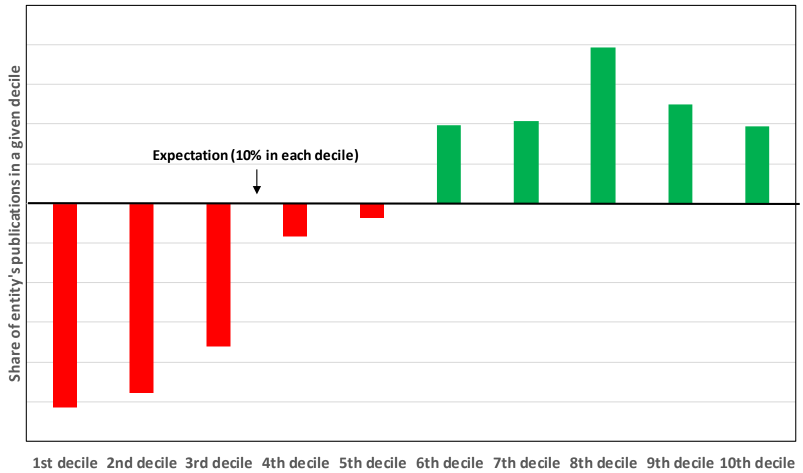
[9] For all citation-based measures, a certain amount of time must be allowed for the published work to have an impact on subsequent research, and for articles to be cited. Accordingly, impact measures for the present study can be computed for articles published in 2013 or earlier. Papers published in 2014 or later have not had sufficient time for citations to accrue.

[10] Two adjustments are made in order to ensure high-quality results, and these pertain to (a) cases where a number of publications are tied in their scores, and (b) cases where the total number of publications is not divisible by 10. For the first case (a), papers tied at the margin of two deciles will be grouped together and then divided proportionately to ensure that

1st decile contains the 10 % of publications with the lowest RC scores; the 10th decile contains the 10 % of publications with the highest RC scores.

For a given research entity, it is expected that the RC scores of its publications will follow the global distribution, with an equal number of publications falling in each of the deciles. The CDC for a given entity compares that entity's scientific impact to the global level by showing how its performance compares to the world level in each of the deciles.



Sample of citation distribution chart (CDC)

Source: Prepared by Science-Metrix

As shown in above the CDC shows 10 colour-coded bars for a hypothetical entity; each bar represents the relative presence of this entity's papers in each corresponding decile. The world level, in contrast, is represented by the horizontal black line, with no bars, as it represents the uniform distribution of all the publications across the 10 deciles. Thus, the bar's colour shows whether the specific entity has more or fewer publications in that decile than expected (i.e., the horizontal line). Green bars denote production exceeding expectation in that decile, red denotes production below expectation in that decile, and the length of the bar shows how far above/below expectation the entity is in that decile. Consequently, the longer the red bar, the fewer number of articles are found in that decile relative to expectation. Conversely, the longer the green bar, the more publications are to be found in that decile, again relative to expectation. Cases where a decile has no bar associated with it show that the entity's performance is exactly in line with the expectation based on global performance. Accordingly, a CDC with no visible bars shows that the entity in question has 10 % of its papers in the 1st global decile, 10 % of its papers in the 2nd global decile, and so on, which, as previously noted, corresponds to the world distribution of papers based on their RC scores.

Ideally, one would hope to over-perform in the highest deciles, where the most impactful publications are found; similarly, one would hope to underperform in the lowest deciles, where the least impactful publications are found. Thus, strong research performance is shown by long red bars on the left of the CDC and long green bars on the right of the graph. In contrast, weaker research performance is depicted with long green bars on the left side (indicating more publications than expected in the less impactful deciles) and long red bars on the right side (indicating fewer publications than expected in the more impactful deciles). The chart below presents distributions related to best-case, good, bad and worst-case scenarios.

each decile contains the right number of papers. In the case of the total number of papers not being divisible by 10 (b), papers will be fractioned to ensure that the deciles are always of exactly equal size.

Various scenarios of citation distribution charts (CDC) and their citation distribution index

	Citation Distribution Chart	CDI
Best case scenario		50
Typical best case scenario		25
World level		0
Typical worst case scenario		-25
Worst case scenario		-50

Source: Prepared by Science-Metrix

The content of the CDC can also be summarised numerically using the citation distribution index (CDI). For each decile, the performance of a given research organisation is compared to the global average, and this ratio is then multiplied by the weight corresponding to that decile. Once a score has been produced in this fashion for each decile, they are summed to calculate the CDI for the research organisation. Thus, having a higher-than-expected number of publications in the 1st decile (i.e., the lowest-impact decile) will reduce the CDI more than having a higher-than-expected number of publications in the 2nd decile. The CDI ranges from -50 (worst case scenario) to 50 (best case scenario) with 0 representing parity with the world level.

Highly cited papers top 10 % (HCP_{10})

Highly cited papers (HCP) are publications that received the highest relative citation score (RC) in their respective field. This indicator is frequently used as a proxy to examine research "excellence" because of the high concentration of citations in this elite group of publications. For this study, the top 10 % most cited publications were selected, and data for the institutions were then produced based on these highly cited papers. The 10 % most cited publications in the database were identified using the relative citation (RC) scores of publications. The fraction of an entity's papers falling among these highly cited publications was then computed, which gives the HCP score of that entity. The $HCP_{10\%}$ is also the proportion of publications found in the 10th decile presented in the CDC.

Average of relative impact factors (ARIF)

The ARIF is a *proxy* often used to measure the scientific quality or prestige of the journals in which an entity's papers are published. It is thus based on the average citation rate of the publication venue (measured by the impact factor of journals) instead of the actual publications.

Thomson Reuters calculates an annual impact factor (IF) for each journal based on the number of citations it received in the previous two years, relative to the number of publications it published in the previous two years. Thus, each journal's IF will vary from year to year. For example, the IF of a journal in 2007 is equal to the number of citations to articles published in 2006 (8) and 2005 (15) divided by the number of articles published in 2006 (15) and 2005 (23) (i.e., IF = numerator [23] / denominator [38] = 0.605). However, as pointed out by Archambault and Larivière, this indicator carries the weight of history and of many choices that were made a long time ago when their effect had not been studied thoroughly.[11]

For example, Moed and colleagues have described the effect of the observed asymmetry between the numerator and denominator of the Thomson Reuters' IF as follows:

> *ISI classifies documents into types. In calculating the nominator of the IF, ISI counts citations to all types of documents, while as citable documents in the denominator ISI includes as a standard only normal articles, notes and reviews. However, editorials, letters and several other types are cited rather frequently in a number of journals. When they are cited, these types do contribute to the citation counts in the IF's numerator, but are not included in the denominator. In a sense, the citations to these documents are "for free.*"[12]

In this study, Science-Metrix therefore computes and uses a symmetric IF based on the document types that are used throughout this entire project for producing bibliometric data using a five-year citation window. The IF of publications is calculated by ascribing to them the IF of the journal in which they are published, for the year in which they are published. Subsequently, to account for different citation patterns across subfields of science

[11] Archambault É. and Larivière V. (2009). History of the journal impact factor: contingencies and consequences. *Scientometrics*, 79(3), 635–649

[12] Moed, H.F., Van Leeuwen, T.H.N., and Reedijk, J. (1999). Towards appropriate indicators of journal impact. *Scientometrics*, 46(3), 575–589

(e.g., there are more citations in biomedical research than mathematics), each publication's IF is divided by the average IF of all papers that were published the same year in the same subfield to obtain a relative impact factor (RIF). The ARIF of a given entity is the average of its RIFs (i.e., if an institution has 20 publications, the ARIF is the average of 20 RIFs, one per publication). When the ARIF is above 1, it means that an entity scores better than the world average; when it is below 1, it means that on average, an entity publishes in journals that are not cited as often as the world level.

Compared to the other citation impact metrics to be used in this study, the ARIF can be computed up to the most recent year available (i.e., up to 2015).

10 Annex E: Impact case studies

The following are the 132 impact case studies developed following the completion of the projects. They are sorted by project number and consequently grouped into themes. Energy projects are yellow, Environment blue, Health green, Industry orange, New Technologies purple, and SI turquoise.

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Future-proofing Europe's gas networks

Europe's renewable energy targets and diminishing natural gas resources require the diversification of energy sources to include non-conventional gases, such as biogas and methane. These gases have different chemical and physical properties to traditional natural gas and need to be well-characterised before entering the gas transmission networks and during 'custody transfer' between different commercial operators. This is crucial to ensuring safe operation and enabling fair trade and environmental decision-making.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Gas pipeline networks are highly complex transmission and distribution systems used to move gas across states, countries or even continents. It is important that gas quality is maintained throughout the network and remains within the requirements set by international natural gas quality guidelines.

The presence of water in energy gases is a particular problem. Quantities of water travelling at considerable speeds through high pressure gas pipelines can cause significant damage to the infrastructure leading to costly network shutdowns and potential litigation. Therefore moisture content is a key parameter of gas quality and it is assessed against industry guidelines (set in Europe by the *EASEE-gas Common Business Practice*) when it enters the network and at each and every custody transfer. For this reason, accurate and cost-effective moisture measuring instrumentation is essential to pipeline operators.

Solution

Traditionally, national measurement standards for humidity (and the related measurement of dew point) were only defined for water in air at atmospheric pressure with corrections required for measurements made for many industrial applications. In order to meet the gas industry's requirements, the EMRP project *Characterisation of energy gases* widened the range of national standards, developing a facility to measure humidity at the highest levels of accuracy in a range of real-world energy gases and gas mixtures at an extended pressure range. This facility is available to assess and validate the performance of industrial equipment.

Impact

Michell Instruments, a leading supplier of humidity and dew point analysers to the natural gas and other industries, has developed a novel optical instrument to measure water content specifically for the gas industry. Working with the project team, Michell Instruments used the new humidity facility to evaluate the instrument's performance at the highest levels of accuracy in conditions relevant to their target market. This not only gave them confidence in the product's performance but also provided robust evidence to support their marketing and sales activities.

Michell's new instrument provides fast and accurate measurements of moisture content and can be used online and in real-time throughout the gas network. The improved performance offers network operators improved confidence in the quality of gas they buy and sell while avoiding unnecessary and costly drying processes before the gas is injected into the network. The product was launched in 2014 and has been installed in a number of locations worldwide. As the only European manufacturer offering this technology at present, the company projects significant sales of the order of €2M per year over the coming years as the market develops.

Besides improving efficiency and confidence across Europe's existing gas networks, the new instrument paves the way for a range of gas mixtures, readying the network for a more renewable, secure gas future.

Innovative technology for moisture measurement

Michell Instruments' new instrument is a tuneable diode laser analyser (TDLAS) using the latest techniques in laser absorption spectroscopy and signal processing power to offer robust high performance analysis optimised for the measurement of moisture in energy gases of widely varying composition. It is a non-contact technology that requires minimal maintenance.

EMRP projects supporting the European Renewable Energy Directive 2009/28/EC

The European Renewable Energy Directive 2009/28/EC requires 20% of European Union energy consumption to come from renewable sources, with 10% of transport fuel coming from renewable sources such as biofuels, by 2020.

EMRP project *Characterisation of energy gases* and its successor project *Metroogy for biogas* are developing the infrastructure to enable the 'inter-changeability' of energy gases so that gaseous fuels from renewable and other non-conventional sources can readily be used in the existing gas grids across Europe alongside traditional natural gas. The ability to measure the physical and chemical attributes of a wide range of gases and gas mixtures is enabling gas producers and transporters to make informed commercial, environmental and safety decisions based on comparable measurements of the energy content, carbon content and physical properties of alternative and renewable gaseous fuels.

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Energy harvesting for greener transport

Transport is responsible for around a quarter of Europe's greenhouse gas emissions, and is the only major sector where emissions are still rising. Cleaner, more efficient vehicles are needed to help Europe reduce emissions and prevent dangerous climate change.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Harvesting waste heat from vehicles could reduce fuel consumption and CO_2 emissions. Most major automotive companies are currently developing thermoelectric generators, which capture waste heat from a car's exhaust and turn it into electricity. This harvested energy can be used to power a car's electrical system, reducing the load on the engine and cutting both fuel consumption and emissions.

To encourage mass-market adoption of the technology, new thermoelectric materials - which turn heat into electricity - are needed to create smaller, cheaper, more efficient thermoelectric generators. Developers need accurate measurements of a material's thermal and electrical properties to evaluate performance, give confidence to potential customers and accelerate commercialisation.

Reference materials allow manufacturers to calibrate measurement instruments in-house and ensure they provide accurate readings. But until recently, few reference materials were able to accurately assess thermoelectric performance, particularly at the high temperatures required by the automotive industry. Manufacturers need new reference materials to enable them to accurately assess the performance of thermoelectric materials, and accelerate the development and adoption of improved thermoelectric generators.

Solution

The EMRP project *Metrology for energy harvesting* developed two new reference materials for measuring the Seebeck coefficient – a material property which strongly influences the efficiency and power output of a thermoelectric generator. This is the first time that reference materials for Seebeck coefficients which perform reliably at high temperatures have been made available to industrial users. Additionally, unlike previous reference materials which could only be used in specific calibration instruments, the new reference materials can be adapted to fit a variety of instruments.

Impact

German manufacturer Netzsch has developed a high-precision instrument for measuring electrical conductivity and the Seebeck coefficient which is marketed with the new reference material. Netzsch intends to sell the instrument and reference material to research and development teams within automotive manufacturing companies.

The reference material will give Netzsch's customers confidence that the thermal efficiency measurements they make are accurate and consistent. This will allow manufacturers to reliably assess the performance of new materials developed for energy harvesting devices, and enable their customers to better compare products, encouraging uptake of the technology.

Netzsch's product provides the measurement capability needed to accelerate development and uptake of improved thermoelectric generators within the automotive industry. By making Europe's vehicles more efficient, energy harvesting technology has the potential to reduce one of the most significant contributions to Europe's greenhouse gas emissions.

Metrology for energy harvesting

This project developed the metrological framework needed to support the development of commercially-successful energy harvesting devices in Europe. Focusing on vibrational and thermal energy harvesting, the project has enabled the traceable measurement of thermal, mechanical and electrical properties, and assessment of the efficiency and effectiveness of energy harvesting technologies in different applications. This will help industry and consumers to make direct comparisons of energy harvesting technologies, and ultimately lead to lower costs and improved product performance.

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Diversifying Europe's energy supply

The recent increase in energy prices and instability of pipeline gas imports over the past few years have heightened concerns about the security, diversity, and competitiveness of Europe's natural gas supply. Coupled to this, alternative fuels are urgently needed to break the over-dependence of European transport on oil. Liquefied natural gas (LNG) could play a major role in diversifying Europe's energy supply and securing a stable, greener future.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

LNG is formed when natural gas is cooled to approximately -162 °C, and occupies around 1/600th of the volume of natural gas in its gaseous state. This makes LNG more economical to transport over large distances, and facilitates the supply of natural gas from new sources where no pipeline infrastructure exists. The environmental benefits of generating energy from gas rather than oil also make LNG a prime candidate for greener transport fuels.

In comparison with fuels such as natural gas or gasoline, there is a high level of uncertainty involved in measuring the delivered energy content when buying and selling LNG. A single shipment of LNG can be worth as much as €50M, with optimistic estimates of the measurement uncertainty representing a financial risk of €400k to both buyer and seller. An improved measurement infrastructure for LNG is needed for Europe to ensure fair and open trade.

Flow metering is promising a more accurate method for measuring the transferred volume of LNG – and in turn, its energy content - than the level gauging method currently used within the industry. However, a lack of test and calibration standards for LNG flow meters is hindering their introduction to the market, and preventing industry from making the high accuracy measurements needed to support LNG's adoption.

Solution

The EMRP project *Metrology for liquefied natural gas* established a system of high-accuracy flow measurement in conditions relevant to the LNG industry, and a new primary flow standard has been developed. Further funding from both industrial sources (~€3M) and a follow on EMRP project (LNG II ~€4.5M) has been secured enabling the commissioning of a new calibration facility for LNG flow and composition in 2016. This will enable LNG metering systems to be calibrated with top-class accuracy under typical operating conditions.

Impact

The results of the project are now being incorporated into legally-binding guidance and written standards for the LNG industry: the revised International Organization of Legal Metrology (OIML) Recommendation R117 *Dynamic measuring systems for liquids other than water*; the 2015 revision of the International Group of Liquefied Natural Gas Importers Handbook; and the ISO standard *Measurement of cargoes on board LNG carriers* (ISO 10976:2012), which focuses on process control measurements for custody transfer. A new ISO working group was formed in 2014 to draft a dedicated draft standard on LNG flow metering systems.

These are important first steps in the international implementation of improved LNG metering, and an example of the strength of Europe's National Metrology Institutes' role in disseminating new measurement knowledge and encouraging the adoption of measurement best practice by end-users. The project has provided a foundation for the metrological infrastructure for LNG, which will promote open and fair trade, reduce financial risks, and result in better and more stable prices for European industry and citizens. By giving confidence to investors and consumers, the results are supporting greater adoption of LNG and a more stable energy future for Europe.

Greener transport fuel

Partial tank transfers, used in the filling of vehicles, also require accurate metering ahead of widespread adoption of this greener transport fuel. The use of LNG to fuel goods vehicles in the Netherlands alone has been calculated to reduce exhaust emissions by 1 million tonnes of CO_2 and by 400-600 tonnes of particulates per year. Trucks running on LNG fuel are significantly quieter than those with diesel engines, reducing their contribution to noise pollution and enabling night-time deliveries in residential locations.

Implementation of improved LNG metering for partial tank transfers will encourage its use as a commercial transport fuel, establishing a more diverse EU energy supply meeting the requirements of the EC integrated energy policy.

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European Metrology Research Programme
Delivering Impact

Smart, stable grids for a greener Europe

The risks posed by climate change and diminishing traditional energy supplies are challenging conventional methods of electricity generation and distribution. To enable the increased use of renewable energy sources, traditional 'one-directional' electricity transmission grids need to evolve into 'smart grids' capable of managing a complex network of decentralised energy supply and demand.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Smart grids are a key component in the energy infrastructure needed to meet Europe's target of 20% of energy consumption from renewable sources by 2020. But widespread adoption of smart grids is dependent on investor and consumer confidence in their ability to provide a stable high-quality electricity supply. As smart grids are managed by radically different instrumentation and control processes to traditional grids, they require the development of an appropriate measurement infrastructure.

Smart grids have to balance fluctuating energy supply with variable demand in real-time to achieve sufficient power quality and grid stability to prevent blackouts. Phasor measurement units (PMUs) are expected to be the 'life-support monitor' for the smart grids of the future. Installed throughout the grid, PMUs assess and compare the power signals across the network, enabling grid operators to monitor and control these complex systems.

Grid operators need PMUs which perform robustly and reliably at high levels of accuracy to ensure grid stability. However, until recently, Europe lacked the necessary underpinning measurement infrastructure, such as national measurement standards traceable to the SI system of units and access to calibration services to validate the performance of PMUs.

Solution

The EMRP project *Metrology for smart electrical grids* developed calibration equipment, software and processes that enable PMUs to be validated against traceable measurement standards for the first time in Europe. Tests of PMUs in operational grids in Greece and Sweden resulted in best practice guidelines for PMU use, which have been incorporated into a revision of the relevant IEEE Standard used by the industry.

Impact

The project has supported the development of cost-effective calibration services by Fluke Corporation and a commercial PMU by Arbiter Systems, as well as the on-going adoption of effective operational practice via the revised IEEE standard.

Fluke Corporation, a manufacturer of testing and calibration equipment, has introduced a PMU calibrator based partly on the methods developed in the project. This is the first commercially available calibrator, outside of National Measurement Institutes, to provide traceability to national standards and compliance with the IEEE standard for smart grids. PMU calibration is a new market for Fluke and has already been delivered to a number of customers since its launch in 2014. The fully automated calibrator enables operators to demonstrate compliance with the revised IEEE standard, and confidently compare PMU measurements across the grid, safe in the knowledge that all devices produce consistent and robust measurements.

Arbiter Systems, a manufacturer of precision timing and power measurement devices, worked closely with the project team to share technical and market knowledge of the emerging market for PMUs for smart grids. As a result of this collaboration, Arbiter is introducing an improved and cheaper combined PMU and power quality measurement instrument for smart grids. Grid operators will be able to use Arbiter's new device to demonstrate compliance with the revised IEEE standard, and make reliable grid stability measurements at an affordable price. Arbiter is anticipating sales to be in the hundreds of PMUs per year, as small-scale renewable energy production rapidly expands to meet consumer needs and European targets.

Increased access to cost-effective calibration services and devices, such as those provided by Fluke and Arbiter, will help operators ensure the stability of smart grids and accelerate their adoption in Europe, in turn supporting widespread renewable energy generation and a more stable, low-carbon energy future for Europe.

Metrology for smart electrical grids

The EMRP project *Metrology for smart electrical grids* and its successor projects, *Smart Grids II* and *GridSens*, are developing the measurement infrastructure needed to support successful implementation of smart grids in Europe. This includes the development of analysis and measurement tools for monitoring grid stability and quality of supply, and revenue metering systems for ensuring fair trade.

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European Metrology Research Programme
Delivering Impact

Supporting smart renewable energy

The risks posed by climate change and diminishing traditional energy supplies are challenging conventional methods of electricity generation and distribution. To support more efficient energy use and increased generation from renewables, traditional 'one-directional' electricity transmission grids need to evolve into 'smart grids' capable of actively managing a complex network of decentralised energy supply and demand.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Smart grids are a key component in the energy infrastructure needed to meet Europe's target of 20% of energy consumption from renewable sources by 2020. But widespread adoption of smart grids is dependent on investor and consumer confidence in their ability to provide a stable high-quality electricity supply. This is underpinned by radically different instrumentation and control processes to traditional grids and requires the development of an appropriate measurement infrastructure.

Maintaining grid stability has been a major hurdle preventing greater introduction of non-conventional power generation into the electricity distribution system. Smart grids have to balance fluctuating energy supply with variable demand in real-time to achieve sufficient power quality and grid stability to prevent blackouts. Phasor measurement units (PMUs) are expected to be the 'life-support monitor' for the smart grids of the future. Deployed throughout the grid, PMUs assess and compare the power signals across the network, enabling grid operators to monitor and control these complex energy networks.

Solution

The EMRP project *Metrology for smart electrical grids* evaluated electrical power stability and quality during trials on smart grids in Sweden and Greece. Knowledge gained during these trials was used to generate best practice guidelines which support PMU users to achieve high-accuracy measurements in operational environments. This improved understanding of PMU and power quality instrumentation was disseminated to the smart grid community via a series of meetings with stakeholders.

Impact

Wind energy has the potential to play a central role in Ireland's transition to a low-carbon economy by 2050. The rapid expansion of wind power in Ireland has highlighted the need for a coherent plan, which allows the stable integration of localised renewable energy into the established grid system. The Micro Electricity Generation Association (MEGA), established to support the Irish government's plans to increase small-scale renewable energy generation, is incorporating best practice developed in the project in its first small-scale smart grid.

With support from South Dublin City Council (Tallaght City), the International Energy Research Centre (IERC - National Tyndall Institute), Siemens, Intel and Microsoft, MEGA is piloting a 'smart energy cluster' in the outskirts of Dublin, which links small-scale renewable energy generators with local consumers through a smart grid. Instabilities arising from the introduction of large-scale renewable power generation into existing grid systems can be avoided by gradually building small cellular smart grids that can be individually linked to the grid or assembled into larger multi-cell local grids.

MEGA's smart cluster distributes locally-generated wind and biogas power using a microgrid power stabiliser incorporating a PMU, which links the cluster to the main grid system and allows inflow of power when renewable generation cannot meet local demand. This removes the previous problems of grid instability and the need to dump conventional power during times of non-conventional power over supply. Through engagement with the project, MEGA received help evaluating the smart cluster's PMU and best practice guidance to enable accurate grid stability monitoring. Support from the project will help to ensure a reliable power supply to users of MEGA's smart cluster and the success of the pilot project.

MEGA hopes to eventually interconnect local small-scale smart grids into a citywide system for Dublin. This will be an important step towards widespread renewable energy generation in Ireland and a more stable, low-carbon energy future for Europe.

Metrology for smart electrical grids

The EMRP project *Metrology for smart electrical grids* and its successor projects, *Smart Grids II* and *GridSens*, are developing the measurement infrastructure needed to support successful implementation of smart grids in Europe. This includes the development of analysis and measurement tools for monitoring grid stability and quality of supply, and revenue metering systems for ensuring fair trade.

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European Metrology Research Programme
Delivering Impact

EURAMET

New standard for safer, greener roads

The EU has committed to cutting its greenhouse gas emissions by at least 20% by 2020 compared to 1990 levels and to improving energy efficiency by 20%. With 14% of the EU's total electricity consumption used for lighting, more efficient lighting technologies can make a significant contribution towards meeting these targets.

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Challenge

Solid state lighting (SSL), which uses LEDs as the light source, is the most energy-efficient lighting technology available, and offers better quality light and visual performance. SSL's extremely long lifetime and low maintenance costs promise savings for consumers and public authorities, and, unlike fluorescent lamps, it does not contain toxic mercury (EU directive 2002/95). All of these properties make SSL an ideal candidate for safe and efficient road lighting.

Italy has one of the largest road tunnel networks in the world, with some 1,500 kilometres of tunnels, all requiring illumination, and the ongoing upgrade to LED lighting will significantly reduce Italy's electricity consumption. However, when conventional tunnel lighting is directly replaced with LED lighting, the resulting glare can reduce a driver's visual performance and increases driver discomfort, creating a driving hazard.

Lamps and luminaires used for tunnel lighting are characterized under daylight (or photopic) conditions, according to current standards. However, our eyes work very differently under the low light (or mesopic) conditions experienced in road tunnels and many other important lighting applications. Improved lighting design, tailored to mesopic conditions, could have a significant economic and environmental impact in such areas.

Solution

The EMRP project *Metrology for solid state lighting* aimed to improve the accuracy of light intensity measurements under mesopic conditions. As part of the project the Italian National Measurement Institute, INRIM, developed a novel mesopic luminance meter and accompanying low light measurement method. These enable industrial testing laboratories to perform traceable measurements of the luminous intensity of LED lighting and to characterize the LEDs performance under low light conditions too.

Project researchers, together with Autostrade per l'Italia, used the INRIM instrument to study Italian highway tunnels with LED lighting and determine safety critical design parameters. They found that by reducing LED lighting intensity to a specific level compared to traditional lighting, induced glare could be minimised and comparable safety conditions for moving traffic maintained but with reduced energy consumption.

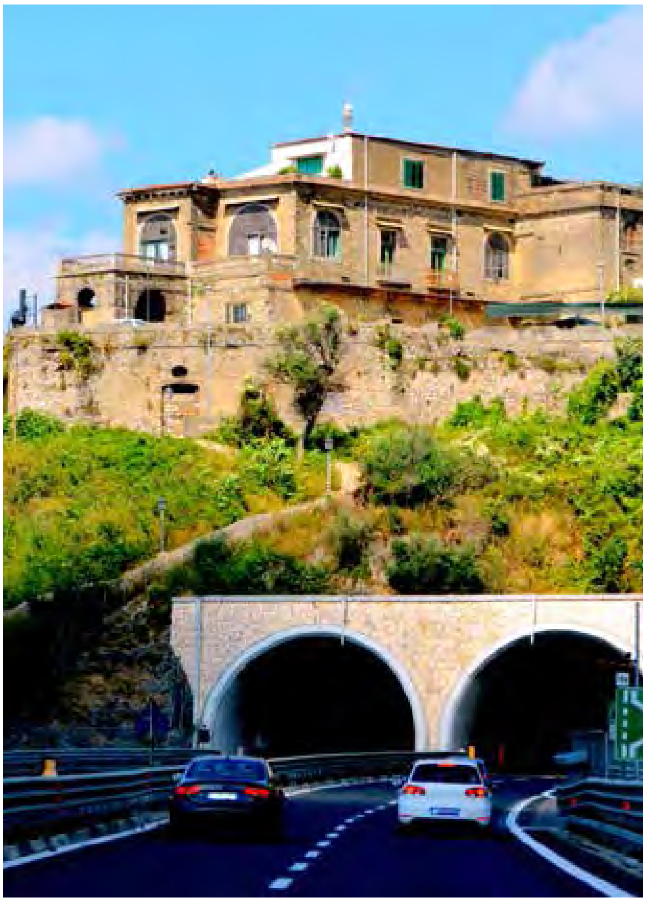
Impact

The Italian standards organisation, UNI, has incorporated this research into a new standard for the illumination of road tunnels. The new standard enables the safe introduction of LED lighting into Italian road tunnels through operation at the reduced light levels identified within the project. In addition to the energy savings introduced through using LEDs over conventional lighting, the reduced operating power leads to a further 33% reduction in electricity consumption.

With LED lighting already introduced into approximately 95% of Italy's 1,500km road tunnel network, this standard will lead to safer roads with significantly reduced power consumption and associated CO_2 emissions.

Metrology for solid state lighting

The EMRP project *Metrology for solid state lighting* aimed to encourage uptake of energy efficient lighting in the form of SSL by providing user confidence in performance claims through good metrology. The project focussed on four interconnected objectives, which provide the foundations for a reliable SSL measurement infrastructure across Europe: definition of suitable quality metrics in which to properly express the performance of SSL lighting systems; investigation of the correlation between proposed physical quality metrics and the human perception of light; development of measurement methods for the reliable measurement of the relevant quality metrics; and the establishment of traceability for SSL measurements through dedicated facilities, instruments and calibration methods.



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European Metrology
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Delivering Impact

Improving power plant efficiency

Despite increases in renewable energy generation, large-scale power plants based on nuclear or conventional fuel provide about 80% of the electricity generated in the EU and are expected to continue to form the backbone of Europe's energy supply over the coming decades. Alongside continued efforts to increase renewables, improving the efficiency of these plants will lower the cost of energy for consumers and reduce greenhouse gas emissions.

Europe's National Measurement Institutes working together

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Challenge

One way to significantly increase plant efficiency is through better measurement of water temperature and flow rate. In nuclear power plants, water is taken in from natural sources (such as lakes and rivers) and pressurised and heated, before being converted into steam in the reactor vessel and used to generate electricity in the turbine hall. Temperature and flow rate of this water must be carefully monitored to ensure efficient plant operation.

Typically, these measurements rely on temperature sensors mounted at fixed points throughout the plant's pipework, giving information at the sensor's location rather than the overall system performance. Operational conditions are also very different to those in which flow meters are calibrated and must be accounted for with extrapolation models, which can lead to inaccuracies in plant measurements. Improved measurements of both temperature and flow rate in a plant's pipework system will give plant operators a better understanding of the system, allowing them to optimise processes and improve efficiency.

Solution

The EMRP project *Metrology for improved power plant efficiency* developed new methods at PTB in Germany and SP in Sweden which allow flow meters to be accurately calibrated in a water pipe simulating typical nuclear power plant operating conditions. KROHNE, a leading manufacturer and supplier of industrial process instrumentation, has used the new methods to demonstrate the accuracy of an improved flow meter, developed by KROHNE following participation in the project.

Besides measuring flow rates, KROHNE's improved flow meter now has the capability to measure fluid temperature using ultrasound. This novel feature can measure average temperatures over a pipe cross-section, rather than just the single point at which the sensor is located. This allows plant operators to monitor temperatures more accurately, and optimise processes based on precise measurements. The validation of the ultrasonic technology in the new facility provided KROHNE with the impetus and confidence to start production of its improved flow meter.

Impact

KROHNE's flow meter has been sold to major electricity provider, E.ON. E.ON is currently trialling the flow meter in one of its plants, to compare its temperature measurement performance against the plant's existing sensors. On-site temperature testing is a requirement before regulatory approval can be granted and the ultrasonic flow meter can be introduced to the wider market as a recognised temperature sensor.

Preliminary indications are that operational efficiencies resulting from the flow meter's use would be around 60 MW, equivalent to the electricity required to power 10,000 extra homes. This is a significant improvement in plant efficiency, and given Europe's dependence on large-scale power plants for the foreseeable future, an important contribution to the efforts to reduce Europe's carbon footprint.

Metrology for improved power plant efficiency

The EMRP project *Metrology for improved power plant efficiency* focused on reducing the uncertainty in measurements of important control parameters used in the operation of power plants, such as temperature, flow rate, thermal energy and electrical output, and researching advanced materials for use in future turbines. The results of the project are expected to contribute to a 2-3% improvement in energy efficiency for all types of large power plant, and a comparable reduction in CO_2 emissions.

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European Metrology Research Programme
Delivering Impact

Next-generation nuclear power

Nuclear power plants play a vital role in securing a stable supply of energy across Europe, generating almost 30% of all electricity and over half of low-carbon electricity produced in the EU. To maintain Europe's world-leading position in nuclear energy technology and to realise the EU's ambitious 2050 low-carbon vision, researchers are developing next-generation nuclear technologies to enable increased electricity production with reduced waste reprocessing requirements.

Europe's National Measurement Institutes working together

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Challenge

The next generation of nuclear reactors currently under development, known as Generation IV, will use a closed fuel cycle, where spent fuel is reprocessed and reused. This conserves natural resources, minimises nuclear waste and hinders nuclear proliferation.

Generation IV reactors will operate at higher radiation levels and temperatures than current reactors to achieve improved efficiencies. Existing temperature sensors, used to monitor conditions in the reactor core and ensure plant safety, are largely based on technologies developed 30 to 40 years ago and cannot be reliably used at the temperatures and radioactivity levels inside Generation IV reactors. New sensors, capable of withstanding the harsher reactor environment, need to be developed and validated under real operating conditions before Generation IV technology can be deployed.

Solution

The EMRP project *Metrology for new generation nuclear power plants* developed new temperature sensors and measurement methods. It focused on extending measurement ranges to higher temperatures and reducing sensor drift in the high-temperature environments encountered in Generation IV reactors. During the research project, Dr Michele Scervini at the University of Cambridge developed, tested and patented a new temperature sensor, capable of operating at temperatures up to 1300 °C.

Impact

Idaho National Laboratory, a key nuclear research laboratory, is validating in 2016 and 2017 a new nuclear fuel for the Very-High-Temperature Reactor - a Generation IV reactor - in its Advanced Test Reactor located in Idaho. This is one of only a few facilities of its sort in the world and, following initial performance trials, Idaho awarded Cambridge the opportunity to test their new sensor in a realistic Generation IV high irradiation and high temperature environment.

The trial will demonstrate the sensor's ability to perform reliably in Generation IV operating conditions, giving confidence to the nuclear industry, for which reliable product performance is of the utmost importance. Increased industry adoption of the technology will help ready the nuclear industry for safe and effective operation of future plants using Generation IV technology, and pave the way to more efficient generation of low-carbon energy for Europe.

Metrology for new generation nuclear power plants

The EMRP project *Metrology for new generation nuclear power plants* provided the necessary metrology infrastructure to help suppliers and regulators develop a safe and secure energy supply using new generation nuclear power plants. The project addressed the challenges posed by Generation IV reactor designs by testing temperature measurements and materials for suitability, and developing new sensors and techniques for measuring temperature and radioactivity in high-temperature, high-neutron flux environments.

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European Metrology Research Programme
Delivering Impact

Supporting biofuel-ready vehicles

The Renewable Energy Directive requires all EU countries to ensure that 10% of their transport fuel comes from renewable sources by 2020. Biofuels, such as biodiesel and bioethanol, will be instrumental in helping countries meet this target, reducing greenhouse gas emissions and improving the security of Europe's energy supply.

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Challenge

Biofuels are gradually being introduced across Europe's transport sector through low-level blending with conventional fuels – of bioethanol in petrol and biodiesel in diesel. Ahead of large-scale implementation, given the significantly different chemical and physical properties of biofuels, we need a better understanding of how they affect engine performance, reliability and safety to build consumer confidence.

Higher proportions of bioethanol in a vehicle's fuel mix can lead to engine corrosion. To overcome this problem, engine developers need to identify materials which can effectively resist the corrosive effects of bioethanol and be used to build safe, efficient biofuel-ready engines. This depends on developers being able to reliably assess the level of corrosiveness of a given bioethanol blend.

The pH value of bioethanol (pHe) can be used as a quick and simple indicator of its corrosiveness, but conventional methods for measuring pH values cannot be applied to bioethanol and, until recently, no internationally-accepted reference methods existed to support accurate, comparable pHe measurements.

Solution

The EMRP project *Metrology for biofuels* developed a reference method to serve as a best practice example for making pHe measurements. These practices have been incorporated into the new ISO standard (17315:2014), Petroleum products and other liquids - Ethanol - Determination of total acidity by potentiometric, enabling users to make pHe measurements of the highest accuracy and reliably compare them across the world.

Impact

International adoption of the new reference method through the ISO standard will enable engine developers to accurately measure the corrosiveness of bioethanol and reliably compare the ability of materials to resist its corrosive effects. Developers will then be able to confidently identify the most suitable materials for use in next-generation engines, built to withstand bioethanol blends.

By enabling the development of biofuel-ready engines and building consumer confidence, this new measurement capability will support higher levels of biofuel blending in Europe's transport fuels. This is an important step towards the increased adoption of low carbon biofuels across Europe, which will be crucial to meeting EU targets for renewable transport fuels.

Metrology for biofuels

The EMRP project *Metrology for biofuels* has made important steps towards European and international harmonisation of the measurement methods for biofuels and their blends with fossil fuels. In addition to pHe measurements, validated, reliable and traceable methods were developed to measure a range of the physical and chemical properties of biofuels, particularly those used in the automotive and aviation sectors.

The results of this research will accelerate the expansion of new technologies, such as engines designed to run efficiently on biofuels. Furthermore, the development of traceable methods for biofuels will help prevent economic subsidy fraud, where subsidies for producers are falsely claimed, and improve investor confidence.

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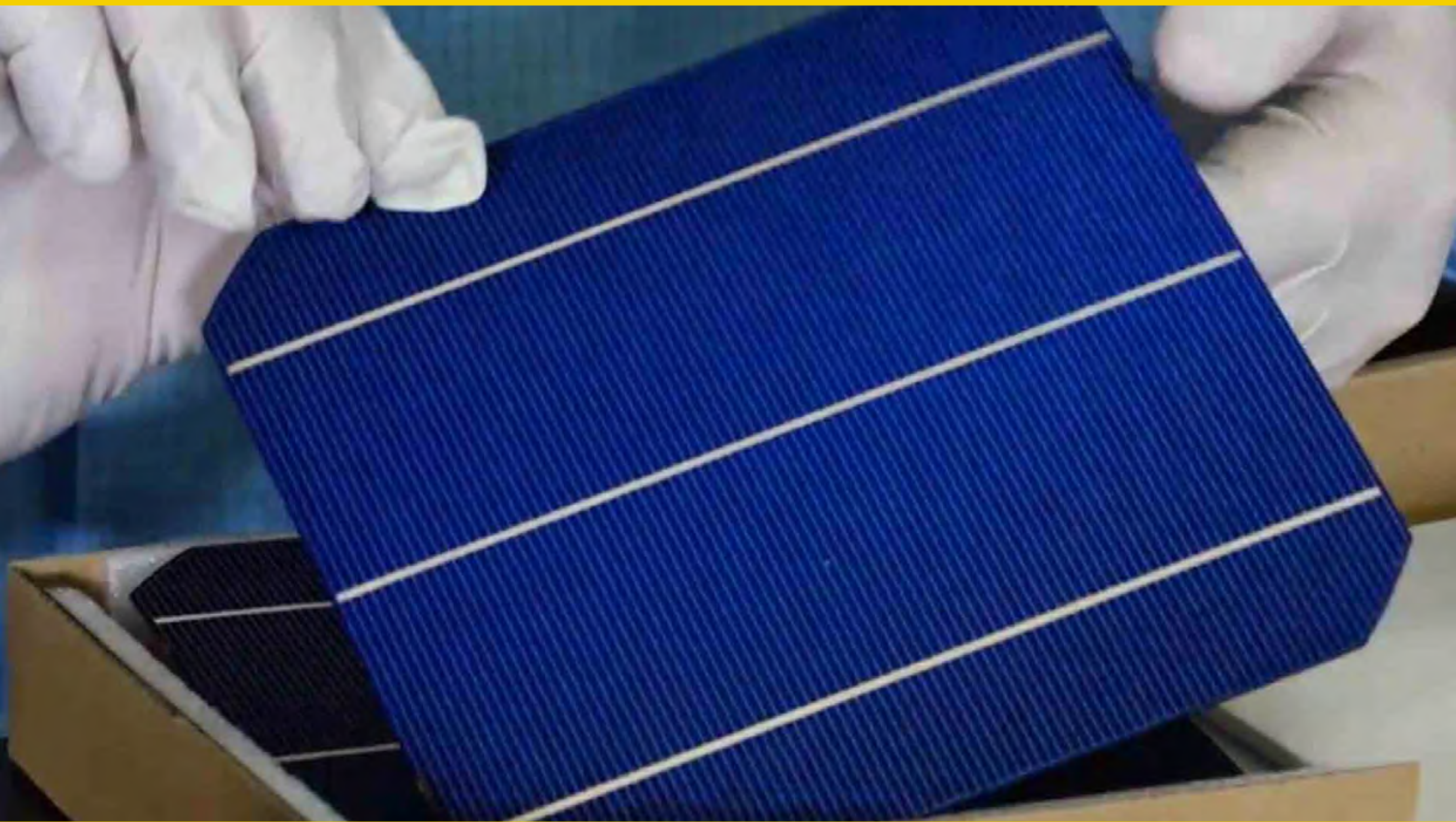

Faster solar cell product development

Recent growth in solar electricity generation capacity was achieved in part from subsidies, that reduced silicon cell costs by stimulating manufacturing efficiencies. Future cost reductions may need to be driven by increased cell efficiency. Multi-junction solar cells are used in high-end space applications where compactness and efficiency are critical requirements. Higher efficiencies could result in such cells becoming cost-competitive with conventional energy sources, but development was slowed by an impractical standard calibration method.

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Challenge

Multi-junction solar cells (MJSC) are made up of layered semiconductors that, together, absorb a wider range of solar energy than silicon alone. Higher energy conversion efficiencies for this type of cells are predicted, that, in time, may enable photovoltaics to become cost-competitive with conventional energy sources. Manufacturing and material advances could lead to breakthroughs, but the process requires precise measurements of cell characteristics. However, development was slowed by an impractical industry-standard calibration method.

MJSC efficiency is measured using solar simulators, that are calibrated using standard solar cells, that, in turn, were calibrated onboard high-altitude balloon flights. This standard had the advantage of removing effects of the atmosphere on incident sunlight but air safety regulations limited flight opportunities, meaning there had only been one flight available between 2005 and 2019.

Measurement of efficiency is critical to MJSC commercialisation, as errors translate in the market to considerable costs from under or over-supply of energy. In a competitive environment where speed to market is essential, a new standard was urgently needed, providing at least the same calibration certainty as for the existing method.

Solution

The EMRP project *Metrology for III-V materials based high efficiency multi-junction solar cells* applied laboratory-based, differential spectral responsivity (DSR) calibrations, using laser-based spectral measuring methods to establish a 'synthetic' multi-junction solar cell calibration standard.

This standard achieved measurement uncertainties comparable to balloon flight calibrations, that could be performed in the laboratory.

Calibration procedures and measurement uncertainty budgets were also included in a good practice guide on multi-junction reference solar cell calibration methods.

Impact

AZUR SPACE, the German manufacturer of high-performance MJSCs for satellite applications, provided solar cell assemblies for use as reference cells for the project. It subsequently contracted project partner PTB to provide ongoing calibration services for its reference solar cells. At the time of writing, this has involved the delivery of four-junction MJSCs on which to perform qualifications and product characterisations, that led to the commercialisation of new cell designs.

Airbus Defence and Space is already a customer and agreed to use AZUR SPACE's four-junction design to power its Neosat telecommunications satellite scheduled for launch by the European Space Agency before the end of 2021.

AZUR SPACE commented that the new synthetic calibration method has become essential for the photovoltaic industry, especially as safety rules continue to limit opportunities for operating balloon flights.

Since 2007, AZUR SPACE has disseminated its technologies developed for the space market to the terrestrial concentrated photovoltaic market, that is a growing part of its business.

Speed is of the essence in solar photovoltaic product development. The new calibration standard for multi-junction solar cells has allowed AZUR SPACE to plan and provide more certainty for its product development process. In the context of a global solar PV market expected to be worth US$134 billion by 2021, higher efficiency cells will, in time, disseminate to the terrestrial energy market, enabling higher returns on investment for end-users, reduced land use requirements, and further growth in overall solar photovoltaic generation capacity.

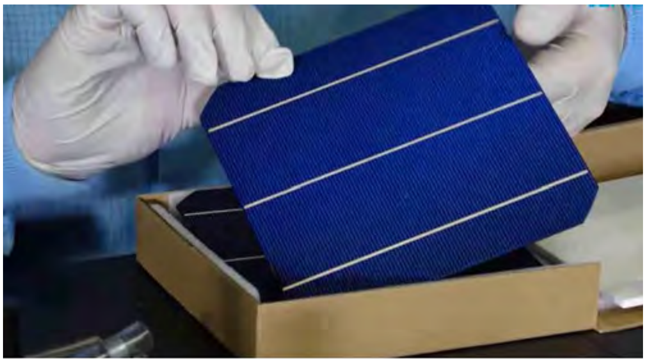
Metrology for more efficient solar cells

The EMRP project *Metrology for III-V materials based high efficiency multi-junction solar cells* developed a range of metrological techniques to support the development of more efficient photovoltaics.

Prior to the project, multi-junction solar cells were recognised as a promising solar cell technology but lacked reliable methods to measure some important properties, including efficiency.

The project developed traceable, reliable, cost-effective calibration methods, and measurement standards, to measure MJSC device efficiency, and other parameters, providing equivalent confidence levels as for silicon cells. Good Practice Guides for MJSC calibration procedures were also produced.

Outputs of the project also included new types of connectors between cells, new modelling methods to understand the movement of electrons across connectors, and new methods to accurately measure electrical properties of MJSCs at the nanoscale.



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12458/0819 - ENG51

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Improved calibrations for solar cells

Solar power offers the potential to be the world's largest source of power by 2050. This would require the adoption of new technologies; including materials other than just silicon or cells composed of multiple layers to increase efficiencies. To validate the performance of these advanced solar cells, essential to promote the uptake of this type of renewable energy, will require new or improved reference cells for calibrating them.

Challenge

The International Energy Agency predicts that by 2050 solar power could cover 69 % of electricity generation, making it the world's largest source of power. For this to happen it will require multiple approaches such as reduced installation costs, increased solar cell efficiencies or the adoption of new technologies.

New types of solar cells, or photovoltaics (PV), entering the market often have an extended or different 'spectral response' to solar irradiance compared to the silicon semi-conducting materials conventionally used. The spectral response is the amount of electricity a cell will produce when exposed to various wavelengths of light. When the response of a PV reference device is significantly different to the cell or module under test this can affect the accuracy of the calibration. As traceable calibration and testing is the basis of assuring the worldwide comparability of efficiency and power output, inaccuracies in this can adversely affect confidence in PV technology as a reliable source of energy.

Improved reference standards for use in both existing and emerging PV technologies are therefore required to encourage the uptake of this source of power.

Solution

The EMRP project *Towards an energy-based parameter for photovoltaic classification* developed new photovoltaic (PV) reference devices with a greater stability and a wider operating spectral range than previously available.

Five silicon solar cells, with different technological variations, were selected by project partners as candidates for use as an improved reference device. Optical properties were then investigated and the most suitable chosen for further optimisation. The silicon in the cell was changed to a different variant which had an improved tolerance to degradation during continuous operation. The thermal conductance of the housing of the proto-type cell was improved two-fold – important to maintain a uniform device temperature under different measurement conditions.

The device was then compared to different PV technologies and the spectral filters, which allow a reference cell to be 'tuned' to match the spectral response of any of the solar cell technologies, were optimised.

Impact

Fraunhofer ISE, the largest solar research institute in Europe, incorporated these improvements into their World Photovoltaic Scale (WPVS) cells; which are used by industry and research institutions all around the world. The WPVS represents the international standard for calibrating solar reference cells to ensure their accuracy and robust traceability to the SI. Different versions of Fraunhofer ISE cells are available which can be selected to match the measurement situation. Additional optical filtering allows the cells to match its spectral response to any module technology, both indoors and outdoors.

These new reference cells, with improved stability and greater accuracy, will contribute to the confidence of measurements made regarding a solar cell's performance. This in turn will encourage the continued uptake of new and emerging solar technologies to meet the targeted market share of renewable energies.

New energy ratings for solar cells

The EMRP project *Towards an energy-based parameter for photovoltaic classification* set out to determine how photovoltaic cells (PVs) could more realistically be measured to quantify operation in the real-world. PV performance was assessed at different climate zones across Europe, incorporating module temperature, angle of the sun and different solar intensities. The data obtained led to the development of a new model for PV rating based on energy output, rather than peak power under fixed conditions.

The project produced new facilities, calibration devices and three good practice guides on making improved measurements. Data from the project was also incorporated into three new international standards in the IEC 61853 series. These new PV ratings, which more closely match a cells performance to the conditions under which it will be deployed, will increase confidence and aid in the competitiveness of this technology.

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European Metrology Research Programme
Delivering Impact

New standards for solar power

Europe aims to generate at least 32% of energy from renewables by 2030 and solar power will significantly contribute to meeting this target. It has been estimated however that for each percentage point of uncertainty between the predicted to actual energy yield by photovoltaics equates to a financial uncertainty worth €500 M a year globally. Decreasing this will reduce financial risks for investors and stimulate uptake of this technology.

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Challenge

The EU's renewable energy directive sets a binding target that at least 32 % of energy consumed in Europe comes renewable sources by 2030.

Electricity generated from solar cells, also known as photovoltaics (PV), will have a vital role but will require an increased uptake of PV technologies. Operators of solar parks need accurate forecasts of the energy likely to be generated from PV modules and since the 1980s such estimations were based on the claim of a module's peak power output, as measured under Standard Test Conditions (STC).

However, STC measurements are based on single, fixed values for module temperature, solar irradiance and solar spectrum characteristics. These affect the energy output from a cell but do not reflect the actual operating conditions in Europe where a range of climates are present.

This can result in a module generating less electricity than has been predicted under STC measurements which can lead to uncertainty when installed in solar parks. This mismatch has financial implications and it has been estimated that each percentage point of uncertainty between the predicted and actual power output equates to a financial uncertainty worth €500 M a year globally.

Incorporating improved measurements for PV performance, that better reflect the energy a module produces during its lifetime, are needed to reduce this economic burden.

Solution

The EMRP project *Towards an energy-based parameter for photovoltaic classification* (PhotoClass) set out to develop a new metric for PV devices more representative of real-world operating conditions.

The project examined various factors effecting the energy output of PVs including the angle of light striking the cell and module temperature. The spectral response over a wide range of irradiances was examined, suitable for PVs that incorporate non-silicon technologies. New measurement facilities were then developed, and the data was validated with robust links to the SI. Based on ground and satellite information the effects of climate at various latitudes around Europe on PV output was assessed - allowing the creation of a Climate Specific Energy Rating (CSER) for solar cells. These new measurement methods, combining device properties, tabulated irradiance and environment data, generated a new energy rating based on standardized energy yields for different climate zones, rather than unrealistic peak power output for PV devices.

Impact

The International Electrotechnical Commission (IEC), that develops international standards for electrical and related technologies incorporated data from the project into three new standards of the IEC 61853 series for PV modules. These three standards, the development of which was led by members of the EMRP project PhotoClass, establish the specifications for determining PV performance, energy rating and CSER and are applicable to all PV technologies. Adherence to International standards constitutes one of the important bases for the removal of technical barriers to trade and the adherence to them is recommended by the World Trade Organisation.

Solar module manufacturers throughout the world are now beginning to produce their products using these additional measurement requirements. These new PV ratings will allow investors the ability to more closely match a module's performance to the conditions of the location under which it will be deployed, reducing financial uncertainty and stimulating the uptake of new and existing PV technologies.

New energy classifications for solar cells

The EMRP project *Towards an energy-based parameter for photovoltaic classification* (PhotoClass) measured the energy output of Photovoltaic cells (PVs) under a range of environmental parameters such as different module temperatures, solar intensities and performance at different climate zones across Europe. This allowed the development of a new model of PV rating based on energy output rather than peak power under fixed conditions. From this, new calibration devices and facilities were developed to provide improved measurement services for PV modules along with three new practice guides. Members of the project led the development of three new international standards in the IEC 61853 series. These new PV ratings, which more closely match a cells performance to the conditions under which it will be deployed, will decrease financial risk for investors, increase confidence and aid in the competitiveness of this technology.

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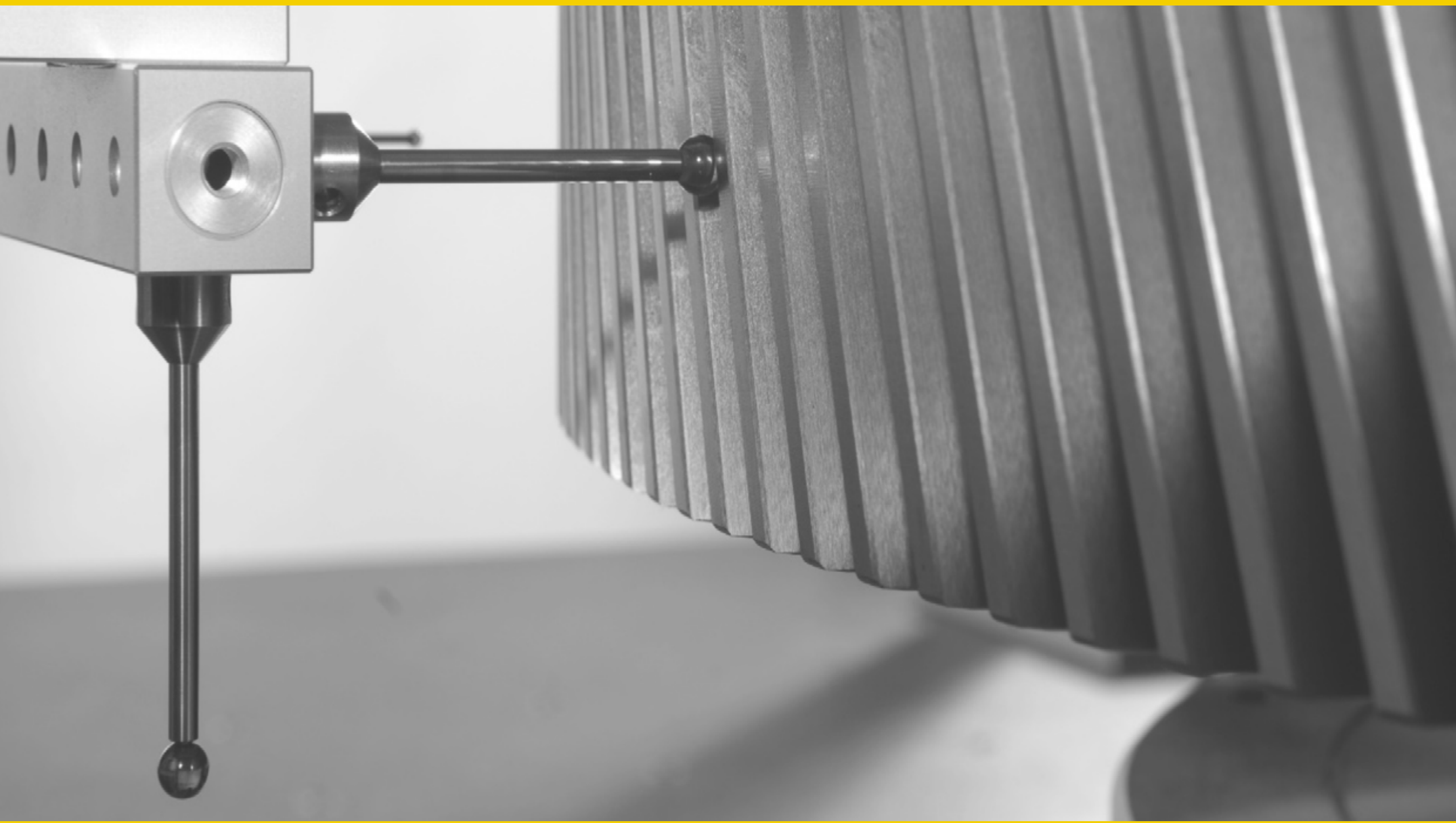


Reliable measurement of turbine gears

Wind-powered electricity generation capacity grew rapidly over the last decade and will need to continue to grow to help meet future targets of the EU's renewable energy directive. However, manufacturing quality issues of the gearing used in wind turbines limited overall reliability and, therefore, returns on investment. Manufacturers lacked processes for producing measurement standards for these large components, while written standards didn't suit the complexities of measuring gear quality.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

While the EU is on course to meet its 2020 target of sourcing 20 % of its total energy consumption from renewable sources, electricity generation capacity will need to continue to grow to meet the next renewable energy directive binding target of 32 % by 2030.

The amount of electricity generated by wind energy systems (WES) has increased by 350 % over the last ten years, but few wind turbines reach the desired lifetime of 20 years without two or more failures, often due to reliability issues in drivetrain components. The competitiveness of the wind sector is diminished by production downtimes that last days or even weeks, reducing income and adding significant maintenance costs.

These systems are large to optimise energy output, yet, in contrast to the automotive sector, manufacturers lacked processes for producing drivetrain components to a consistently high standard. Irregularities in the surface of gears can reduce the durability of these highly-stressed components. Also, the coordinate measuring machines (CMMs) used to measure gear quality weren't optimised to measure some types of surface imperfections, while written standards didn't address factors such as temperature variations and gravity, limiting inspection quality and reducing trust among users of these high-cost devices.

Solution

The EMRP project *Traceable measurement of drivetrain components for renewable energy systems* improved drivetrain component reliability by developing new measurement strategies, new measurement standards and new procedures providing traceability to the SI.

Ten measurement standards were developed and optimised for industrial use, capable of robustly calibrating gear size, form, and surface irregularities of large drivetrain components.

Six good practice guides established and quantified the main sources of uncertainty influencing industrial measurement capability using CMMs, including for effects of temperature and gravity.

Impact

Before participating in the project, Zeiss Industrial Quality Solutions – the leading manufacturer of multidimensional metrology solutions – applied its own strategy for measuring large gears, but this method only offered indirect traceability.

The project enabled Zeiss to improve its software, add functionality to a controller and a sensor feature. Significantly for the company, another outcome was confirmation of its business strategy. The project's comparison of different CMMs using the new standards renewed confidence in own capacity to provide traceability and reliability, and, therefore, enhance trust in its measurement capabilities among its customers in the wind market.

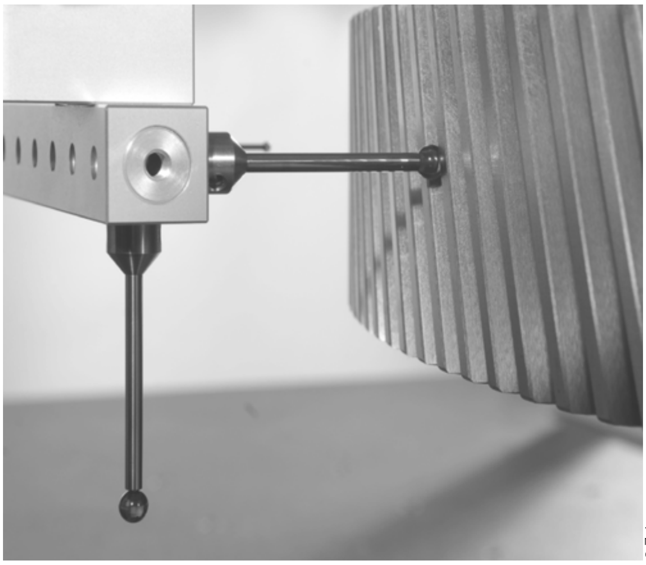
There was also a direct market impact for Zeiss. The collaboration resulted in the sale of a Xenos CMM to Czech Metrology Institute for a newly accredited gear calibration service. In the context of a global CMM market experiencing 6.7 % growth according to Index Markets Research, real increases in sales were detected, as Zeiss generated above 10 % annual sales growth of its CMMs business over the last five years.

Traceable measurements will improve WES performance by advancing quality control in manufacturing processes, generating sales for measurement equipment and calibration suppliers. New procedures will lead to improved wind turbine reliability, enabling higher returns on investment that will incentivise the growth of this type of zero-carbon electricity generation, while helping European states meet renewable energy commitments.

Metrology for reliable wind energy systems

The EMRP project *Traceable measurement of drivetrain components for renewable energy systems* developed measurement techniques for wind energy system (WES) components and traceable measurement standards to enable manufacturers to increase component reliability.

The project developed the first ever measurement standards and calibration procedures capable of establishing traceability and measurement uncertainty for WES gears and bearings. It also established traceability and uncertainty estimations for WES drivetrain components; developed design modules and numerical models to simulate sources of error in measuring large components; and developed and tested Good Practice Guides for measuring dimensional and surface properties of WES drivetrain components.



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Improving wind turbine reliability

Wind power capacity has grown rapidly over the last decade and will need to continue to grow in line with efforts to meet EU targets for renewable energy generation. However, manufacturing quality issues of the gearing used in wind turbines limited overall reliability and returns on investment. Manufacturers lacked suitable measurement standards for these large components, while the complexities of measuring gear quality undermined confidence in measurement solutions.

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Challenge

Although the EU is on course to meet its renewable energy directive 2020 target of 20 % of its total energy consumption to be sourced from renewable sources, expansion in generation capacity must continue to reach the equivalent 2030 target of 32 %.

Electricity generation by wind energy systems (WES) has increased by 350 % over the last ten years, but few wind turbines reach the desired lifetime of 20 years without two or more failures of major drivetrain components. The resulting downtimes last days or even weeks, reducing income and adding significant maintenance costs, particularly for offshore installations.

Wind energy systems are large to optimise energy output. Transferring power effectively between turbine blades and generator, requires WES drivetrains (bearings, shafts and gears) to be correspondingly large. In these highly-stressed conditions surface irregularities cause reduced lifetimes, as, in modern steels, failures tend to be initiated at the surface. However, manufacturers lacked processes for producing these components to consistently high standards.

To ensure sufficient quality, coordinate measuring machines (CMMs) are used to measure these components. However, environmental conditions, such as variations in temperature that influence acclimatisation times, can affect measurements. Also written standards didn't address some crucial factors, limiting inspection quality and reducing trust among users of these high-value devices.

Solution

The EMRP project *Traceable measurement of drivetrain components for renewable energy systems* improved drivetrain component reliability by developing measurement standards and procedures that provided traceability to SI units. This was achieved by enabling reliable estimations of measurement uncertainty.

The developed measurement standards were optimised for industrial use, to calibrate gear size, form, and surface irregularity parameters of large drivetrain components.

Virtual measuring processes were developed to traceably measure large drivetrain components, to minimise measurement errors. Numerical simulations and practical experiments to overcome environmental effects were also performed to produce recommendations for improved CMM scanning parameters.

New algorithms developed for incorporation in CMM control software were made available to suppliers. Guidance, including on thermalisation times of large gear and large ring measurement standards, was published in six Good Practice Guides.

Impact

Hexagon Manufacturing Intelligence, the leading metrology and manufacturing solutions provider based in Wetzlar, Germany, considers its Leitz CMMs the most accurate products in the CMM market. Maintaining that lead was a significant motivator for participating in the project.

As a result, Hexagon enhanced its gear evaluation software and gear evaluation plots to offer higher quality inspections and more reliable results. A developed algorithm was incorporated into its *QUINDOS Gear* software and made available to all of its customers.

Users previously experienced challenging thermal drift effects, that reduced measurement reproducibility. The Good Practice Guides proved helpful for guiding Hexagon's customers and potential customers by providing reassurance in instrument performance as well as improved inspection quality.

Hexagon was told that about half of its 2019 sales of large Leitz Gantry CMMs were positively influenced by its involvement in the project.

Ultimately, traceable measurements will lead to improved quality and reliability of manufactured WES components. This will enable higher returns on investment from wind energy systems, support expansion of this type of zero-carbon electricity production and help EU states meet renewable energy commitments.

Metrology for reliable wind energy systems

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A new calibration for current sensors

Lowering carbon dioxide emissions from fossil fuels requires an increased use of renewable sources for electricity generation. Integrating these non-conventional energy sources into the grid can cause problems with supply security and power quality. New current and voltage sensors are needed to monitor network performance, and these will require different calibration methods to ensure their accuracy and traceability to the SI.

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Challenge

Europe aims to generate at least 32 % of energy from renewables by 2030 but traditional power networks find it difficult to incorporate these sources of energy which can be variable and bi-directional. This can produce harmonics that distort the AC current already flowing through the grid which compromises the power quality and lead to blackouts or outages in supply. To address this new smart grids are being rolled out that can monitor and respond to changes in the network in real-time. However, these grids require a new generation of current and voltage sensors to monitor their stability and performance. In turn these novel sensors require new ways to calibrate them to ensure their accuracy and traceability to the SI.

A Rogowski Coil (RC) is a type of current sensor that can withstand a wide range of voltages, react to fast changing currents and is not damaged by large over-loads. These have the potential to be used both as a sensor for electrical networks or as a calibration device for other sensors. However, the accuracy of a RC can be affected by external currents or magnetic fields near the coil which has limited their use.

Solution

The EMRP project *Non-conventional voltage and current sensor for future power grids* tested a number of emerging technologies designed to monitor electrical networks.

During the project a magnetic shield for a RC was developed which reduced the interference from external currents down to 10 µA/A, or 10 parts per million, which is a 100-fold improvement on existing coils.

The calibration performance of the improved coil was then validated in test setups at both high and medium voltage levels. TÜBİTAK UME, the National Measurement Institute of Turkey, now has an accredited Calibration and Measurement Capability (CMC) for using the coil and now offers a calibration service using this device.

Impact

One of the first users to take up TÜBİTAK UME's new calibration service was ALCE Elektrik, a global supplier of services and instrumentation to the energy sector, which counts major industrial companies such as Siemens, ABB, Alfanar and GE amongst its clients.

The company approached TÜBİTAK UME, as an impartial National Metrology Institute, to assess a novel current sensor it had developed for medium level voltages. A successful test series against the RC validated the new sensor's performance and the data obtained led to further improvements in the device. *ALCE* Elektrik anticipates that the prototype sensor will be released in 2020 and gain an eventual 20 % market share in Europe. Based on this the company predicts that these sales will generate 1,000,000 € per year - comprising 2.5 % of the company's annual sales.

The successful use of RCs as a calibration standard for non-conventional current sensors represents a significant step forward for validating the new types of measurement instruments required for the power grids of the future.

Novel sensors for smarter power grids

The EMRP project *Non-conventional voltage and current sensor for future power grids* examined emerging measurement technologies required for monitoring the smart electrical grids that are being introduced to better integrate sources of renewable energy. Novel optical current and voltage sensors were developed with the potential to monitor networks over larger distances than conventional instruments. As well as these, a 100-fold improvement in shielding against environmental interference for a non-conventional current device, used for calibrating high and medium voltage transformers, was also demonstrated. As a result, the national measurement institutes PTB, METAS, TÜBİTAK UME, VSL and MIKES now provide calibration services for new types of sensors. These advances in instrument technology and calibration capabilities will enable the real time monitoring of the power grids of the future and enable delivery of a stable, sustainable and secure electricity supply.

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New instruments for new power grids

Electricity from renewables is helping reduce the emissions that would otherwise be produced from fossil fuels, but network operators struggle in integrating these more distributed sources of energy. One solution is to use smart grids capable of monitoring and responding to network conditions in realtime, helping to increase stability and optimise efficiency. However, realising these grids requires the development of a new generation of measuring instruments.

Europe's National Measurement Institutes working together

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Challenge

Traditional power grids transmit electricity from a central power plant over transmission lines to substations, from which power is distributed to consumers. This one-way flow lacks real-time monitoring and is not optimised with over 6% of the energy generated lost during transmission. These grids also struggle to integrate the energy from renewables, such as wind or solar power, which are more distributed and can cause harmonics or surges of power leading to outages and failures. One way to address these problems is using smart grids, with digital control technologies, that can monitor the networks in real time, make automatic changes that reduce energy waste and allow them to operate at higher capacities. However, existing measurement instruments were not designed for these tasks, and new, accurate and SI traceable devices are required to control the additional demands of a more distributed network where power sometimes flows in different directions.

Solution

The EMRP project *Non-conventional voltage and current sensor for future power grids* examined emerging measurement technologies capable of monitoring the state of electrical networks; from the high voltage transmission grid to the medium and low voltages of the distribution grid. One output from the project was the development of novel optical current and voltage sensors for distributed measurements on the power grid.

Conventional optical sensors are based on polarimetry, which measures polarised light, and is not suitable for long 'step-out' distance measurements. The novel sensors do not use this principle and instead can utilise the existing optical telecommunication fibres that are typically integrated with the power system. Furthermore, the sensors are passive, not requiring a separate power supply at the measurement points.

Impact

Synaptec, a company that makes high-performance instrumentation for network monitoring, took up further development on the current and voltage sensors. As part of a consortium, formed through a Innovate UK Energy Catalyst project, three current and three voltage sensors were installed at the Power Network Demonstration Centre (PNDC) in Scotland and validated for use in the medium voltage network (11 kV) of the electrical distribution grid. The live-testing of the current sensors will soon be demonstrated in pilot projects with the European grid operators Statnett in Norway and SSE in the UK.

Synaptec's secondary-connected current sensor is now part of a large Ofgem funded project with partners including GE Grid Solutions and the grid operator SP Energy Networks, that aims to develop an efficient and effective digital substation of the future.

This sensor technology has since been developed to the point where up to 50 current and/or voltage sensors can be daisy chained along a network allowing monitoring of an unprecedented 100 km of the power grid. This advance in technology will facilitate the novel system protection, control and diagnostics features required for the smart grids of the future.

New instruments for new power grids

The EMRP project Non-conventional voltage and current sensor for future power grids examined emerging measurement technologies capable of monitoring the state of networks that integrate multiple sources of energy. The project demonstrated a 100-fold improvement in shielding against environmental interference for a current-sensing device used for calibrating high and medium voltage transformers. The project also developed novel optical current and voltage sensors with the potential for fault detection in networks over larger distances than conventional instruments. As a result of the EMRP project, two Good Practice Guides on calibrating and installing non-conventional sensors have been developed to assist and support those working in this developing field. These advances in technology will enable the real-time monitoring of smart grids, aid integration of energy resources and ultimately deliver a sustainable and secure electricity supply, whilst the newly published guides will support those making the transition.

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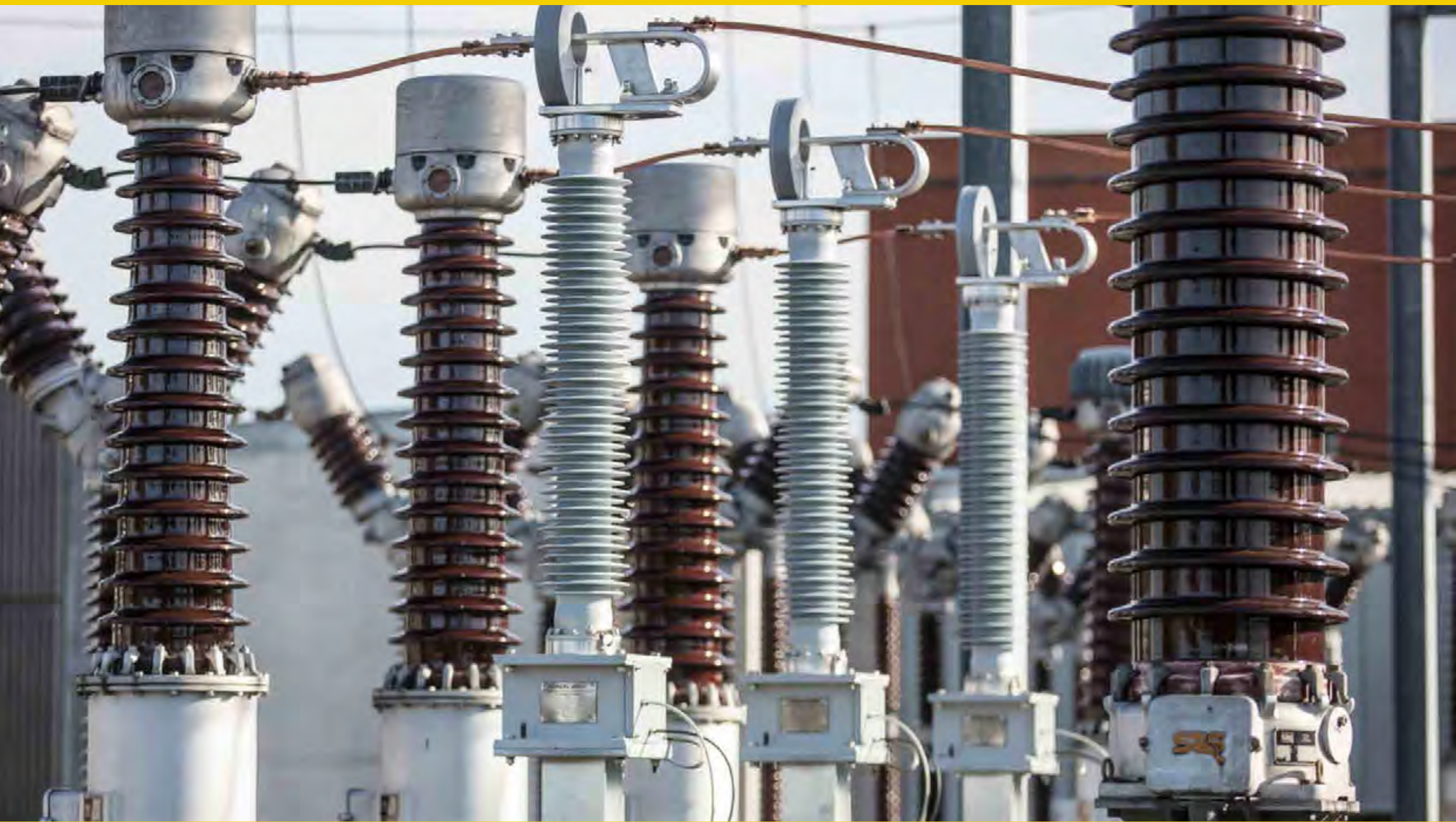

New sensors for the high voltage grid

Conventional electricity grids are being replaced by smart grids which can rapidly respond to changes in electricity flow in real-time and better integrate energy from renewable sources. To monitor these grids a new generation of network sensors, termed 'low-power instrument transformers' are being introduced which must be compliant to international standards. However, the variety of primary sensors, and secondary converters, brings up new challenges for the calibration of such instruments.

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Challenge

The increased use of renewables is problematic for electrical networks as these sources of energy can cause harmonics, where the alternating current (AC) is distorted, leading to outages or degraded power quality. To address this, smart grids are being developed which can help stabilise a network by monitoring it in real-time and automatically react to changes in the electricity flow.

A new generation of measuring instruments are being introduced to help implement these grids, including novel, non-conventional voltage and current sensor technologies. These devices measure the continuous analogue output of the voltage and current transformers and convert it to a discrete sequence of digitised samples. These 'sampled values' are then sent over the internet to instrumentation involved in grid control.

International standards are in place regarding such sensors however there is a lack of calibration services covering all the functions of the new instruments. As calibration is a requirement to demonstrate performance and conformity to standards there is a pressing need to ensure measurement services are available to support the introduction of these new technologies.

Solution

The EMRP project *Non-conventional voltage and current sensor for future power grids* examined emerging measurement technologies capable of monitoring the state of electrical networks.

From project results METAS, the National Metrology Institute (NMI) for Switzerland, developed a set-up, along with software architecture based on **code** created at the University of Strathclyde, allowing the calibration of a wide range of measurement instrument types. The new service allows sensors sending sampled values to establish robust traceability to the international standard IEC 61850-9-2. This standard defines the requirements for the communication protocols for intelligent electronic devices to ensure their interoperability. As instrumentation may be geographically separated or produced by different manufactures this is an essential requirement for the introduction of smart grids.

Impact

CONDIS SA, a Swiss manufacturer and technological leader in the area of high and medium voltage capacitors and solutions, employed METAS to calibrate a prototype Electronic Fiber Optic Current Transformer (EFOCT). This sensor developed by PROFOTECH JSC and manufactured in partnership with CONDIS SA presents an alternative to conventional current transformers and can be configured to a range of different applications. The EFOCT is fully compliant to the IEC 61850-9-2 standard with additional features such as a high frequency bandwidth and an oil-free and compact design. Due to its passive sensor design it does not require active liaison to the grid which greatly increases safety for test operators.

Following METAS' calibration services an independent Swiss laboratory confirmed the high quality of the new device in terms of measurement precision. CONDIS stated that having an official test-report from a renowned measurement institute like METAS will help its entrance into the market for highvoltage instrument transformers that are based on optical measurement technology.

This new calibration service provides traceability to the SI for next-generation network sensors and is a significant step towards ensuring the operational capability of smart grids.

New instrumentation for smart grids

The EMRP project *Non-conventional voltage and current sensor for future power grids* examined the emerging measurement technologies that are required for monitoring the electrical smart grids of the future. It developed novel optical current and voltage sensors with the potential for fault detection in networks over larger distances than conventional instruments. A 100-fold improvement against environmental interference for a current-sensing device, currently used for calibrating voltage transformers, was also demonstrated. Data from the project led to the publishing of two good practice guides on calibrating and installing non-conventional measurement instruments.

The European National Metrology Institutes PTB, METAS, TUBITAK UME and VSL now offer calibration facilities for next generation network sensors, essential for establishing their accuracy and traceability. These services represent a significant step towards ensuring the operational abilities of the power grids of the future.

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Measuring roadside air pollution

Air pollution, such as that generated by road vehicles, is known to harm public health, damage biodiversity and contribute to climate change. In response, Europe has made air pollution one of its main concerns and developed an extensive body of legislation, establishing limit values for major air pollutants such as NO_2 and particulate matter, to improve human health and environmental quality.

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Challenge

Congested areas such as city centres still suffer from elevated levels of certain pollutants - in particular NO_2, which is associated with adverse effects on health including reduced life expectancy. To tackle the problem, Switzerland, a leading player striving towards cleaner air, is introducing improved automotive exhaust emissions monitoring. Authorities in major Swiss cities are striving to monitor emissions at the challenging concentration levels (parts per billion) permitted by European regulation and need improved measurement capabilities.

Instruments used to monitor NO_2 pollution ideally require calibration in-situ to ensure they provide reliable measurements at such low concentrations. But certified low concentration gas mixtures of NO_2 in pressurised cylinders drift over time, meaning that the most reliable way of calibrating monitoring instruments requires accurate levels of NO_2 to be generated on-site. This involves transporting the equipment needed to generate NO_2 out into the field; however, previously, this was a bulky and costly process and unsuitable for some monitor locations.

Solution

As part of the EMRP project *Metrology for chemical pollutants in air (MACPoll)*, METAS (the Federal Metrology Institute of Switzerland) developed a new traceable mobile NO_2 permeation generator, which can be used to accurately produce NO_2-mixtures at the parts-per-billion level into installed monitoring instruments. This simpler approach enables instruments to be easily and reliably calibrated on-site, improving the reliability of their measurements through traceability to national standards.

Impact

The METAS NO_2 generator has already been used by the City of Zürich Health and Environment Department and in other Swiss cities to calibrate installed instrumentation and perform national comparison exercises on behalf of the Swiss Federal Office for the Environment, FOEN. More accurate measurements of NO_2 pollution will support the evaluation of pollution reduction strategies and continue the successful reduction of NO_2 pollution in Zürich city centre and throughout Switzerland.

The Swiss government recently awarded funding to METAS and LNI Swissgas, a leading manufacturer of environmental gas calibration systems and gas generators, to commercialise a novel compact NO_2 permeation generator, which incorporates features of the METAS prototype into LNI Swissgas's existing product, resulting in a fully traceable and user-friendly transfer standard.

The resulting generator could have a significant impact in the pollution monitoring market, which is expected to expand as new micro-sensor technology gains popularity. These small and relatively cheap sensors have the potential to significantly increase the capability of current air monitoring networks and supply real-time data to support public health advice and pollution warnings – warning, for example, against cycling on congested roads at particular times. Ahead of deployment, a portable and compact field calibration instrument is needed to confirm the performance of each NO_2 micro-sensor installed within a network.

The new portable calibration method provides crucial support to this expansion of Europe's air monitoring networks, which is an important step towards more comprehensive pollution monitoring and the effective protection of Europe's citizens.

METAS traceable mobile NO_2 permeation generator

The transportable NO_2 generation system developed by METAS within the EMRP project drives a controlled and stable gas flow through a chamber containing a permeation tube maintained at a constant temperature to produce an accurately-defined NO_2 reference gas mixture. NO_2 concentrations of between 10 and 500 parts-per-billion can be generated, enabling instrument certification at operating conditions for the first time. The new generator has reduced measurement complexity by removing the need for individual gas standards of NO_2 and synthetic air or ozone, which then need to be diluted to the parts-per-billion levels measured in the environment, while reducing measurement uncertainties.

Metrology for chemical pollutants in air

Reliable indoor and outdoor measurements of chemical pollutants in air are required to underpin and implement European air quality legislation designed to protect human health and the environment. The EMRP project *Metrology for chemical pollutants in air* made a significant contribution to fulfilling the air quality objectives of European legislation by establishing the metrological infrastructure needed to produce accurate measurements for robust short- and long-term assessment of a range of indoor and outdoor pollutants.

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European Metrology Research Programme
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Improving the quality of indoor air

Air pollution is harmful to public health, damages biodiversity and contributes to climate change. The EU has developed legislation to improve health and environmental quality. However, while significant progress has been made in improving outdoor air quality, indoor pollutants have received less attention. Given that many people spend the majority of their time indoors, research is urgently needed to enable the regulation, assessment and improvement of indoor air quality.

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Challenge

Volatile organic compounds (VOCs) are a type of organic chemical commonly found in furniture, carpets and paints used indoors. VOCs easily evaporate at room temperature into the air, and given that some are known to cause respiratory problems, the ability to reliably control exposure to VOCs is crucial to protecting public health.

The Construction Products Regulation (305/2011 EU) introduced requirements for VOC emissions labelling of construction materials, but until recently, there was no harmonised labelling scheme or supporting standard test in the EU, resulting in individual member states implementing their own testing schemes. This prevents implementation of the CE mark, which demonstrates that a product complies with EU requirements, hindering trade of construction materials across Europe.

A draft CEN standard (prEN 16516:2015) is under development, which will define a test method for the complete measurement process involved in VOC emissions labelling, from test sample to material certification. Ahead of the CEN standard's introduction by the end of 2016, testing laboratories which issue VOC emissions certificates to construction material manufacturers will need a robust VOC-emitting reference material, in order to demonstrate the traceability of their measurements and comply with the CEN standard.

Solution

In the EMRP project *Metrology for chemical pollutants in air* (MACPoll), BAM (Bundesanstalt für Materialforschung und –prüfung) has developed a new reference material, which reproduces the VOC emitting behaviour of a typical construction product and has the required consistency, stability and transportability that previous reference materials lacked. This enables testing laboratories to validate complete VOC measurement systems in compliance with the forthcoming CEN standard for the first time.

Impact

All testing laboratories across Europe will be able to use the new reference material to demonstrate compliance with the upcoming CEN standard and their ability to carry out robust VOC emissions measurements and certification. This marks the first step towards EU harmonisation of construction product labelling and the implementation of the CE mark for VOC emissions, which will help remove barriers to international trade and ensure reliable monitoring of indoor environments to protect public health.

As one example, eco-INSTITUT performs testing of construction materials, including paints, varnishes and floor coverings, and issues VOC emissions certificates to manufacturers. As part of the project, eco-INSTITUT took part in a comparison exercise organised by BAM , using the new reference material and proposed CEN test method to demonstrate the capability of their VOC emission measurement system. The results of the exercise confirmed eco-INSTITUT's ability to perform traceable measurements of VOC emissions in compliance with the draft CEN standard.

eco-INSTITUT is now implementing the CEN standard ahead of its formal introduction, performing traceable measurements of VOC emissions from construction materials. Manufacturers can therefore be confident in the accuracy of eco-INSTITUT's measurement system, which has been benchmarked against the standard, and the emissions certificates issued for their products.

Metrology for chemical pollutants in air

Reliable indoor and outdoor measurements of chemical pollutants in air are required to underpin and implement European air quality legislation designed to protect human health and the environment. The EMRP project *Metrology for chemical pollutants in air* made a significant contribution to fulfilling the air quality objectives of European legislation by establishing the metrological infrastructure needed to produce accurate measurements for robust short- and long-term assessment of a range of indoor and outdoor pollutants.

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Improved air pollution monitoring

Air pollution, such as that generated by road vehicles, is known to harm public health, damage biodiversity and contribute to climate change. In response, the EU has made air pollution one of its main concerns and developed an extensive body of legislation to improve human health and environmental quality. Central to this regulatory framework is the European Air Quality Directive (2008/50/EC), which establishes limit values for major air pollutants such as NO_2 and particulate matter.

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Challenge

Pollution from road vehicles is regulated to protect ambient air quality and new passenger cars must meet the Euro emissions standards before they can be approved for sale in the EU. However, congested areas such as city centres still suffer from elevated levels of certain pollutants - in particular NO_2, which is associated with adverse effects on health including reduced life expectancy. More accurate real-time roadside measurements are required to enable vulnerable members of the public to minimise health risks by, for example, avoiding cycling on congested city centre roads.

The introduction of new gas micro-sensor technology promises to significantly increase the capacity of NO_2 monitoring networks within our cities. Micro-sensors provide real-time measurements, which indicate changes in pollution levels rather than absolute levels, offering the potential to rapidly disseminate pollution warnings to vulnerable city dwellers. The Air Quality Directive permits the use of these indicative NO_2 measurements, provided a link is made to the high-accuracy reference instruments maintained by national air monitoring networks.

Solution

The EMRP project *Metrology for Chemical Pollutants in Air* (MacPoll) developed a test protocol for micro-sensors using a specially-designed chamber at JRC Ispra, enabling micro-sensor measurements to be linked to the traceable reference instrumentation operated by national air monitoring networks. The facility can be used to evaluate sensor performance at pollutant levels specified in the Air Quality Directive, under typical field conditions, where variations in temperature, humidity and gas composition can easily effect measurements.

Impact

Through participation in the project Alphasense, a developer and manufacturer of gas sensors, has revised and improved its innovative NO_2 micro-sensors for roadside monitoring measurement platforms.

Tests carried out within the project using the facility at JRC Ispra indicated that micro-sensor measurements of NO_2 at the levels typically encountered in the environment are affected by ozone. Nevertheless, Alphasense's new sensor has the sensitivity, selectivity and stability needed to reliably measure NO_2 pollution in the presence of ozone at typical monitoring conditions. Using Bluetooth or SIM card technology, the new sensors can relay high-accuracy data to air quality monitoring databases in near real time, providing a cost-effective method of implementing a traceable pollution monitoring network.

Alphasense's new product will help to improve monitoring of air pollution by enabling the use of cheaper indicative sensors, traceable to national standards, at numerous roadside locations. Sales of around 5,000 are anticipated in the first year, with this figure expected to rise to 20,000 over the next three years, as demand for indicative measurements in support of the Air Quality Directive increases.

By establishing traceability to national standards, this project has enabled micro-sensors such as Alphasense's to be used in support of the Air Quality Directive, validating their use as a robust yet cost-effective technology for real-time air pollution monitoring. This confidence is crucial to the expansion of Europe's air monitoring networks, and an important step towards more comprehensive pollution monitoring and the effective protection of our citizens.

Metrology for chemical pollutants in air

Reliable indoor and outdoor measurements of chemical pollutants in air are required to underpin and implement European air quality legislation designed to protect human health and the environment. The EMRP project *Metrology for chemical pollutants in air* (MacPoll) made a significant contribution to fulfilling the data quality objectives of European legislation by establishing the metrological infrastructure needed to produce accurate measurements for robust short- and long-term assessment of a range of indoor and outdoor pollutants.

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European Metrology Research Programme
Delivering Impact

Improved exhaust monitoring

Air pollution continues to be responsible for more than 430,000 premature deaths each year in Europe. Automotive vehicles are a major source of air pollution - of particular concern are the fine particles emitted by diesel and direct injection petrol engines. To improve public health and environmental quality, the EU regulates pollution from road vehicles and new passenger cars must meet the European emission standards (the standard currently in force is known as *Euro 6*) before they can be type approved.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Since their introduction, the Euro regulations have significantly reduced exhaust pollution by progressively decreasing the permitted emissions. As a consequence, the low levels of particulate permitted by the next iteration of Euro regulations, *Euro 6c*, due to be implemented in September 2017, are now beyond the sensitivity of currently-used technology.

The *Euro 6* standard and its predecessor *Euro 5* introduced a particle number limit in addition to the particle mass-based limits. The UNECE Particle Measurement Programme, an intergovernmental research programme set up to develop improved measurement procedures to support Europe's emission standards, has identified condensation particle counters as the best technology for this purpose.

However, previously, the only way manufacturers and accredited testing laboratories could validate the performance of these instruments was through inter-laboratory comparison exercises. A traceability chain is required to link the measurements made by test laboratories directly to the SI units, enabling the production of robust, comparable emissions measurements which meet the stringent requirements of *Euro 6c*.

Solution

EMRP project *Emerging requirements for measuring pollutants from automotive exhaust emissions* has helped to establish this traceability chain through contribution to a new ISO standard (ISO 27891:2015) and the development of a new facility for calibrating condensation particle counters, that enables emissions testing laboratories to make particle number measurements directly traceable to the SI for the first time. This improved accuracy will ensure instruments are available that can detect the low levels of particulate permitted by the upcoming *Euro 6c* standard and support consistent emissions testing across Europe.

New particle number concentration calibration facilities at METAS were used to supply traceability for a comparative study conducted by the Swiss Laboratories for Materials Science and Technology. This study tested new diesel, petrol and natural gas vehicle engine types using UNECE defined test procedures and demonstrated their compliance with the *Euro 6* particle number limit.

Impact

TSI, a leading manufacturer of condensation particle counters, was one of the first beneficiaries of a new calibration facility to support the implementation of the ISO standard. After calibration at NPL, TSI's internal reference instrument can now be used in conjunction with the ISO standard to provide traceability for TSI's commercially-available condensation particle counters, which are used by engine manufacturer and emissions testing laboratories.

This will link the measurements made by engine manufacturers and testing laboratories to the SI, ensuring robust, comparable measurements of exhaust emissions to meet the forthcoming *Euro 6c* standard. By supporting the implementation of a key piece of the EU's air quality policy framework, this is an important step towards realising Europe's goal of improving health and environmental quality through cleaner air.

Tackling exhaust emissions

EMRP project *Emerging requirements for measuring pollutants from automotive exhaust emissions* provided the underpinning metrology infrastructure to better understand, measure and consequently control automotive exhaust emissions. The research focussed on the three main pollutants in exhaust emissions for which measurement infrastructure was lacking: soot particles, platinum group elements and mercury.
The capabilities developed will simplify, and increase the comparability and accuracy of, vehicle particle emission measurements, leading to the more effective implementation of legislation designed to protect human health.

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European Metrology Research Programme
Delivering Impact

Supporting reduced exhaust emissions

Air pollution continues to be responsible for more than 430,000 premature deaths each year in Europe. Automotive vehicles are a major source of air pollution, particularly fine and ultrafine particles emitted by diesel engine exhausts. To improve public health and environmental quality the EU regulates pollution from road vehicles.All new passenger cars must meet European emission standards for particle number (defined in the *Euro 5b and Euro 6b* regulations) before they can be type approved for sale in the EU.

Europe's National Measurement Institutes working together

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Challenge

Euro 5b and *6b* and its predecessors involve both the initial type testing of new automotive engines and, as emissions change over time, the periodic testing of engines throughout their lifetimes. *Since their introduction, the Euro regulations have significantly reduced exhaust pollution by progressively decreasing the permitted emissions*. As a consequence, the low levels of particulate permitted by the regulation are now beyond the sensitivity of opacity-based technology currently used for periodic emission testing. With the introduction of *Euro 6c* in September 2017 for the first time engine emission testing under real driving conditions, a concern of regulators, is covered. To comply with these new regulations for particle number concentration, new capabilities are urgently required to enable robust and practical exhaust emissions measurements at these low levels with traceability to national standards to ensure consistency across Europe.

Solution

The EMRP project *Emerging requirements for measuring pollutants from automotive exhaust emissions* developed a facility at PTB, the German national measurement institute, to calibrate and validate automotive particle emission instruments which measure particle number concentration to the low levels required by the regulation. Within the project, the facility was used to compare the performance of existing opacity-based tests against innovative commercial instruments for particle number measurements, to identify candidate technologies for the proposed testing requirements of the *Euro 6c* standard.

Impact

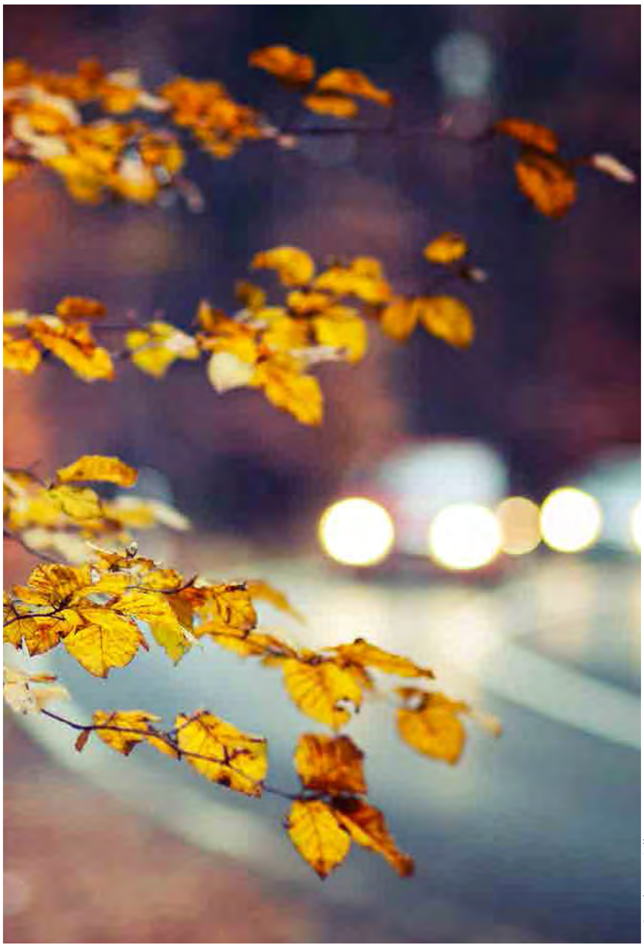
Testo AG, a world leader in the field of portable measurement technology, took part in the comparison exercise with an innovative exhaust monitoring instrument for particle number concentration. Using the results and expertise gained, Testo was confident that, after further modifications, the new technology would be suitable for launch in both the new engine type test market and the mandatory periodic vehicle test market.

Testo's instrument for engine type testing, used to approve new vehicles for sale, has since been launched and is enabling its customers to demonstrate that new engines comply with the upcoming *Euro 6c* emissions standard. The company has also developed a new portable version, suitable for periodic vehicle testing, including under normal driving conditions, which will be available in the near future. The market for this instrument is expected to be significantly larger than the market for the engine type approval test instrument, as test centres across the EU will be required to include particle emission measurements in a wider range of test conditions as part of periodic vehicle testing.

The introduction of the updated regulations will ensure that vehicles deliver reduced engine exhaust emissions over their entire life span. This is a key piece of the EU's air quality policy framework and an important step towards realising Europe's goal of improving health and environmental quality through cleaner air.

Tackling exhaust emissions

EMRP project *Emerging requirements for measuring pollutants from automotive exhaust emissions* provided the underpinning metrology infrastructure to better understand, measure and consequently control automotive exhaust emissions. The research focussed on particulate air pollutants in exhaust emissions for which measurement infrastructure were lacking: soot particles, platinum group elements and mercury. The capabilities developed will simplify, and increase the comparability and accuracy of, vehicle particle emission measurements, leading to the more effective implementation of legislation designed to protect human health.



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Delivering Impact

Monitoring exposure to UV radiation

The World Health Organization estimates that a 10 % increase in surface UV radiation could cause an additional 300,000 skin cancers and at least 1.6 million more cases of cataracts worldwide every year. Balancing the risks and benefits of solar UV radiation is a challenge for policymakers and health advisors, and improved UV measuring instrumentation is needed to produce reliable measurements on which to identify long-term trends and base decisions.

Europe's National Measurement Institutes working together

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Challenge

Earth-based measurements of solar UV radiation are currently made using complex scanning spectroradiometers, installed at a limited number of monitoring stations worldwide. These instruments are expensive to purchase and maintain, and time consuming to use. The introduction of newer, faster compact CCD array spectroradiometers, based on the technology used in digital cameras, will provide a cost-effective alternative to conventional instruments and have the potential to increase the worldwide UV monitoring network.

Before this expansion can take place, the new instruments need to be well characterised, and best operating practices defined, to ensure they produce high-quality UV radiation data that is compatible with measurements made with scanning spectroradiometers.

Solution

The EMRP project *Traceability for surface spectral solar ultraviolet radiation* developed new transfer standards and best practice guidelines to improve the accuracy and comparability of solar UV measurements. These best practice guidelines were disseminated to 60 operators from environmental monitoring stations across the globe during an instrument comparison exercise at the World Meteorological Organization in Davos, Switzerland. This comparison enabled operators to compare their CCD array spectroradiometers to the world standard instrument, QASUME, giving direct traceability for this type of instrument for the first time. All participants also received training in the methods developed within the project to improve solar UV measurements in the field.

The new transfer standards, capable of in-situ use, enable traceability for installed UV spectroradiometers without the need to send instruments to Davos for direct comparison against QASUME. Instrumentation previously validated in situ using the new transfer standards demonstrated better accuracy during the comparison exercise than non-validated instrumentation reinforcing the importance of traceability to instrument performance.

Impact

Public Health England (PHE) has a remit to monitor the public's exposure to all types of radiation and routinely publishes UV exposure data from its monitoring network, spread throughout the UK, for research and trend analysis. PHE developed a prototype array spectroradiometer for monitoring exposure of competitors and spectators at the 2012 London Olympics, and took this prototype instrument to the comparison exercise at Davos. Following interaction with the project, the PHE prototype spectroradiometer, operated with the new best practice procedures, demonstrated improved performance and better agreement with the world reference instrument.

El Arenosillo, an atmospheric research observatory of Spain's space agency, Instituto Nacional de Técnica Aeroespacial, also took part in the Davos comparison exercise. The exercise highlighted interference problems caused by the instrument's refrigeration unit, and interactions with the other participants have increased measurement know-how and will enable informed decisions on proposed system upgrades. El Arenosillo has now embraced the best practice guidelines derived in the project, improving the comparability and compatibility of both aerial and ground based measurements performed at the monitoring station.

These are just two early examples of how the UV monitoring community has adopted improved measurement practices, following interaction with the project. This will lead to improved confidence in future measurements of UV radiation measurements used in climate forecasting and decision making in health policy. The introduction of faster, cheaper CCD arrays for UV monitoring will also increase networked coverage and improve warnings of hazardous UV levels.

Traceable UV measurements

The EMRP project *Traceability for surface spectral solar ultraviolet radiation* aimed to significantly improve the reliability of solar UV radiation measurements made from the Earth's surface, to support health protection agencies and atmospheric research. The project accomplished this through a number of major achievements: the reduced uncertainty of the world reference spectroradiometer; the improved characterization of array spectroradiometers; the establishment of a new portable UV reference spectroradiometer; and the development of new technologies, methods and software for applications in the solar UV end-user community responsible for environmental and human health protection.

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EURAMET

Better optics for UV monitoring

The ozone layer protects us from the harmful effects of solar ultraviolet (UV) radiation, such as increased incidences of skin cancer and cataracts. International treaties such as the Montreal Protocol have been put in place to reduce the use of ozone depleting chemicals such as CFCs. Changes in ozone and UV radiation are monitored across Europe to improve understanding of the recovery of the ozone layer and the effects of UV exposure.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Brewer spectrophotometers are among the most sophisticated instruments currently used to measure stratospheric ozone and solar UV radiation. Global solar UV radiation entering the spectrophotometer is sampled by a diffusion plate to measure its intensity. The diffusion characteristics of this entrance optic is one of the most important components of these complex measurement systems and currently the most suitable available material is Teflon. However Teflon presents a number of problems. The material distorts with temperature change and is damaged over time by the UV radiation that falls onto it, requiring the introduction of time-consuming corrections. The accuracy of Teflon-based instruments is significantly affected by the position of the Sun in the sky – by as much as 10% between the Sun is at its maximum height and the low angles at sunrise, sunset and during the winter months. To increase the accuracy and comparability of UV radiation measurements, the research community needs improved instrumentation, capable of providing accurate measurements regardless of the time of day or year.

Solution

The EMRP project *Traceability for surface spectral solar ultraviolet radiation* developed improved calibration methods, instruments and procedures to enable better comparability of UV radiation measurements. These research outputs were used to improve the measurement performance of the world's primary spectrophotometer, QASUME to which all other measurements are linked.

Impact

Project partner, Aalto University, working with industrial partners, Kipp & Zonen and CMS Ing.Dr.Schreder GmbH, designed new diffusion plates for Brewer spectrophotometers using novel quartz-based materials. The new quartz materials can be more easily formed into complex shapes and improve the accuracy of low angle solar UV measurements. Simulations performed by Aalto University were used to optimise the new design and prototype optics were validated using QASUME. Products incorporating the new optics will soon be commercially-available to customers requiring highly-accurate measurements of solar UV for ozone studies.

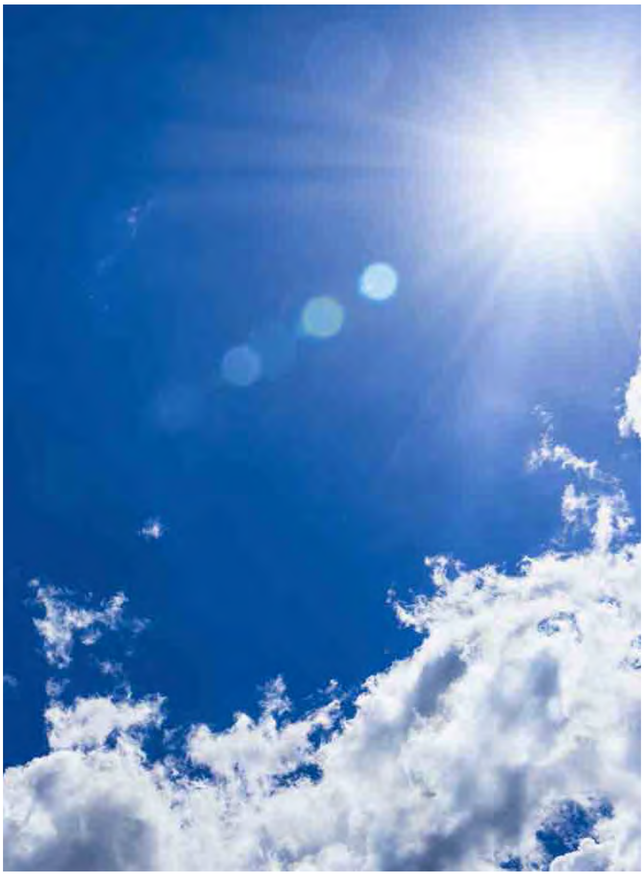
CMS Ing.Dr.Schreder GmbH, an Austrian instrumentation company, is marketing the system for research institutes and companies that already have UV spectrophotometers, enabling them to upgrade their instruments to make improved low angle measurements.

Kipp & Zonen, a leading manufacturer of solar radiation measurement instruments, will introduce upgraded optics in its commercially-available spectrophotometers as a result of interactions with the project and will also launch a kit to enable installation of the improved optics system on customers' existing instruments.

The incorporation of the quartz optics into new and existing spectrophotometers is giving the UV community greater confidence in the accuracy of the solar UV measurements and helping atmospheric researchers and health protection agencies to reliably assess long-term changes in the Earth's protective ozone layer.

Traceable UV measurements

The EMRP project *Traceability for surface spectral solar ultraviolet radiation* aimed to significantly improve the reliability of solar UV radiation measurements made from the Earth's surface, to support health protection agencies and atmospheric research. The project accomplished this through a number of major achievements: the reduced uncertainty of the world reference spectroradiometer; the improved characterization of array spectroradiometers; the establishment of a new portable UV reference spectroradiometer; and the development of new technologies, methods and software for applications in the solar UV end-user community responsible for environmental and human health protection.



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European Metrology Research Programme
Delivering Impact

Confidence in climate data

Central to our understanding of climate change are reliable Earth models. These models depend on complex measurements for validation of variables such as ice cover, cloud cover, sea level and temperature that can only be made from space using satellites. The Earth observation community needs to be able to compare and combine these satellite data, regardless of the conditions under which they were collected, to ensure robust climate forecasts.

Europe's National Measurement Institutes working together

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Challenge

The instruments used on board satellites to make measurements of key climate variables are calibrated prior to launch to ensure their accuracy. However, instrument performance can change during launch into space, and once in flight instruments operate in a very different environment to that in which they were calibrated. Changes in instrument response post-launch, due for example to the effects of reduced gravity, can be estimated but this makes the calculation of measurement uncertainties – and therefore the accuracy of the measurements – problematic.

Without sufficient knowledge of how accurate measurements are, it is very difficult to compare climate data produced from different sources, using different methods, at different points in time. This limits the usefulness of available data, both historic and current. Improved uncertainty evaluation methods are required to enable greater confidence in climate data and the climate projections they underpin.

Solution

The EMRP project *European metrology for Earth observation and climate* carried out research to better understand the performance of climate monitoring instrumentation in space and the measurement uncertainties that arise in this operating environment. Based on this extensive study, project researchers developed a method that enables the most robust comparison to date of historic and modern climate data from satellites. The method is freely-available to climate researchers in a good practice guide.

Impact

The UK Met Office generates some of the most comprehensive climate projections ever produced, to help decision-makers assess the UK's risk exposure to climate change and inform mitigation and adaptation strategies. These predictions are guided by climate data generated from a number of sources, both historic and current.

The Met Office will use the new uncertainty evaluation method developed within the project, to enable the combination of climate data collected on the most recent European Sentinel satellite missions with its existing datasets. This opens up a significant amount of additional climate data to the Met Office for climate monitoring and modeling purposes, improving the quality and range of measurements available to guide its climate projections.

The method and the research it is based on have also been assembled into a course and textbook for Earth observation scientists, to be made freely-available online in the near future, due to continuing funding support from EMRP. This is a significant step towards improving understanding and use of measurement uncertainty evaluation in the climate research community and will contribute to improved climate models and projections.

Earth observation metrology

The EMRP project *Metrology for Earth observation and climate* developed new measurement standards, methods and calibration facilities to support the validation of sensors used in Earth observation satellites, both prior to and during flight. These outputs will ensure that accurate, laboratory-quality measurements of key climate parameters can be made from space and used to underpin robust predictions of changes to the Earth's climate.

Courtesy of ESA

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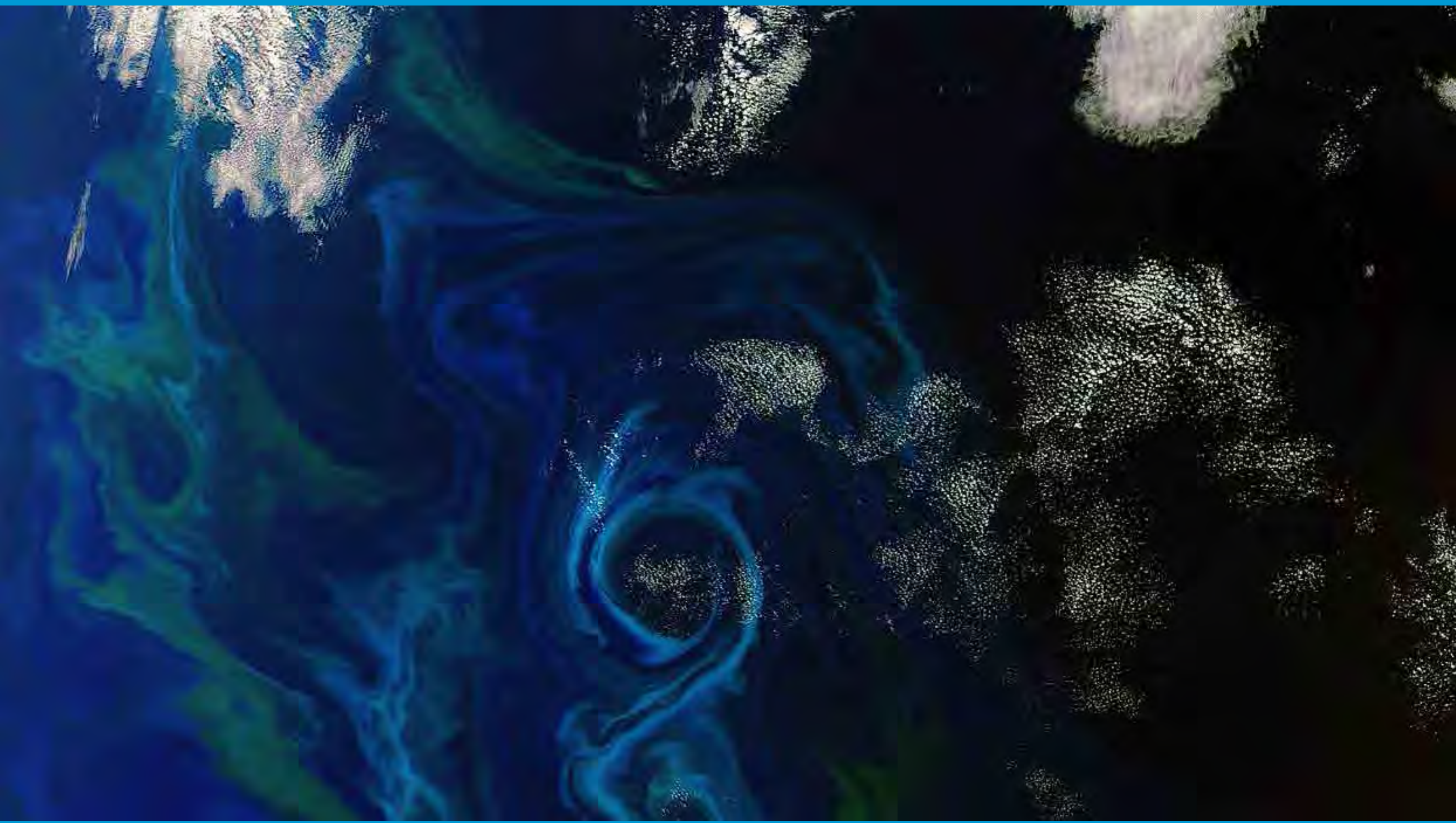

Seeing ocean colour from space

Oceans are the largest active carbon sinks on Earth, absorbing more than a quarter of anthropogenic carbon emissions. Phytoplankton in the ocean, such as microscopic plants and algae, have a major impact on the ocean's ability to absorb carbon dioxide. Satellite measurements of the sunlight reflected by the ocean – 'ocean colour' – can be used as a measure of phytoplankton concentrations and provide vital information for monitoring the global carbon cycle and climate.

Europe's National Measurement Institutes working together

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Challenge

To analyse and assess ocean colour requires satellite measurements sensitive enough to distinguish small changes in the little light reflected by the ocean from the brighter background light reflected by the atmosphere. Radiometers, the instruments that measure ocean colour, are calibrated pre-launch, but due to demanding accuracy requirements and degradation in use must also be calibrated regularly post-launch against measurements made at sea. Given the challenging nature of ocean colour measurements, the quality of this post-launch calibration process is vital to ensuring satellite data is accurate.

Specially designed research buoys, moored in the open ocean, are equipped with instruments to make local measurements of a range of variables essential to climate models, including ocean colour. These reference measurements are compared to those taken by satellites passing overhead, and used to make corrections to satellite data. Regular 'in situ' calibration of these buoy based sensors to National Metrology Institute based accuracy levels is needed to link the satellite measurements to the SI units. This will ensure data is of the quality needed to support robust climate change monitoring. However, light sources conventionally used to calibrate these instruments at the detail and accuracy levels needed are both bulky and heavy, making them unsuitable for transportation to research buoys or local shore based facilities.

Solution

The EMRP project *European metrology for earth observation and climate* developed a novel spectrally-tuneable laser-based light source. This easily transportable source enables in situ or near in-situ calibrations, providing traceability not only to the equipment on ocean buoys but also to satellite measurements of ocean colour. The new calibration standard's compactness and ability to be used under vacuum will make pre-flight satellite calibrations at nearer to operating conditions possible. Future adaptations of the light source may enable in-flight SI-traceable satellite radiometer calibration.

Impact

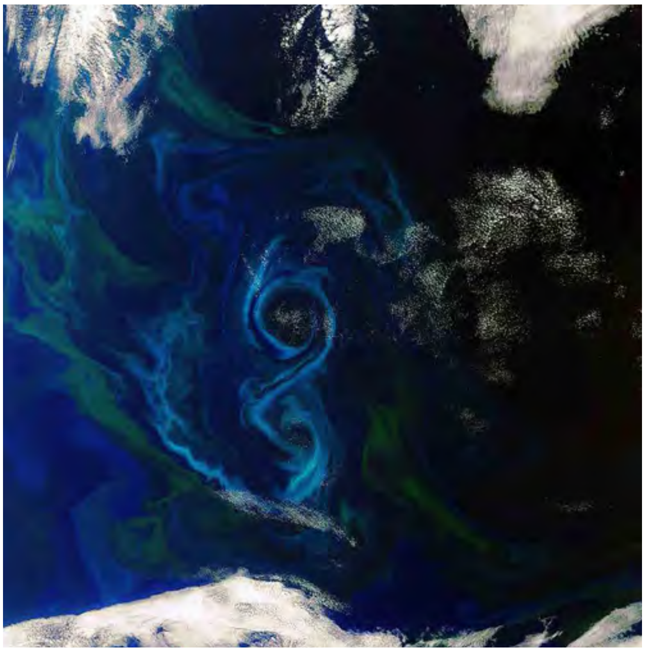
One of the first beneficiaries of the new portable calibration standard was BOUSSOLE, an international project supported by a range of organisations including the European Space Agency (ESA) and French space agency CNES. BOUSSOLE was established in 2000 to support the calibration and validation of ocean colour sensors in order to better assess long-term changes in the ocean resulting from climate change. Located in the Mediterranean Sea approximately 60 kilometres off the coast, the BOUSSOLE buoy hosts reference instruments used to validate the measurements of overflying satellites or aircraft-borne sensors.

Instrumentation on the BOUSSOLE buoy has now been calibrated using the new portable standard developed within the EMRP project. The measurements demonstrated that buoy traceability can be improved, and with appropriate funding will enable regular calibration to high quality standards traceable to the SI. The buoy is currently being used to confirm the response of the European Ocean Land Colour Instrument (OLCI) recently launched on the Copernicus Sentinel 3 satellite.

This is just one example of how the new calibration standard is improving the accuracy and traceability of ocean colour measurements, and ultimately supporting more robust carbon cycle trend analysis and climate monitoring.

Earth observation metrology

The EMRP project *Metrology for Earth observation and climate* developed new measurement standards, methods and calibration facilities to support the validation of sensors used in Earth observation satellites, both prior to and during flight. These outputs will ensure that accurate, laboratory-quality measurements of key climate parameters can be made from space and used to underpin robust predictions of changes to the Earth's climate.



Courtesy of ESA

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European Metrology Research Programme
Delivering Impact

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Ensuring accuracy in the upper atmosphere

Variations in ozone and aerosols in the Earth's atmosphere affect air quality, weather and climate. One critical example of this is climate change, where the build-up of greenhouse gases is driving the warming of the planet's surface. To assess the impact of tiny variations in atmospheric composition on long-term climate change, the Earth observation community needs highly-accurate, comparable measurements of atmospheric composition made using ground-based, aircraft- and satellite-borne instruments.

Europe's National Measurement Institutes working together

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Challenge

Recognising this need, organisations including the European Space Agency (ESA) now require the instrumentation they use to meet the Quality Assurance Framework for Earth Observation (QA4EO) guidelines, which specify the need for measurement traceability. However, while carefully calibrated on the ground prior to launch, Earth observation instruments on board aircraft and satellites can degrade during take-off and while in flight. If these instruments are to provide traceable measurements, they need to be validated in-flight, post launch.

Infrared (IR) Fourier Transform (FT) imaging Spectroradiometers, which provide highly-accurate measurements of the chemical composition of the Earth's atmosphere, are particularly vulnerable and can undergo significant drift during use in-flight. Consequently, their performance needs to be periodically checked against a standard to ensure the reliability of the data they provide.

However, the deep cavity black bodies traditionally used at National Measurement Institutes to calibrate this type of imaging spectroradiometer are too bulky for use on board aircraft and satellites. Compact, lightweight, and highly accurate transfer standards are required to enable airborne IR spectroradiometer validation for studies of atmospheric composition.

Solution

Within the EMRP project *European metrology for earth observation and climate* the new vacuum and low background IR calibration facility at PTB, the German National Measurement Institute was used to provide traceability for airborne spectroradiometers. Two novel robust and compact black body radiation sources, developed in collaboration with University of Wuppertal, were calibrated using the new facility prior to use as transfer standards on board a research aircraft.

Impact

One of the first Earth observation instruments to benefit from the developed blackbody sources characterized on the new calibration facility was GLORIA (the Gimballed Limb Observer for Radiance Imaging of the Atmosphere) the first of a new generation of spectroradiometers for Earth observation. GLORIA's novel infra-red camera measures trace gases in the atmosphere, as well as temperature and cloud structures, with an unprecedented combination of vertical and horizontal resolution that relies upon highly-accurate calibration.

The black body radiation sources have been used in two extensive measurement campaigns on board Russian and German research aircrafts, Geophysica and Halo, to provide traceability to GLORIA for the first time. During the Halo flight from southern Germany around Africa and over the Antarctic, the new transfer standards enabled the first traceable mid infra-red measurements of thermal emissions – a significant step forward in Earth observation research.

When used in combination with the transfer standards developed in the project, GLORIA has demonstrated the suitability of IR spectroradiometers to traceably measure radiance high in the Earth's atmosphere. Black body designs have been further developed and new variants are now available. This newly traceable technology can now be used on board balloons and satellites, plugging the gap in high-quality data needed for robust climate change assessment.

Earth observation metrology

The EMRP project *Metrology for Earth observation and climate* developed new measurement standards, methods and calibration facilities to support the validation of sensors used in Earth observation satellites and aircrafts, both prior to and during flight. These outputs will ensure that accurate, laboratory-quality measurements of key climate parameters can be made from space and used to underpin robust predictions of changes to the Earth's climate.

Courtesy of ESA

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European Metrology Research Programme
Delivering Impact

Understanding our oceans

Oceans play a key role in regulating the global climate system. The interaction of oceans with the Earth's atmosphere is strongly linked to seawater properties such as salinity and pH, which must be accurately monitored to identify long-term climate trends. However, measurements of these properties are challenging without a traceability chain to link them to units defined in the SI, which would ensure they are comparable regardless of where and when they are made.

Europe's National Measurement Institutes working together

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Challenge

The oceanography community most commonly measures ocean salinity using the 'Practical Salinity Scale', which is based on comparing seawater electrical conductivity with the conductivity of a commercially available standard solution made from North Atlantic seawater. This salinity is then used to calculate other properties, like density and sound speed. However, small chemical changes in the standard solution, and in the ocean itself due to climate change, make relationships between Practical Salinity and these other properties uncertain. One such change arises from increases in dissolved carbon dioxide. This means small changes in ocean properties cannot be reliably identified.

The equation of state for seawater, from which the thermodynamic properties of seawater can be derived, is another key component of global climate models. The inclusion of density and speed of sound data in the equation of state will assist in the determination of other properties, including salinity and temperature, especially for deep-sea regions where precise measurements are difficult to make, and further improve the reliability of the climate models they feed into.

Ocean going vessels equipped with acoustic sensors could provide a cost-effective, extensive seawater temperature measurement network, via speed of sound, to supplement satellite data for climate models. However, improved SI traceability for the probes used to measure the speed of sound in seawater is needed before this type of monitoring system can be implemented.

Solution

The EMRP project *Metrology for ocean salinity and acidity* has provided a reference method for ocean salinity, which makes Practical Salinity measurements traceable to the SI units through density measurements. This means that possible long-term drifts in the chemical composition of the standard seawater solution can now be accounted for and eliminated.

In addition, probes used to measure the speed of sound in seawater can now be traceably calibrated under typical operating conditions at newly-developed facilities at project partners PTB and INRIM – the National Measurement Institutes of Germany and Italy. Measurements at sea have confirmed the performance of a prototype transfer standard developed at INRIM, bringing easily achievable traceability to ship-based probes, and have assisted in the generation of in-situ measurement best practice.

Impact

As a result of the EMRP project, NMI members have for the first time been invited to sit on the prestigious Joint Committee for the Properties of Seawater, the organisation responsible for maintaining and improving seawater standards (including the Thermodynamic Equation of Seawater – 2010: TEOS-10). The committee is keen to promote measurement traceability and ensure data compatibility in the years to come.

Ocean Scientific International Ltd (OSIL) is going to incorporate density measurements into the preparation of its standard seawater, which is the only internationally-recognised calibration standard for the measurement of practical salinity. This will provide SI traceability to ocean salinity measurements across the globe and allow the oceanography community to reliably identify even small changes.

The project outputs will make a substantial contribution towards improving the accuracy of ocean salinity and density measurements which provide key input into global climate models.

Ocean metrology

The EMRP project *Metrology for ocean salinity and acidity* developed measurement methods, standards and tools to improve the measured ocean data used for climate monitoring and modelling. Focussing on both thermodynamic quantities – salinity, density, speed of sound and temperature – and chemical quantities – pH, oxygen content and composition – the project's outputs enable the traceable calibration of sensor networks and satellite systems. This will allow scientists to reliably identify small changes in long-term oceanographic data series.

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The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

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European Metrology
Research Programme
Delivering Impact

Understanding ocean acidity

Oceans are the largest active carbon sinks on Earth, absorbing more than a quarter of anthropogenic carbon emissions. The ocean's interaction with the atmosphere, and its ability to absorb carbon dioxide, is strongly influenced by properties of seawater, such as salinity and acidity. Reliable and comparable measurements of these properties are of crucial importance to climate researchers, enabling them to detect small changes in ocean dynamics over decades and even centuries.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

As the amount of carbon dioxide in the Earth's atmosphere has increased, so too has the acidity of our oceans. The carbon balance between the oceans and the earth's atmosphere is extremely delicate with small changes in acidity having a significant effect on the marine eco-system. Monitoring pH is vital if we are to protect marine life and keep the effectiveness of the ocean as a carbon reservoir.

The high ionic strength of sea water, arising from the relatively large amount of dissolved salts, means that conventional approaches fail to produce accurate pH measurements. Research in marine science requires an extremely small uncertainty in pH but discrepancies between results given by different methods mean that pH measurements have lacked the accuracy required for robust analysis.

Solution

The EMRP project *Metrology for ocean salinity and acidity* has helped to establish the traceability chain for seawater pH via the development of primary and reference methods for pH measurements. These were used to demonstrate traceability, with a full measurement uncertainty budget, for measurements based on the commonly used spectrophotometric pH method.

Impact

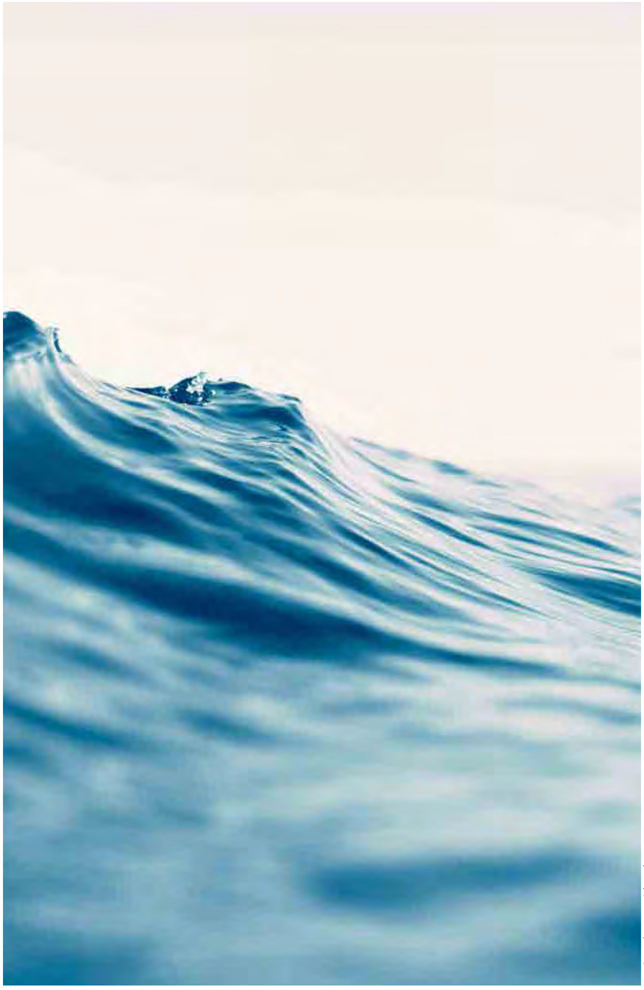
The accurate methods developed in the project are being taken on board by the oceanographic community to improve seawater pH measurements in a number of ways. The project team contributed validation methods to new ISO standard for spectrophotometric methods (ISO/CD 18191 *"Determination of pH in seawater – Method using the indicator dye m-cresol purple"*) and are working with the Scripps Institution of Oceanography which is the sole provider of a seawater buffer solution used to calibrate field-based oceanographic instrumentation.

The team is also contributing to the two key influential committees that define key parameters and methods: the pH sub group of the Joint Committee on the Properties of Seawater that is responsible for maintaining and improving the seawater equation of state TEOS-10 (a key tool in ocean science); and a new group of the International Union of Pure and Applied Chemists, focused on measuring acidity in seawater, is using the outcomes of the project to ensure greater harmonisation of the measurement methods employed by the oceanographic community.

These improved linkages between the metrology and oceanography communities will in the longer-term pave the way for improved measurements of ocean acidity and a robust understanding of the effect on the Earth's climate.

Ocean metrology

The EMRP project *Metrology for ocean salinity and acidity* developed measurement methods, standards and tools to improve the measured ocean data used for climate monitoring and modelling. Focussing on both thermodynamic quantities – salinity, density, speed of sound and temperature – and chemical quantities – pH, oxygen content and composition – the project's outputs enable the traceable calibration of sensor networks and satellite systems. This will allow scientists to reliably identify small changes in long-term oceanographic data series.



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European Metrology
Research Programme
Delivering Impact

Monitoring ocean oxygen levels

Oceans play a vital role in regulating the global climate system and absorb more than a quarter of anthropogenic carbon emissions. Consequently, decreasing oxygen levels in the world's oceans, driven by increasing ocean temperatures, are expected to have a major impact on the carbon cycle and our climate, as well as ocean life. Accurate measurements of dissolved oxygen concentrations are needed to enable reliable monitoring of this influential ocean health parameter.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Today, the majority of dissolved oxygen measurements made by the oceanographic community are made using amperometric and optical sensors. While the performance of these sensors has improved dramatically over recent years, accurate measurements are still difficult to obtain due to the influence of numerous sources of measurement uncertainty. This led the recent World Ocean Atlas produced by the US National Oceanographic Data Center to reject all sensor-based dissolved oxygen data, in favour of that obtained using lab-based chemical titration methods, such as the Winkler titration method.

However, oceanographers need access to large amounts of dissolved oxygen data, collected around the clock over long periods of time, to underpin robust ocean and climate models. Only sensor-based automatic measurements can satisfy this need. Consequently, action is needed to improve the quality of dissolved oxygen sensors, to ensure the data they produce meets the level of accuracy required for oceanographic trend analysis.

Solution

The EMRP project *Metrology for ocean salinity and acidity* investigated the measurement uncertainties associated with the Winkler titration method and generated best practice procedures to further improve its accuracy and enable users to generate reliable, comparable results. Project partner SYKE, the Finnish Environment Institute, together with University of Tartu organised a comparison exercise on board a research vessel R/V Aranda in the Gulf of Finland, to compare the dissolved oxygen measurements provided by commercially-available sensors to those made using the traceable Winkler titration method for the first time.

Impact

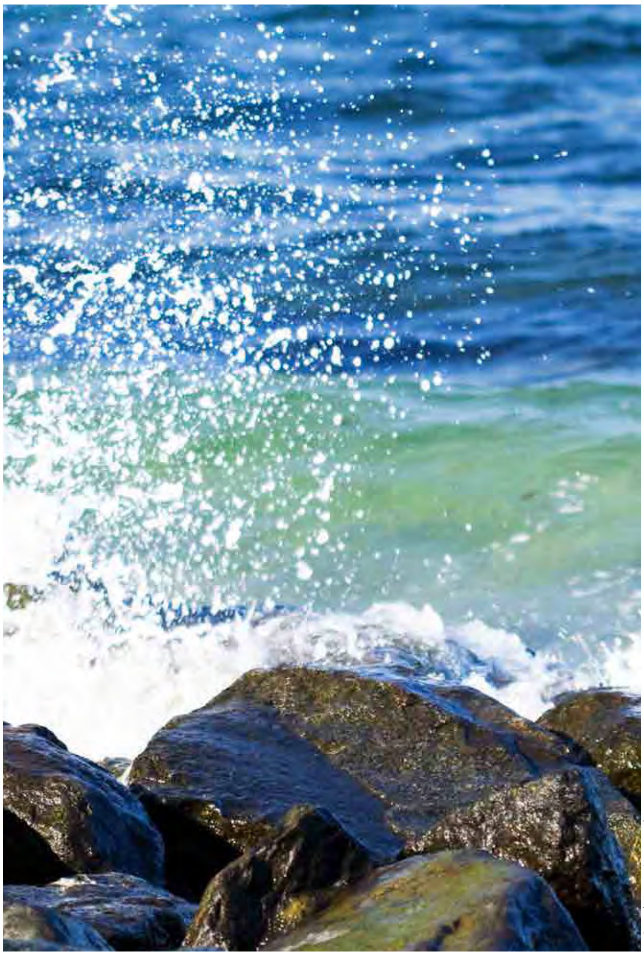
The sensors were deployed from the research vessel to known depths and at the same time water samples were collected for on-board high-accuracy Winkler titration analysis using the procedure developed within the project. This enabled a direct comparison of the results given by the two methods without the need to store and transport samples to land-based laboratories.

EHP-Tekniikka, a provider of environmental monitoring services and equipment, took part in the comparison exercise, using a PONSEL OPTOD oxygen sensor - an optical sensor designed with an internal calibration capability. EHP-Tekniikka was able to directly compare the instrument's response to that given by the traceable Winkler titration method. The positive results obtained have given confidence in this type of instrument's internal calibration capability and its applicability for high-accuracy measurements of dissolved oxygen concentrations.

The comparison exercise organised through the project has helped promote best measurement practice within the oceanography community, including well-quantified uncertainty determination using the Winkler titration method, and validated the performance of commercial sensors under typical operating conditions. This validation paves the way to increased use of automated oxygen sensors and will lead to a significant increase in the oceanography community's capacity to produce high-accuracy dissolved oxygen data for robust climate trend analysis.

Ocean metrology

The EMRP project *Metrology for ocean salinity and acidity* developed measurement methods, standards and tools to improve the measured ocean data used for climate monitoring and modelling. Focussing on both thermodynamic quantities – salinity, density, speed of sound and temperature – and chemical quantities – pH, oxygen content and composition – the project's outputs enable the traceable calibration of sensor networks and satellite systems. This will allow scientists to reliably identify small changes in long-term oceanographic data series.



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European Metrology Research Programme
Delivering Impact

Building environmental metrology skills

The growing use of distance learning via the internet is opening up access to a diverse range of subjects to millions of students across the globe. Given metrology's crucial role underpinning many areas of trade, industry and scientific research, modules dedicated to measurement science are an effective way of improving skills to support data quality, effective process control and experimental rigour.

Challenge

Science and engineering students and many industrial process and quality control professionals require a grounding in best measurement practices and the calculation of measurement uncertainties, in order to produce accurate, comparable data to inform decision making. This knowledge often forms part of university syllabuses but a wider appreciation across academia and industry supports greater confidence in data.

Chemists in particular often face challenging uncertainty analyses during routine procedures to test, for example, air and water quality due to the complex composition of real-world samples. Easily accessible and freely available courses disseminating best practice in measurement and uncertainty analyses in chemical analysis will help improve the skills of chemists in industry and public sector agencies as well as tomorrow's research scientists.

Solution

The Winkler titration method is used to determine the concentration of dissolved oxygen in water samples in water quality studies. It is a complicated method requiring complex uncertainty calculations if it is to be to be used effectively. The EMRP project *Metrology for ocean salinity and acidity* investigated the uncertainties associated with the Winkler titration method and generated a best practice method for its use. While the project was focused on assessing ocean parameters predominantly for climate change research the method for oxygen concentration has wide applicability in water quality assessments more broadly.

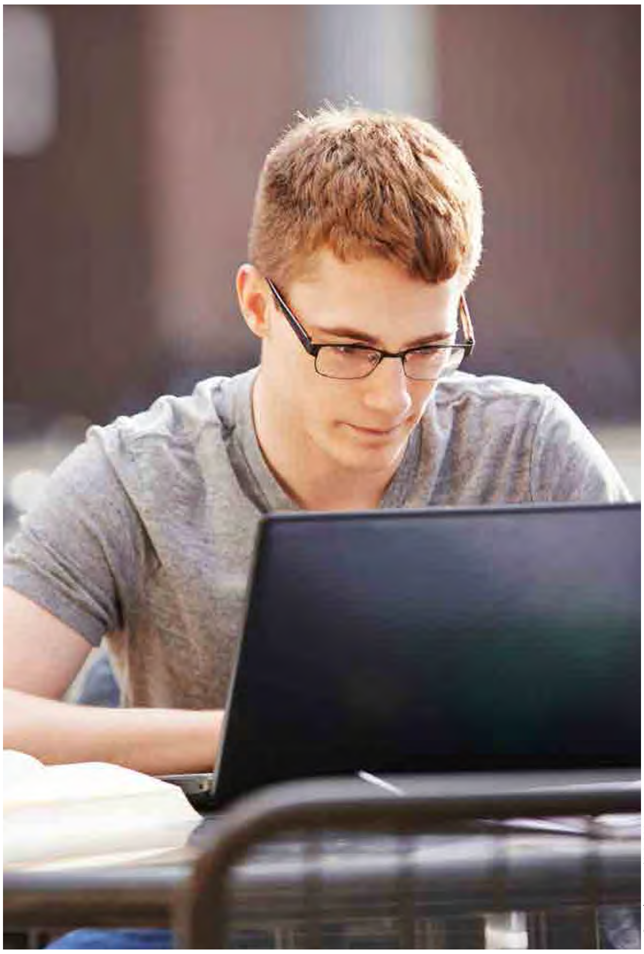
Impact

The best practice uncertainty evaluation method provided a key component of a new online course *Estimation of Measurement Uncertainty in Chemical Analysis* developed by project partner, the University of Tartu in Estonia. The course, delivered as a MOOC (Massive Open Online Course), is widely available and has not only been taken by 700 students so far but is also being used by SP, the Technical Research Institute of Sweden, to train environmental testing laboratories working towards Nordtest accreditation. Nordtest is the Nordic area conformity assessment body whose role is to harmonise compliance with standards and remove barriers to trade across the Nordic countries, which includes the accreditation of measurement and testing and conformity assessment laboratories in support of its mission: 'approved once - accepted everywhere'.

Therefore the project's outputs are not only contributing to important climate change research but are supporting the development of skills for practical and effective environmental monitoring.

Ocean metrology

The EMRP project *Metrology for ocean salinity and acidity* developed measurement methods, standards and tools to improve the measured ocean data used for climate monitoring and modelling. Focussing on both thermodynamic quantities – salinity, density, speed of sound and temperature – and chemical quantities – pH, oxygen content and composition – the project's outputs enable the traceable calibration of sensor networks and satellite systems. This will allow scientists to reliably identify small changes in long-term oceanographic data series.



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European Metrology Research Programme
Delivering Impact

Improving atmospheric data

Greenhouse gases are accumulating in the Earth's atmosphere and have created a heat-trapping layer which is driving climate change. Satellite instruments are used high in the atmosphere to generate gas concentration data but require on-going performance validation post launch. A more direct link of satellite measurements to the SI throughout their lifetime is necessary to give greater robustness to the data used in climate trend prediction.

Challenge

Spectro-analytical techniques are used to identify and quantify concentrations of greenhouse and other gases in the atmosphere. These techniques are based on the unique spectral 'finger prints' generated by molecular interactions with specific radiation selected in the near and mid infrared wavelengths of the electromagnetic spectrum.

Satellite borne spectral instruments calibrated pre-launch require on-going performance validation, which is provided by a network of ground based instruments situated in remote locations – one of the largest of many ground based monitoring networks is the Total Carbon Column Observing Network, TCCON. Checking the performance of these remote Earth-based instruments is currently achieved using the World Meteorology Organisation (WMO) in-situ scale, as traceability directly to the SI is both difficult and expensive to achieve.

Spectral measurements from different altitude satellite, air craft and ground based spectrometer measurements made at different temperatures and pressures. These require different pressure and temperature correction procedures for spectrum evaluation before comparison using research databases to produce gas 'fingerprints'. This enables identification of the different gases present and their concentrations. However, only a very small subset of the spectral data in research databases is underpinned by measurements traceable to the SI units, leading to unnecessarily high levels of uncertainty in atmospheric models.

Accurate spectral data and improved ground station instrument traceability directly to the SI is required to reduce measurement uncertainties and generate more robust data for climate predictions.

Solution

The ESA ENVINET satellite launch is leading a significant European investment in atmospheric monitoring for greenhouse gases and in support of this the EMRP project *Spectral reference data for atmospheric monitoring* has enabled development and commissioning of a new validated spectral line data measurement facility capable of greenhouse gas line data generation with improved traceability to the SI.

Impact

The spectral data generated within the project is due to be included in an upcoming revision of the HITRAN database, one of the most widely used spectral databases in the world. Originally compiled in the 1960s, the current HITRAN database is maintained by the Harvard-Smithsonian Center for Astrophysics and contains over 7 million spectral lines for 47 different molecules. However, some of the data accumulated over the years lacks the quality required for robust long-term climate trend analysis.

The project's contribution will mark a significant increase in the amount of traceable spectral data available to researchers using HITRAN. One of the key users of the database is TCCON, made up of 23 ground-based atmospheric monitoring stations distributed across the globe.

The accuracy of TCCON's measurements of carbon dioxide, methane and other gases is dependent on the absolute values of the line strengths and widths in the spectral data bases used in fitting spectra. The inclusion of traceable line data into the data base will reduce remote station reliance on side-by-side validation and calibration, which is both difficult to achieve and expensive to perform.

The improved data provided by TCCON-validated ESA satellites will make a valuable contribution to reducing the uncertainties involved in climate models and support robust predictions of long-term climate change.

Metrology for atmospheric monitoring

The EMRP project *Spectral reference data for atmospheric monitoring* established a European spectroscopy infrastructure enabling traceable measurements of spectral line data under well-controlled conditions. This will support improved accuracy in the measurements used to remotely monitor specific substances in the atmosphere, including gases that are important for assessing climate change and pollution levels.

Courtesy of ESA

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New Arctic Meteo in-situ calibration

Accurate assessment of climate change relies on a world-wide network of monitoring stations that provide the high-quality data used in climate models to produce climate predictions. This requires measurements of internationally agreed essential climate variables, such as pressure, temperature and humidity, which must be comparable regardless of where they're collected – be it from a mountain in the Himalayas or an Arctic peninsula.

Challenge

Providing the traceability to the SI units needed to ensure globally comparable measurements, even in the most remote monitoring locations, poses a key challenge to environmental monitoring. The extreme conditions encountered in many remote locations can significantly affect the response of environmental sensors, making accurate and dedicated calibration of utmost importance.

Until recently, instruments had to be sent away to distant calibration laboratories, a process which means they are unavailable for extended periods of time. In addition, usual calibration procedures may not provide accurate results when instruments are then operated in harsh environmental conditions of, for example, an Arctic winter.

The ability to calibrate sensors in the field would ensure their accuracy under typical operating conditions and would prevent gaps in the data during calibration periods.

Solution

The EMRP project *Metrology for pressure, temperature, humidity and airspeed in the atmosphere* is taking traceability to remote monitoring locations through a newly-developed portable calibration chamber for temperature, humidity and pressure sensors. Known as EDIE (Earth Direct Investigation Experiment), the chamber can be used to calibrate sensors in situ using their normal operating conditions. This allows remote monitoring stations to easily compare their sensors against reference instruments directly traceable to national standards, a process which would previously have been extremely challenging or even impossible.

Impact

Svalbard, a Norwegian archipelago in the Arctic Ocean, is home to one of the northernmost settlements in the world: Ny-Ålesund. Made up of an international scientific community operating a number of meteorological, marine, geological and atmospheric monitoring stations, Ny-Ålesund's arctic location is ideal for environmental monitoring, as changes in the Earth's climate occur more rapidly in the Arctic due to the characteristic polar environmental conditions. Instruments at Ny-Ålesund face some of the most challenging operating conditions on Earth.

Taken on board the summer supply boat, EDIE was temporarily installed at Ny-Ålesund, enabling the island's atmospheric monitoring instruments to benefit from traceable calibration without having to be transported to distant calibration laboratories and unavailable for long periods of time. The AWIPEV Arctic Research Base was one of the first research stations in Ny-Ålesund to benefit from EDIE. Scientists from France and Germany work together at AWIPEV to monitor surface and upper-air meteorological parameters, contributing to, for example the Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN). With state-of-the-art ground based instruments, GRUAN provides long-term, high-quality climate data to calibrate the more comprehensive measurements taken from space and the upper atmosphere that support robust climate monitoring and trend prediction.

The short and easily implemented traceability chain provided by EDIE, has enabled for the first time, on-site calibration of GRUAN's ground instruments in simulated conditions closer to those during operation in the harsh Arctic environment. Further developments to EDIE are underway to make a more robust and compact version suitable for long term installation in Ny-Ålesund - a first step towards a permanent arctic calibration laboratory that will support multi-national climate observation and research at Svalbard.

Metrology for climate variables

The EMRP project *Metrology for pressure, temperature, humidity and airspeed in the atmosphere* focussed on providing traceability to surface and upper-air measurements of key variables involved in climate change. As well as developing novel instruments and improved calibration procedures and facilities, the project provided improved validation methods for climate parameters with associated uncertainty budgets.

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European Metrology Research Programme
Delivering Impact

Protecting Europe's water resources

Water pollution has a significant negative impact on human health and the environment. Increasing demand from citizens and environmental organisations for cleaner rivers and lakes, groundwater and coastal beaches has led the European Commission to make water protection one of its priorities. The European Water Framework Directive (WFD) was established to protect and improve water quality and prevent further deterioration through legal limits on a wide range of known pollutants.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

The WFD specifies a list of 33 priority water pollutants, for which maximum allowable concentrations have been defined – these are known as Environmental Quality Standards (EQS). EU member states are required to implement monitoring programs to ensure their water bodies comply with the EQS. Some of the priority pollutants identified by the WFD are toxic to a wide range of living organisms, making them liable to accumulate within the food chain. The permitted levels specified by the EQS for such pollutants are consequently very low.

One such toxic pollutant is tributyltin (TBT), a compound used in protective coatings for boats. The use of TBT is now strictly regulated, but TBT levels in the coastal waters of most developed countries remain high enough to pose a threat to living organisms. However, until recently, no standardised methods existed for detecting TBT in water at the low levels required by the EQS. Determining TBT levels from real water samples, as required by the EQS, is even more challenging due to the presence of other contaminants, such as suspended particles present in natural water. Accurate methods for measuring pollutants at low levels in real water samples were needed, to serve as a reference for test laboratories and underpin the requirements of the WFD.

Solution

The EMRP project *Traceable measurements for monitoring critical pollutants under the European Water Framework Directive* developed two such reference methods, based on different mass spectrometry techniques, for measuring TBT levels in real water samples. Both methods are traceable to the SI and meet the requirements of the WFD regarding the limit of quantification (which describes the smallest concentration that can be reliably measured) and measurement uncertainty. This enables testing labs to benchmark their methods, demonstrate compliance with the regulations, and perform water monitoring services more accurately, efficiently and economically.

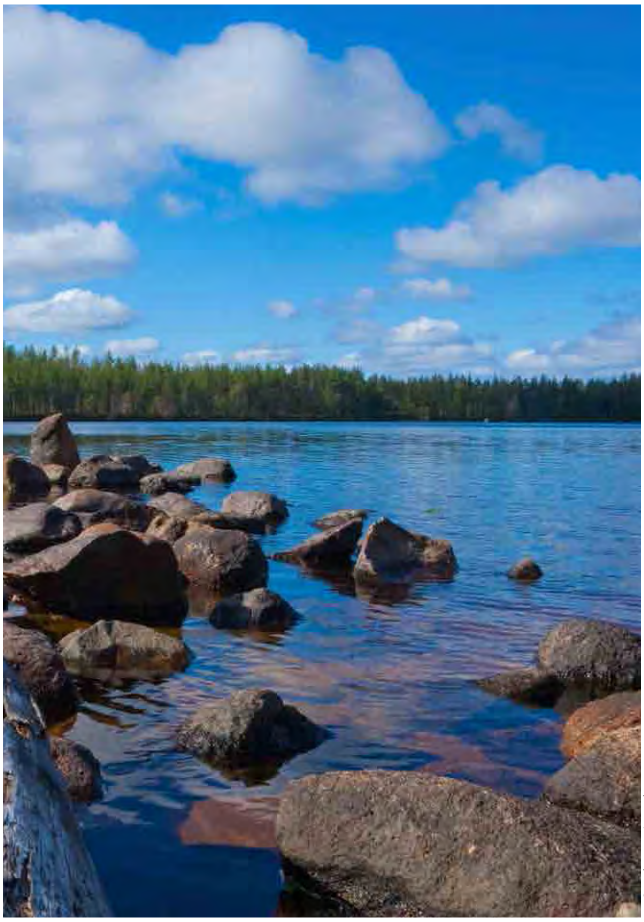
Impact

The improved method for TBT analysis developed in the EMRP project has already been adopted by IPROMA, an organisation contracted for water quality measurements by numerous Spanish Regional Authorities. IPROMA can now offer its clients an improved low-level TBT concentration test, enabling them to demonstrate that TBT levels in the open water systems used to supply cities and towns meet the requirements of the WFD. The new method is more efficient, requiring less time and labour, and costs 20% less to implement than its predecessor.

This improvement in measurement capability, along with other outputs of the project, will help ensure that levels of toxic pollutants in Europe's water resources are carefully monitored, protecting the public and environment.

Metrology in support of the Water Framework Directive

The EMRP project *Traceable measurements for monitoring critical pollutants under the European Water Framework Directive* was undertaken to support the implementation of the WFD and related directives, through improvements to the quality and comparability of data used to monitor the ecological status of Europe's inland water sources. The project developed primary reference methods for selected water pollutants, and produced new concepts for whole water reference materials and test materials that can meet the requirements of the legislation. The improvements will ensure long-term reliability and global comparability of water monitoring data obtained under the WFD and support better decision-making in the field of water management.



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European Metrology Research Programme
Delivering Impact

Supporting the Water Framework Directive

Water pollution has a significant negative impact on human health and the environment. Increasing demand from citizens and environmental organisations for cleaner rivers and lakes, groundwater and coastal beaches has led the European Commission to make water protection one of its priorities. The European Water Framework Directive (WFD) was established to protect and improve water quality and prevent further deterioration through legal limits on a wide range of known pollutants.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

The Water Framework Directive specifies a list of 33 priority water pollutants which present a significant risk to or via the aquatic environment. The Environmental Quality Standards (EQS) Directive specifies maximum allowable concentrations of these pollutants in surface waters such as rivers, lakes and coastal waters. EU member states are required to implement monitoring programs to ensure their water bodies comply with the EQS.

Some of the priority pollutants identified by the Water Framework Directive are toxic, persistent and liable to accumulate within the food chain and can endanger a wide range of living organisms - the permitted levels specified by the EQS for such pollutants are consequently very low. As a result, implementation of the European Water Framework Directive requires the ability to measure and monitor a range of pollutants at very low concentration levels.

However, a review by the CEN Technical Committee on Water Analysis identified a lack of appropriate standardised measurement methods for five important pollutants and pollutant groups identified in the WFD as 'priority hazardous substances'. In 2008, the European Commission tasked CEN to develop and improve standards in support of the WFD.

Accurate measurement of priority pollutants at the concentrations specified by the EQS requires the development of primary analytical methods and traceable reference materials at National Measurement Institutes and Designated Institutes, as well as practical methods and well-characterised materials for use in test laboratories on a routine basis. These new methods also need to be valid for 'whole water' - real-world water samples, where pollutants are not only found in solution but also bound to other materials such as colloids and suspended particulate matter.

Solution

The EMRP project *Traceable measurements for monitoring critical pollutants under the European Water Framework Directive* focused on three pollutants and pollutant groups (Tributyltin (TBT), Polybrominated Diphenylether (PBDE) and Polycyclic Aromatic Hydrocarbons (PAH)), bringing together experts from 11 European metrology institutes to develop primary analysis methods and the first ever reference materials for these substances in whole water. In parallel, the CEN community developed practical methods for test laboratories.

Impact

The project team provided well-characterised reference materials to enable CEN to undertake a validation intercomparison of test methods in support of the Water Framework Directive and provided method development advice to a working group of the CEN Technical Committee on Water Analysis. This work contributed to three draft standards developed by CEN for the analysis of the pollutants TBT, PBDE and PAH. These draft standards were published in 2015.

The project team also worked closely with end-users and quality assurance communities to ensure best practice and traceablility to national standards will be adopted widely. An intercomparison of test laboratories based on the new reference materials was undertaken to allow them to assess their in-house methods against the requirements of the European Directives, and traceable references values were provided for a Proficiency Testing scheme for field laboratories in France.

The adoption of the CEN standards and traceable measurements will improve pollutant testing processes across Europe and help keep priority hazardous substances in waters at a safe level. This will contribute to achieving the objective of the Water Framework Directive – high quality of surface, ground and coastal water in the EU and a reduction in the effects of pollution on the environment and human health.

Metrology in support of the Water Framework Directive

The EMRP project *Traceable measurements for monitoring critical pollutants under the European Water Framework Directive* was undertaken to support the implementation of the WFD and related directives, through improvements to the quality and comparability of data used to monitor the ecological status of Europe's inland water sources. The project developed primary reference methods for selected water pollutants, and produced new concepts for whole water reference materials and test materials that can meet the requirements of the legislation. The improvements will ensure long-term reliability and global comparability of water monitoring data obtained under the WFD and support better decision-making in the field of water management.

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Fingerprinting nuclear waste

Nuclear power accounts for more than a quarter of the EU's electricity supply and will continue to play a major role in the energy sector as Europe tries to meet growing energy demands while reducing carbon emissions. Over the next 25 years, around 250 nuclear facilities across Europe are scheduled for decommissioning. To protect public health and the environment, the millions of tonnes of waste generated needs to be sorted and appropriately stored according to the level of radioactive contamination.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

A large proportion of nuclear power plant waste has minimal radioactive content, well below biologically hazardous levels, and once classified as 'free release' it can be sent for recycling. However, all nuclear waste is necessarily subject to strict regulations governing its release and the criteria for free release into the environment are particularly stringent.

Measurements of both the nuclear fingerprint and radioactive half-life of waste are used to determine the appropriate level of storage and accurate knowledge of these properties is key to avoiding unnecessary storage time and costs. Until recently, site measurements have lacked the necessary accuracy to enable waste fingerprint characterisation for 'free release' waste designation. Improved on-site nuclide specific waste assessment and segregation methods would help minimise disposal costs and enable the rapid consignment of different waste types to the most appropriate storage or disposal facilities.

Solution

Research carried out within the EMRP project *Metrology for radioactive waste management* has enabled the construction of the first dedicated transportable waste assessment facility for this purpose. The project developed improved fast testing methods, which enable the precise determination of nuclear waste fingerprints - an essential capability for identifying the most appropriate disposal routes.

Impact

Through participation in the project, ENVINET, a leading provider of products and services for the monitoring of environmental radiation, has developed a new transportable waste measurement facility. This facility takes the new measurement methods developed within the project directly to decommissioning sites. The improved accuracy and speed of the results enable efficient on-site measurement of waste assumed for free release - in particular, the correct identification of waste suitable for free release should avoid the significant costs associated with unnecessary long-term storage.

Within the project, ENVINET was able to both validate the transportable facility and also demonstrate to the Czech authorities that it had developed the expertise needed to meet the stringent criteria governing the free release of nuclear waste, enabling a site license to be granted. Subsequently, the first consignments of 150 tonnes of accumulated waste at the ÚJV Řež site in the Czech Republic have been accurately and efficiently sorted prior to release for disposal. The ENVINET facility will next be used at a decommissioning site in Italy.

As more and more nuclear plants become available for decommissioning, and those reactors that have been cooling for several decades reach the final dismantling stages, increasing amounts of waste will require efficient and accurate sorting. ENVINET's transportable waste facility, made possible through the research carried out within the EMRP project offers a timely and cost-effective solution to this growing problem.

Plant decommissioning in Europe

After nuclear fuel removal and draining of fuel ponds, the reactor building, the most heavily contaminated part of the site enters a period of radioactive decay prior to complete disassembly to return the site to near its original state. Other buildings and structures (e.g. the turbine hall and cooling circuits) have significantly less radioactive contamination and can be removed soon after plant de-fuelling. These contain the majority of the slightly contaminated waste material requiring safe disposal but are none the less hugely expensive to monitor and remove.

Spain's Vandellos 1, a 480 MWe gas-graphite reactor which suffered a fire, underwent reactor decommissioning and dismantling after an initial 13y cool down period over 63 months costing EUR 93 million. The reactor vessel is in Safstor for another 15y.

Germany has 11 plants for dismantling and a budget of EUR 30 billion set aside for this purpose.

In France the CEA is decommissioning the UP1 fuel reprocessing plant at Marcoule, work is expected to spread over 40y and cost some EUR 5.6 billion.

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Traceability for mercury measurements

Mercury, a highly toxic metal, can be released into the environment from human sources. European and international treaties are in force to limit its emission, introducing the need for reliable mercury monitoring. Cheap and easy to use sensors that can be deployed anywhere in the world and capable of operating without power supplies are needed for monitoring atmospheric mercury levels.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Mercury is a ubiquitous and naturally occurring metal which can be released into the environment through natural processes, but a major source is from human activities such as mining or the use of fossil fuels. Highly toxic in all its forms, mercury compounds can be spread through the air and accumulate in both terrestrial and aquatic bio-systems. This has led the World Health Organisation (WHO) to label this metal as a priority hazardous substance and one of the top ten groups of chemicals of major public health concern. In 2013 the Minamata Convention was held with the aim of minimising the man-made releases of mercury into the environment and from this an international treaty came into force in 2017. In support of this European directives aim to progressively reduce its discharges, emissions and losses to zero within the next 20 years.

Monitoring networks are now being set up throughout the world to track mercury emissions and the success of reduction strategies. However, determining ambient mercury levels in the atmosphere is difficult as mercury easily volatilises or adsorbs onto surrounding surfaces. This, along with a lack of validated measurement methods with robust SI links for assessing low mercury concentrations, means it is currently not possible to defensibly assess mercury levels at internationally agreed limits. Simple, cost effective mercury sensors are needed to increase network measurement capability, especially those which can operate without the need for external power supplies on technical intervention.

Solution

The EMRP project *Traceability for Mercury Measurements* developed a new prototype "passive sensor" for determining mercury in ambient air. Researchers at the National Research Council of Italy's Institute of Atmospheric Pollution Research (CNR-IIA) used novel materials based on an adsorbent layer of titanium nanoparticles finely decorated with gold to form a regular structure able to trap mercury. As well as being low cost, these sensors are re-usable and designed to give information about average mercury pollution levels down to ultra-trace amounts, with robust links to the international system of units (SI).

Comparable in performance to traditional sensors they can be deployed in the field for times ranging from few hours to weeks/months and have the added advantage in that they do not require an external power supplies or technical expertise for use.

Impact

The United Nations Environment Programme and the World Health Organization through a cooperation with the CNR-IIA have used the project's passive sensors at 10 sites worldwide in a pilot study for the development of a global monitoring system to meet the requirements of the Minamata Convention. In addition, these new sensors are being used in a comparative study currently organised by CNR-IIA in the EU funded project Integrated Observing Systems for Persistent Pollutants. This project is developing measurement instruments for mercury and other persistent pollutants supporting the new Group on Earth Observation's Flagship, "GOS4M" (Global Observing System for Mercury) that aims to develop a global observation system for mercury.

Increasing mercury measurement coverage around the world will lead to an increased knowledge of the scale of this global problem and help identify were efforts are most needed to reduce mercury release to the environment so reducing its potential for damage in the future.

Monitoring mercury in the environment

The EMRP project *Traceability for Mercury Measurements* developed a calibration system for airborne mercury and used it to calibrate environmental monitoring sensors based on accurately determining mercury vaporisation weight loss, to provide a potential replacement for currently used empirical equations. This calibration system was used to characterise an SI traceable transfer instrument that circulated between the project partners enabling the generation of international equivalence for the first time. It also confirmed the performance of project developed innovative, low-cost, mercury-in-air monitoring sensors demonstrating their suitability for use in monitoring for atmospheric traces of mercury. These have subsequently been trialled by an international monitoring network. Working with multiple biota samples, the project optimised and validated preparation procedures for determining mercury content in fish and used these to establish inter-species differences resulting from variation in fat content or habitat. This is important for analysing samples drawn from rivers and oceans to determine mercury uptake in the food chain.

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Better digestion for mercury analysis

Mercury is highly toxic and once released into the environment bioaccumulates into fish and seafood. Released from burning fossil fuels and broken fluorescent light fittings its emissions are regulated by international treaties and EU Directives. For industrial polluters to demonstrate regulatory compliance mercury emissions are carefully monitored. But the continuing use of an empirical equation for calibration and non-optimised chemical analysis methods hinder a robust measurement hierarchy.

Europe's National Measurement Institutes working together

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Challenge

Highly toxic mercury affects the immune system and damages the nervous system. Produced naturally by volcanoes, and forest fires, it is also released during burning fossil fuels and from broken energy saving fluorescent lamps. Once in the atmosphere it bioaccumulates into fish and seafood. For these reasons EU Directives classify mercury as a Priority Hazardous Substance and require member states to progressively reduce emissions to zero over the next 20 years.

Currently all mercury in air measurements are traceable to an empirical equation derived in a 1980s that was subsequently adopted internationally by instrument manufacturers. Reference measurement data from using this equation is reported in atmospheric monitoring, but confirming the accuracy of this equation is difficult. A more rigorous approach based on a measurement hierarchy with robust links to SI units would help improve the quality of atmospheric mercury monitoring.

Plants discharging mercury into the environment use filters and impingers, devices that trap particles in a liquid, for this purpose. Collected particles are digested using a chemical procedure that produces a syrupy solution for transfer through thin tubes into sensitive analytical instruments – a process prone to blockages. This method, underpinned by European Normative documentary standards, is based on operators using highly reactive HF acid which can cause deep painless burns that have the potential to destroy tissue unless treated immediately.

Greater accuracy for determining mercury that is trapped by industrial plants and that released into the atmosphere is needed to enable improved compliance with EU Directives.

Solution

The EMRP project *Traceability for Mercury Measurements* developed a new digestion method based on aqua regia, a strong acid, for preparing mercury-containing samples for analysis. This method produces a solution that is easy to transfer to the analytical instruments used - removing previous problems with clogged analytical instrumentation. Now incorporated into an annex to the relevant mercury measurement EN standard it has made the first steps towards use in regulatory emission monitoring.

To improve the accuracy of measurements of mercury in air the project developed a consistent method based on weighing mercury losses for use in instrument calibration. This method has robust links to SI units and good reproducibility. Increased use in instrument calibrations will decrease reliance on the interpretation of an empirical equation and assist in greater result comparability.

Impact

The mercury measurement community requires accurate reference data and robust instrument calibrations to make meaningful measurements. Currently there is an increasing debate about the validity of reference data arising from different sources. There are now several competing datasets that do not agree, some with historical authority and others with more robust links to SI units. To overcome this dilemma an international committee is required to propose the way forward and methods to confirm data reliability.

The NMI community is proposing that the CCQM could be the arbiter for data quality. The BIPM maintains a materials database of reference data and this could be extended to include NMI derived data on mercury in air with robust links to the SI. An international decision on this is required to make progress in this area. The introduction of a robust measurement hierarchy underpinned by accurate reference data will help industrial plant comply with EU Directives on mercury emissions.

Monitoring mercury in the environment

The EMRP project *Traceability for Mercury Measurements* developed a calibration system for airborne mercury and used it to calibrate environmental monitoring sensors based on accurately determining mercury vaporisation weight loss, to provide a potential replacement for currently used empirical equations. This calibration system was used to characterise an SI traceable transfer instrument that circulated between the project partners enabling the generation of international equivalence for the first time. It also confirmed the performance of project-developed innovative, low-cost, mercury-in-air monitoring sensors demonstrating their suitability for use in monitoring for atmospheric traces of mercury. These have subsequently been trialled by an international monitoring network. Working with multiple biota samples, the project optimised and validated preparation procedures for determining mercury content in fish and used these to establish inter-species differences resulting from variation in fat content or habitat. This is important for analysing samples drawn from rivers and oceans to determine mercury uptake in the food chain.

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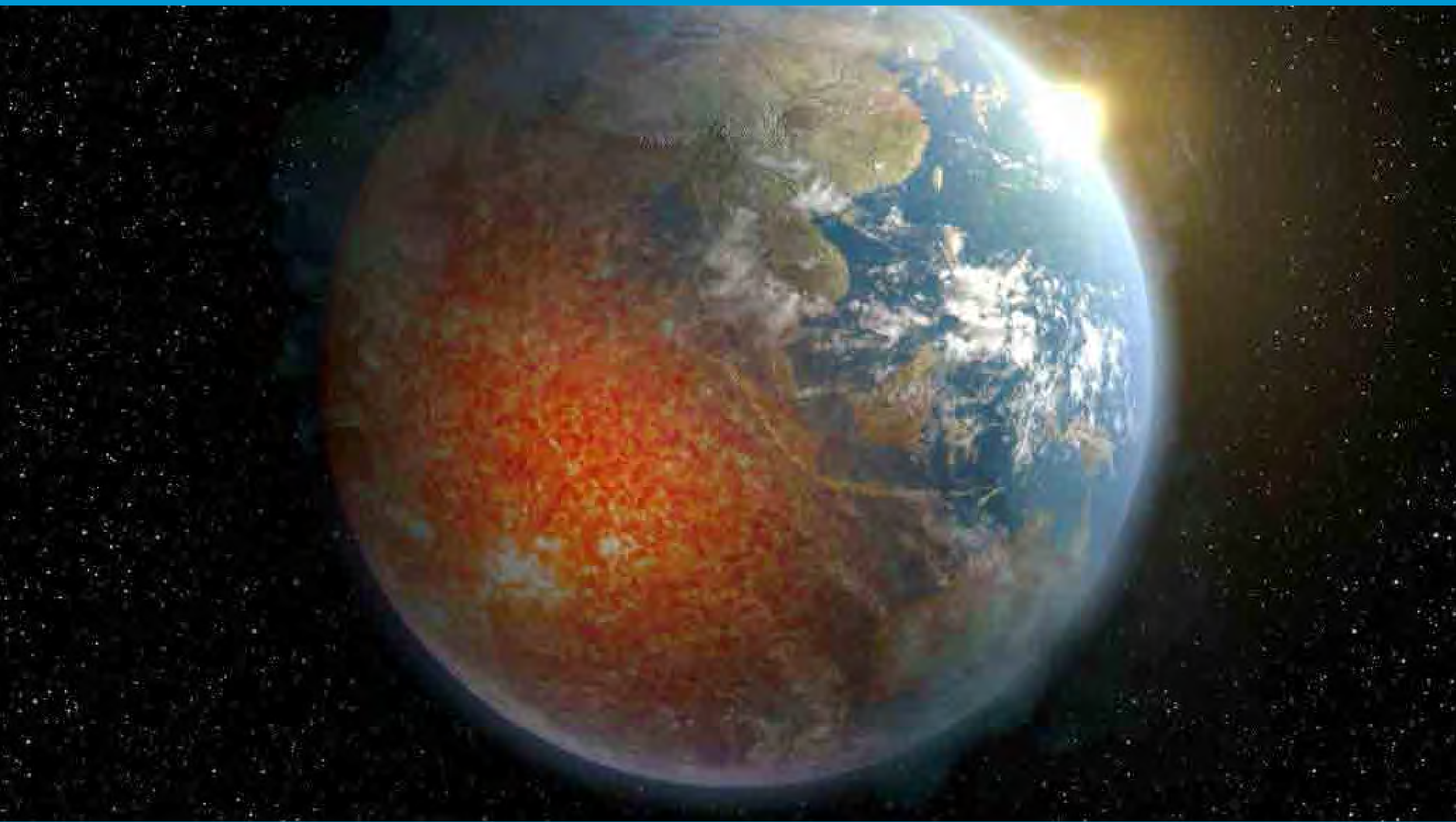

Detecting new pollutants in the air

Atmospheric greenhouse gases are driving global warming. Amongst the most damaging are those containing fluorine and other halogens, frequently used as refrigerants. Per molecule, these are many times more potent than carbon dioxide. Whilst international treaties regulate many of these gases, new variants are continually entering use. To determine their source and atmospheric trends, networks of monitoring instruments need robust calibration standards for measurement accuracy.

Europe's National Measurement Institutes working together

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Challenge

Halogenated gases such as hydrofluorocarbons and chlorine containing compounds, have Global Warming Potentials thousands of times greater than that of carbon dioxide, and can remain in the air for decades to centuries, so even trace amounts can damage the environment. European regulations aim to considerably cut halogenated gas emissions by 2030 but newer compounds are continually being introduced for use as refrigerants in fridges and in car air-conditioning systems.

Establishing the source of these pollutants and determining atmospheric trends relies on monitoring stations often at geographically remote locations. Detecting gas traces at the part per trillion level present in the atmosphere requires highly accurate gas standards for instrument calibrations. Currently, these gas standards are produced at only a limited number of specialist atmospheric monitoring institutes, and these are trying to keep up with the rapid introduction of new gas compounds. Gas standards with robust links to SI units would increase the number of suppliers from the NMI community, but first the accuracy of these standards must increase to match user community expectations.

Solution

The EMRP project *Metrology for High-Impact Greenhouse Gases* developed a method for making fluorinated gas mixture calibration standards suitable for use by halogenated gas monitoring networks. These standards are extremely accurate and involve several precise dilution stages using highly accurate weighing and mass flow control to achieve the required halogenated mixture in a single gas cylinder. The creation of a mixed gas standard enables users at monitoring stations to perform calibrations for several gas compounds in a single operation so reducing the complexity and time required to establish ongoing instrument performance.

Impact

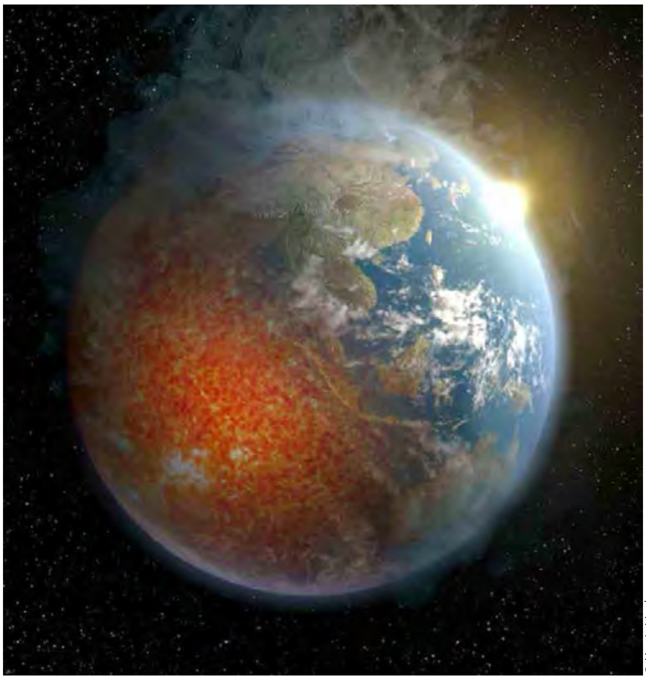
The Swiss Federal Laboratories for Materials Science and Technology, Empa is a material testing and air quality research institute, which runs the Swiss air monitoring network, including the high-altitude station at Jungfraujoch. This is part of the AGAGE network that tracks and records hydrofluorocarbons and chlorine containing compounds in the atmosphere.

Empa has used the project's new halogenated standard with their own dilution system to produce a reference gas mixture with a composition similar to the one part per trillion level in the atmosphere. Satisfied with its suitability for use at a monitoring station, a canister containing this mixture was tested and included into the international monitoring networks' measurement scale. A careful comparison between it and the existing standards must first be conducted to ensure measurement continuity and the early identification of any issues that a change in preparation methods might introduce. Once the new SI traceable standards suitability for use has been confirmed, a greater number of institutes around the world will be able to share the responsibility for producing these complex halogenated standards essential for detecting atmospheric halogenated gas trends and pollution sources.

Accurate monitoring of greenhouse gases

The EMRP project *Metrology for High-Impact Greenhouse Gases* developed CO_2 standards isotopically matched to the ratio of $^{13}CO_2$ to $^{12}CO_2$ in the atmosphere along with improved point-of-use standards for CO_2, CO, CH_4, N_2O, and halogenated gases - all with traceability to the SI. A synthetic "zero" air gas was also generated containing quantified trace amounts of contaminants for use in reference gas production and setting instrument background responses. In addition, an SI-traceable optical transfer standard for spectroscopic measurements of CO and CO_2 was developed and the use of Optical Isotopic Ratio Spectroscopy for measuring different isotope abundance in analysis samples was investigated. Isotope analysis is important for increasing the accuracy of calibration standards and determining greenhouse gas sources.

This new suite of reference standards will improve the measurement accuracy for gases that drive global warming, help in locating the source of the producers and aid the enforcement of International treaties.



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Fibre-optics for structural integrity

Ensuring the integrity of large nuclear structures such as waterways supplying coolant or geological disposal facilities for high level long lived radioactive waste is important for our safety and that of the environment. Temperature measurements based on optical sensing could provide key information on long-term structural integrity but generating confidence in a monitoring system that will operate for tens of years relies on rigorous testing of all its constituent parts.

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Challenge

Monitoring the long-term strength of large structures used in the nuclear power industry is essential to safeguard the environment from radioactive contamination. Dykes formed of natural materials such as gravel, clay, or sandy soil provide the constraining banks of major rivers supplying water cooling to nuclear power plant. Temperature differences between the materials used in dyke construction and the water carried create erosion that undermines their integrity. Whilst for the envisaged deep geological disposal for high level radioactive waste, temperatures need to remain below 90 °C in clay to ensure that the surrounding rock retains strength.

Distributed temperature sensing based on embedded optical fibres and instrumentation for detecting and interpreting the laser signals used, can provide temperature information at every metre along the fibre's length. This means that a single fibre can provide thousands of temperature probes over kilometre distances, creating a cost-effective thermal monitoring system for large structures.

To have confidence in the long-term performance of distributed temperature sensing systems it is important to be able to interchange their control and interpretation instrumentation due to age-related failures or technology advances. Ensuring that system components meet specification and variants from different suppliers are compatible relies on the development of well characterised test set-ups based on pulse-echo measurement principles.

Solution

The EMRP project *Metrology for decommissioning nuclear facilities* developed a facility for studying the performance of key sensing components in distributed temperature sensing systems. To simulate in-service conditions, optical fibres in a 25 m long heater are used to create test signals for assessing the performance of detection and interpretation instrumentation. Procedures for operating this facility are being incorporated into a new IEC standard that will enable greater test uniformity for temperature monitoring using optical sensing. This is an important step that will enable users in the nuclear and other industries to have greater confidence in the adoption of this novel temperature monitoring technique.

Impact

ANDRA, the French National Agency for Radioactive Waste Management, has used the projects test facility to perform independent assessments of commercially available distributed temperature sensing system components to determine inter-operability. Results are informing the selection of candidate control and interrogation units for trials deep underground to simulate realistic repository conditions. Selecting the best currently available technologies is essential to ensure the long-term structural integrity of the radioactive waste repository envisioned in the vicinity of Bure district.

EDF has installed distributed temperature sensing systems for monitoring water dykes with safety-related requirements such as preventing hazards associated with flooding at nuclear power plant. Due to evolving requirements and specifications regarding system performance, EDF is undertaking assessment projects using this test facility. Their objective is to select technologies that meet operational requirements where long-term durability is essential.

Independent testing of distributed temperature sensing is providing the nuclear industry with reliable performance assessments and generating increased confidence for further adoption in the monitoring of safety critical structures. Ensuring the long-term integrity of nuclear industry structures is essential to avoid significant radioactive release into the environment.

Technologies for nuclear decommissioning

The EMRP project *Metrology for decommissioning nuclear facilities* investigated methods and sampling regimes for in-situ radioactive contamination mapping and extended the capability of a nuclear waste handling system developed in the previous EMRP project *Metro RWM* to cover both waste segregation and free release category assessment. New methods for assessing highly radioactive waste drum integrity based on acoustic thermometry were investigated and prototype instruments for monitoring hazardous gas emissions of tritium or carbon-14 from waste containers were developed and evaluated. A new facility for assessing components in distributed temperature sensing systems is now providing nuclear industry operators with the needed confidence to enable this technology to be considered as a candidate for use in the planned nuclear repository nearby Bure.

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Ammonia monitoring networks

Agriculture is responsible for 94 % of all ammonia emissions, 75 % of which is from intensive livestock farming, contributing to wide-ranging environmental problems. The EU's National Emission Ceilings Directive sets ammonia reduction goals, and the UK is developing strategies to support farmers to reduce emissions. To assess their effectiveness and track reductions against targets, with high measurement accuracy are needed.

Europe's National Measurement Institutes working together

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Challenge

Intensive farming practices, relating to livestock, such as slurry spreading or maintaining herds indoors, are major contributors to ammonia emissions. When released, ammonia can deposit on and damage ecosystems and it can also react with atmospheric gas to produce fine particulate matter ($PM_{2.5}$) that is hazardous to our health.

The EU's National Emission Ceilings Directive, 2018, establishes ambitious goals for reducing ammonia emissions and requires member states to monitor environmental ammonia levels and demonstrate via inventory reporting decreasing ammonia pollution. Monitoring networks mainly use passive samplers to trap ammonia from air for subsequent laboratory analysis. These are augmented at a small number of sites by active ammonia measurements used for network calibration and quality assurance purposes.

Manufacturers of passive samplers provide users with equations on ammonia uptake for calculating how the amount of trapped ammonia relates to its concentration in air. However, due to the variety of trapping systems available, the number of different equations used, and the effects of site positioning and prevalent environmental conditions comparing the results obtained is challenging.

A greater understanding of the performance of different sampler types, coupled with the development of traceable reference materials suitable for use in the field is required to enable samplers to be robustly compared under real environmental conditions. Resulting improvements will support monitoring networks in demonstrating the accuracy of ammonia measurements.

Solution

The EMRP Project *Metrology for ammonia in ambient air*, extended the capabilities of NPL's existing Controlled Atmosphere Test Facility (CATFAC) - which provides gas sensor testing - to be suitable for ammonia passive sampler measurements. This included developing new stable ammonia reference standards at part per million levels; cylinders of gas containing ammonia at precise concentrations for subsequent dilution to the part per billion levels encountered in atmospheric monitoring.

This facility and the project's reference gas standards were employed to assess a selection of passive samplers routinely used in monitoring networks. An accurate knowledge of the supplied gas concentration made it possible to derive new equations that better reflect the relationship between ammonia concentrations and sampler uptake rate. These underpin the accuracy with which environmental levels of ammonia can be determined in the field.

Impact

The Centre for Ecology & Hydrology (CEH), which operates the UK National Ammonia Monitoring Network on behalf of Defra and the Devolved Administrations, has 9 sites with parallel active samplers for long term calibration of the network. As a result of interactions with the project team, CEH now hosts an annual comparison exercise to assess ammonia sampling device performance.

Through controlled releases of the project's reference materials during field trials using passive ammonia sampling devices, CEH was able to demonstrate that CATFAC derived equations gave more accurate results and that local climate and conditions are key for understanding and delivering high quality traceable ammonia passive sampler measurements. These studies have contributed to information used in a new CEN measurement standard that will enable users and manufacturers of passive ammonia sampler manufacturers to develop improved traceable high-quality approaches for ambient ammonia monitoring.

Measuring ammonia in air

The EMRP project *Metrology for Ammonia in Ambient Air* developed ammonia reference gas standards for use in calibrations and in-the-field device performance assessments and upgraded the existing CATFAC facility for use with ammonia. This was then used to evaluate material/ammonia interactions to help inform user selection decisions. The facility has enabled the exposure of ammonia measuring devices to well characterised ammonia atmospheres similar to those encountered in the field and followed by a pioneering field study, has enabled manufacturers to appreciate the importance of reliable characterisation data for sampler measurement accuracy. Testing using the CATFAC facility to supply both environmental levels of ammonia and water vapour has enabled accurate characterisation of laser-based spectroscopy technologies suitable for real time ammonia monitoring. Greater measurement accuracy for ambient ammonia concentrations will assist member states demonstrate compliance with the EUs Industrial Emissions Directive.

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Greater accuracy for ammonia monitors

Ammonia is a harmful pollutant produced by intensive farming which damages ecosystems. Monitoring networks assess environmental ammonia levels and the success of strategies for meeting EU emissions targets. Performing spot checks and ensuring test exercises supply specified ammonia concentrations to the samplers used requires accurate real-time measurements. Optical gas measurement technologies could provide these, but first ways to compensate for effects created by water vapour in the sample are needed.

Challenge

When released, ammonia reacts with atmospheric acids to form harmful particles which damage the environment, ecosystems and human health. To combat this, the EU National Emission Ceilings Directive has set emissions reduction goals, requiring member states to track ammonia emissions reductions via a network of monitors. These monitors collect ammonia samples from air, and laboratory analysis provides the average amount of ammonia in the environment.

Accurate real-time ammonia measurements could help build a more detailed picture of peaks and troughs in emissions and could also validate ammonia levels used in exercises to assess sampler performance during environmental monitoring.

Laser-based optical techniques such as Cavity Ring-down Spectroscopy have the potential to provide these real-time measurements. A laser beam specifically tuned to the absorption wavelength of ammonia is shone into a cavity containing the sample under analysis. Highly reflective mirrors in the cavity quickly fill it with light to a pre-set intensity, then the laser is abruptly turned off. The remaining light steadily loses its intensity and the time for the light to die away or "ring down" is measured. This is used to calculate the concentration of ammonia in the gas sample. Based on fundamental physical properties, this technology is stable long-term, which greatly reduces instrument calibration requirements.

However, results from laser-based measurement techniques are distorted by variations in atmospheric water vapour content created by ambient weather conditions. To improve their reliability, new facilities are needed for characterising instrumentation under conditions that simulate those in the environment.

Solution

The EMRP Project, *Metrology for Ammonia in Ambient Air,* investigated how humidity levels affect ammonia measurements.

The Controlled Atmosphere Test Facility for environmental gas testing, CATFAC was extended in the project to cover ammonia testing permitting researchers to create highly precise compositions of ammonia gas with well-defined humidity levels. This enabled the evaluation of laser based optical techniques, allowing comparison of measured results with known accurate compositions. These results improved understanding of how water vapour interacts with laser signals, information which was used to develop models to remove humidity effects, and so improve the accuracy of optical techniques.

Impact

Picarro, a leading provider of gas measurement technologies, became an early user of the upgraded CATFAC facility to assess and improve its Cavity Ring Down Spectrometer, a laser-based ammonia monitoring instrument.

Picarro were able to evaluate their instrument's performance by measuring samples containing accurately known concentrations of water vapour and ammonia. This enabled Picarro to improve their models and to minimise water vapour interference effects that reduce the accuracy of ammonia measurements. These measurements, performed at the CATFAC facility, provided independent validation of their spectrometer, increasing confidence in its performance.

These improvements enable the instrument to operate at higher levels of accuracy, making it viable as a transfer standard for comparing laboratory-based calibration results to those achieved by sampling devices in the field. It also opens applications in other areas where precise ammonia monitoring is required, such as leak detection in semiconductor cleanrooms. This will bring greater accuracy to environmental ammonia monitoring, which will be important for spotting trends and assessing the success of ammonia reduction strategies.

Measuring ammonia in air

The EMRP project *Metrology for Ammonia in Ambient Air* developed ammonia reference gas standards for use in calibrations and in-the-field device performance assessments and upgraded the existing CATFAC facility for use with ammonia. This was then used to evaluate material/ammonia interactions to help inform user selection decisions. The facility has enabled the exposure of ammonia measuring devices to well characterised ammonia atmospheres similar to those encountered in the field and followed by a pioneering field study, has enabled manufacturers to appreciate the importance of reliable characterisation data for sampler measurement accuracy. Testing using the CATFAC facility to supply both environmental levels of ammonia and water vapour has enabled accurate characterisation of laser-based spectroscopy technologies suitable for real time ammonia monitoring. Greater measurement accuracy for ammonia emission reporting will assist member states demonstrate compliance with the EUs Industrial Emissions Directive.

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Monitoring ammonia

Ammonia is a harmful pollutant, which damages ecosystems, harms human health and contributes to global warming. The EU has set targets for its reduction and introduced Directives for its regulation, verifying compliance requires accurate ammonia sensors that do not interact with the gas they measure. Improved material test and calibration facilities with robust links to SI units are needed to support the development of sensors based on ammonia inert materials.

Europe's National Measurement Institutes working together

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Challenge

Intensive farming practices are producing growing ammonia emissions from animal waste and fertiliser use. Once in the air, ammonia reacts with other atmospheric chemicals to produce very small particles which are harmful when inhaled and gases that contribute to global warming. Under the 2012 UNECE Gothenburg protocol, EU member states must cut ammonia emissions by 6 % and particles by 22 % by 2020. Accurate monitoring schemes are required to track these reductions.

Whilst monitoring for other environmental pollutants has improved dramatically in recent years, ammonia monitoring has lagged behind. A major reason is that ammonia is very reactive making it hard to measure. When sucked into measurement sensors, ammonia has a habit of sticking to the sides, therefore the air measured does not contain the same concentration as that present in the atmosphere. A similar problem exists during ammonia sensor calibration with the ammonia gas cylinder standards appearing to reduce in concentration overtime as ammonia sticks to cylinder walls.

To increase the accuracy of ammonia monitoring, new techniques for testing materials and evaluating sensors, are needed to ensure all the sampled ammonia reaches the detector and none has been lost due to sticking to the gas sampling system.

Solution

The EMRP Project, *Metrology for Ammonia in Ambient Air,* extended the capabilities of The Controlled Atmosphere Test Facility (CATFAC), an existing testing facility which evaluates how polluting gases interact with materials at the low concentrations encountered in the atmosphere. Gases simulating atmospheric pollution levels are pumped around a chamber containing the material under test. Gas absorption by the material undergoing testing is confirmed by accurately monitoring the gas concentration in the system.

As part of the project, the facility evaluated materials commonly used in ammonia sensors, and tested sensor performance under conditions similar to those found in environmental monitoring, providing valuable data to sensor manufacturers. The project also investigated the use of proprietary coating to reduce ammonia interactions with gas cylinder materials and discovered that a SilcoTek coating improved the long-term stability of precise ammonia gas calibration standards contained in cylinders.

Impact

MIRICO, a manufacturer of high-performance gas sensing instruments was one of the first to employ project derived gas calibration standards to identify the most suitable materials for use in a prototype ammonia sensor. This sensor is being developed for standalone use and for inclusion into MIRICO's air quality monitoring platform.

The sensor sucks gas into a cell and shines a laser through the sample, calculating the ammonia concentration based on changes to the laser light's properties. As a result of this testing, MIRICO identified materials that have little interaction with ammonia, so increasing confidence in the sensors accurate measurement of low-level ammonia concentrations.

Ammonia sensors also have applications in the semi-conductor industry, where manufacturers need to confirm ammonia used in production has not leaked into cleanroom air and is compromising product quality. Sensor advances made by MIRICO and others, through access to the upgraded gas standards and CATFAC facility, will help increase the accuracy of monitoring both global and local ammonia emissions. This in turn will help inform and enforce current emission reduction measures, reducing the harm to health and the environment that ammonia causes.

Measuring ammonia in air

The EMRP project *Metrology for Ammonia in Ambient Air* developed ammonia reference gas standards for use in calibrations and in-the-field device performance assessments and upgraded the existing CATFAC facility for use with ammonia. This was then used to evaluate material/ammonia interactions to help inform user selection decisions. The facility has enabled the exposure of ammonia measuring devices to well characterised ammonia atmospheres similar to those encountered in the field and followed by a pioneering field study has enabled manufacturers to appreciate the importance of reliable characterisation data for sampler measurement accuracy. The CATFAC tests also included water vapour as a cross interferent at levels likely to be observed in the environment and assisted the introduction of laser-based spectroscopy technologies for real time ammonia monitoring. Greater measurement accuracy for ammonia emission reporting will assist member states demonstrate compliance with the EUs Industrial Emissions Directive.

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European Metrology Research Programme
Delivering Impact

Formaldehyde emissions monitoring

Formaldehyde, emitted from furnishing and construction materials and from the combustion of organic materials, can cause health problems. Regulations govern safe limits, and monitoring systems check these are not exceeded. Gas standards – cylinders with accurate formaldehyde amount fractions – are used to calibrate these systems, but as air quality limits become stricter, new methods are required for producing standards with lower, stable amount fractions to confirm the performance of monitoring instrumentation.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Trace amounts of volatile organic compounds (VOCs), such as formaldehyde, are released into the environment by the manufacture of housing materials such as furnishings, wood-based products, plastics and varnishes and also from the combustion of ethanol added to petrol to reduce carbon monoxide. Traces of formaldehyde can make people feel unwell, and prolonged exposure can cause respiratory problems, and in rare cases may induce nasal cancer.

EU regulations limit acceptable levels in buildings and the environment for VOCs, limits which are expected to be tightened. The World Meteorological Organization Global Atmosphere Watch (WMO-GAW) has implemented a worldwide VOC monitoring programme, and Europe alone has more than 50 monitoring stations, to evaluate air quality and track global trends.

To confirm air quality meets data quality objectives, monitoring instruments must be calibrated to detect trace amounts of formaldehyde at the low levels found in air. This requires stable standards – gas cylinders containing accurate amount fractions of formaldehyde – against which instruments can be calibrated.

However, formaldehyde is very reactive and sticks to the cylinders, so its amount fraction may reduce with the passage of time. As air quality regulations become stricter, new formaldehyde standards are needed which use inert materials to ensure their contents remain stable over time, in order to reliably confirm the performance of monitoring instrumentation.

Solution

The EMRP Project *Metrology for VOC indicators in Air Pollution and Climate Change* investigated materials which are inert to formaldehyde and used these to improve the design of systems used to generate formaldehyde gas standards, and the cylinders used for storing them.

This led to the development of a new dynamic production facility for creating very low-level formaldehyde mixtures for use as calibration standards. The inert facility creates known quantities of formaldehyde and carefully dilutes them with VOC-free gas to produce amount fractions of one part per million (ppm), which is very low for a gas reference standard. The project also investigated the stability of cylinders containing formaldehyde gas standards over time through repeated testing with highly accurate measurement instruments and confirmed that their amount fractions held and therefore these are fit for purpose.

Impact

Air Liquide, the world's largest supplier of industrial gases, routinely supplies reference gas standards to industry and academia, including formaldehyde standards. It was one of the first to use the new project developed LNE dynamic production facility for formaldehyde gas standards to calibrate its own in-house standards.

Air Liquide anticipates increasingly stringent building regulations and outdoor air directives with tighter VOC emission requirements, which will increase the market for low level standards for confirming the performance of formaldehyde monitoring instrumentation. Air Liquide aims to be ready with a capability in place to provide these low part-per-million formaldehyde standards.

Access to more accurate standards will help polluting industries such as builders and fuel producers, as well as governments and local authorities, to monitor, control and reduce formaldehyde emissions and to demonstrate compliance with increasingly strict regulations.

Monitoring volatile organic compounds in air

The EMRP project *Metrology for VOC Indicators in Air Pollution and Climate Change* developed new point-of-use reference materials and gas standards at the low amount fractions required for monitoring volatile organic compounds (VOCs) in the environment. The project investigated the use of coatings and materials to reduce interactions between VOCs and metal surfaces which is important in both maintaining gas standard stability in storage as well as the in-situ production of gas standard before use to characterise analytical instrumentation. The project standards were used to evaluate the performance of low-cost gas sensors for environmental monitoring of VOCs and generated increased knowledge in the use of this type of sensors. This work builds on outcomes from the EMRP project *Metrology for Chemical Pollutants in Air*.

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Accurately monitoring trace pollutants

Man-made and naturally occurring volatile organic compounds, such as methanol or acetone, affect air quality and the climate by the formation of ozone and aerosols. The World Meteorological Organization's Global Atmosphere Watch monitoring network tracks these trace compounds and aerosols to increase our understanding of climate trends and the success of mitigation strategies. Improving the accuracy of networks monitoring data requires improved links between lab-based calibrations and networked instruments.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Traces of man-made and naturally occurring volatile organic compounds (VOC) and oxygenated VOCs such as methanol or acetone react with other atmospheric trace gases to create ozone and aerosols, which impact on air quality and climate. Sources of these include fossil fuel and biomass burning, and the use of solvents in paints and coatings. The World Meteorological Organization's monitoring network Global Atmosphere Watch observes these trace gases and monitors atmospheric chemical changes to enable an improved understanding of how human activities create climate change and the success of mitigation strategies. Detecting climate trends relies on accurate monitoring of trace gas pollutants. To obtain accurate measurement data, air sampling procedures and reliable calibrations of field-based analytical instruments are essential.

Monitoring stations collect air samples to pre-concentrate trace gases prior to analysis. However, oxygenated VOCs are very reactive and are prone to sticking to any metal surfaces they come in contact with, such as sampling lines and storage containers. This introduces measurement errors as gas traces are reduced from the levels present in the atmosphere. Shipping from remote locations to measurement centres for precise analysis may introduce additional gas adsorption losses. A similar effect occurs in the gas standards used to calibrate analysis instruments at monitoring network measurement centres. Ensuring that highly accurate measurement results are achieved requires the use of inert materials in gas transfer lines and vessels and the development of stable calibration standards and methods to reliably compare performance across all the networks calibration laboratories.

Solution

The EMRP project *Metrology for VOC Indicators in Air Pollution and Climate Change* developed methods to quantify oxygenated VOC absorption by metal surfaces and found that a proprietary coating manufactured by SilcoTek™ significantly improved their long-term stability. Zero gases, such as nitrogen, free of volatile carbon containing compounds were also developed to ensure the accuracy of calibration standards and the zeroing of gas analysis instrumentation free from spurious VOC traces.

Impact

The German meteorological service (DWD) operates the Global Atmosphere Watch trace gas monitoring station Hohenpeissenberg. DWD was also a partner in the EU 2020 Horizon Aerosol, Cloud, and Trace Gases Research Infrastructure (ACTRIS) project in which they organised an assessment exercise to confirm oxygenated VOC (OVOC) analytical laboratory performance using the EMRP projects new developed OVOC gas standards. This exercise was the first joint side by side comparison of prospective European ACTRIS calibration facilities and included the GAW World Calibration Centre. It demonstrated facility proficiency in measuring atmospheric OVOCs and provided the first opportunity to calibrate all participating measurement systems with the new OVOC calibration gas.

In the future DWD plans to regularly perform similar exercises to assess VOC lab capabilities, to test new VOC analytical instruments, and to circulate calibration gas mixtures to help ensure that ACTRIS and GAW networks labs are producing high quality and comparable VOC data.

This interaction has increased links and improved the understanding of the importance of SI traceable measurements between European NMIs and the atmospheric monitoring community. As a result, the Dutch NMI VSL expects to be appointed as a lead Global Atmosphere Watch Central Calibration Laboratory for OVOC measurements, paving the way for increased future collaborations between these two communities that will increase measurement accuracy in atmospheric trace gas monitoring.

Monitoring volatile organic compounds in air

The EMRP project *Metrology for VOC Indicators in air Pollution and Climate Change* developed new point-of-use reference materials and gas standards at the low concentrations required for monitoring volatile organic compounds (VOCs) in the environment. The project investigated the use of coatings and materials to reduce interactions between VOCs and metal surfaces which is important in both maintaining gas standard stability in storage as well as the transfer of sampled air to analytical instrumentation. The projects gas standards were used to evaluate the performance of low-cost gas sensors for environmental monitoring of VOCs and generated increased knowledge in the use of this type of sensors. This work builds on outcomes from the EMRP project *Metrology for Chemical Pollutants in Air* and supports increased measurement accuracy for detecting trace pollutants in the atmosphere.

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European Metrology Research Programme
Delivering Impact

Accurately measuring indoor pollutants

Many manufactured products in homes and offices, such as building materials and furnishings, can emit chemical vapours which make people feel ill. EU directives require samples of these materials to be tested to ensure emissions stay within safe limits. But this process is complex, and testing labs need more sophisticated reference materials to confirm their instruments are accurately measuring the wide variety of chemical vapours that these materials can emit.

Europe's National Measurement Institutes working together

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Challenge

Some people find themselves getting headaches or skin and eye irritations in certain buildings. One cause of these symptoms is the presence in air of volatile organic compounds (VOCs), chemicals used in the manufacture of building materials or household products such as furnishing, carpets, wood, and varnishes, which are vaporised at room temperature.

The EUs Construction Products Regulation requires manufacturers of building products to demonstrate that material outgassing stay within safe limits, a precondition of achieving the CE mark which allows sale in Europe. To demonstrate compliance, they undergo rigorous testing at accredited laboratories. Here, materials are placed in a climate chamber with standardised airflow, relative humidity and temperature, and vapours are collected by air sampling in a sampling tube. Gas analysis techniques are used to identify which compounds are present in the tube.

These labs must periodically demonstrate that their instruments are measuring accurately by checking them against well-defined gas reference materials (RMs). Because potential VOCs are varied, it is important that these reference materials reflect the wide range of compounds that need to be detected. An added complication is that compounds have different boiling points, so some will only be vaporised on very hot days. Improving measurement accuracy requires new gas reference materials that more closely reflect the range of VOCs found in construction products and furnishings. These will enable labs to prove their proficiency in testing aiding measurement harmonisation across the EU.

Solution

The EMRP Project, *Metrology for VOC Indicators in Air Pollution and Climate Change* developed new reference standards with a wider range of VOCs.

A previous project, MACPoll, developed reference materials for a specific set of VOCs in sorbent tubes – stainless steel tubes containing materials that adsorb specific low boiling point VOCs, commonly emitted from furnishings and other construction materials. This project investigated the suitability of other sorbents and the improvement of using coated tubes when preparing reference materials for another set of higher boiling point VOCs. Once loaded in the original sorbent in coated tubes, the VOCs are stable and transportable, making them suitable to be used to compare calibration lab performance.

Impact

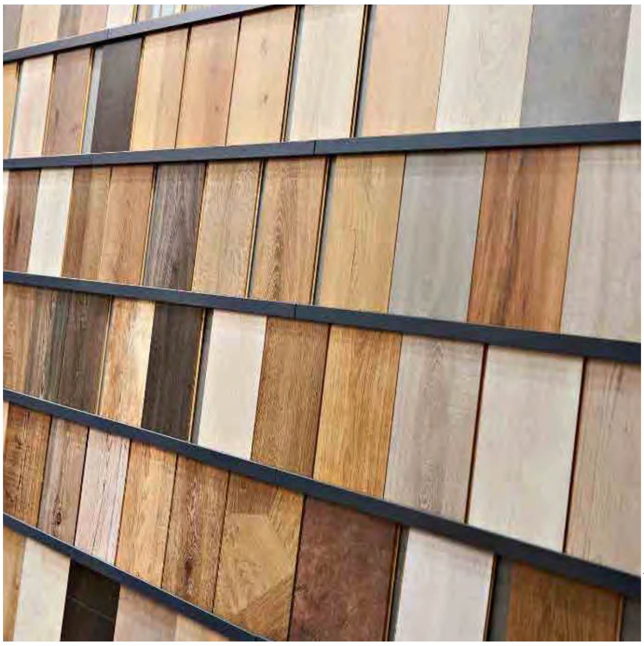
Danish Technological Institute (DTI), an ISO 17025 accredited test laboratory which provides VOC testing services to manufacturers and suppliers of construction products, furniture, coatings, toys, and textiles, has confirmed its measurement accuracy and improved customer confidence, as a result of the project.

DTI took part in a round robin test arranged by BAM and VSL, which provided the world's most reliable interlaboratory comparison of VOC measurement performance. All participating test laboratories used VOC reference substances to calibrate instruments, then carried out measurements of VOCs emitted from an unknown reference material sample, and the results were subsequently evaluated and shared. This helped DTI identify potential measurement biases in its system and validate its instrumentation and processes.

Their confirmed measuring accuracy enables DTI to maintain its accreditation and helps its customers obtain reliable assessments of emitted VOCs and facilitates safer product design identification for indoor use.

Monitoring volatile organic compounds in air

The EMRP project *Metrology for VOC Indicators in Air Pollution and Climate Change* developed new point-of-use reference materials and gas standards at the low concentrations required for monitoring volatile organic compounds (VOCs) in the environment. The project investigated the use of coatings and materials to reduce interactions between VOCs and metal surfaces which is important in both maintaining gas standard stability in storage as well as the transfer of sampled air to analysis instrumentation. The projects standards were used to evaluate the performance of low-cost gas sensors for environmental monitoring of VOCs and generated increased knowledge in the use of this type of sensors. This work builds on outcomes from the EMRP project *Metrology for Chemical Pollutants in Air* and supports increased measurement accuracy for detecting trace pollutants in the atmosphere.



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Nuclear incident alerts

In the event of a nuclear incident, authorities need to know how to respond to protect the public. A pan-European monitoring network, using Geiger-Mueller counters, stands ready to detect sudden increases in ionising radiation. These counters measure radiation levels accurately, but cannot distinguish between different photon energies, originating from different radionuclide. Modern instruments can make this distinction but need better characterisation before they can be deployed in monitoring networks.

Europe's National Measurement Institutes working together

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Challenge

Following a major nuclear incident, fast decisions are needed on issues from protecting the public to prevention of contaminated food entering the supply chain. Different radioactive isotopes, or radionuclides, present different risks. For example, radioactive iodine can accumulate in the thyroid gland, whilst caesium on grass consumed by dairy cows can contaminate milk supplies. Different responses to the specific risks present are required to minimise disruption.

Radiological dose rate monitoring networks were introduced in Europe following the Chernobyl disaster. Most networks use robust and simple to operate Geiger-Mueller counters for detecting changes in radiation levels, but these cannot detect the type of radionuclide present. Identifying specific radionuclides in real-time would allow faster and more appropriate countermeasures. It would also solve a problem created by naturally occurring radon, which is mostly harmless, but when rain washes its decay products from the atmosphere increasing the natural radiation background detectors incorrectly record a false positive response.

Newer radiation detection methods use scintillation materials, which produce flashes of light in proportion to the incoming energy from ionising radiation emitted by various radionuclides. Light is measured with spectrometry instruments to identify the radionuclides present. These detectors could increase the information available for decision-making but need better characterisation to increase confidence in their performance before deployment in monitoring networks.

Solution

The EMRP project *Metrology for Radiological Early Warning Networks in Europe* compared a range of scintillation detectors, using radioactive sources to simulate the nuclides in different types of radioactive contamination following an incident. This comparison demonstrated that these detectors would be suitable for use in radiation monitoring networks. The project also evaluated historic data on naturally occurring radon gas background dose rates and monitor positioning to understand how different factors affect measurement results. Finally, it performed comparison studies in the field to demonstrate expected scintillation detector performance post installation.

EMRP projects operate a scheme enabling workers from other EU institutions to acquire improved skills by visiting sister organisations. As an example, a Polish researcher active in maintaining Poland's early warning monitoring system gained valuable experience in measurement best practice during a fixed-term contract at PTB in Germany.

Impact

As a result of the project, major upgrades have been made to monitoring networks in Poland and Germany.

Polish company TD-ELECTRONICS, has upgraded their electronics and software in new compact spectro-dosimetric probes developed for use in Poland's dose rate monitoring networks using project derived knowledge and field trial performance evaluations. These are being installed in Poland's National Atomic Energy Agency radiation monitoring network, with further upgrades to 13 existing and 30 new stations anticipated in the near future.

BfS, operator of Germany's radiological monitoring stations, has developed a complete detection system using novel scintillation materials, with automatic data relay and upgraded analysis software that was performance tested in the project. This system can create automated alerts for elevated radiation levels, whilst also differentiating between real events and false positives from radon decay product wash out.

These new systems help rapidly identify real contamination events and relay accurate hazard information for authorities making decisions on countermeasures, whilst reducing false positives that have the potential to cause costly and unnecessary interventions.

Greater accuracy for radiation monitoring networks

The EMRP project *Metrology for Radiological Early Warning Networks in Europe* characterised a range of scintillation-based spectrometric detectors to determine their suitability for dose rate and contamination monitoring in Europe's radioactive early warning networks. The effects of the natural radiation background and detector positioning were investigated for installed instrumentation, leading to the generation of corrections which increase dose rate measurement accuracy by typically a factor of two. Novel prototypes of airborne radioactivity monitoring instruments for networked real-time radionuclide identification were tested using simulated contamination on spiked filters in the project. To increase the harmonisation of data supplied to EURDEP, databases of historic data were compiled for use in identifying trends in ambient background radiation and for preventing false alarms. These developments will contribute to the greater availability of robust data for authorities making decisions that affect public safety in the event of trans-border radioactive contamination spread.

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Weather data for climate change

To understand climate change, scientists need detailed data on many different environmental parameters. Data on temperature, humidity and pressure – currently captured by weather stations for forecasting – could provide important additional data for climate monitoring. But to use this data reliably, climate scientists need confidence that measurements collected from different stations, which are managed and calibrated by several different networks, are comparable and can be robustly linked to the SI.

Europe's National Measurement Institutes working together

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Challenge

The World Meteorological Organisation (WMO), a specialised agency of the United Nations, oversees global monitoring of the Earth's weather. This includes maintaining networks of Automatic Weather Stations (AWS) which measure temperature, humidity and pressure around the world, data which is used to make short term local and national weather forecasts. This data could also be used by climate scientists as a way to monitor long term global climate change trends and assess the effect of mitigation initiatives.

Weather monitoring networks are run independently, by national or supra-national bodies. Each use their own instrumentation and measurement approaches and have their own calibration labs. This works well for local forecasting, but climate researchers need to be sure they are looking at a consistent set of global data between networks.

The WMO runs the Commission for Instruments and Methods of Observation (CIMO) which is responsible for ensuring instrument accuracy across networks. Through this agency, it hopes to harmonise measurements across global networks, so all results are comparable and traceable to the same standard, and have links to the SI. To do so, it needed to develop methods to test the ability of calibration labs to perform reliable and consistent calibrations.

Solution

The EMRP Project *Metrology for Essential Climate Variables,* identified suitable existing instruments for reliably measuring temperature, humidity and pressure, and a protocol for using these to confirm calibrations.

The instruments were identified based on their robust links to the SI, stability over time, and suitability for transportation to different labs around the world without losing accuracy. The project developed a protocol for setting up and using these instruments, which enables the comparison of calibration lab performance using the same instruments as a reference. This allows different AWS networks to compare their calibrations against SI-linked instruments and demonstrate their proficiency.

Impact

Following the project, the WMO requested a comparison between national monitoring networks throughout Europe, using the newly developed project protocols. This was performed by the University of Ljubljana, which sent out instruments to European calibration labs and collated the results. The comparison exercise demonstrated that European labs did indeed have good results. Their calibration labs' approaches can now be shown to be consistent and traceable to the SI, allowing them to confirm harmonised results.

The project derived protocol is now included by the WMO in a new CIMO instrument guide on meteorological instruments and methods of observation that will be rolled out to AWS networks around the world. This will bring all AWS calibration labs in line with each other, creating harmonisation between global temperature, humidity and pressure measurements. As a result, climate scientists will have the confidence they need to use AWS data to inform ongoing climate monitoring and trend predictions. Feeding this additional data into climate models will improve their accuracy and help governments make better informed decisions about the best ways to mitigate and adapt to climate change.

Improvements for climate change monitoring

The EMRP project *Metrology for Essential Climate Variables* investigated the performance of various climate-monitoring instruments under conditions likely to be encountered in their upper atmosphere, deep sea, or mountain operating environments. It developed a humidity calibration chamber for radiosonde instrumentation used to monitor water vapour in the upper atmosphere, and a high-pressure calibration facility for temperature sensors used deep under the ocean. Automatic weather station performance was also assessed, leading to an increased understanding of the effects of back reflected radiation from the ground or surroundings on sensor accuracy. The project derived protocol for confirming the equivalence of calibrations performed on temperature, pressure and humidity instrumentation used at weather stations has been adopted by the World Meteorological Organisation Commission for Instruments and Methods of Observation for use in large scale laboratory performance comparisons. These developments will increase weather monitoring data accuracy and increase its potential for use in climate change predictions.

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Improved climate change monitoring

Climate change presents many challenges to society, including the effects of global warming and an increase in severe weather event frequency. Data from weather stations generated for short-term forecasting could be used to identify climate change trends, but higher quality measurements are needed. To achieve more accurate air temperature measurement, for example, sources of error caused by weather station siting and poor housing design need to be better understood.

Europe's National Measurement Institutes working together

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Challenge

Around the world, automatic weather stations measure parameters including temperature and humidity, with networks gathering data from multiple locations to generate short-timescale weather forecasts. This data could also be used to make climate change predictions, but characterising long-term trends, such as global warming, requires better data quality.

Weather measurements can be affected by various unwanted influences, with poorly designed shielding, for example, causing potential errors when measuring air temperature. Consider how the temperature inside a car with its windows closed rises rapidly in sunshine, a similar affect can also be experienced by sensors inside weather station shielding introducing air temperature measurement errors. Poor weather station shielding designs can also expose temperature sensors to back-reflected solar radiation from their surroundings. In mountainous or polar regions, snow cover can act as a reflector, whilst for urban weather stations, buildings or roads nearby can raise temperatures artificially.

To make weather station measurements sufficiently accurate for use in climate predictions, unwanted effects of weather station design, siting and other local conditions need to be minimised. More accurate temperature measurement, for example, could be achieved with better shielding, as improved designs would minimise heat trapping and shield temperature sensors from high levels of back-reflected solar radiation such as that from snow cover.

Solution

The EMRP project *Metrology for Essential Climate Variables* assessed the effects on weather station measurement accuracy including the influence of nearby features such as buildings or trees, housing design, and other local conditions. The influence of these was shown to have a smaller effect on measurement parameters, including temperature, than previously estimated in a World Meteorology Organisation guide. This information has now been incorporated in to a recent revision of this important guide for the weather monitoring community, removing reliance on overestimated corrections.

Different solar shields for weather station instrumentation were tested in the project, with a new novel design that shields temperature sensors from direct and back-reflected solar radiation whilst minimising heat trapping effects demonstrating significantly reduced measurement errors. The results demonstrated that up to 3 °C in temperature variation was attributable to the "albedo effect" where snow reflects sunlight onto a temperature sensor. This demonstrates the importance of good solar shield design.

Impact

Barani Design, an SME producing weather station sensors, had a prototype solar shield independently validated in the project. In addition to the shielding of instrumentation from direct and reflected radiation, the prototype's novel helix design was shown to allow free airflow over housed sensors so minimising heating effects. These design features improve ambient air temperature measurement accuracy by reducing errors caused by solar radiation heating and the trapping of warm air. The validated helical shielding will be launched commercially in 2019. The product's affordability will make it attractive in regions currently lacking a developed meteorological infrastructure such as Africa and south-east Asia.

Improvements for climate change monitoring

The EMRP project *Metrology for Essential Climate Variables* investigated the performance of various climate-monitoring instruments under conditions likely to be encountered in their upper atmosphere, deep sea, or mountain operating environments. It developed a humidity calibration chamber for radiosonde instrumentation used to monitor water vapour in the upper atmosphere, and a high-pressure calibration facility for temperature sensors used deep under the ocean. Automatic weather station performance was also assessed, leading to an increased understanding of the effects of back reflected radiation from the ground or surroundings on sensor accuracy. The project derived protocol for confirming the equivalence of calibrations performed on temperature, pressure and humidity instrumentation used at weather stations has been adopted by the World Meteorological Organisation Commission for Instruments and Methods of Observation for use in large scale laboratory performance comparisons. These developments will increase weather monitoring data accuracy and increase its potential for use in climate change predictions.

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Forecasting snow-related hazards

The extreme environments of high mountain regions cause a range of natural hazards. Weather conditions introduce risks, creating avalanches from snow cover or downstream river floods from meltwaters. To help assess these risks, networks of weather stations monitor local conditions. Temperature data is a key input for hazard forecasting, but measurement errors resulting from poor sensor shielding design need reduction to improve both measurement accuracy and risk assessments.

Europe's National Measurement Institutes working together

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Challenge

The stability of snow cover in mountain regions is highly dependent on the weather – local conditions, for example, will influence the occurrence of avalanches, or river flooding due to an increase in meltwater production. To estimate the risk, networks of weather stations are used to gather the data needed to help forecast the likelihood of these snow-related natural hazards. Because air temperature, for example, influences mountain snow cover stability and the associated risk of avalanche, more accurate measurements are needed to improve hazard forecasting.

The accuracy of weather station measurements can be affected by a variety of influences arising from station siting and the design of protective shielding for instrumentation. In the extreme conditions of mountain regions, ground snow cover can reflect a significant amount of solar radiation on to unshielded thermometers within a weather station's housing. Consequently, air temperature measurements can be in error by several degrees Celsius due to this unwanted heating. The effect of snow-reflected radiation on air temperature measurement accuracy must therefore be addressed if forecasting snow-related risks from avalanches or river flooding due to meltwater is to be improved.

Solution

The EMRP project *Metrology for essential climate variables* assessed influences on weather station measurement accuracy including the effects of nearby features such as trees or buildings, station housing design, and other local conditions.

The project investigated radiation shields designed to prevent weather station thermometers from receiving unwanted direct and back-reflected solar radiation, such as from ground snow cover in mountainous regions or buildings in urban areas, whilst also preventing heat trapping within the housing itself. With testing conducted over snow-covered ground, a difference of up to 3 °C was observed when comparing air temperature measurements from thermometers shielded with a prototype design versus a commercially available shield. Well-designed solar shielding is important to reduce errors introduced by the "snow albedo" effect created by reflected solar radiation. Improving the accuracy of temperature data from weather stations monitoring snow cover data will help improve forecasting of snow-related risks such as those from avalanches or meltwater production.

Impact

CAE SPA, a leading company in environmental monitoring and warning systems, had prototype shielding and sensors independently evaluated during the project. As a result of this testing, CAE have upgraded their weather station shielding and temperature sensor combination, using the new superior design.

The Regional Authority for the Environmental Protection of Piedmont (ARPA), Italy, is responsible for assessing risks associated with snow cover in the regions mountains and has started introducing the upgraded CAE weather stations. By installing the newly validated design to run alongside other weather stations in their network ARPA is able to compare results and gain insights into differences between the measurements obtained, as required by the WMO. This is important to avoid step changes in trend analysis that are difficult to understand.

Predicting avalanches or snow-melt river flooding risks in mountain regions requires accurate temperature data for forecasting models. By adopting technologies such as the improved solar shielding to minimise temperature measurement errors, forecasts are improved, thereby providing more accurate natural hazard warnings for people living and working in mountainous regions like Piedmont.

Improvements for climate change monitoring

The EMRP project *Metrology for Essential Climate Variables* investigated the performance of various climate-monitoring instruments under conditions likely to be encountered in their upper atmosphere, deep sea, or mountain operating environments. It developed a humidity calibration chamber for radiosonde instrumentation, used to monitor water vapour in the upper atmosphere, and a high-pressure calibration facility for temperature sensors used deep in the ocean. Weather station performance was also assessed, leading to an increased understanding of the effects of back reflected radiation from the ground or surroundings on sensor accuracy. The project derived protocol for confirming the equivalence of calibrations performed on temperature, pressure and humidity instrumentation used at weather stations has been adopted by the World Meteorological Organisation Commission for Instruments and Methods of Observation for use in large scale laboratory performance comparisons.

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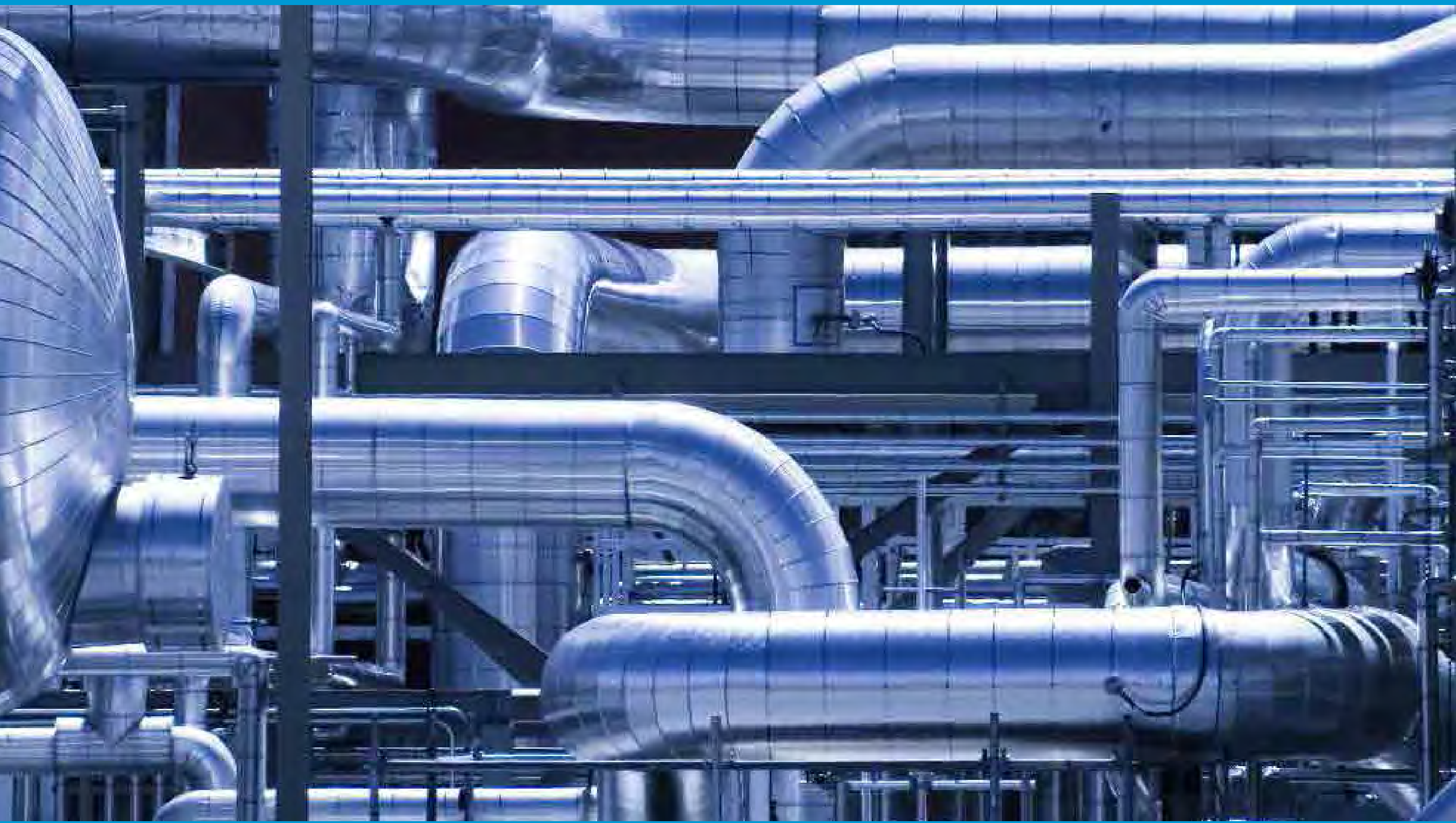

Improving gas plant leak detection

Supporting global efforts to reduce greenhouse and polluting gas emissions, the EU's Industrial Emissions Directive introduces new limits and reporting rules. Europe's gas plant operators are expected to identify and measure leaks, but tougher limits require greater measurement accuracy beyond that of current authorised methods. Advanced optical measurement techniques exist but these need robust performance evaluation and protocols for use before consideration as methods for demonstrating compliance with the Directive.

Challenge

Accidental releases of natural gas from leaky plant equipment wastes resources and contributes to global warming, as its main constituent, methane is a greenhouse gas. Although less persistent in the atmosphere than carbon dioxide, methane has much greater heat-trapping effects.

The oil and gas sector is a significant source of methane emissions with an estimated 2.2 % of all gas production being lost due to leaks. The climate change consequences of this prompted industry group Oil and Gas Climate Initiative to target a 20 % reduction to its members' methane emissions in upstream operations.

To comply with the European Industrial Emissions Directive, gas plant operators need to apply methods outlined in an EU Commission Best Available Technique (BAT) document for monitoring emissions and detecting leaks from industrial plant. Optical sensing technologies can be used to find these, but standard 'sniffer' methods that collect gas in bags for subsequent analysis must be used to determine their size. This method is labour intensive and unsuited for hard-to-access leaks.

To enable the use of highly accurate and rapid handheld optical gas imaging cameras to detect and measure gas plant leaks, a standardised measurement protocol written into European CEN standards is required, coupled with rigorous comparisons to existing authorised techniques. This would pave the way for optical measurement techniques to be authorised as a BAT method in the future.

Solution

The EMRP project *Metrology to Underpin Future Regulation of Industrial Emissions* validated new test and controlled-release facilities, that simulate leaks from industrial plants. These were used to robustly validate optical technologies in trials at a former gas plant and included optical gas imaging.

Best practice protocols for each technology were developed to increase measurement accuracy, repeatability and result comparability. These protocols are being incorporated into a European Draft CEN standard, an important step towards future use as an authorised BAT method for regulatory compliance.

Impact

FLIR, a manufacturer of optical gas imaging cameras, was one of the first to use the NPL developed controlled-release facility during testing to demonstrate that a new optical gas imaging camera can meet the required standards for use on American gas plants. This instrument, based on FLIR's gas imaging technology used in conjunction with the Providence Photonics QL320 analysis system creates Quantitative Optical Gas Imaging for use in establishing the precise location and size of gas leaks from a safe distance. In recognition of FLIRs actions to reduce methane emissions, the company received the *Leadership in Innovative Technology* award at the 2018 Oil and Gas Methane Leadership Awards.

In order for European gas plant operators to benefit from developments in optical sensing, such as that developed by FLIR, the projects measurement protocols must first be included into CEN standards, and then robust comparisons made to existing BAT authorised techniques. Increasing the ability to detect gas plant leaks and rapidly determine their size will help operators meet the Industrial Emission Directive requirements and the EU to achieve its greenhouse gas reduction targets.

Accuracy for emissions monitoring

The EMRP project *Metrology to Underpin Future Regulation of Industrial Emissions* developed new reference materials and stack simulation facilities to aid calibration and assessment of plant emissions measuring instrumentation. These were used to validate optical spectrometry-based techniques during site testing at a disused gas plant leading to the development of best measurement practice. This is being incorporated into a new EN standard and once published will enable the greater use of optical techniques for industrial plant emission monitoring – a first step towards adoption for regulatory compliance as a Best Available Technology.

The project also investigated sources of measurement uncertainty in continuous stack monitoring systems where variations in flow can have large effects on emission reporting. Using computational fluid dynamic modelling the project was able to suggest improvements to flow measurement regimes that will increase the overall accuracy for reporting averaged emissions.

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Industrial emissions mapping

The EU's Industrial Emissions Directive, which aims to protect human health and the environment, requires pollution reporting from oil and gas plant operators against regulated emissions limits. Strict standards are being established for monitoring total plant emissions, but current measurement techniques lack the required accuracy to meet new lower emission limits. Optical measurement techniques can meet requirements, but to be authorised for use, must first be rigorously validated.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

The EU's Industrial Emissions Directive now requires industrial polluters to monitor emissions from the entire industrial site, including leaks from tanks and pipes in addition to those from stacks to ensure these meet revised lower limits. This Directive sets the framework for operators to demonstrate compliance with mandatory emission limits and requires the use of Best Available Techniques, BAT, that are documented in normative standards. To address a shortfall in this area, the European Commission has mandated the relevant European Committee for Standardisation (CEN) to draft new standards for on-site monitoring.

Industrial emissions, such as those from oil refineries, create large sources of volatile organic compound pollution, major contributors to ozone depletion and greenhouse gas production. However, now the Directive requires all plant emissions to be monitored, requiring new methods for reliably assessing leaks from pipes and tanks in addition to conventional stack monitoring systems. Remotely operated optical spectrometry techniques, such as laser-based DIAL or sunlight using Solar Occultation Flux could offer a solution. These spectrometry-based techniques take advantage of the way different chemicals absorb specific light wavelengths leading to their detection. In this way it is possible to rapidly map all emissions across a site.

Before these optically-based techniques, can be considered for inclusion as a Best Available Technology and used on plant, a sound measurement procedure covered by a CEN standard to ensure its results are consistent and comparable is needed.

Solution

The EMRP project *Metrology to Underpin Future Regulation of Industrial Emissions* investigated and performance validated optical spectroscopy techniques including DIAL and Solar Occultation Flux using a controlled release facility that simulates plant emissions.

Well-characterised amounts of volatile organic compounds were released into the atmosphere at a redundant gas plant to enable performance confirmation for these optical techniques in the hard to reproduce air turbulence conditions frequently present during on-site measurements. Researchers used modelling and previous measurement data to improve understanding of how parameters such as wind affect measurements.

Through this work, the project established measurement best practice for optical emission assessment methods, that are being incorporated into a new CEN standard – a first step towards their inclusion as a Best Available Technology for regulatory compliance.

Impact

FluxSense AB is a Swedish SME spun out of Chalmers University, which manufactures innovative Solar Occultation Flux instruments and expects to be an early beneficiary of the need for increased plant monitoring required under the new Industrial Emissions Directive.

The company has developed these instruments for mapping and quantifying gas emissions from industrial facilities such as oil refineries, water treatment plant and product storage tanks. Solar Occultation Flux offers plant operators the opportunity to perform cost-effective seasonal surveys to better establish an annual emissions baseline that produces information on whether site leaks are increasing and enables evaluation of strategies to reduce overall emissions.

Accuracy for emissions monitoring

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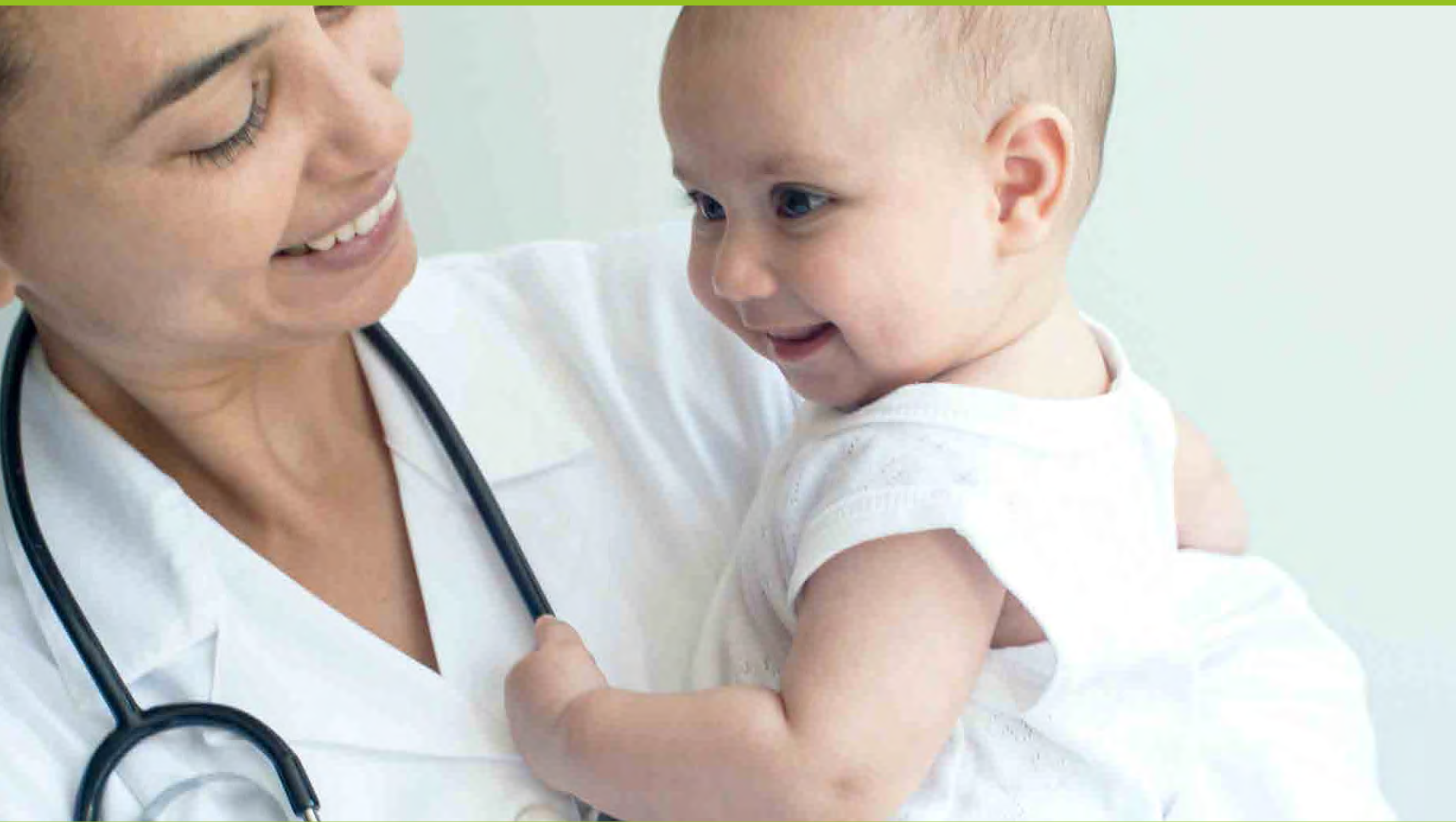

Better infant hearing tests

Three in every 1000 babies are born with hearing impairment, which hampers development of language skills. Rapid identification is key for early intervention, so many national health authorities have hearing testing programs for babies. However the headphones used for hearing tests are set up using ear simulators designed for larger adult ears. Tailoring these to smaller ear sizes will improve the accuracy of assessments of hearing loss in young children.

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Challenge

Hearing defects in a child's early years leads to language development problems, so national health authorities run programmes to identify affected babies and young children. Testing uses small headsets to provide a known sound stimulation, then measures the response in the infant's ear or brain.

The small headsets currently used for infant testing are calibrated using the same ear simulators used for much larger adult headphones. This mismatch between the adult ear simulator and the smaller infant ear leads to differing sound intensities from the same test sound; just as an alarm clock would be heard differently in a small box compared to across a large room. The smaller size and shape of an infant's ear, which changes as they rapidly grow, requires a range of small ear simulators to ensure the correct sound intensity is being used in testing.

Calibration methods for infant hearing test headsets therefore need to be modified to reflect the difference in perceived sound intensity resulting from changing infant ear sizes and shapes. The current use of adult sized ear simulators provide inadequate calibrations for the smaller headsets used in infant hearing assessments. New smaller ear simulators are required to help improve the diagnosis of hearing impairment in infants.

Solution

The EMRP Project, *Metrology for a universal ear simulator and the perception of non-audible sound* developed a prototype infant ear simulator for calibrating the headsets used to test hearing in babies.

Through extensive sound testing and modelling, the project identified the most important factors needed to design better ear simulators, and produced a series of specifications for ear simulators to match ear shapes from birth to young adult.

Impact

Acoustic Metrology Ltd (AML), a UKAS accredited calibration laboratory, evaluated the prototype ear simulator developed by the project, confirming that they were suitable for calibrating the small headsets used for infants. By using existing calibration set-ups, AML demonstrated that current equipment and methods could be easily adapted to make use of the new ear simulator.

Before these ear simulators are used for routine infant headset calibrations, the relevant IEC standards used by hearing calibration services need to be updated. A new IEC working group has been set up to review the current standard with a view to incorporating the use of infant sized ear simulators developed in this project, as well as other improvements to child hearing assessment testing.

Once an agreed international standard exists, national testing programmes can mandate its use in headset calibrations and so ensure uniform standards are applied across health authorities. Through using ear simulators designed to match the ear being tested, diagnosis of hearing impairment in infants can be improved and earlier interventions started to enable development of key language skills.

Metrology for hearing health

The EMRP project *Metrology for a universal ear simulator and the perception of non-audible sound* addressed two aspects of human hearing. The first part of the project improved the quality of hearing impairment diagnosis, particularly for neonates and children, through the development of new instrumentation for calibrating the acoustic stimuli used in clinical hearing assessments. The second combined methods from audiology and brain imaging to better understand physiological responses to sound outside of the conventional frequency range of hearing, and used this to create a basis for new guidance on the hazards presented by infrasound and ultrasound.

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Spotting inter-cell communications

Extracellular vesicles are small cell-derived particles present in all body fluids. They are fundamental to biological processes and have been recently shown to be involved in the spread of cancer around the body. The detection and counting of extracellular vesicles gives an opportunity to develop new diagnostic tools and treatments for many diseases. However, these rely on first producing high quality blood samples for analysis using robust, simple and standardised approaches.

Europe's National Measurement Institutes working together

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Challenge

Many diseases, including cancers, diabetes and heart disease increase the number of small cell particles, extracellular vesicles (EV) or microvesicles in the bloodstream. These have recently been discovered to both indicate disease and also play an important role in spreading cancer around the body. Being able to make earlier disease diagnosis, monitor the effectiveness of treatments, and potentially deliver drugs to target cells could all be possible by measuring and using blood borne EV.

Before EV can be used for any of these purposes, we need reliable, reproducible and standardisable ways to measure them. This presents a number of challenges, the first of which is preparing high quality blood samples for measurement. Preparation methods must ensure that EV are retained in the sample for analysis whilst contaminating molecules that will interfere with EV detection are removed. Reliable, accurate, standardised methods are needed for collecting samples, separating out the small EV particles, and storing them before measurement.

Solution

The EMRP Project *Metrological characterisation of microvesicles from body fluids as non-invasive diagnostic biomarkers* identified optimal procedures for EV blood sample collection, and its preparation and storage prior to analysis. The project developed a recommended approach for EV collection and purification. It identified that rapid freezing in liquid nitrogen and maintaining at -80 °C was important in ensuring samples did not deteriorate before analysis.

One of the most important findings of the project was that traditional separation methods, which involve ultra-centrifugation - spinning samples at very high speed – has problems that prevent the production of reproducible samples. The team found that ultra-centrifugation leads to the loss of some EV particles; extreme pressures experienced in repeated spin cycles can damage EV particle structures and collection of other materials along with EV can affect result accuracy.

The project demonstrated that size exclusion chromatography (SEC) - a separation method in which the sample is filtered through a 'mesh' – is a robust and reproducible EV sample separation method, which produces pure EV samples. This has the potential to open up the use of EV for disease diagnosis.

Impact

Izon Science, a manufacturer of precision instrumentation for nano- and micro-scale particle analysis, has taken the project's SEC EV separation method and generated an easy to use kit for clinics and medical researchers. The kit is inexpensive and only requires 15 minutes to produce a pure EV sample, a huge advance on the 2-3 hours required by the less accurate centrifuging technique.

Over 250 labs worldwide are now using the improved EV sample preparation methods developed in the project - highlighting the growing interest in these micro-particles for medical research. The project's sample preparation methods have been incorporated into good practice guidance being drafted by the leading international bodies involved in EV research. This is a first step towards a new ISO standard for EV separation and analysis which will lay the foundations for using EV measurements in new point of care diagnostic devices.

EV research, especially that examining communication between cells, is advancing rapidly, and holds huge promise in the diagnosis and treatment of many serious diseases. The approaches identified by this project, and the kits commercialised by Izon, will be critical to ensuring the quality of samples on which this research depends.

Metrology for extracellular vesicles

The EMRP project *Metrological characterisation of microvesicles from body fluids as non-invasive diagnostic biomarkers* developed measurement methods and reference materials to improve standardisation of extracellular vesicles concentration measurements. Extracellular vesicles or microvesicles are cell fragments found in bodily fluids, which differ in patients suffering from medical conditions such as cancer and cardiovascular disease and so can be used as biomarkers, enabling earlier diagnosis of a range of conditions through routine analysis of bodily fluids. The project results improved the comparability of extracellular vesicles measurements in 30 hospital laboratories worldwide, supporting increased exploitation of extracellular vesicles as novel diagnostic biomarkers.

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Counting particles to spot cancer

New research into extracellular vesicles, small particles in the blood, is leading to exciting new possibilities for detecting and treating life-threatening diseases such as cancer, diabetes and heart problems. Extracellular vesicles can indicate when a patient has a disease, and may play a role in how it spreads. Developing reliable extracellular vesicles measurement methods could lead to fast, routine diagnosis techniques and new treatments, improving quality of life and reducing healthcare costs.

Europe's National Measurement Institutes working together

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Challenge

Fragments of cells shed into the bloodstream can indicate the presence of diseases such as cancer, diabetes and heart disease. These fragments – called extracellular vesicles (EV) – are generating excitement in the medical research community as their role in spreading diseases between cells is being discovered. New diagnostic methods and drug delivery systems based on detecting and counting these small cell fragments is tantalisingly close, but requires better and standardized measurement methods to ensure reliable and consistent detection.

The challenge is that EV are nano-sized and hard to detect. A technique called flow cytometry holds potential for counting EV accurately, and is used by 70% of EV research labs. It works by passing particles through a laser and measuring how light is reflected. However greater standardisation in instrument settings and sample analysis methods are needed to increase comparability of results across the EV research community. This would increase the potential for EV counting to become a reliable technique for new diagnostic devices and drug development.

Solution

The EMRP Project, *Metrological characterisation of microvesicles from body fluids as non-invasive diagnostic biomarkers* researched tools and procedures for a consistent approach to laboratory EV measurements.

A number of techniques were investigated and flow cytometry was identified as having the greatest potential for accurately measuring EV, but that consistent instrument settings between laboratories are needed to ensure reliable results.

The project identified optimal ways to set up flow cytometry to measure EV particles, and developed a reference material which can be used to accurately calibrate flow cytometry instruments. For the first time, mathematical links were made between the instrument's response to the reference material and the range of far smaller EV particles of interest to researchers. This ensures that measurements of different EV particles can all be directly linked to a well characterised reference standard.

Impact

The International Society on Thrombosis and Haemostasis (ISTH) is actively promoting research into EV and is keen for its uptake into new diagnostic devices. Aware of problems in making comparable measurements ISTH funded a comparison exercise using the projects reference material. Thirty three international laboratories participated, all receiving a reference sample containing EV and another unknown EV sample. Results demonstrated that the labs using the methods developed in the project for preparing flow cytometry instruments produced more accurate results than those that did not. This highlighted to the EV research community the need for a standardised measurement approach.

ISTH, with two other influential organisations - the International Society for Extracellular Vesicles, and the International Society for Advancement of Cytometry – have now formed a new working group to develop guidance on EV measurement practice (evflowcytometry.org). This will highlight the importance of using reference materials linked to the sizes of EV particles in the preparation of instruments for measurement. The guidance is a first step towards a future IEC standard.

Improving the robustness of EV counting is a pre-curser to developing diagnostic devices based on these small particles that indicate diseases.

Metrology for extracellular vesicles

The EMRP project *Metrological characterisation of microvesicles from body fluids as non-invasive diagnostic biomarkers* developed measurement methods and reference materials to improve standardisation of extracellular vesicles concentration measurements. Extracellular vesicles – cell fragments found in bodily fluids – differ in patients suffering from medical conditions, such as cancer and cardiovascular disease, and can so be used as biomarkers, enabling earlier diagnosis of a range of conditions through routine analysis of bodily fluids. The project results improved the comparability of extracellular vesicles measurements in 30 hospital laboratories worldwide, supporting increased exploitation of extracellular vesicles as novel diagnostic biomarkers.

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High intensity ultrasound treatments

High Intensity Focused Ultrasound (HIFU) is a promising new cancer treatment technique. It uses multiple soundwave beams which travel to tumours without harming healthy cells on the way – enabling safer treatment and opening possibilities for treating cancers deep within the body and brain. But as a new technology, it so far lacks standards and measurement methods to ensure accurate delivery of the sound energy that destroys the cancer.

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Challenge

High Intensity Focused Ultrasound (HIFU), used with imaging techniques, is a promising new treatment of prostate cancer and brain disorders. It focuses multiple high energy soundwaves onto a single spot, generating enough heat to destroy a tumour. Unlike ionising radiation, these beams do not cause long term harm to DNA, and in addition have potential for precisely treating cancers deep in the body.

For treatment to be effective, the strength of the strongly focused beam must be precisely calibrated to deliver a treatment dose personalised to each patient – too little and the therapy's temperature is insufficient to treat the cancer; too much power and it becomes dangerous for surrounding healthy tissue. Approaches to calculating the correct dose are in their infancy hampered by a lack of accurate calibration facilities and instruments to transfer calibrations from these facilities to the clinical HIFU machine.

A new hydrophone – a type of underwater microphone – capable of withstanding the heating generated by the very high pressure ultrasound waveforms is needed to make the link between lab-based calibration facilities and clinics performing HIFU. This missing traceability link is inhibiting the introduction of new HIFU treatments.

Solution

The EMRP Project, *Dosimetry for Ultrasound Therapy*, extended ultrasound measurement and calibration facilities to meet the requirements of clinical HIFU machines. As a result of the project, HIFU hydrophones can now be fully calibrated in a water bath using a well characterised ultrasound beam. Hydrophones are then further tested using sound beams similar to those produced by medical devices to achieve a robust calibration.

Best measurement practice developed by this project has contributed to two published IEC standards, one on HIFU safety and another on HIFU power measurements. A third IEC document incorporating the project's calibration method for clinical HIFU hydrophones is currently under development. These documents provide hospitals with clear guidance on traceably calibrating HIFU machines.

Impact

GAMPT mbH, a world leader in ultrasonic measurement technology, in collaboration with project partner PTB designed and validated a new hydrophone suitable for calibrating clinical HIFU instruments.

The HIFU Hydrophone, the only one of its kind, can measure the very high pressure waveforms of HIFU beams without being damaged by their high intensity. Once calibrated using the project's new facilities and expertise, the hydrophone can transfer calibrations to other clinical HIFU machines. This hydrophone is now on sale and extends GAMPT's range of sound measurement devices to include HIFU applications.

As confidence in HIFU grows as a result of new IEC standards and traceability routes, its use is set to expand rapidly into new clinical applications such as essential tremor and other deep seated brain disorders. GAMPT expects demand to rise and is well placed to support this promising future market, which includes cancer treatment clinics, manufacturers of therapeutic devices and sensors, certification institutes, and measurement labs.

Metrology for ultrasound therapy

The EMRP project *Dosimetry for ultrasound therapy* developed new measurement methods and modelling capabilities to improve ultrasound dosimetry and support robust, personalised treatment plans for patients. The last decade has seen a dramatic increase in the use of ultrasound as a surgical and therapeutic tool, with many promising new uses emerging in the treatment of cancer and stroke. The project results will improve understanding of the response of tissue to differing ultrasound doses, supporting safe and effective treatment with existing and new ultrasound therapies.

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Simpler disease diagnostics

Biomarkers are small molecules found in the bloodstream, which can be directly related to diseases such as cancer, HIV and Hepatitis. At the heart of many new diagnostic tools, biomarkers enable early detection of disease making successful treatment more likely. However, their small size and often low numbers can hamper detection without expensive specialist equipment. Innovation in measurement cell design is needed for simple and low-cost biomarker detection in complex samples.

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Challenge

Certain molecules within biological samples - known as biomarkers - can be indicative of serious diseases, such as cancers, HIV and Hepatitis. Detecting their presence and determining how these small molecules interact with each other and cells in the body holds considerable potential for developing new diagnostic tools which detect disease much earlier and help understand how new treatments perform.

In order to aid their detection, biomarkers are often bound to a probe molecule, which has a specific property that enables it to be imaged - for example it fluoresces. However, this process often involves complex preparation methods, specialised equipment, and requires highly trained staff. Although they offer large benefits, current detection methods are both complex and costly.

Simple, cost effective and fast detection methods, with potential for use in a clinical setting are needed. Significant problems in developing new diagnostic methods using probe-biomarker combinations are the lack of an easy sample preparation method and suitable containers to hold naturally wet bio-samples during analysis by routine laboratory instruments. New measurement cells that match these needs are required as a pre-curser to developing new point of care methods for disease diagnosis.

Solution

The EMRP project *Metrology for the characterisation of biomolecular interfaces for diagnostic devices* successfully demonstrated a new easy-to-use sample cell for detecting single biomarkers in real biological samples.

A group of researchers at Chalmers University of Technology in Sweden tested the performance of this novel measurement cell by detecting Alzheimer's biomarkers in human cerebral spinal fluids and were able to distinguish between samples from healthy individuals and patients suffering from Alzheimer's.

The cell is designed as an add-on to be used with a standard optical microscope. It produces an image of the cell-sample interface by binding biomarkers down to the cell's surface in a highly selective manner. This simple system enables fast single biomarker detection in a highly complex biological sample. The innovative measurement cell and its novel method of containing and positioning liquid bio-samples for optical analysis is being patented prior to commercialization.

Impact

Researchers at BOKU University in Vienna and the University of Göttingen, are already using the Chalmers' measurement cell to study biological reactions. There has also been considerable interest from a major drug company. The device has potential to be developed into a simple diagnostic device for detecting a range of specific biomarkers. This could lead to on-the-spot tests for cancer, Alzheimer's disease and viral infections such as HIV and Hepatitis.

Researchers involved in drug discovery are also excited by the capability this cell presents to observe binding and unbinding of biomarkers as this opens up the possibility of studying the making and breaking of bonds between biomarkers and surface functionalized molecules. Understanding these chemical interactions is hugely important for research into viral infections, cell-to-cell communications in cancer and degenerative diseases, as well as in drug delivery systems.

Improving our understanding of the functions and interactions of small molecules in the body will increase our knowledge of some of the world's most devastating diseases, which will help researchers and doctors reduce suffering through earlier diagnosis and more effective treatment.

Metrology for diagnostic devices

The EMRP project *Metrology for the characterisation of biomolecular interfaces for diagnostic devices* developed methods and reference materials to reliably and consistently measure the performance of biochemical interfaces used in in-vitro diagnostic devices (IVDs). These biochemical interfaces detect target molecules in patient samples that are indicative of disease, infection or other adverse health conditions. The project developments will allow IVD manufacturers to develop increasingly accurate and reliable devices for a broader range of health conditions, resulting in faster diagnoses at the point of care and driving down healthcare costs in Europe.

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Increasing access to anaemia testing

Anaemia is a common health condition that affects around 2 billion people worldwide. Timely treatment effectively restores health and can raise national productivity levels by as much as 20 %, according to the World Health Organisation. However, the current reference diagnostic test uses potassium cyanide to measure haemoglobin levels in blood, and the difficulties in procuring and disposing of this toxic compound are driving demand for alternative test methods.

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Challenge

The haemiglobincyanide (HiCN) reference method has been the gold standard for measuring haemoglobin concentrations in blood, indicative of anaemia, for more than 50 years. Used around the world to diagnose anaemia and monitor response to treatment, the HiCN method is both effective and benefits from readily-available stable calibration standards.

The method uses potassium cyanide as a reagent to release haemoglobin from red blood cells - a spectrophotometer can then be used to determine haemoglobin concentration from the optical density of the solution. However, the disposal of large volumes of reagent containing cyanide creates a potential toxic hazard, and, in some countries, cyanide reagents are no longer available. In this case, alternative methods must be used and no reference method is available.

New methods are needed which can measure haemoglobin levels without the use of toxic chemicals, in addition to being both cost-effective and easy-to-use. One promising alternative uses a non-toxic alkaline haematin detergent (AHD) and similar spectrometers to those used in the HiCN method. However, a standardised test procedure linking AHD measurements to the SI units is needed before the method can become an internationally-accepted reference method for the diagnosis and management of anaemia.

Solution

The EMRP project *Metrology for metalloproteins* developed a reference material which links AHD measurements to the SI units for the first time. The project also developed an AHD measurement method protocol, which was tested in haematology laboratories to ensure its practicality. These results ensure that haemoglobin measurements produced by the test are reliable and comparable between users, and ultimately suitable for clinical use.

Impact

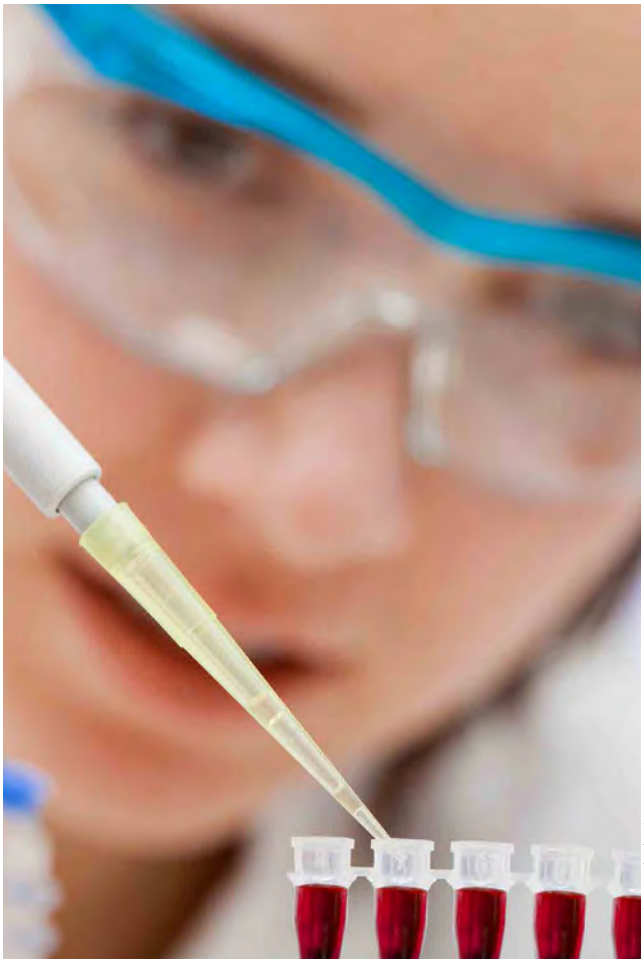
The German standards organisation DIN is revising its existing standard on reference methods for analysing blood samples (DIN 58931) to incorporate the AHD method developed by the project, supporting its recognition and use as an alternative to the HiCN method. DIN has also proposed that CEN undertake a new work item on reference methods for determining haemoglobin concentrations in blood, an important first step towards the AHD method's inclusion in an international standard.

As part of the project, two reference laboratories, Instand e.V. and RfB (Reference Institute for Bioanalytics) were trained in the traceable AHD method and are implementing it in their laboratories. Both labs expect to provide benchmark values in the course of 2017 and conduct interlaboratory comparisons to ensure the quality of clinical results produced by labs using the AHD method.

The results of the project have removed major barriers preventing the AHD method from being internationally recognised as a reference method for the diagnosis of anaemia. When underpinned by international standards, the AHD method will be able to replace the HiCN reference method, removing the associated toxic waste stream and reducing the cost of anaemia diagnosis and management. This, in turn, will support timely treatment of this widespread condition, promoting personal health and increased productivity worldwide.

Metrology for metalloproteins

The EMRP project *Metrology for metalloproteins* developed reference measurement methods to separate, identify and quantify a range of metalloproteins – proteins containing metallic ions. Metalloproteins play a crucial role in a range of biological processes, from respiration to photosynthesis. This makes their analysis a powerful tool in the diagnosis and treatment of diseases such as anaemia and cancer. The methods developed by the project will directly improve the quality of measurement results obtained from patient samples in clinical laboratories and ensure improved diagnosis and treatment outcomes.



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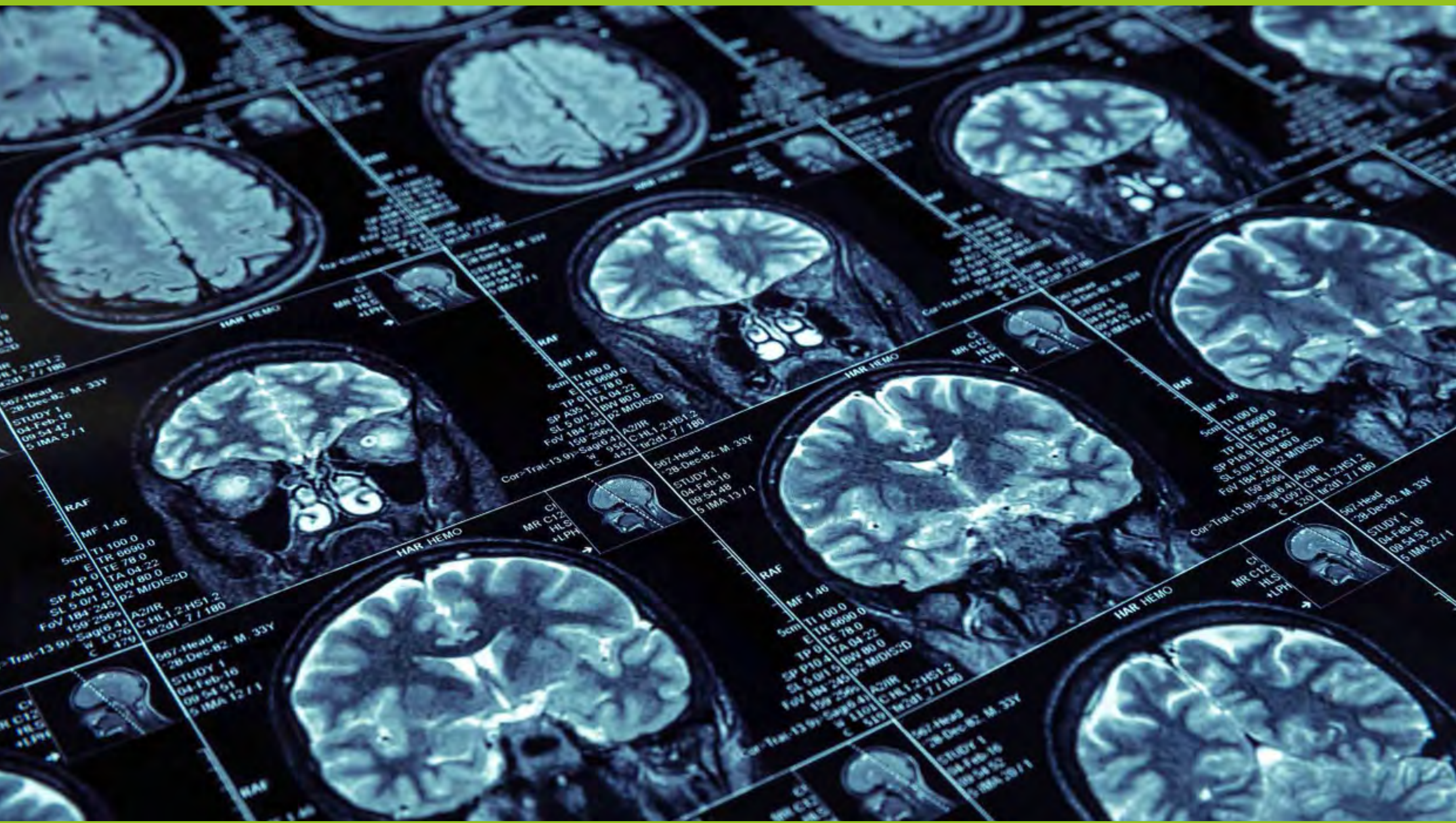

High resolution brain scans

Magnetic Resonance Imaging (MRI) is an effective way to diagnose serious brain conditions and also has potential use in diagnosing degenerative diseases like Alzheimer's. Using more powerful MRI magnetic fields will improve disease diagnosis, but may also create risks for patients. Before new powerful MRI machines can enter routine clinical use, hospitals and manufacturers must have improved measurement methods and standards to be able to demonstrate patient safety.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Magnetic Resonance Imaging (MRI) is a highly effective technique for peering into the body and looking for evidence of serious problems such as tumours and damaged blood vessels. Over 30 million patients already have MRI examinations annually across the EU, and now higher resolution 7T MRI scanners are able to offer even better early disease diagnosis and the potential for detecting Alzheimer's, Parkinson's and Multiple Sclerosis.

Currently hospitals use MRI scanners with 1.5 or 3 tesla (T) magnetic field strength - devices shown to be safe for hospital use. For 7T MRI to be introduced into routine clinical use, it is necessary for MRI manufacturers and hospitals to have confidence in staff and patient safety.

MRI machines apply a high magnetic field to the body and the greater the magnetic field, the greater the resolution of the images. But an MRI scanner is more than just a strong magnet; it also exposes the patient to radio waves so powerful, patients need constant direct supervision to prevent injury. The stronger the magnet, the higher the frequency of these radio waves and the more complicated their interaction with the patient's body. As a result, computer simulations are now required to determine the patient's safety where robust and reliable hardware had previously been adequate. New measurement tools are needed to evaluate simulations and enable demonstration that the radio waves from 7T MRI are safe to use.

Solution

The EMRP Project *Metrology for next-generation safety standards and equipment in MRI* developed measurement tools and validated simulations which show the impact on patients of the radio waves created by 7T MRI. The radio-frequency fields can be computed throughout the patient's body and procedures were developed to validate these simulations by measurements. As a result, protocols were devised and used to demonstrate how patient safety could be established through improved MRI design.

Project findings will be reflected in future updates of the IEC safety standard for the use of clinical MRI, providing a route by which 7T MRI scanners can be designed for safe operation. This paves the way for 7T MRI scanners to enter routine clinical use and so improve disease diagnosis whilst maintaining confidence in patient safety.

Impact

MRI manufacturers including Philips and Siemens have developed 7T scanners for medical research and want to sell these for clinical use. Building on the revised IEC standard, they can now demonstrate that suitable safety measures can be implemented based on the project's validated simulations.

The current IEC standard facilitates CE marking for 7T MRI scanners based on conformance to EU regulatory requirements. This now makes these ultra-high resolution MRI imaging machines available for clinical use, albeit with restrictions. Clinics will now have a more powerful imaging tool capable of enabling earlier diagnosis of serious and degenerative brain diseases and other treatable conditions creating the potential for earlier life-changing treatments. Future editions of the IEC standard will waive these current restrictions and broaden the range of 7T MRI uses in clinical medicine.

Metrology for improved MRI safety

The EMRP project *Metrology for next-generation safety standards and equipment in MRI* improved the diagnostic value and efficiency of magnetic resonance imaging (MRI) by developing measurement methods and models which enhance the safety of patients and staff while simultaneously eliminating unnecessarily restrictive exposure limits. A new patient safety concept developed in this project will help manufacturers to speed up innovation cycles, supporting faster market introduction of emerging technologies, and will allow the safe scanning of previously excluded patient groups. In addition a robust magnetic field compatible traceability chain has been introduced for MRI-guided radiotherapy, a new use for MRI in cancer therapy.

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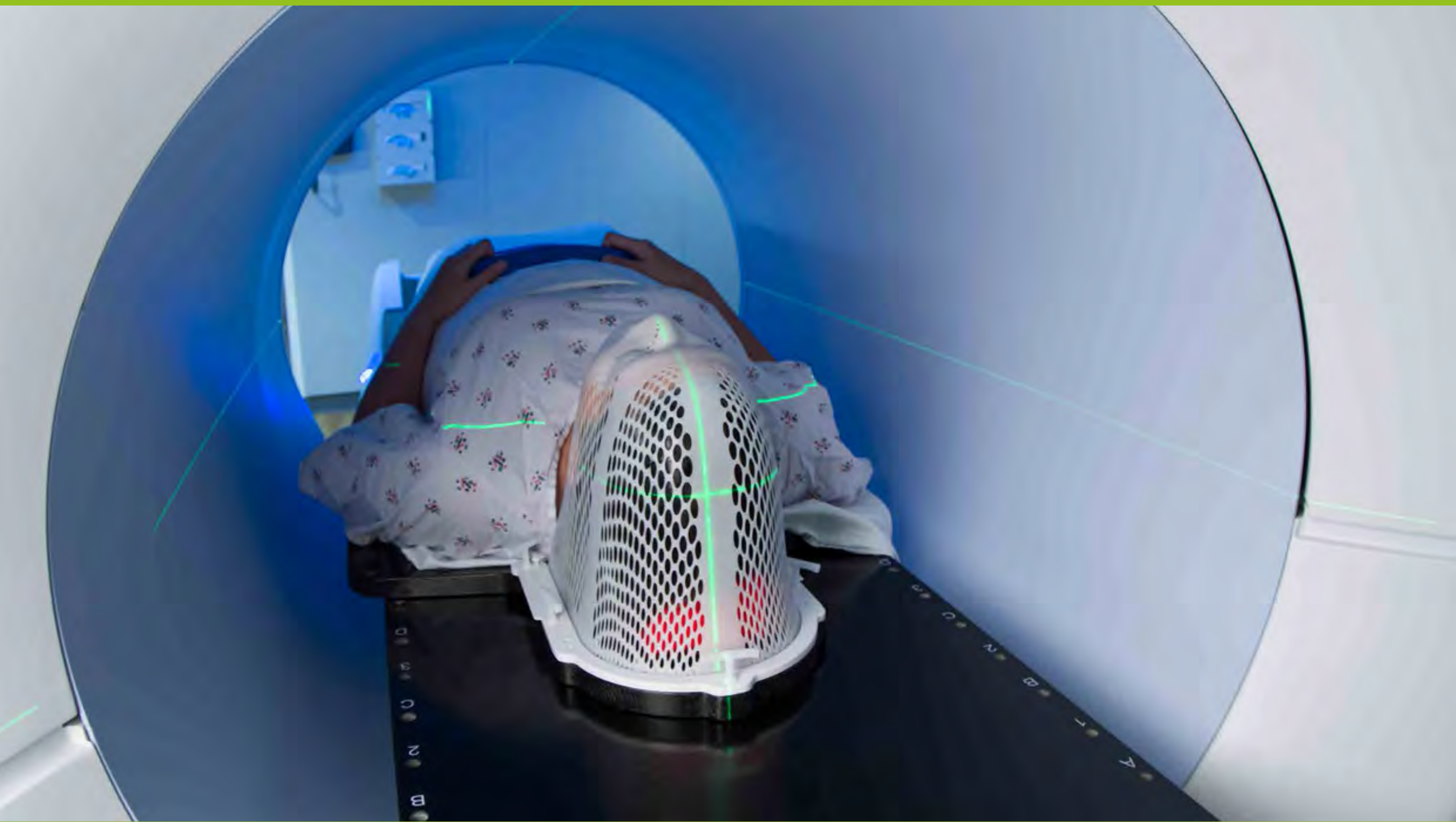

Improving radiotherapy success

Radiotherapy is a powerful tool in modern cancer treatment – around 40 % of people who survive cancer do so because of radiotherapy. MRI-guided radiotherapy can further improve the success of radiotherapy by offering more targeted treatment through real-time imaging. However, before this new technique can be widely adopted in clinics, accurate dosimetry needs to be established to ensure patients are consistently treated with safe and effective doses of radiation.

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Challenge

Radiotherapy has been a mainstay of cancer treatment for over a century. It most commonly involves using a linear accelerator (linac) to deliver high-energy beams of X-ray radiation to patients, killing cancerous cells by damaging their DNA. Prior to treatment, patients are imaged in a CT scanner (using X-rays) to identify the target site. However, the position, size and shape of tumours around the chest and abdomen can change significantly during treatment because of the patient's breathing, limiting the accuracy with which these tumours can be targeted.

Compared to CT, magnetic resonance imaging (MRI) offers a greater depth of contrast and better visualisation of tissue boundaries, without the ionising radiation. This gives it the potential to provide more detailed images of patients during their treatment. MRI would enable clinicians to track changes to the target site in real time and ensure they are focusing radiation beams as closely as possible on the tumour, improving treatment outcomes for patients.

Delivery of a precise dose of radiation is essential to maximising the success of any radiotherapy treatment, while minimising adverse side effects due to radiation exposure. The problem is the electromagnetic field induced by MRI has the potential to affect a linac's radiation beam and calibration procedures, and consequently the dose delivered to patients. These effects must be well understood and new methods for calibrating specific MRI-linac combinations developed. This will support the introduction of MRI-guided radiotherapy into hospitals and clinics and improve cancer treatments delivered by external beam radiotherapy.

Solution

The EMRP project *Metrology for next-generation safety standards and equipment in MRI* developed the first calibration procedure for clinical MRI-guided radiotherapy machines that works in the presence of a magnetic field and allows users to accurately determine the radiation dose delivered to patients. Using a new, compact water calorimeter, MRI-linacs can be calibrated at the hospital and the measurements they make directly linked to national standards. This is a significant improvement over the current calibration method for conventional linacs, in which the linac ion chamber must be calibrated against another ion chamber, itself calibrated at a National Measurement Institute.

Impact

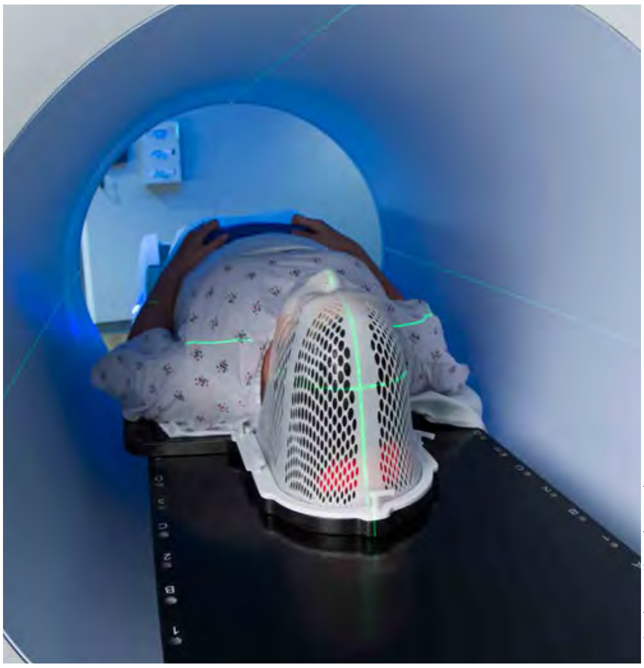
Elekta and Philips, two leading European companies in the fields of radiotherapy and MRI imaging, are part of a consortium developing a combined MRI-linac, which hopes to introduce the new treatment to clinical practice in 2017. The new calibration method developed has enabled Elekta and Philips to calibrate the beam strength and improve beam control of the MRI-linac, enabling customers to have confidence in its ability to provide the right quantity of radiation to a small targeted area. This will support improved treatment of tumour cells, while minimising exposure of surrounding healthy tissue.

The robust and easy-to-perform calibration method developed by the project provides essential support to the safe, effective introduction of the improved image quality offered by MRI into standard radiotherapy treatments. Consequently, the project has made a significant contribution to the development of an innovative, high-value medical technology and the benefits it brings to Europe's economy and quality of life for citizens.

Speaking of the MRI-linac's development, Kevin Brown, Global Vice-President of Scientific Research at Elekta, said: "The EMRP project contributes exact and reliable radiation dosimetry to this endeavour, an indispensable precondition before any patient can be treated."

Metrology for improved MRI safety

The EMRP project *Metrology for next-generation safety standards and equipment in MRI* improved the diagnostic value and efficiency of magnetic resonance imaging (MRI) by developing measurement methods and models which enhance the safety of patients and staff while simultaneously eliminating unnecessarily restrictive exposure limits. A new patient safety concept developed in this project will help manufacturers to speed up innovation cycles, supporting faster market introduction of emerging technologies, and will allow the safe scanning of previously excluded patient groups. In addition a robust magnetic field compatible traceability chain has been introduced for MRI-guided radiotherapy, a new use for MRI in cancer therapy.



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MRI standards spur innovation

With 30 million scans per year in Europe, Magnetic Resonance Imaging (MRI) is an important medical imaging technique that is increasingly being used during surgical procedures. However, staff tending patients also experience effects from the strong MRI magnetic fields and safe exposure limits are set by EU Directives. Highly accurate magnetic field measurements and ways to relate them to exposure are needed to ensure staff and patients remain safe at all times.

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Challenge

Magnetic Resonance Imaging (MRI) is a diagnostic tool used to detect serious medical conditions, including cancers, heart disease and strokes. Thirty million MRI scans are performed in the EU each year providing doctors with valuable 3D images without the need for invasive investigations or patients being exposed to ionizing radiation.

Increasingly, more powerful MRI scanners are being used to guide surgeons performing delicate key-hole procedures. This places medical staff close to the operating scanner and exposes them to the static magnetic fields MRI generate. When staff move "motion-induced" effects due to the magnetic field can cause sensations of nausea, vertigo and also disturb vision. This introduces concerns for both patient and staff safety.

The EU Directive 2013/35/EU introduced in 2014, set legal exposure limits for workers performing tasks in magnetic fields and requires risk assessments to be performed to ensure they remain safe. The Directive requires the characterisation of workers' exposure to the so-called "motion-induced" effects. Specific procedures for exposure assessment are needed based on highly accurate and robust calculation methods and simulations to ensure the safe use of this important imaging technique and enable its extension into new surgical procedures.

Solution

The EMRP Project, *Metrology for next-generation safety standards and equipment in Magnetic Resonance Imaging* developed new computational tools and models to calculate the physical effects induced within the bodies of medical staff moving through the strong stationary magnetic field of MRI scanners. These tools can be used to predict both the maximum variation of the magnetic field experienced by workers performing tasks near to the scanners entrance and also the corresponding induced electric field, which could stimulate the nervous system creating sensory effects.

The extensive use of the project's computational tools has led to a wide survey of different MRI platforms and many different staff movements. This has generated a body of evidence on how some movements performed near to the scanner entrance can create the conditions needed to exceed safe MRI exposure limits.

Impact

National health authorities and regulators rely on reference documents from International safety standardization organizations when setting legal limits for worker safety across many risk areas. One such reference is the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2014 publication on specific exposure levels for staff performing tasks near operating MRI. These are used in the EU Directive 2013/35/EU which governs worker safety near operating MRI magnetic fields.

European Hospitals are required by this Directive to conduct risk assessments to ensure staff do not exceed safe working conditions during the performance of their duties. Hospitals must link proposed staff movements to ICNIRP exposure limits. The projects assessment procedure provides hospitals with a validated framework to use to evaluate the safety of staff movements when planning new surgical procedures. This enables hospitals and staff to have greater confidence in identifying critical situations where movements may exceed safety limits and the early introduction of strategies to reduce worker exposure and reduce the incidence of "motion-induced" sensations. An important step towards safe performance of new MRI guided surgical procedures.

Metrology for improved MRI safety

The EMRP project *Metrology for next-generation safety standards and equipment in MRI* improved the diagnostic value and efficiency of magnetic resonance imaging (MRI) by developing measurement methods and models which enhance the safety of patients and staff while simultaneously eliminating unnecessarily restrictive exposure limits. A new patient safety concept developed in this project will help manufacturers to speed up innovation cycles, supporting faster market introduction of emerging technologies, and will allow the safe scanning of previously excluded patient groups. In addition a robust magnetic field compatible traceability chain has been introduced for MRI-guided radiotherapy- a new use for MRI in cancer therapy.

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Safer MRI for metal implant wearers

Magnetic Resonance Imaging (MRI) can detect cancers, as well as joint and spinal injuries. However there are restrictions on MRI scanning for patients with metal implants as the implants can move or generate heat due to the MRI's strong magnetic field interacting with the metal. A better understanding of MRI heating effects will contribute to making this imaging technique as safe as possible.

Europe's National Measurement Institutes working together

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Challenge

Magnetic Resonance Imaging (MRI) plays a vital role in diagnosing conditions such as joint, spine and tissue problems, as well as various cancers. Thirty million patients in the EU undergo MRI exams each year. However, 8–10% of the European population have metal implants meaning that additional precautions have to be taken to ensure MRI scans are safe for them.

MRI magnetic fields can cause heating in metal stents necessary to keep blood vessels open or permanent pins and plates holding broken bones in place. If they get too hot, this can damage surrounding tissue. However, in many cases MRI can be adapted to be safe for patients with implants. Shorter scans can be used to reduce heating effects, and modern MRI scanners allow much more operator control of magnetic imaging fields. Knowing exactly how MRI affects implants relies on accurate measurements of tissue heating caused by MRI magnetic fields. New measurement methods are needed so that MRI operators can confirm that imaging of a patient with a metal implant is safe.

Solution

The EMRP project *Metrology for next-generation safety standards and equipment in MRI* developed new methods to measure the power of MRI fields absorbed by torso and head models of the body and then related this to the heat it would generate if a metal wire implant was present. This approach enables the replacement of existing numerical simulations with a robust measurement method and a validated theoretical model.

The project used a replica of the human body to determine the reflected radiofrequency waves and related this to actual fields measured during MRI scans. With this information the team were able to derive a method for accurately measuring the reflected radiofrequency waves and validate computer simulations for tissue heating for specific implants during MRI scanning.

Impact

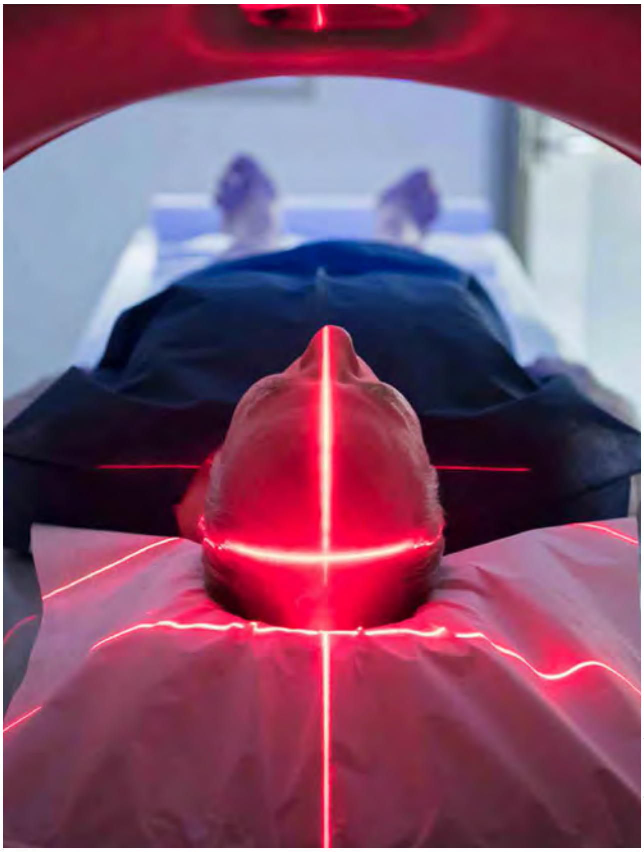
Medical technology company and MRI manufacturer, Philips, has built on project evaluations of tissue heating caused by metal implants during MRI scanning to offer hospitals greater confidence in the safe use of its scanners for patients with metal implants. The project's innovative radiofrequency field measurement method based on detecting reflected waves was used by Philips to design improved controls for its new MRI scanners. New software upgrades have been introduced by Philips, leveraging the project simulations that relate MRI field strength to heating induced in metal implants and surrounding tissue.

This enables MRI operators using Philips technology to estimate the effects of imaging on patients with metal implants and make adjustments to scan procedures to ensure these are within pre-set safety requirements. This will make it possible to tailor imaging to individual patient safety requirements by using a weaker field or shorter imaging times. Philips are about to start marketing new machines which can monitor tissue heating ensuring the safety of patients with metal implants – an innovative market leading capability.

As new scanners incorporating improved strategies for patient safety are rolled out, MRI scans will be opened up to more of the population with the ultimate goal of making this type of advanced medical imaging safe for everyone.

Metrology for improved MRI safety

The EMRP project *Metrology for next-generation safety standards and equipment in MRI* improved the diagnostic value and efficiency of magnetic resonance imaging (MRI) by developing measurement methods and models which enhance the safety of patients and staff while simultaneously eliminating unnecessarily restrictive exposure limits. A new patient safety concept developed in this project will help manufacturers to speed up innovation cycles, supporting faster market introduction of emerging technologies, and will allow the safe scanning of previously excluded patient groups. In addition a robust magnetic field compatible traceability chain has been introduced for MRI-guided radiotherapy, a new use for MRI in cancer therapy.



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Better flow measurement, safer patients

Vulnerable patients receiving drug infusions in intensive care or for palliative relief require low volume drug delivery over extended time periods. Infusion systems operating at very slow rates are used to deliver these drugs. Accurate calibrations of the entire infusion system, from the drug reservoir to the patient are required, but current European calibration facilities cannot match hospital needs. Improved EU calibration facilities are required to support delivery of these crucial drugs.

Europe's National Measurement Institutes working together

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Challenge

Low flow-rate drug delivery is required for diabetics, neonates, palliative care and patients in intensive care or undergoing anesthesia. Often, the drugs must be delivered continuously over many hours, and often the amounts prescribed are the maximum that can safely be given. Infusion systems rely on pumps that must be both reliable and accurate, and also on a range of disposables - syringes, filters, and infusion lines. However, for reasons of economy, disposables are not always those recommended by the pump manufacturer and this may create greater concern over the systems performance.

Infusion drugs may need to be administered at rates in the milliliter per hour range although for diabetics and those receiving palliative care even slow rates are delivered by implanted infusion devices. Hospitals routinely use calibrated "master" meters to confirm infusion system performance. Currently European national metrology facilities cannot match such low flow rates. New and highly accurate low flow rate facilities are urgently needed to provide the accurate flow rate calibrations required to ensure the most vulnerable patients will receive vital drugs safely.

Solution

The *Metrology for Drug Delivery* project has developed low flow rate calibration facilities which can now deliver improved traceability for the extremely low flow rates required by hospitals for drug infusions – a reduction in the lowest traceable flow rate achievable by one thousand times. The project also investigated the effects of using various disposables and pump combinations on flow rates. It was found that interchanging infusion line disposables could significantly change the (transient) flow rate and should be avoided in the interests of delivering effective and safe infusion line treatments.

Impact

The *Garcia de Orta* hospital in Portugal was one of the first to benefit from using a new calibration service created as a result of the project. The hospital's master calibration meter, used to check the performance of all the infusion line systems used in the hospital, underwent the first calibration for low flow to be performed in Portugal. This removed the need to send it away for calibration, thus avoiding considerable downtime.

Garcia de Orta has already implemented a robust QA system that requires the entire infusion line from the pump to the patient to be calibrated as a whole. They were keen to use the Portuguese NMI's new calibration service and welcomed the opportunity to have their QA system externally validated during the project. As a result, they now have greater confidence in the robustness of their total infusion line calibrations and their ability to identify if non-compatible disposable components have entered the hospital stocks.

As a result of the project's newly introduced European facilities for calibrating hospital meters routinely used for drug infusion systems, clinical staff can have greater confidence in being able to precisely administer vital lifesaving drugs to the most vulnerable of patients.

Metrology for drug delivery

The EMRP project *Metrology for Drug Delivery* developed primary standards and characterization methods which have enabled the healthcare community to assess the performance of drug delivery devices. Device properties such as flow rate and temperature dependency need to be well-characterized to ensure safe and efficient patient treatment, as dosing errors can have critical consequences for patients – for example, dangerous under and overshoot of blood pressure in preterm neonates. The measurement tools developed by the project, together with a greater emphasis on the causes and impact of dosing errors, will ultimately reduce these dosing errors.

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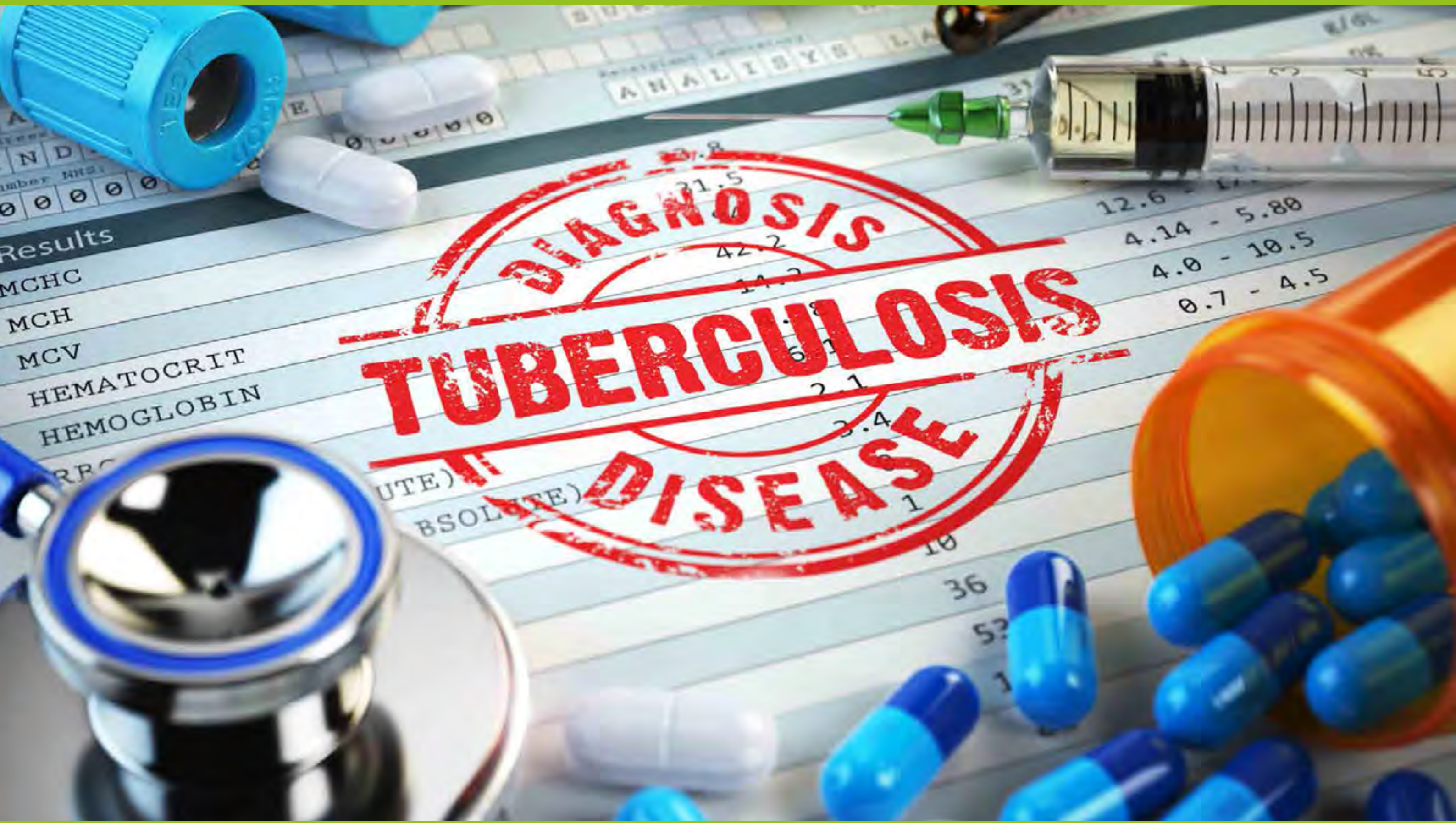

Faster TB diagnosis

Tuberculosis (TB) is caused by bacteria which are becoming increasingly resistant to antibiotics. Doctors in the developing world have to frequently rely on diagnostic techniques that are insensitive or slow leading to the over prescription of antibiotics. By providing access to faster diagnostic methods, doctors will be able to target treatment effectively slowing the development of drug resistant TB bacteria.

Europe's National Measurement Institutes working together

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Challenge

Tuberculosis (TB) is a global problem made more serious by challenges associated with diagnosis and identification of drug resistance. A major challenge is quickly identifying the presence of TB causing bacteria in a patient's sample. Conventionally, for the most accurate diagnoses, samples are cultured for six weeks before being tested and while newer culture methods have reduced this, several days are still needed. Modern laboratories increasingly use an analysis technique called Polymerase Chain Reaction (PCR) which specifically detects bacterial DNA - if the pathogen is present - in a matter of hours.

Many different routine PCR techniques are used in TB diagnosis around the world, and increasingly automated instruments that do not need specialised laboratories and highly trained staff are being introduced. This makes these methods suitable for use in developing countries where TB prevalence is high. To ensure the accuracy with which labs can routinely detect disease bacteria in patient samples they participate in externally run quality assessment schemes during which all participants analyse the same material. This enables the results to be compared and a labs disease diagnosis capability to be assessed. However, robustly relating participant results is challenging due to a lack of well characterised reference materials and appropriate highly accurate and traceable analysis methods.

Solution

The EMRP project *Metrology for monitoring infectious diseases, antimicrobial resistance, and harmful micro-organisms* developed and validated highly accurate Digital PCR (dPCR) based approaches for counting the quantity of specific bacterial DNA sequences in a sample.

The UCL Centre for Clinical Micro-biology, based at the Royal Free Hospital in the UK, an internationally recognised centre for micro-bacteriology research provided the project with TB bacterial samples to enable the generation of appropriate reference materials. These materials enabled the calibration of other clinical PCR techniques and allowed their direct comparison to the dPCR assigned values. This created a traceable measurement route for clinical PCR techniques.

The project also identified best practice for sample preparation and storage to to enable delivery of the most accurate results across all techniques.

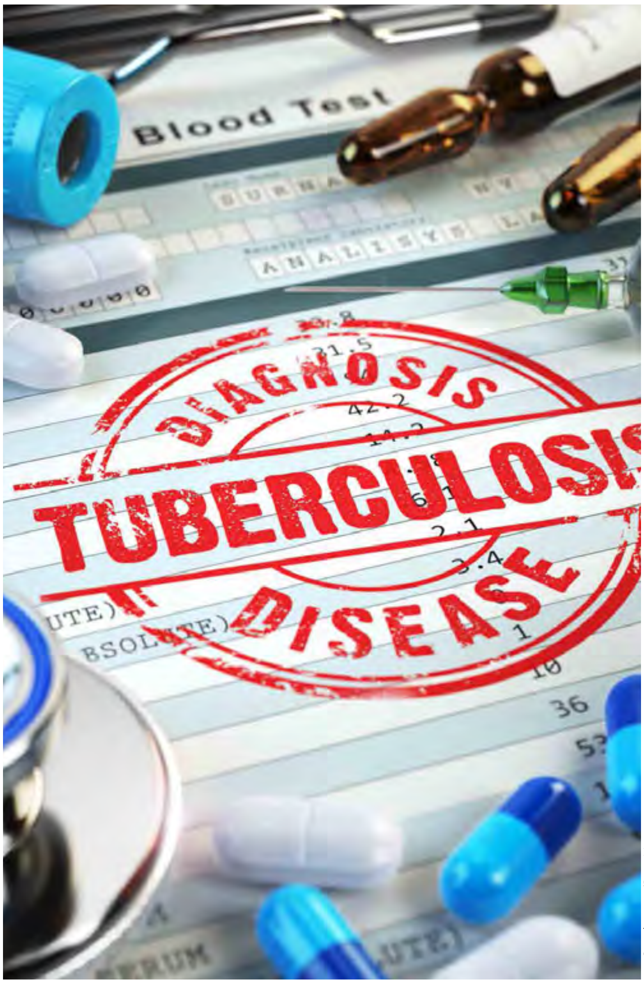
Impact

The TB reference materials assessed during the project were used in a comparison exercise to evaluate the performance of diagnostic tools by nine project partners and collaborators. Great Ormond Street Hospital, an important TB pathology laboratory in the UK, participated in this exercise and were able to confirm that PCR techniques correctly detect TB bacteria. The project's reference material established a reliable and traceable baseline, allowing organisations to demonstrate the robustness of their techniques in detecting the bacterial DNA.

The reference materials and best practice guidance developed as a result of this project are helping to assure the performance of PCR-based measurements and will increase confidence in the accuracy of TB testing. Faster rigorous TB diagnosis will help doctors prescribe and modify drug regimens to maximise effectiveness, minimise side effects, and slow the development of drug resistant bacteria.

Metrology for infection control

The EMRP project *Metrology for monitoring infectious diseases, antimicrobial resistance, and harmful micro-organisms* developed new measurement methods and materials to enable accurate quantification of infectious disease-causing pathogens in clinical samples. Infectious diseases account for over 20 % of human deaths globally and reliable diagnostic tools, such as these, are vital for public health protection. The project results provide much-needed support to emerging molecular approaches for efficient, harmonised and rapid diagnosis and monitoring of infectious diseases.



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Targeting tumours accurately

External radiotherapy is aimed at killing cancerous cells, but can be dangerous to healthy ones. Modern radiotherapy machines focus multiple radiotherapy beams on tumours, which minimises harm to surrounding healthy tissue. To ensure that just the right amount of energy is delivered to kill the cancer, clinicians rely on beam strength measurements. As beam areas get smaller, new measurement methods are needed to accurately measure the strength of the highly focused beams used.

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Challenge

Treating cancerous tumours with radiotherapy requires precisely targeted treatments to be delivered directly to the cancerous cells without harming surrounding healthy tissue. For example with facilities like gamma knife, up to 200 low power beams, which individually do little harm can be focused to a single area of just a few millimetres on the cancerous cells. The combined deposited energy of all these beams destroys the tumour. It is therefore vital that each of these beams is performing as expected, small errors across multiple beams can quickly add up and over or under delivery of planned treatments can occur.

Clinics are required to check their radiotherapy instruments monthly and perform further daily checks to confirm beam performance and ensure delivery matches prescription. Silicon diodes, widely used for these calibrations, are damaged by the radiation they are measuring and their response changes over time. Radiation resistant measurement instruments are needed to ensure accurate delivery of therapeutic doses during radiotherapy and to enable confirmation that delivered treatment matches the patient's individual treatment plan.

Solution

The EMRP project *Metrology for radiotherapy using complex radiation fields* tested and demonstrated the validity of a breakthrough new diamond detector which could in the future be used to accurately calibrate all types of small radiotherapy beams.

The diamond detector developed and validated for electron and photon beams an earlier Euramet project, has had its performance evaluated in this EMRP project for proton and carbon-ion beams. This has shown that this innovative detector is suitable for use with all current forms of radiotherapy beams.

The EMRP project also used simulations and performance testing with photon beams to generate highly accurate correction factors that in the future will enable the diamond detector's use for clinical beam calibrations with direct traceability to the SI.

Impact

PTW, a market leader in dosimetry equipment for radiation therapy, now markets the microDiamond dosimeter based on a detector prototype developed in a pre-cursor Euramet project, to radiotherapy centres for measuring the strengths of their multi-therapy beam machines. MicroDiamond has significant advantages over silicon diodes in that it is small and easy to use, gives a response which is easy to relate to the response of body tissue, and does not suffer from radiation damage. The detectors ease of use and stability over time is making it popular with users and encourages more frequent beam performance checks.

PTW anticipates that the project derived small correction factor will soon enable the microDiamond detector to provide the ultimate calibration for radiotherapy machines.

Greater accuracy in measuring multi-beam radiotherapy delivery will give clinicians increased confidence in being able to match planned dose to that delivered, opening up further the potential for individually designed patient therapies.

Metrology for complex radiotherapy fields

The EMRP project *Metrology for radiotherapy using complex radiation fields* developed an improved calibration chain linking absorbed dose to water standards to clinical instruments and patient treatment for the small radiation fields used during cancer surgery and therapy. Modern cancer treatments use complex radiation fields generated by a range of high energy radiotherapy beams delivering intense radioactive doses to areas of only a few millimetres across. As a result of this project, it is now easier for therapies to meet the requirements set out by the International Commission on Radiation Units and Measurements (ICRU) and clinicians are able to more accurately link delivered therapeutic dose to treatment plans across all therapy types.

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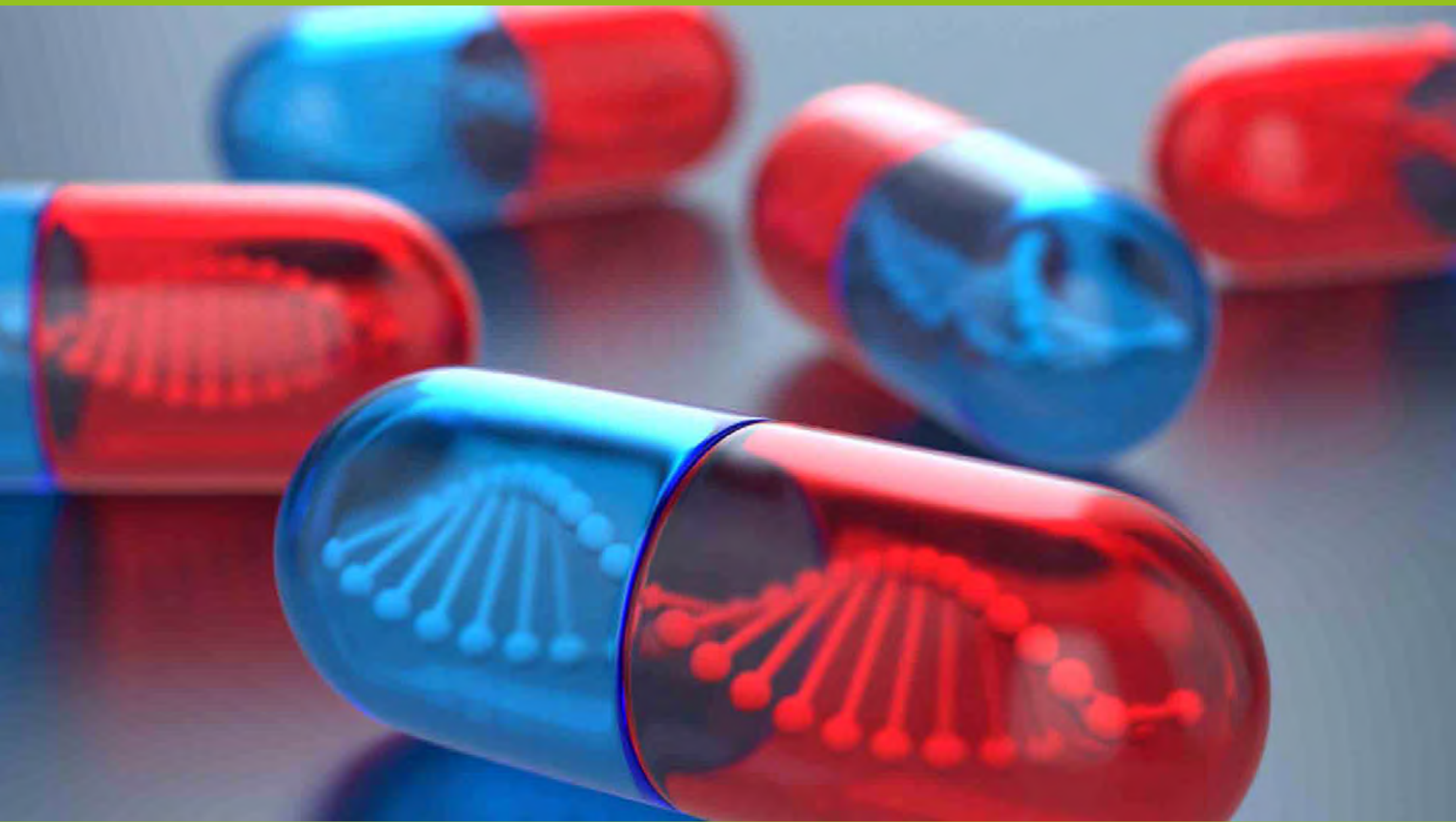

Fast track to drug discovery

Identifying new drugs is an expensive business. Drug discovery takes time and may offer developers a relatively low payback, especially for new antibiotic compounds. New, rapid methods to identify potential drugs could reduce cost and accelerate the introduction of new treatments. This is particularly important for antibiotics where many of our current drugs are becoming ineffective as resistance to them develops in the microorganisms they are designed to attack.

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Challenge

Developing potential new drugs often involves costly laboratory-based evaluations and drug discovery is currently based on finding new molecules similar to existing ones with known properties. Key to new drug development is an improved understanding of how existing drugs destroy microbe cells and how this relates to the drug's bio-molecular structure and function – its chemical and physical properties. This knowledge could be used to rapidly identify new drug compounds and would avoid the costly conventional trial and error laboratory-based approaches used for screening new candidate drug compounds.

Many of the drugs we rely on, such as antibiotics, are losing their efficacy through the development of resistance. The effectiveness of others is reduced if administered by mouth as they are degraded by acids within the stomach and therefore fail to reach the bloodstream. Streamlining selection methods for new drug discovery and coupling this with more efficient methods of drug delivery could boost the effectiveness of new drugs, get them into a patient's bloodstream faster, and reduce development costs.

Solution

The EMRP project *Metrology for biomolecular origin of disease* generated a validated set of characteristics that can be used to accurately determine the relationship between bio-molecular structure and function. For the first time ever, this project successfully showed how and where an antibiotic attaches to a microbe's cell membrane using high resolution spectroscopy. How a bacterial cell and an antibiotic interact are key to the antibiotic's effectiveness in destroying the microbe.

All the data generated by the project was synthesised into a single generic method that enables the prediction of antimicrobial action and resistance. The overall result is a new template based computer model that can identify potential compounds suitable for development as new antimicrobial drugs with high accuracy, removing the need for the initial trial and error laboratory-based screening studies.

Impact

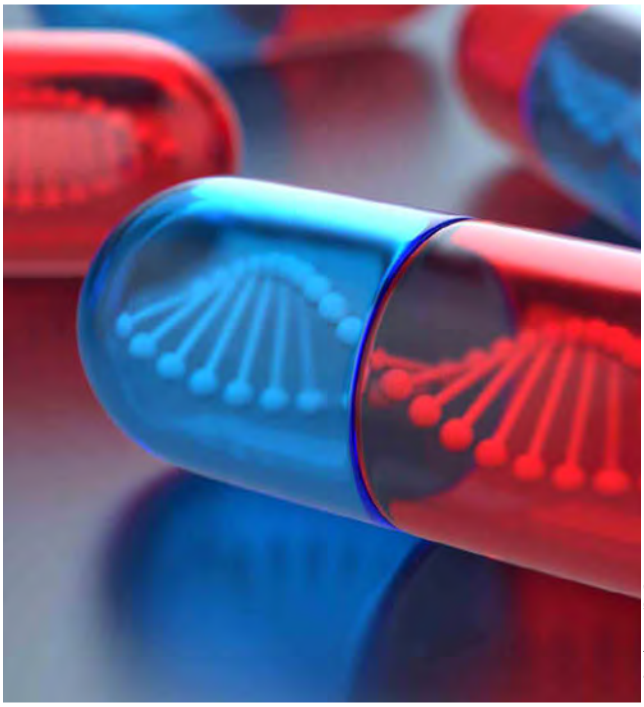
An early user of the projects drug design template are a team based at Oxford University's Biochemistry department who are developing new drug compounds. The Oxford team is collaborating with Malvern Cosmeceutics Limited in researching the application of through skin drug delivery for new antibiotic compounds. Some antibiotics and pain relieving drugs are deactivated by the digestive system, so finding an alternative delivery method could increase their effectiveness or open up new types of compounds for medical use.

The EMRP project's drug development template has enabled the Oxford team to cost effectively identify new drug compounds for through the skin delivery without the need for traditional trial and error laboratory-based screening studies. These candidate compounds have also been matched to the requirements for delivery via Malvern Cosmeceutics innovative Lipodisq® advanced skin penetration system. Funding for clinical trials is currently being sought to test this novel skin-based drug-delivery technology as an alternative to drug delivery via the digestive system or the use of injections just under the skin.

As antimicrobial drug resistance increases and the number of antibiotics capable of treating many infections decreases, cost effective methods are needed to both narrow and accelerate the search for replacement drugs. The project's new drug development template offers one such method and gives researchers an opportunity to accelerate the identification of new and urgently needed drugs to fight the ever increasing number of drug-resistant diseases.

Metrology for drug development

The EMRP project *Metrology for biomolecular origin of disease* established critical design principles which link a drug's molecular structure to its desired therapeutic effect and demonstrated the use of these principles for creating next-generation antibiotics in the fight against antimicrobial resistance. The results have improved the precision and specificity with which therapeutically-relevant biological activity can be measured, evaluated and exploited. This makes the design process for drugs such as antibiotics more commercially attractive and will support the development of more effective treatments.



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11326/0317 - HLT10 16061

European Metrology Research Programme
Delivering Impact

Accurate dose means effective therapy

Molecular radiotherapy can target cancers by going directly to the cancer site. Getting the right amount of a radioactive drug to the cancer is critical, but we are all different and individual responses vary to the same treatment. Accurate radioactivity measurements and sophisticated imaging techniques with the potential to measure the drug's delivery inside the body are needed to ensure effective personalised cancer care.

Europe's National Measurement Institutes working together

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Challenge

Molecular radiotherapy (MRT) is often used when other cancer therapies have failed, but it has real potential to be a very effective first line cancer treatment. This therapy directly targets organs with tumours whilst leaving surrounding healthy body tissue unharmed. The treatment uses a range of radioactive drugs to target specific tumours such as radioactive iodine-131 for thyroid cancer or the direct injection of radioactive microspheres into liver tumours. The key for wider use of MRT is accurate measurement of the actual radioactive dose delivered to the tumour.

However, there are no standardised methodologies that accurately relate the radioactivity of the drug administered to the patient to the actual dose delivered. The current approach, called "as high as safely administered" is based on generic responses of patients during clinical trials. It ensures patient safety, but does not necessarily deliver the optimum dose to the individual patient's cancer so the benefits of the treatment are variable. A new EU Directive coming into force in February 2018 will require dose planning for individual patients to be based on dose taken up by the body at the cancer site.

Solution

The EMRP project *Metrology for molecular radiotherapy* has developed new dose measurement methods for MRT based on accurate monitoring of radioactivity at the tumour site. These use body phantoms (models) and a variety of advanced medical imaging techniques, such as Single-Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET) to measure radioactivity in specific targeted organs.

Together these advances have enabled the formulation of improved protocols to relate measured administered radioactivity to the actual doses delivered to a patient's tumour and to normal tissues. This helps ensure maximum therapy efficacy, whilst demonstrating high levels of patient safety.

Impact

Nuclear medicine clinicians and researchers require high quality guidance and reference documents to assist them in providing the very best care to patients undergoing radiotherapy. One organisation that provides independent and highly respected publications in this field is the International Atomic Energy Agency (IAEA). Currently the IAEA is drafting a new Health Series publication on Dosimetry for Radiopharmaceutical Therapy. The publication will include methods developed in the project to accurately measure the doses received by individual patients from MRT.

Nuclear medicine clinicians will be able to easily access the project's methods via this single IAEA publication aimed at improving the delivery of better patient treatments and therapy for cancers. Using these methods clinicians will take a major step towards implementing the new EU directive through the delivery of personalised treatment planning, reduce treatment costs and potentially increase success rates for treating cancer.

Metrology for molecular radiotherapy

The EMRP project *Metrology for molecular radiotherapy* was the first European project to develop standard methods for measuring the absorbed dose received by patients undergoing molecular radiotherapy (MRT). This enables radiation doses to be better tailored to individual patients, increasing the effectiveness of treatment for conditions such as cancer and thyroid disease while minimising side effects. The project results will form a valuable basis for implementing individual dosimetry in MRT clinics across Europe and improving treatment outcomes.

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European Metrology Research Programme
Delivering Impact

Traceability Boosts Cancer Therapy

Molecular radiotherapy (MRT) effectively targets cancer while minimising damage to healthy tissue. It relies on safely getting short-lived radioactive products directly to the tumour and monitoring up-take using complex patient imaging. The accuracy of these measurements depends on the calibration of instruments for measuring radioactivity, using a method that gives traceability to the SI. Reducing the existing calibration chain will increase administered drug accuracy and lead to optimised individual MRT patient therapies.

Europe's National Measurement Institutes working together

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Challenge

For many years molecular radiotherapy, MRT, has been used for palliative cancer care, but it has great potential to become a potent first line cancer treatment. The therapy uses radioactive drugs to target specific tumours, for example radioactive yittrium-90 microspheres are used to treat liver cancers.

However, accurate activity measurements of administered short-lived radioactive drugs in the clinic are needed to make sure that the tumour receives just the right radioactive dose. Therefore, both the activity meters used to make these measurements and the cameras taking images to confirm therapy delivery require accurate calibration. The calibration of activity meters typically involves hospital nuclear medicine departments measuring highly radioactive solutions and then sending these to expert laboratories for a rigorous activity determination. This extended traceability chain is time-critical as the radioactivity of nuclear medicine drugs drops rapidly. A more direct calibration chain would remove the need to transport highly radioactive and short-lived materials large distances and also increase the accuracy of clinical measurements.

Solution

The EMRP project *Metrology for molecular radiotherapy (MetroMRT)* devised a method for determining the dose to tissue per administered MRT to a patient, as a chain of measurements traceable to the SI units of dose and activity. Using the principles of metrology it was possible to evaluate the contribution to the dose measurement of the uncertainty due to the activity measurement. This demonstrated the importance of reducing the uncertainty in activity measurements.

A portable scintillation counting system, based on a technique which counts light flashes generated as radioactive decay occurs in a scintillant solution, was developed to measure the activity of the therapeutic agents used in MRT. This method has the advantage that it self-calibrates and does not rely on any other reference standards or materials. The counting system, initially developed in the EMRP project *MetroFission*, was validated in *MetroMRT* and has now been used for the first time to directly measure the activity of Yittrium-90 outside of a calibration institute.

The new portable system opens up the possibility of hospital nuclear medicine departments being able to calibrate their clinical activity meters with direct traceability to the SI units on site.

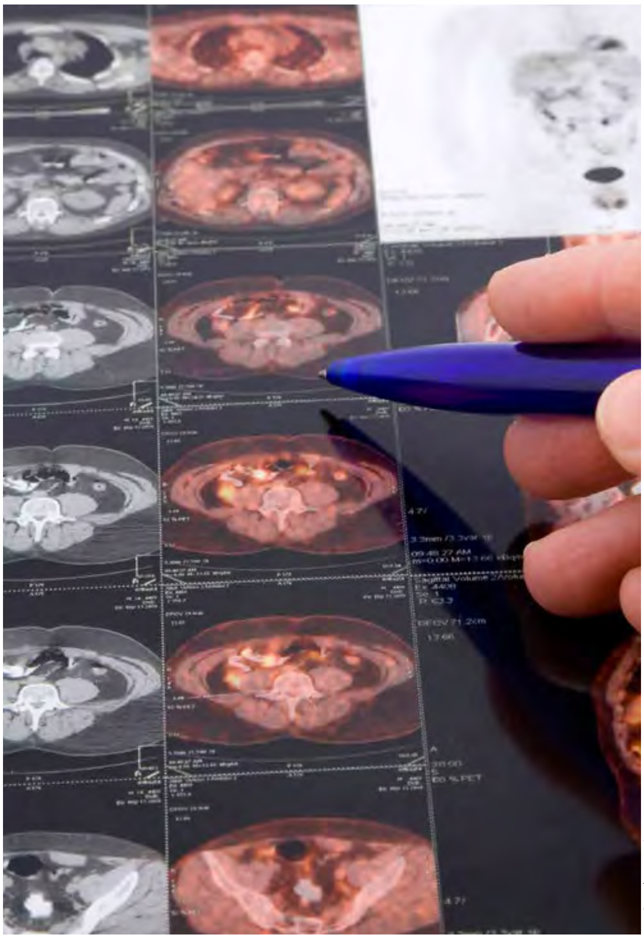
Impact

Italian cancer centres, Regina Elena National Cancer Institute and the Bambino Gesù Children's Hospital in Rome, have successfully used the project's portable system to calibrate their activity meters directly, by comparing measurements of sample activities of MRT drugs. Now these hospitals have more accurate calibrations for the instruments used to measure radioactive therapies before injection into patients and also for imaging cameras used to assess its delivery.

Sirtex, a company that markets Yittrium-90 microsphere technology for MRT, is keen to have medical institutions use the project's portable scintillation counting system and is actively supporting its widespread adoption across the EU. Direct hospital calibrations for instruments and cameras used to measure radioactive drugs and therapy delivery will increase accuracy of measurements of patient doses and open the way to greater effectiveness in personalised MRT cancer care.

Metrology for molecular radiotherapy

The EMRP project *Metrology for molecular radiotherapy* was the first European project to develop standard methods for measuring the absorbed dose received by patients undergoing molecular radiotherapy (MRT). This enables radiation doses to be better tailored to individual patients, increasing the effectiveness of treatment for conditions such as cancer and thyroid disease while minimising side effects. The project results will form a valuable basis for implementing individual dosimetry in MRT clinics across Europe and improving treatment outcomes.



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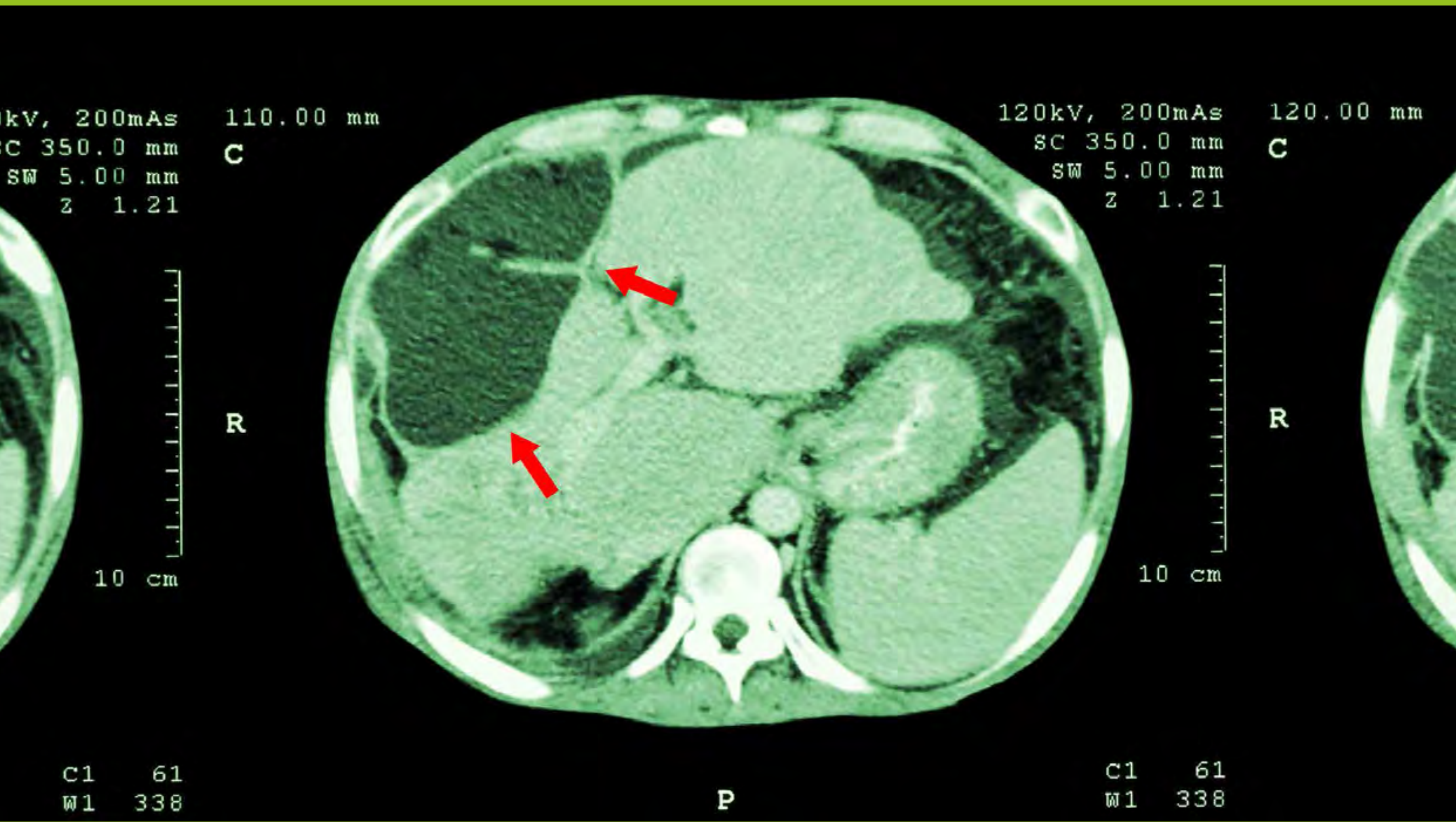

Hitting the target for cancer

Molecular radiotherapy (MRT) is an innovative treatment that effectively targets cancer cells and has great potential to offer personalised treatment tailored to an individual patient's needs. The key to wider use of MRT is accurate measurement. Improved measurement methods and use of sophisticated medical imaging techniques are needed to ensure that the dose delivered to the tumour can be confidently predicted from the measured radioactivity of the pharmaceutical or device before use.

Europe's National Measurement Institutes working together

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Challenge

For many years molecular radiotherapy (MRT) has been used for palliative care of cancer patients, but it has great potential to become a potent first line cancer treatment. The therapy uses radioactive drugs to target specific tumour locations, for example by injection of radioactive microspheres into tumours in the liver via its artery.

Currently, the delivered therapeutic dose is estimated by measuring the radioactivity of the pharmaceutical or device used, before it is administered. This method has a well-established calibration chain for routine liquid radioactive pharmaceuticals in standardised containers. However, these calibrations do not easily transfer to innovative treatments such as the use of radioactive resin microspheres and other novel delivery systems.

Clinicians are keen to relate radioactivity per unit volume of therapy given to patients to the radiation dose delivered to the tumour as monitored using imaging methods. To be able to do this reliably it is necessary to achieve greater activity accuracy and to be able to track activity delivery to the cancer. Improved activity measurements and a better understanding of the relationship between activity of the radiopharmaceutical and the actual delivered therapeutic dose at the tumour site are needed to increase treatment effectiveness and to encourage the more wide-spread use of novel delivery systems, such as microspheres.

Solution

The EMRP project *Metrology for molecular radiotherapy (MetroMRT)* developed a radiotherapy dose measurement method for radioactive microspheres based on accurately monitoring radioactivity both at the point of administration and at the tumour site. The project identified issues that hamper the activity measurement of radioactive microspheres, such as variations in the dimensions of vial wall thickness and microsphere solution density. The work enabled improved radioactivity measurement traceability, and established a robust link to conventional activity measurements in the clinic for Yittrium-90 in solution before the microspheres are administered to the patient. The administered activity is a critical parameter in the use of Yittrium-90 microspheres to treat liver cancer patients.

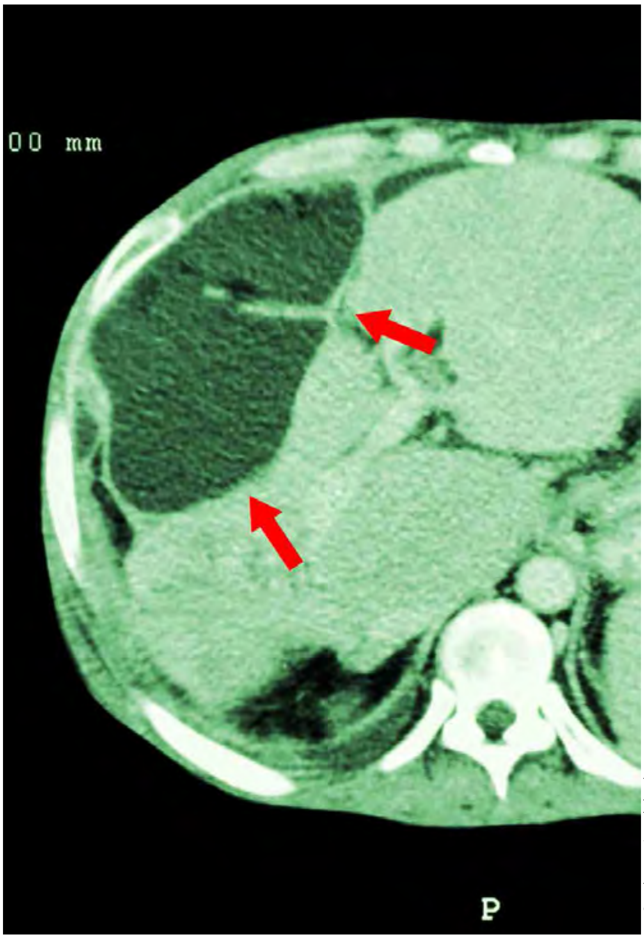
Impact

Sirtex is an international company specialising in developing and delivering effective cancer treatments using small particles. The rigorous activity calibrations and error analysis developed in *MetroMRT* have enabled Sirtex to improve microsphere treatment delivery. Sirtex have assessed their whole product handling process based on the project's findings, to ensure a greater accuracy in measuring the radioactivity administered in individual treatments.

Integrating improved measurements of the microspheres' radioactivity with Sirtex's own imaging methodology will help link activity administered to the actual therapeutic dose delivered to individual patients supporting the current European drive to establish safer and more effective MRT treatments. Overall, these developments are contributing to an increased use of MRT as a front line treatment for cancer in addition to its current role in palliative care.

Metrology for molecular radiotherapy

The EMRP project *Metrology for molecular radiotherapy* was the first European project to develop standard methods for measuring the absorbed dose received by patients undergoing molecular radiotherapy (MRT). This enables radiation doses to be better tailored to individual patients, increasing the effectiveness of treatment for conditions such as cancer and thyroid disease while minimising side effects. The project results will form a valuable basis for implementing individual dosimetry in MRT clinics across Europe and improving treatment outcomes.



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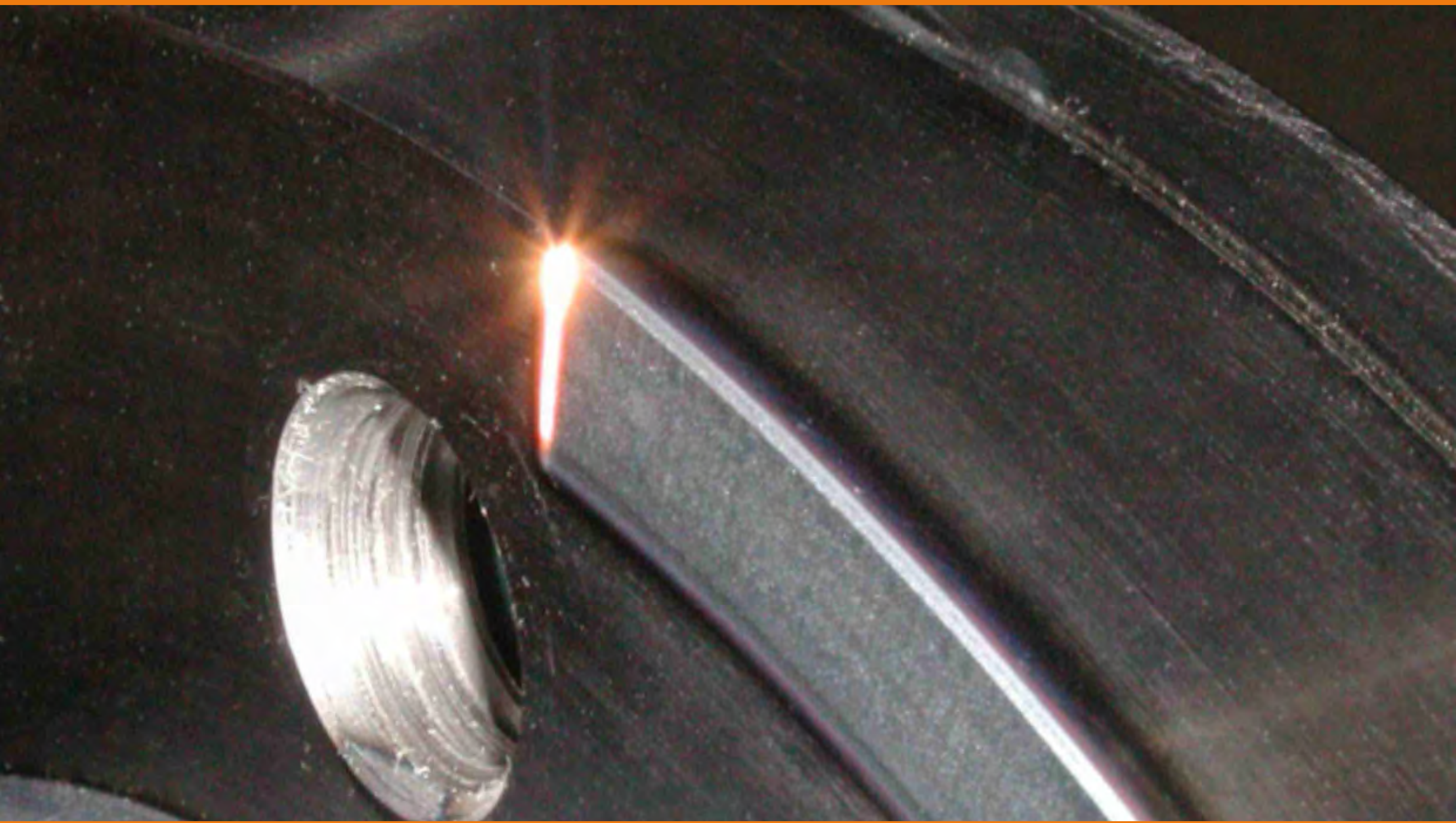

Better heat-treatment process control

Temperature measurements above 1000 °C are difficult to make but essential for a wide range of industrial processes, many of which require close temperature control to be effective. Laser hardening at high temperatures is used to harden the surface of components used in the automotive, aerospace, power generation, construction and many other sectors, but it is hard to make reliable surface temperature measurements due to the challenging measurement conditions.

Europe's National Measurement Institutes working together

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Challenge

Europe's manufacturers face the challenge of producing consistent, high-quality products using high-temperature heat treatments. Laser hardening is a surface strengthening process in which a laser heats a small area of a component's surface to high temperatures just below the melting point to create a hard and wear-resistant finish that significantly improves the part's in-service life span.

Precise temperatures are required to achieve the most effective hardening and are measured via non-contact temperature sensors. Over time the line of sight to the sensor becomes progressively contaminated affecting the sensors ability to measure and control temperature accurately. Typically, deterioration in the treated component's quality has been the only indicator of temperature drift, as well as the only indicator available to adjust the process back to the required temperature. This off-line inspection leads to both wasted material and process downtime. Until recently, there were no practical devices or methods available to calibrate and correct the high-temperature sensors *in-situ* to ensure the laser-hardening process remained optimal over long periods of time.

Solution

The EMRP project *High temperature metrology for industrial applications (>1000 °C)* developed a portable 'high-temperature fixed-point' calibration device validated for the temperature range 1000–1400 °C for direct use in industrial settings. Such high temperature fixed points, with very reliable melting points above 1100 °C, have only become available for industrial use through the work of this project. The project developed the device and demonstrated the feasibility of using it to calibrate temperature sensors in an industrial laser-hardening system.

Impact

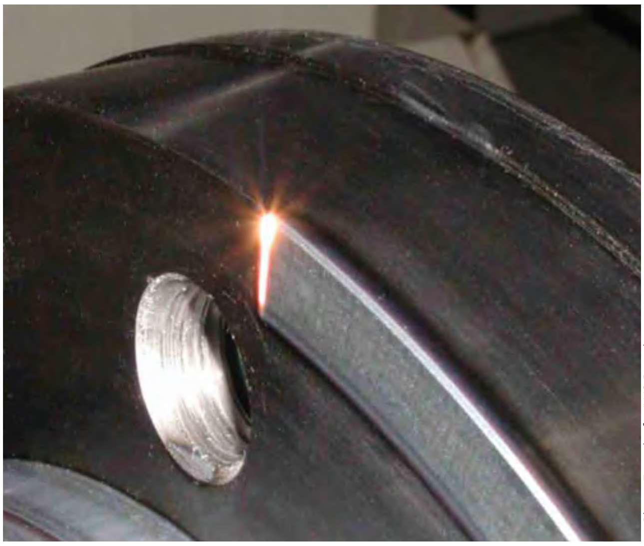
The portable fixed-point calibration device was tested at the German industrial research centre Fraunhofer IWS, Dresden, and its spin-out company ALOtec Dresden GmbH, which provides laser-hardening services.

This industrial testing revealed that the device could both identify and correct for large deviations from the ideal processing temperature. This confirmed its suitability for calibrating and correcting installed thermometers in laser-hardening processes, where a deviation of more than 10 °C above or below the required temperature can cause faulty parts. As a result ALOtec has been able to optimise performance of its laser-hardening process providing an improved service to its customers in the machine building, automotive and power generation sectors.

In addition, a major European engine component manufacturer is interested in a miniaturised version of the calibration device for installation in an automotive camshaft production facility. The plant is due to undergo a major improvement to its laser-hardening equipment including the replacement of the process thermometers. Being able to calibrate the thermometers and therefore assess temperature accurately will vastly improve the commissioning procedure for the new laser-hardening equipment. The alternative is a trial-and-error approach where the temperature of the hardening process is adjusted until the quality of the output meets specification. This not only takes time but results in faulty camshafts until the correct output is achieved. The plant produces 100,000 camshafts per year for major automotive manufacturers, so speeding up the commissioning procedure will reduce production downtime and material waste and minimise the impact on the company's, and its customer's business.

High-temperature metrology for industry

The EMRP project *High temperature metrology for industrial applications (>1000 °C)* developed and extended accurate temperature measurements at high temperatures to support a wide range of manufacturing processes. It addressed specific problems associated with both contact and non-contact thermometry techniques and calibration methods in hostile high-temperature environments with a focus on practical *in-situ* measurement techniques. By enabling effective control of temperature-dependent processes the research supports improved safety, product quality, reduced waste and reduced energy use.



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European Metrology
Research Programme
Delivering Impact

Improving nuclear reactor safety

Few instruments and sensors will survive inside a 2000 °C furnace. Yet such high temperatures must be measured accurately, if we are to keep improving the materials which are manufactured at or submitted to such temperatures - materials which are key to industries like aerospace and energy. New methods are needed to provide reliable measurement of the extremely high temperatures which underpin vital industrial processes.

Europe's National Measurement Institutes working together

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Challenge

Many industrial processes, such as steelmaking, glass and ceramics manufacture, and materials research are done in industrial furnaces operating at very high temperatures. Reaching the required temperature is important for producing the right material properties and reliable temperature measurement is key to demonstrating such temperatures have been attained.

Accurately measuring these high temperatures is challenging and is frequently carried out using non-contact thermometers performing measurements through protective windows. These thermometers suffer from measurement inaccuracies caused by the harsh environments produced by the industrial processes. Reliability is further reduced as the windows become covered with a contaminant film of vaporised material from the furnace, depressing the measured temperature by an unknown amount.

Overcoming these measurement problems requires new measurement approaches which can provide traceable, *in-situ* calibration of optical thermometers, without being compromised by the harsh, hot environments.

Solution

The EMRP project *High temperature metrology for industrial applications (>1000 °C)* (HiTeMS) developed and tested new calibration standards for the high temperatures within industrial furnaces.

Small high-temperature fixed-point blackbody cells were developed containing a combination of metal carbon eutectic alloys – cobalt-carbon, ruthenium-carbon and rhenium-carbon - which melt at precise temperatures. Such high temperature fixed points, with very reliable melting temperatures above 1100 °C, have only become available for industrial use through the work of the HiTeMS project. Rigorous laboratory testing was undertaken to ensure they would withstand hostile industrial environments, including very rapid temperature excursions likely to be encountered in industry.

These cells are placed directly in the industrial furnace. For *in-situ* calibration the control non-contact thermometer views the fixed point blackbody. The fixed point melts at a known temperature, against which the thermometers can be calibrated. This *in-situ* calibration against traceable temperature standards creates more accurate and reliable measurements, automatically compensating for the changing window transmission and so allowing industrial processes to be run at optimal temperatures.

Impact

The Alternative Energies and Atomic Energy Commission (CEA), a key player in nuclear power and safety research, is the first user of the temperature cells developed by the project.

The CEA is investigating the properties of materials formed at the very high temperatures in the event of a nuclear reactor accident. Reliable property data for these materials is essential for reliable nuclear power plant safety modelling. Such reliable data can only be obtained if precise material temperatures are known, this demands accurate temperature measurement. However, up to now it has not been possible to perform *in-situ* non-contact thermometer calibrations, leading to potentially significant errors in the furnace operating temperature. The CEA is now using the project's temperature cells to regularly recalibrate their non-contact temperature sensors.

The CEA has greatly increased precision of high temperature measurement using the in-situ standards developed by this project, reducing measurement uncertainties and in particular improving assurance of the furnace operating temperature. The CEA now has increased confidence that materials have been formed at the specified temperatures and reliable test results will improve models used for severe nuclear accident prevention and management. They are also promoting the use of the project's temperature cells to other members of the EURATOM FP7 Framework project SAFEST, which is researching the control of accidents in nuclear power plants.

Projects such as these should ensure that, in the extreme event of an accident in a nuclear power plant, damage is contained and the consequences minimised.

High-temperature metrology for industry

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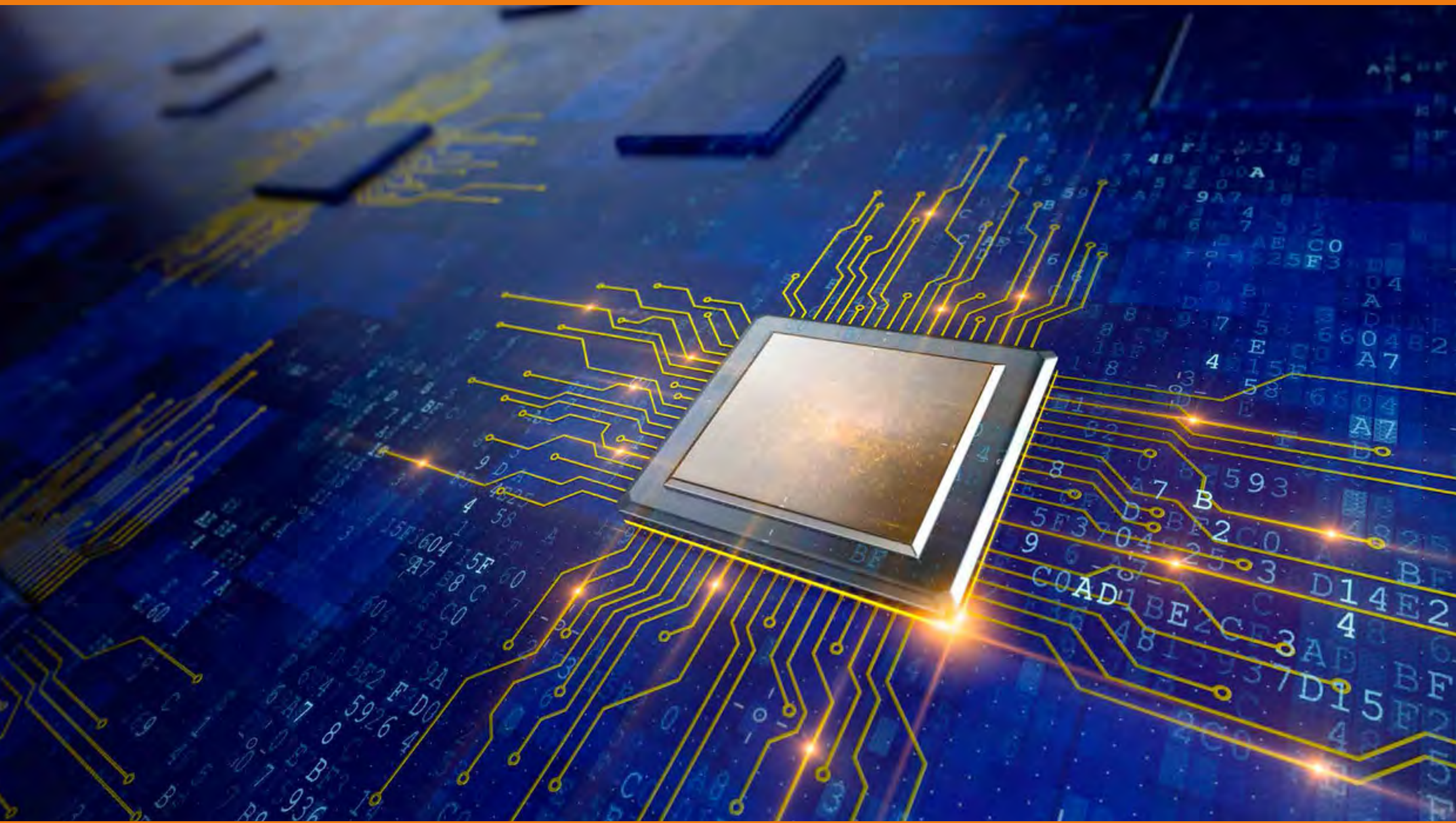

Investigating nano-defects

As electronics get ever smaller, detecting defects during quality control becomes more difficult. NSMM, a scanning microscopy technique, offers a new way to spot defects by measuring electromagnetic properties and has potential for investigating new materials for faster chips. For it to be viable for either of these, traceable calibration methods are needed so ultrafast electronics manufacturers' have confidence in its use.

Europe's National Measurement Institutes working together

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Challenge

Ultrafast electronics must be manufactured with high precision. Many of the features of complex nanoscale circuits are built up on wafers using EUV masks, which can develop cracks, leading to circuit defects. As electronics get smaller and operate at higher frequencies, there is a need for more accurate ways of checking for such defects.

A technique with potential for this application is Atomic Force Microscopy-based near-field scanning microscopy (NSMM). NSMM introduces an electric field into the material and, by measuring field disturbances, can determine the material's electromagnetic properties.

Microchips' electromagnetic properties relate to their geometries. NSMMs can verify whether chip properties are as designed, or identify the size of any defect on it by comparing the expected and measured disturbance. NSMM can also be used in research to characterise electrical properties of materials, such as those being investigated to replace silicon.

Uptake of this technique is limited by a lack of traceable calibration. At such small scales, manufacturers need to be sure that responses which indicate defects are not due to instrument performance effects. More reliable calibration methods are needed to give confidence in NSMM use in both research and quality control for the next generation of high speed electronics.

Solution

The EMRP Project *Electromagnetic characterisation of materials for industrial applications up to microwave frequencies* developed traceable reference materials and methods which enable calibration of NSMM instruments. The project also developed improved models and algorithms which offer much greater accuracy to NSMM instruments opening up a new method for materials characterisation in ultrafast electronics and communications applications.

The project reference materials consist of silicon chips with silicon nitride windows onto which precise nano meter scale gold features are added to generate known disturbances in the instrument's electrical field. Their size and location is known with great accuracy, so they produce an extremely well defined electrical response. For the first time it is possible to traceably calibrate the electromagnetic response of NSMM.

Impact

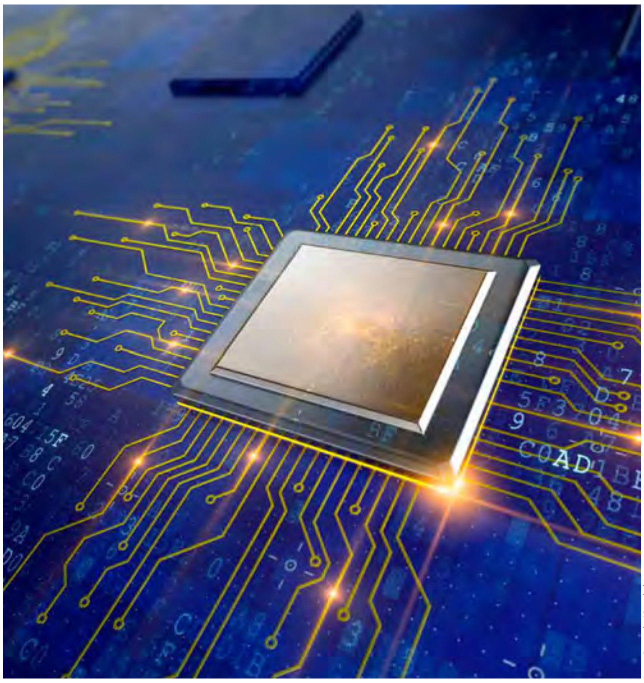
Project partner Keysight Technologies Inc, a major manufacturer of test and measurement equipment, assisted the project in the evaluation of prototype NSMM calibration standards using their state-of-the art research instruments. Through this interaction, Keysight gained a valuable insight into how customers use NSMM to make rigorous assessments of a materials electromagnetic properties - particularly important to the ultrafast electronics industries search for candidate materials to replace silicon.

Using the projects reference materials and methods, Keysight has been able to generate a traceable calibration route for its NSMM instruments. Upgrades to their analysis software are also being implemented to incorporate the project's models and algorithms providing improved accuracy to their instruments analytical results. These improvements, are helping Keysight to deliver higher NSMM accuracy giving improved confidence to their customers.

Increasing the traceability of NSMM as a measurement and characterisation tool, will enable the technique to play an important role in materials development and quality control in the electronics industry, as faster and smaller circuits are developed for the next generation of high speed communications and computers.

Metrology for advanced electronics materials

To develop faster electronics and effective microwave communication systems, developers need to understand the electromagnetic performance of materials at radio and microwave frequencies. The EMRP project *Electromagnetic characterisation of materials for industrial applications up to microwave frequencies* developed a range of tools for the accurate measurement of key electromagnetic properties, which provide valuable information on the capacitance, conductivity and permittivity of materials. These tools will support the electronics industry to improve the performance of existing materials and enable the uptake of new materials needed for ultrafast applications.



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European Metrology Research Programme
Delivering Impact

High-performance self-heating materials

PTC thermistors are an important component in many electronic products, such as lithium-ion batteries, due to their ability to limit current and regulate temperature. However, these functions rely on the incorporation of well-characterised self-heating materials in their design. Improvements to the metrology underpinning the characterisation of these materials will help the electronics industry manufacture existing products more efficiently and support the development of new products with improved performance.

Europe's National Measurement Institutes working together

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Challenge

Positive temperature coefficient of resistivity (PTCR) ceramics are a type of material which becomes highly resistive when heated beyond a threshold temperature. This behaviour makes PTCR ceramics ideal for use as thermistors in electronic devices and in the heating elements of consumer products such as car window demisters and space heaters.

More accurate measurements of the self-heating and current-limiting effects generated in PTCR ceramics are needed to enable the design of components for improved electronics and more effective process control during manufacturing. However, until recently, industry did not have access to the capabilities it needs to make traceable measurements of these properties.

Solution

The EMRP project *Electromagnetic characterisation of materials for industrial applications up to microwave frequencies* developed a traceable calibration system for PTCR ceramics, which provides fast, non-destructive characterization of samples, reducing design and production costs. Research carried out by the project has contributed greatly to the quantification and improvement of uncertainties involved in these measurements, supporting the efficient development of materials for the electronics industry.

Impact

The measurement test cells developed are now being used by the Jožef Stefan Institute (IJS) in Slovenia. IJS develops prototype PTCR ceramic materials for use in electronic devices and was looking to reduce its R&D costs through an automated, traceable and reliable measurement system for characterising samples of PTCR ceramics.

New measurement test cells were constructed, tested and validated within the project, and the complete system automated for use in IJS's materials development facility, enabling it to make measurements of samples directly after they have been produced. This system can now be used for quality control during manufacture or for gathering information on newly-developed materials for IJS's customers in the electronics industry.

One such customer, STELEM is a major European producer of thermistors for applications such as home appliances and vehicles. They are using the research facilities at IJS to provide traceable characterisation of their components assuring their performance.

This is just one early example of how the results of this EMRP project are supporting manufacturers to develop improved products for the electronics industry.

Metrology for advanced electronics materials

To develop faster electronics and effective microwave communication systems, developers need to understand the electromagnetic performance of materials at radio and microwave frequencies. The EMRP project *Electromagnetic characterisation of materials for industrial applications up to microwave frequencies* developed a range of tools for the accurate measurement of key electromagnetic properties, which provide valuable information on the capacitance, conductivity and permittivity of materials. These tools will support the electronics industry to improve the performance of existing materials and enable the uptake of new materials needed for ultrafast applications.

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European Metrology Research Programme
Delivering Impact

Pressure strengthened engines

High pressure can be used to strengthen materials by changing their structure. These stronger materials have many applications, with one of the most important being in diesel injection engines, where stronger components are needed for more fuel efficient designs. However, until recently, the automotive sector couldn't ensure the accuracy of the high pressure process delivering this strength.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

High-pressure technologies are increasingly being used to create more durable materials in industries such as petrochemical, pharmaceutical and automotive. This is of particular importance in the manufacture of diesel injection fuel systems: improving engine efficiencies to meet new EU vehicle emissions regulations, requires manufacturers to significantly increase the pressure used to inject fuel. In order for engines to withstand such increased pressures, the inner surfaces of components in diesel engines need to significantly increase in strength.

One solution is 'autofrettage', a technique which applies enormous pressure to a component, causing structural changes which give a strengthened finish. The pressures required for autofrettage and other high pressure manufacturing and testing techniques were beyond the upper limit of pressure calibration laboratories – around 1 gigapascal (GPa). Until recently, production engineers had no reliable, traceable method for confirming that engine components had been subjected to a sufficiently high pressure to produce the required strengthening. New calibration facilities capable of meeting demands for ever higher industrial process pressures were needed.

Solution

The EMRP project *High pressure metrology for industrial applications* developed a new high pressure facility capable of calibrating pressures of 1.6 GPa, suitable for techniques such as autofrettage.

Building equipment which could withstand such high pressures with durability was a challenge and the project took extensive materials measurements to understand how they responded to different pressures. This data was used to model the facility, which was then built. Rigorous testing validated its performance, which proved stable with low uncertainties.

The facility now provides calibration services for commercially available pressure sensors, enabling traceability transfer to the production line.

Impact

HBM, a global supplier of measurement instruments, has created the P3MB Blue Line Top Class transducer©, a calibrated, high pressure sensor which is giving confidence to their customers that pressures are being accurately applied in industrial processes. HBM has been able to calibrate this durable high pressure sensor as a direct result of the project. These 'Top Class' sensors can now be used as a transfer standard to calibrate HBM's own sensors and also as a tool to calibrate and verify customer instruments.

Another early adopter of the capability, Maximator GmbH, supplies autofrettage to the automotive industry. By calibrating its autofrettage systems at the new facility, Maximator is also able to provide the required confidence to its customers that its systems operate at the required pressures. This allows European manufacturers to confidently produce components for more fuel efficient diesel engine designs, and so ensure compliance with the latest EU emissions rules.

An immediate effect is to help carmakers develop engines with reduced exhaust emissions and greater fuel economy, which is essential for continuing competiveness of European vehicle manufacturers and for reducing the environmental impact of vehicle emissions.

Metrology for high-pressure manufacturing

The EMRP project *High pressure metrology for industrial applications* developed a capability to measure pressures up to 1.6 GPa, from which industrial users can calibrate their pressure measurement devices. The standards and calibration procedures developed will allow European industry to use high-pressure techniques, including autofrettage, hydroforming and isostatic pressing, to manufacture durable, high-performance products and to meet challenging sustainability requirements.

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www.euramet.org/project-IND03

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Delivering Impact

EURAMET

Confidence in recycled steel

Almost half the steel produced in Europe is recycled from scrap materials. These materials come from a variety of sources, some of which may be radioactively contaminated, such as waste from industry, medical facilities and decommissioned nuclear power plants. Given the potential hazards posed by radiation exposure, improved measurement methods and standards are needed to assess the radioactivity of recycled steel and comply with EU regulations designed to protect Europe's citizens.

Europe's National Measurement Institutes working together

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Challenge

Any recycled product has the potential to harbour various forms of contamination from its previous use, but this is particularly true of steel, which is retrieved from a huge variety of settings. Inadequate monitoring of radioactivity levels in recycled metals can have major consequences for public health – for example, in 1982, radioactive steel scavenged from a nuclear reactor was recycled and used in the construction of apartment buildings in Taiwan, resulting in the radiation exposure of an estimated 10,000 people.

Recognising these risks, the EU has implemented Council Regulation 333/2011, which requires scrap metal recycling companies to provide certificates based on the radioactive content for each consignment produced. To support this, the steel recycling industry needs traceable methods for reliably measuring radioactivity levels in steel.

However, until recently, there were no calibration standards for steel in the forms commonly encountered in steel recycling, making it difficult for recyclers to ensure the accuracy of their measurements. New calibration standards, designed to reflect the actual samples measured, would enable steel recyclers to reliably certificate their products in compliance with the Council Regulation, supporting the protection of the public and environmental safety.

Solution

The EMRP project *Ionising radiation metrology for the metallurgical industry* developed certified radioactive steel calibration standards, which enable highly-accurate measurements at the sensitivity levels required to comply with EU regulations. The new standards will lead to improved and more consistent certification of steel consignments and a reduction in the costs arising from disputes due to inconsistent measurements between different companies.

Impact

Two major steel recycling companies, Sidenor Aceros Especiales and Cyclife Sweden AB, formerly part of Studsvik Nuclear AB, have already adopted the calibration standards to assure the performance of their radioactivity monitoring systems.

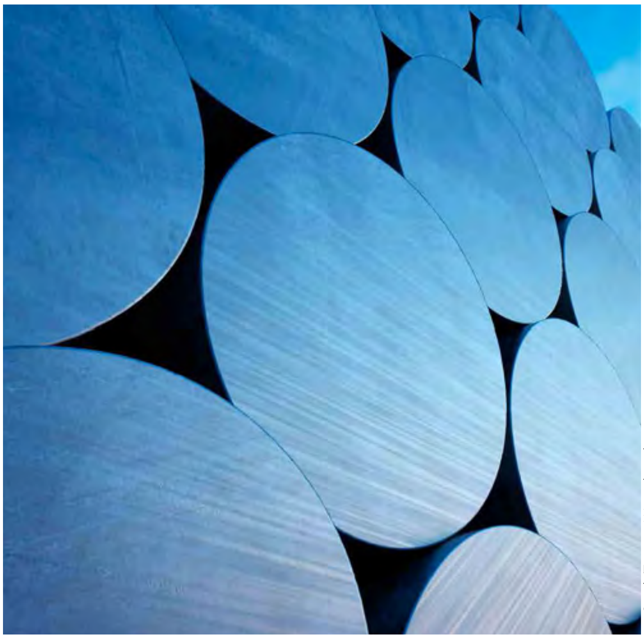
Sidenor Aceros Especiales, a leading steel recycler in Europe, is using the project's calibration standards for process monitoring at one of its plants in Spain. The standards are being used as part of weekly quality assurance checks of Sidenor's radioactivity monitoring systems, ensuring the measurements they provide are of the highest accuracy and giving customers confidence in the contamination-free certificates issued to Sidenor's products.

Cyclife is one of only a few steel producers able to recycle radioactive steel from the nuclear industry. Cyclife used the project's calibration standards to confirm the response of its radioactivity detectors, generating greater confidence in the measurements they routinely make of recycled steel. As Europe's nuclear industry decommissions plants over coming decades, there will be a larger volume of radioactive steel coming into recycling facilities which needs to be made safe. Accurate measurements of radioactivity levels will help avoid accidental plant contamination, which can cost up to €10 million to remedy.

As Europe's steel industry adopts these new standards more widely, end-users will have confidence in the contamination-free certification applied to recycled steel consignments and their safety for use.

Vacuum metrology for industry

The EMRP project *Ionising radiation metrology for the metallurgical industry* has successfully established the basis for common standards for radioactivity monitoring in steel mills and the certification of the radioactive content of scrap metals. This was achieved through the production of SI traceable reference standards and methods for radioactivity measurements. These outputs are expected to lead to significant cost savings, due to a reduction in down time and clean-up costs at industrial sites, and will reduce the risk of potentially hazardous radioactive materials leaking into the environment.



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Plastic deformation testing

Materials producers want to develop plastics with enhanced properties for new industrial applications. At the same time, they want to reduce environmental impact by recycling plastics into new products. Both goals make production more complex. To advance research into innovative and more environmentally friendly plastics, new methods are needed to better understand the dimensional and mechanical properties of plastics and how they change during their life.

Europe's National Measurement Institutes working together

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Challenge

Innovative plastics are increasingly incorporated into car manufacturing and building materials, making products lighter and more cost-efficient. However, plastics deform under stress and over time. This problem is made more complicated as manufacturers recycle old plastics into new products. Blending recycled and raw materials results in plastics with different physical properties, both across the material as a whole, and localised in small areas. Producers face the challenge of developing plastics that need to remain stable and fit for purpose for decades from less well understood feedstocks.

One suitable method for testing materials properties on a very small scale is a technique called nano-indentation testing. This is used to understand the mechanical response of a material by measuring how much pressure is required to form an indentation and how it deforms over time. This technique is established for testing many metals but requires significant improvements to make it suitable for the complexities involved in measuring plastics.

Solution

The EMRP project *Dynamic mechanical properties and long term deformation behaviour of viscous materials* investigated how plastics deform over time using a variety of nano-scale measurement techniques including nano-indentation creep testing. Extensive physical measurements of mechanical properties and deformation rates were made for different plastics and other viscous materials leading to the derivation of best measurement practice for the mechanical testing of plastics. A new analysis model that can link mechanical material properties and predict their behaviour was validated using project test results.

Information on the best practise in performing nano-indentation creep testing generated in the project has contributed to the development of a new standard on this type of testing: a new work item has been proposed and approved as a new part of the ISO standard 14577 'Metallic materials - Instrumented indentation test for hardness and material parameters' as currently there is no equivalent standard for plastics.

Impact

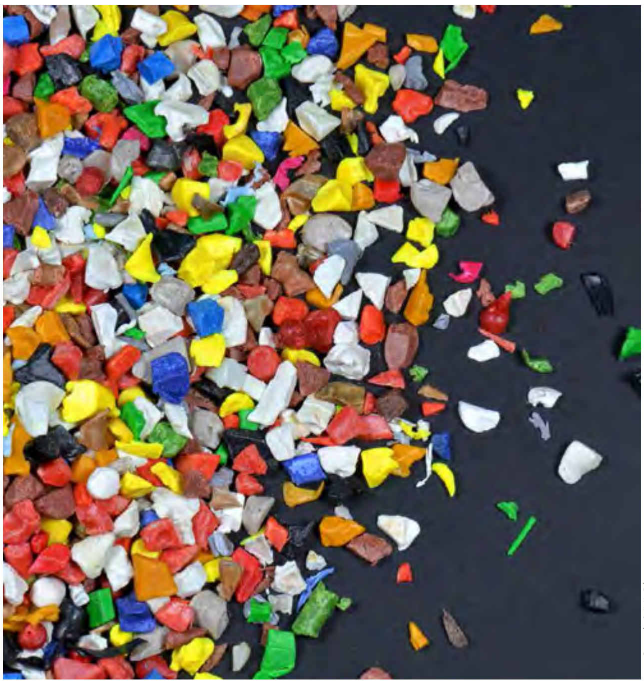
Anton Paar GmbH, a specialist in instrumentation for materials characterisation, made improvements to an instrument prototype specifically designed for nano-indentation testing of plastics as a result of interaction with the project. They redesigned its load control to achieve the low loads needed for plastics testing and integrated the new material property computer model into their software. This enables more reliable measurement analysis and corrections for the complex properties of plastics. These improvements have also been rolled out to their other nano-testing instruments.

Through the project, Anton Paar was able to demonstrate the thermal stability and versatile use if its instruments on a wide range of hard, soft, and multiphase materials. It can now provide customers - including global plastics developers such as Dupont and Dow - with traceable, validated measurements of plastics which give a reliable indication of their in-service life. It is estimated that over 15 million Euro in increased sales will result from the introduction of these new and upgraded Anton Paar instruments.

Standardised measurements and instruments specifically validated for plastics will enable manufacturers to have greater confidence in their performance under in-service conditions. This will promote innovation across a wide range of industries, leading to products with improved life times, lower production cost, and reduced environmental impact.

Dynamic mechanical properties and long term deformation behaviour of viscous materials

The EMRP project *Dynamic mechanical properties and long term deformation behaviour of viscous materials* provided validated indentation and contact methods to measure the shape, mechanical properties and deformation rate of viscous materials. New calibration routines and detailed analyses of measurement errors are helping instrument manufacturers to understand and improve the performance of their products, and new measurement and analysis protocols will improve the ability of the nano-indentation community to measure viscous materials.



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European Metrology Research Programme
Delivering Impact

Validating high-performance polymers

Polymers offer advantages from reduced weight to precise shape manufacture and are widely used in many applications. However, their effective use in specialist precision products has been hampered by a lack of reliable data detailing their mechanical properties and small-scale surface features. Improvements to the profilometers used to measure polymers, and the data they provide would support their uptake in high value applications.

Challenge

Polymers are widely used in high-performance applications such as electronic coatings and medical implants and are finding increasing use in precision instruments incorporating sophisticated plastic optics. Plastic optics readily provide more complex optical shapes than glass and need to be accurately manufactured and well characterised in shape and surface profile to ensure their performance.

Micro surface features and other small height change measurements (profilometry) are used to control manufacturing and quality assurance processes. These delicate measurements are usually made with a thin probe in contact with the surface of the material being measured. The weight of the probe requires careful control so that it doesn't damage the material or cause material build-up on the probe itself, both of which effect the measurements. This is particularly difficult to achieve for polymers that are relatively soft and can be easily distorted by the measurement process. Improvements to the profilometers used to measure polymers would support an increased understanding of their properties and allow more-effective exploitation in innovative products.

Solution

The EMRP project *Dynamic mechanical properties and long term deformation behaviour of viscous materials* developed algorithms for profilometer contact probes, which enable correction for the distortions created during surface measurements of soft materials such as polymers. The project team produced well-characterised step height change reference materials and used these to compare surface contour measurement methods. This has enabled the development of new calibration methods with well characterised uncertainties for profilometry measurements.

Impact

Mahr GmbH, a leading manufacturer of measurement equipment, used the step height reference materials to assess its profilometer's performance when measuring polymers. The knowledge gained through this assessment, along with the project's correction algorithms have helped Mahr to optimize the measuring force of its profilometers. This significantly reduces surface damage and measurement problems caused by material accumulating on the profilometer probe itself. Applications include measurements of plastic optics, as well as diamond-turned moulds for optical components.

The profilometer correction algorithms developed by the project have been incorporated in the DIN 32567 standard. This ensures wider access to these data correction techniques for instrument manufacturers and will ultimately lead to improved profilometry data for their customers.

Metrology for viscous materials

The EMRP project *Dynamic mechanical properties and long term deformation behaviour of viscous materials* provided validated indentation and contact methods to measure the shape, mechanical properties and deformation rate of viscous materials. New calibration routines and detailed analyses of measurement errors for the instruments used in the project will help instrument manufacturers to understand and improve the performance of their products, and new measurement and analysis protocols will improve the ability of the nano-indentation community to measure viscous materials.

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European Metrology Research Programme
Delivering Impact

Modelling material change

Manufacturers need to understand the surface properties of new materials and coatings before these can be incorporated into innovative products. However, a whole range of measurements are needed to fully characterise surfaces. This can be time consuming as often only a single parameter can be ascertained by an individual type of test. Therefore models relating different surface properties to each other are needed to deliver lifetime in-service performance predictions.

Europe's National Measurement Institutes working together

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Challenge

When manufacturers of plastic's or coatings develop new products, they need confidence in how they will perform in service when subjected to mechanical forces. For example, understanding how a material's surface performs in wear situations is important in determining a products durability. Wear is a complex process with many mechanisms involved, therefore, new products are often optimised using physical models or simulation which require data from testing.

How a material's surface responds to loads over time relies on inter-related mechanical properties and these can be measured on a micro-scale using nano-testing techniques. The interpretation of test results in order to generate mechanical property data is often difficult as you need to physically evaluate contact measurements in order to understand the mechanical properties of the surface. Many individual property tests are needed to model or simulate a surface's performance. This takes a significant length of time and slows the adoption of innovative new materials into products.

Speeding this process through accelerated testing techniques and inter-relating their results using software models would enable industrial researchers to predict how surfaces will perform under expected in-service conditions, based on measurements of just a few parameters. This could reduce the need for extensive long term materials testing, saving considerable time for companies wanting to implement innovative materials.

Solution

The EMRP Project *Dynamic mechanical properties and long term deformation behaviour of viscous materials* developed and validated models which could reduce the level of physical testing needed to establish a material surface's behaviour over its lifetime.

The deformation model developed by the project relates different material surface properties, including creep and dynamic parameters to each other. This enables surface property predictions to be made based on a smaller range of measurements. The project measured different plastic materials using a variety of trusted techniques, creating extensive, reliable data on creep and other properties, which was used to validate the model. This validation established the model as a recognised method of relating different surface mechanical properties to each other.

Impact

The Saxonian Institute, a surface mechanics consultancy, improved and validated its materials models within this project. These models have been incorporated into its commercially available software Film Doctor©, and are now helping users better understand the inter-relation of material surface mechanical properties and how these will impact new products. Saxonian Institute customers in automotive, engineering and consumer products are already benefiting from these extended models.

Anton Paar, a manufacturer of material characterisation instrumentation has incorporated the Saxonian Institute's approach into their nano-indentation instrument, improving their instrument's ability to provide detailed surface material property measurements to customers.

The model has also been licenced to the FP7 Project, iStress, which is investigating novel coatings for reducing wear in diesel engine fuel injectors. The Saxonian Institute has modified the model to enable it to be used as a design tool to predict coatings performance. The most promising coatings formulations can then be tested to confirm properties. This reduces early stage testing and quickly homes in on the most promising research areas.

These and other industrial research applications will benefit from the material property models through reduced testing time of materials and components, allowing manufacturers to bring improved products to market more quickly.

Metrology for mechanical properties and deformation rates of viscous materials

The EMRP project *Dynamic mechanical properties and long term deformation behaviour of viscous materials* provided validated indentation and contact methods to measure the shape, mechanical properties and deformation rate of viscous materials. New calibration routines and detailed analyses of measurement errors are helping instrument manufacturers to understand and improve the performance of their products, and new measurement and analysis protocols will improve the ability of the nano-indentation community to measure viscous materials.

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Advancing quantum communications

From banking to healthcare, data security is crucial to modern society. Quantum Key Distribution (QKD), which creates shared encryption keys using single photons, offers a level of security beyond that possible with classical communication techniques. To support the roll-out of this technology, new methods are required to precisely characterise the lasers and detectors used and ensure the performance of QKD systems.

Europe's National Measurement Institutes working together

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Challenge

The secure exchange of keys used to encrypt and decrypt information is a weak spot in many cryptography systems. Quantum Key Distribution (QKD) uses single photons to share encryption keys between two parties, who are connected via an optical (fibre or free-space) channel. By measuring the photons' properties, it's possible to detect whether anyone has intercepted the key, due to the changes induced in the intercepted quantum states. If no one has, data can be exchanged with guaranteed security.

Implementation of QKD requires its systems to be trusted by potential users. But QKD's guarantee of secure communications relies on measurements to demonstrate that the encryption systems have not been compromised. This makes successful market uptake of QKD technologies and products dependent on the solution of a number of measurement challenges.

Single photon generation, transmission and detection all need improved characterisation and measurement protocols to make quantum communication systems a reality. This requires the development of facilities and standards to measure single photons, applicable to operation under conventional telecom network operating conditions.

Solution

The EMRP project *Metrology for industrial quantum communication technologies* developed a series of measurements sensitive enough to characterise the properties of photons produced by pulsed laser diodes, as well as the detectors QKD systems use. The work has laid the foundations for a European measurement infrastructure capable of validating the performance of QKD systems, and other technologies that use and manipulate single photons. This capability will be essential to the development of next-generation communication systems.

Impact

Toshiba has used the results of the project to demonstrate a prototype communications system secured using QKD. The measurement capabilities developed as part of the project were used to characterise Toshiba's laser system, measuring the intensity and spectrum of each pulse of light. This gave Toshiba confidence in the commercially-available laser's use as a single-photon transmitter, a crucial element in the prototype system's performance.

After this performance validation, the laser was used as part of the first public demonstration of a QKD system using commercially-available components on a standard fibre optic network. The success of this demonstration, conducted at BT in the UK, provides confidence in this next-generationcommunications technology and is an important step towards the widespread implementation of QKD networks for secure data transmission.

Dr Tim Whitley, Managing Director of Research & Innovation at BT, said: "Quantum Key Distribution is an exciting new frontier in security technology. Through collaboration, we're helping to push the boundaries of what is currently possible and opening up new possibilities for this technology to be used more widely in the future."

Metrology for quantum communications

The EMRP project *Metrology for industrial quantum communication technologies* developed measurement techniques, standards and methods for the development of new quantum communication technologies, focussing on three areas: emitters, channels and receivers. Reliable characterisation of these technologies is crucial for security analysis, and is contributing to the standardisation of commercial QKD systems which is being led by the European Telecommunications Standards Institute (ETSI).

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European Metrology Research Programme
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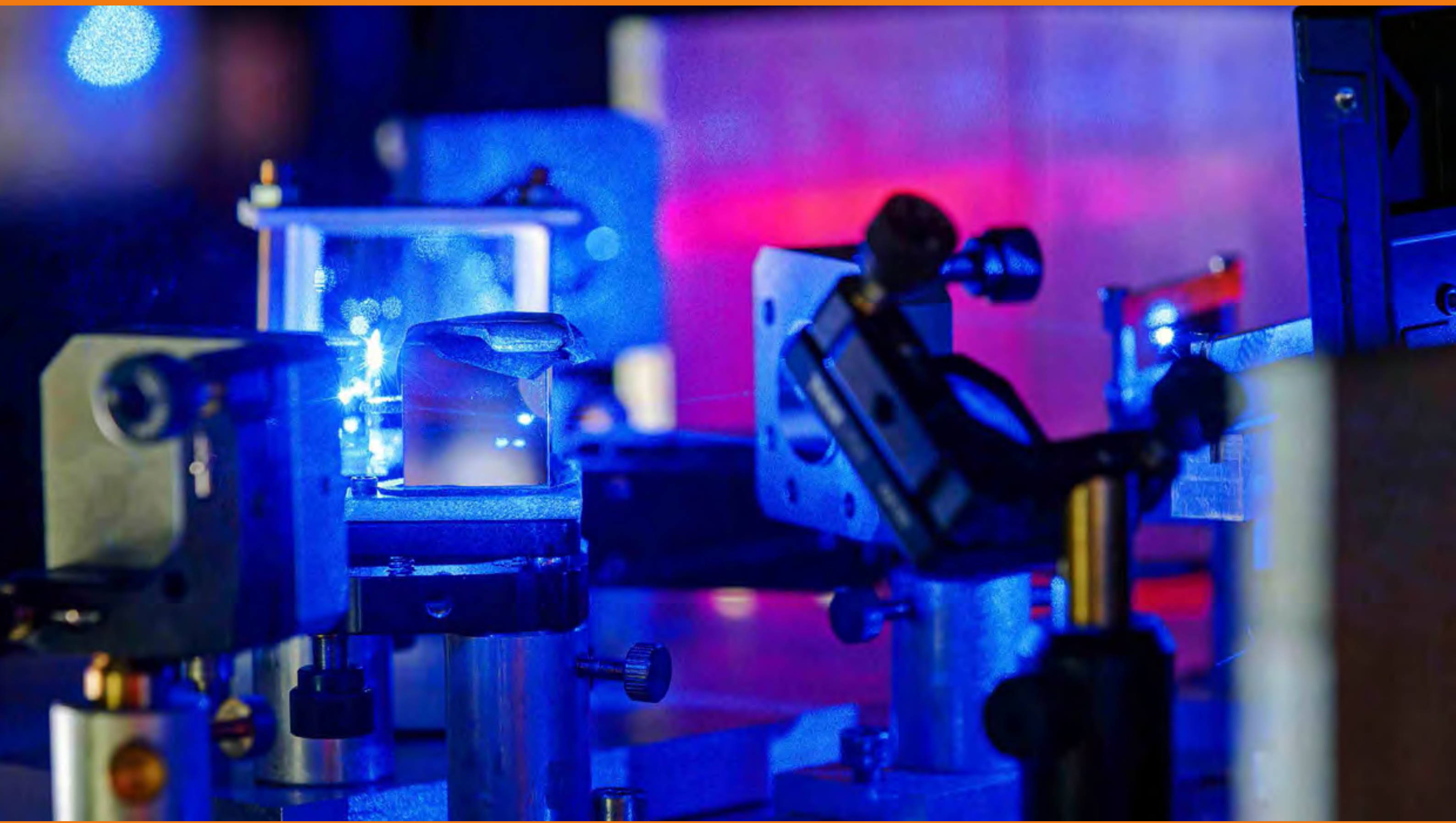

Building trust in quantum technologies

Single-photon detectors are the key component underpinning many new and emerging photonic technologies, including quantum communications, quantum computing and atmospheric sensing. To enable further developments in these fields and encourage more widespread adoption, measurements tools are needed which can validate the performance of single-photon detectors and provide confidence to end-users.

Europe's National Measurement Institutes working together

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Challenge

The ability to measure single photons of light is gaining importance in emerging research applications from space-earth communications with weak laser light sources, to event counting in biochemical microscopy important for tissue sample analysis, to silicon chip failure diagnostics using light emitted from transistors. All these potential applications hinge on being able to accurately distinguish and count specific individual light photons.

Characterisation of classical communications system components that transmit light through fibre optic cables is well-established. However being able to orientate the electric and magnetic properties of light photons for sending information and being able to detect single light flashes from a very specific source is very difficult. This requires precise characterisation of light sources and detectors to enable system assembly. Currently there are very few facilities that can attempt to do this.

Europe is a leading player in the development of photonics technologies but a lack of validation and standardisation of measurement practices is limiting confidence in using techniques that require accurate detection of single light photons. Precise component characterisation is needed to demonstrate performance and give confidence to users that new technologies incorporating these components will perform as intended.

Solution

The EMRP project *Metrology for industrial quantum communication technologies* developed the measurement tools needed to characterise the properties of commercial single-photon detectors, including their detection efficiency, and their ability to accurately register every countable event. This work has laid the foundations for a European measurement infrastructure capable of validating the performance of technologies that use and manipulate single photons, supporting the development of next-generation photonics technologies.

Impact

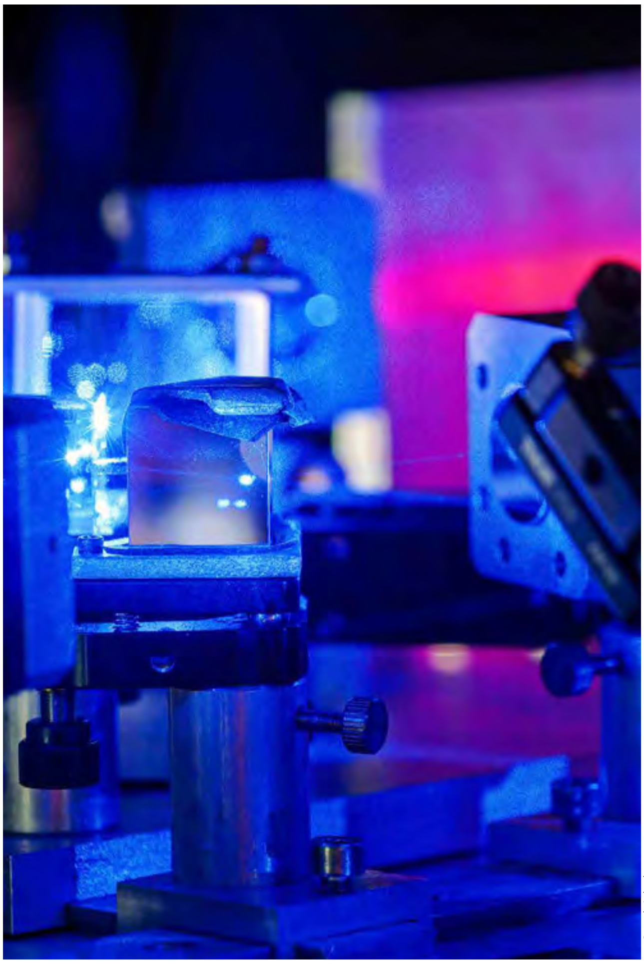
As a result of the project, new facilities are available for the characterisation of single-photon detectors used in photon counting. One of the first beneficiaries of this facility has been Micro Photon Devices (MPD), a research establishment of Microgate Srl, a leading producer of professional timing systems and real-time control-electronics for the large adaptive mirrors of the biggest telescopes on earth.

MPD produces single-photon counters specifically designed and optimized for applications requiring low-noise and low-power measurements, such as single molecule detection and fluorescence lifetime measurements or atmospheric sensing performed using lasers for time of flight pollution monitoring. Precise characterisation at the new facility allowed MPD to improve the accuracy of its product specifications, giving customers in highly technical sectors greater confidence in the performance of MPD's detectors.

Reliable specifications for the photonic components underpinning many emerging technologies will build end-user confidence and accelerate the introduction of next-generation technologies. Examples of these emerging technologies keen to implement single photon counting include optical quantum computing and life sciences where atomic photon emissions act as indicators of drug delivery to specific cells.

Metrology for quantum communications

The EMRP project *Metrology for industrial quantum communication technologies* developed measurement techniques, standards and methods for the development of new quantum communication technologies, focussing on three areas: emitters, channels and receivers. Reliable characterisation of these technologies is crucial for security analysis, and is contributing to the standardisation of commercial QKD systems which is being led by the European Telecommunications Standards Institute (ETSI).



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European Metrology Research Programme

Delivering Impact

High-performance thin film technologies

Lower costs and improved reliability in the manufacturing of thin films have enabled the development of a huge range of high-value technologies, from electronic displays to solar cells. However, many new thin-film technologies are highly sensitive to degradation from exposure to air and moisture, and improved measurement techniques are needed to support the cost-effective production of protective barrier layers and keep Europe at the forefront of this high-value sector.

Europe's National Measurement Institutes working together

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Challenge

Barrier layers, used to increase the lifetime of sensitive thin-film products, are currently manufactured in ultra-clean rooms to avoid introducing defects through which water can permeate. These facilities are expensive to maintain, contributing to around 40% of total production costs. To assess the suitability of alternative, more cost-effective production techniques, measurement facilities are needed which can reliably characterise the performance of barrier layers and determine whether they provide adequate protection for the products.

However, for advanced applications, barrier layers must be capable of protecting the encapsulated product from extremely small amounts of water vapour. For example, organic LEDs used in phones and televisions need barriers capable of preventing the ingress of even a few micrograms per square metre per day – roughly equivalent to one drop across an area the size of a football pitch over a month – if they are to achieve acceptable product lifetimes. Current measurement techniques cannot detect the transmission of such small amounts of water vapour through films.

Solution

The EMRP project *Metrology for the manufacturing of thin films* has developed a new facility which allows users to measure the water vapour transmission rate through barrier layers accurately and traceably at the low levels required by industry. The facility and associated measurement method was validated in an international comparison exercise, organised in collaboration with the Organic Electronics Association, and applied to commercial barrier layers to provide vital information about the effect of manufacturing conditions on barrier layer quality.

Impact

One of the first users to benefit from the new facility was Plasma Quest, a developer of thin film materials and deposition technology for customers in the electronics industry. Plasma Quest used the facility to test barrier layers made using different production techniques and successfully demonstrated a new technique which enables high-volume production of barrier layers whose performance is unhampered by any dust in the production environment.

The ability to create effective barrier layers without the expense of maintaining clean room conditions will significantly reduce manufacturing costs without any reduction in product performance. Plasma Quest has already received enquiries from several manufacturers of mobile phone screens looking to upscale the new technique.

Plasma Quest is just one of the early adopters of the new facility established by the project. The precise characterisation of barrier layer performance it enables will support the development of durable thin film devices, leading to significant cost savings for industry, reducing product prices and opening new markets.

Metrology for the manufacturing of thin films

The EMRP project *Metrology for the manufacturing of thin films* developed new methods and advanced reference materials to support quality control in thin film manufacturing. By supporting reduced costs and time-to-market of innovative products based on thin films, the results of the project will help to maintain European leadership in the multi-billion euro global market in thin film optoelectronics, including printed electronics and display screens.

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Advanced magnetic sensing

Magnetic sensors are used in a range of applications that require high-resolution data on an object's direction and position, for example, orbiting satellites and safety systems in the automotive industry. Rapid developments in these fields require advanced sensors with significantly improved specifications, including resolution, reliability, and signal-to-noise ratio. To verify sensor specifications, users need to be able to accurately test, characterise and calibrate them.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Magnetic sensors can be found in a broad range of applications in the communications, oil and gas exploration and aerospace industries. A major challenge in these sectors is the determination of exact position, for example, of engine components during the ignition cycle or satellites during space flights. Magnetic sensors detecting small changes in magnetic fields offer a potential measurement method. This relies on the precise calibration of sensors. However, the magnetic properties of sensor materials exhibit strong variation with temperature, and, until recently, data extrapolation was the only way to relate material properties to temperatures other than that at which the calibration was performed.

This poses a problem, as magnetic sensor applications such as space navigation commonly experience significant temperature variations. Spacecraft use fluxgate sensors (a type of magnetic sensor which senses the direction of the Earth's magnetic field) to carry out manoeuvres such as orientation correction. By measuring the Earth's magnetic field, a spacecraft can determine its position in space and, if necessary, correct it. However, temperatures in space change drastically, dependent on whether the spacecraft is shielded from or exposed to the sun, meaning that sensors often operate under conditions far different from those in which they were calibrated.

Improved procedures and facilities are needed which enable sensor calibration to be performed under conditions closer to those experienced in real-life use, to ensure reliable data is produced over a sensor's working temperature range.

Solution

The EMRP project *Metrology for advanced industrial magnetics* developed an improved calibration facility for advanced magnetic sensors. This facility enables a sensor's response to specific magnetic fields to be determined over an extended temperature range, from -80 °C to 200 °C. This enables sensor performance to be characterised over a temperature range closer to that experienced in the harsh conditions of space and other extreme environments, giving a more accurate indication of in-service performance. Crucially for devices designed for use in space the low magnetic fields at this facility enables compensation for the Earth's own magnetic field.

Impact

Bartington Instruments, a UK-based manufacturer of high-performance fluxgate sensors, was one of the first users of this new calibration facility. Bartington tested four fluxgate sensors in the new calibration facility, validating their sensor's response across an extended temperature range. Using these results, Bartington have upgraded their own measurement procedures and validated the performance of in-house test equipment. They are now also able to offer customers a UKAS accredited calibration service for magnetic sensors as a result of project interaction.

RAL Space, at the Rutherford Appleton Laboratory (RAL) in the UK, is using Bartington's validated sensors as part of navigational instrument preparations for future gravitational astronomy missions like LISA. These missions require spacecraft to be 'magnetically clean' ensuring it is possible to correct these sensors for the effects of small magnetic fields induced by spacecraft components.

This is just one early example of the impact created by the new magnetic field calibration facility, which will benefit not only the space industry, but all industries that require magnetic sensor calibration with improved accuracy over a more extended temperature range.

Metrology for magnetic sensors

The EMRP project *Metrology for advanced industrial magnetics* delivered measurement tools and methods to enable the development, testing and calibration of advanced magnetic sensors, and accelerate their application in present and emerging technologies. The new capabilities allow users to carry out traceable characterisation of advanced materials and traceable measurements of the magnetic properties of devices, to support the development of advanced sensors with improved specifications, such as reliability, operation temperature, device size, field range and calibration uncertainty.

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Under pressure: sensors for new engines

Accurately measuring pressure shocks generated by contained explosions is challenging. European automotive, aerospace and defence industries rely on measuring these types of dynamic pressure changes in developing new products. There is currently no traceable calibration method for dynamic pressure, and existing static sensor calibrations may not represent performance in dynamic pressure applications. Companies require reliable information on sensor performance in dynamically changing pressure extremes.

Challenge

Dynamic pressure changes involving a near instantaneous shock wave are generated in many applications. For example, during the fuel ignition sequence of an internal combustion engine a rapid increase in pressure occurs from atmospheric to several hundreds of atmospheres. Even more extreme conditions arise when airbags inflate during rapid decelerations or when guns are fired and momentary pressure excursions of tens of thousands of atmospheres are possible. The safe operation of all of these relies on testing during design and production.

Sensors calibrated using static or very slowly increasing pressures may not have the same response to such rapidly fluctuating and extreme short-lived pressure excursions. New pressure calibration facilities are needed that are capable of producing shock pressures with greater similarity to in-service conditions to address growing industrial demand for more relevant traceability.

Solution

The EMRP project Dynamic: *Traceable Dynamic Measurement of Mechanical Quantities* validated a facility to provide accurate dynamic calibrations for pressure sensors based on shock tubes. This system generates a near instantaneous shock wave by increasing pressure at one end of the tube, until a separating diaphragm ruptures. The sensor under test is mounted at the other end of the tube, and experiences this well-characterised sudden pressure change. The standardised, controlled pressure increases in the shock tube underpin this traceable measurement, allowing a characterised and accurate calibration of the sensor under test, and recreating conditions more reflective of those in-service.

Impact

Kistler Instrumente AG, a global market leader in dynamic measurement technology, develop measuring systems and sensors that push the physical limits. As a manufacturer of dynamic pressure sensors, Kistler was keen to be one of the first users of the new calibration facility. The validated sensor performance data the calibration system provided to Kistler is supporting them in the extreme challenges posed by the applications of their sensors.

Accurate dynamic pressure measurement is key in the design of more fuel efficient and less polluting engines which will operate at higher pressures and temperatures than current models. Kistler is proposing to use the facility to characterise new prototype sensors during the design process, reassuring them that they perform to specification. Their sensor technology aims to support engine research and development aimed at enhancing efficiency and power, improving comfort, and reducing emissions. A key component in achieving these goals will be the assessment and comparison of measured engine parameters such as cylinder pressure for combustion analysis.

The shock tube calibration system provides improved confidence in sensor performance during rapid dynamic pressure excursions allowing companies to demonstrate that sensors meet their stated specification. More realistic calibration conditions particularly benefit customers in the gas turbine and combustion engine industries, where improved engines as a result of dynamic pressure sensor testing contribute to competitiveness.

Traceable Dynamic Measurement of Mechanical Quantities

The EMRP project *Traceable Dynamic Measurement of Mechanical Quantities* developed validated calibration devices to provide traceable dynamic measurements of force, torque and pressure. Traceable dynamic measurements help the automotive, aerospace and defence industries to design and operate safety critical ballistic systems more reliably and ensure the efficiency of dynamic systems such as car engines. The methods and devices developed by the project enable calibration under dynamic conditions closer to those experienced during operation, and provide important estimations of accuracy and uncertainty.

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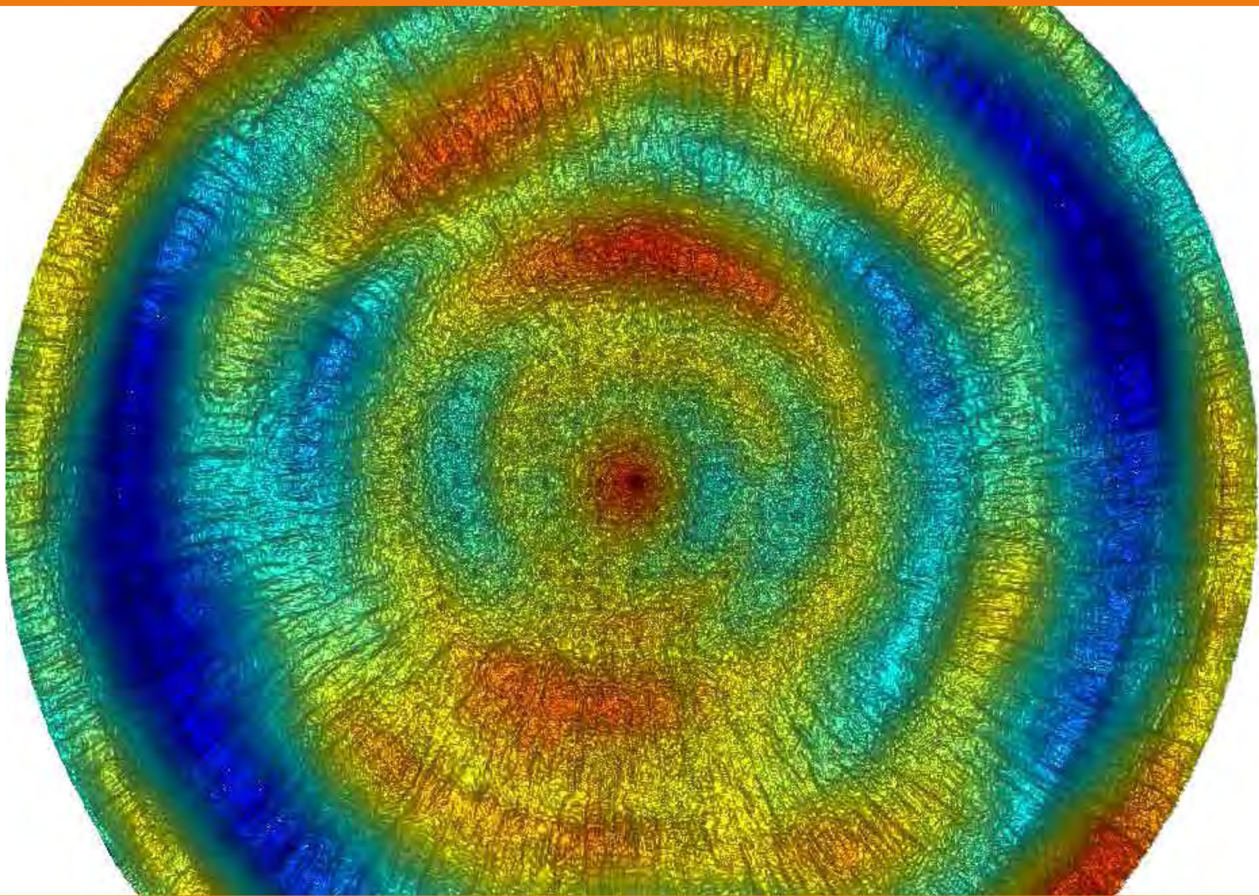

Supporting high-quality consumer optics

Photonics – the science of light – is one of the key enabling technologies for Europe and is used in applications as diverse as smartphones and astronomy. In 2012, the European photonics industry employed around 377,000 workers in a market worth over €65 bn. State-of-the-art measurement techniques which enable the development and manufacture of sophisticated optical components are needed to ensure Europe sustains its strong position in this rapidly growing market.

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Challenge

Many photonic technologies require optical components, such as lenses or mirrors, with more complex geometries than traditional spherical systems. High-quality consumer optics such as eyeglasses, cameras and DVD players all use free-form lenses. These lenses offer superior imaging quality over spherical lenses, and a single lens can be used where previously a much larger, multiple lens system would have been necessary. This allows manufacturers to produce smaller, lighter, higher-quality devices.

The shape of the surface of free-form lenses strongly determines their performance, and they must be accurately fabricated to meet demanding specifications. Advanced manufacturing techniques are capable of shaping optical surfaces with nanometre resolution, but accurate surface measurements are essential if components are to meet design specifications. The accuracy needed for this surface topography measurement still is highly challenging.

Thus, more accurate and efficient measurement techniques were needed to support the production of improved optical components and enable development of the innovative technologies which exploit them.

Solution

The EMRP project *Optical and tactile metrology for absolute form characterisation* significantly improved the absolute form measurement of components. One example of project delivery is improvements to the design of a free form optics interferometer, based on the Tilted-Wave Interferometry principle. The Tilted-Wave Interferometry approach illuminates a surface from several directions at once, enabling quick, high-precision measurements of small and strongly curved samples.

The project also developed new and improved measurement methods for determining the spatial resolution and sources of errors during measurement of both flat and curved surfaces. To efficiently handle the large data sets produced during form measurements new topography combination software was validated and a new procedure developed for the quantitative comparison of surface topography measurements made by instruments based on different techniques.

Impact

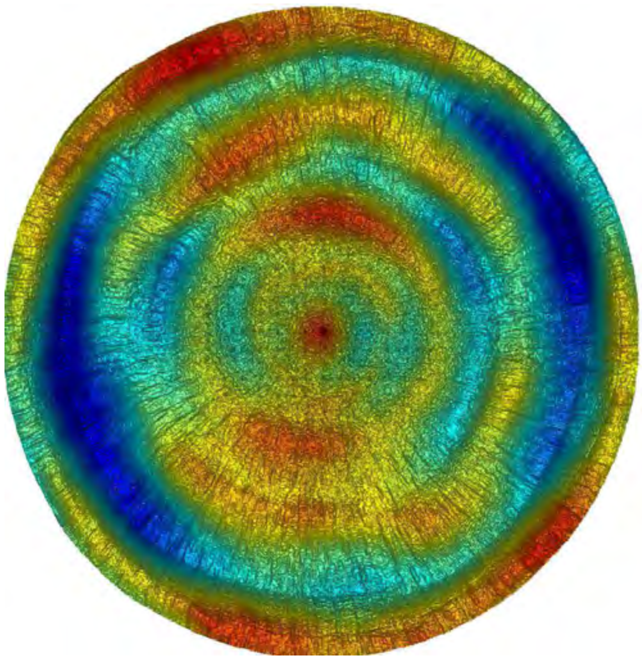
Mahr GmbH, a leading metrology instrument manufacturer has developed an improved prototype Tilted-Wave Interferometer (TWI) for precisely measuring aspheric and free-form lenses and mirrors. This innovative instrument can make measurements fast and with great accuracy.

Mahr has been able to confirm the accuracy of their prototype TWI and has improved the instruments environmental control system. A commercial instrument is now available, offering Mahr's customers a new faster, cheaper and more accurate way of characterising aspheric and free-form lenses. This gives Mahr a commercial edge in an increasingly demanding and rapidly-expanding market.

Manufacturers of a wide range of optical products from eyeglasses to DVD players purchasing this instrument will benefit from increased production efficiency and decreased design costs.

Metrology for optical surfaces

The EMRP project *Optical and tactile metrology for absolute form characterisation* significantly improved the absolute form measurement of optical components – ranging from flat surfaces to aspherical and free-form surfaces. Different physical probing principles were combined and compared to develop improved measurement techniques, tools and standards which support the accurate measurement of optical surfaces. These capabilities will lead to the design of better optical components and systems, which can be manufactured with less energy and waste, and help strengthen Europe's position in the global photonics market.



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Supporting the Belgian diamond industry

Antwerp has been a trading hub for the diamond industry for several centuries, and is regarded by many as the world's diamond capital. In 2013, 84% of the world's rough diamonds were traded in Antwerp, with a total value of $55 billion. The income and jobs generated make the sector of crucial importance to the Belgian economy; consequently, preserving Antwerp's world-class reputation in the characterisation of cut diamonds is vital.

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Challenge

With the growth of diamond trading hubs in India and China, an improved infrastructure is needed to support the classification of cut diamonds at the highest standards and preserve Antwerp's world-class reputation. This will give traders greater confidence in the diamonds they buy and sell in Antwerp, encouraging trade and strengthening Belgium's position in a competitive high-value market.

The dimensions and angles of the facets of a cut diamond affect the level of optical reflection which gives a diamond its brilliance. This ability to scatter light is a major contributing factor to a diamond's value, and cut diamonds are routinely evaluated by measuring facet profiles. To ensure the accuracy of these measurements, commercially-available diamond-measuring instruments must be regularly calibrated using reference diamonds of known dimensions and angles. The reference diamonds themselves are measured using highly-accurate micro co-ordinate measurement machines.

According to Hugo Piree, from the Division Metrology SMD-ENS of the Federal Public Service (ministry) Economy of the Belgian government, the Belgian diamond industry needs to be able to measure these reference diamonds to within an uncertainty of better than 300 nm (0.0003 mm) to guarantee the quality and value of its products. To achieve this level of accuracy, the uncertainty with which micro co-ordinate measurement machines can measure reference diamonds needs to be reduced.

Solution

Using methods that were developed in the EMRP project *Optical and tactile metrology for absolute form characterisation,* reference standard surfaces were measured using both an optical measurement machine from the Belgian Diamond Research Centre and a high accuracy tactile precise measurement machine at the Belgian Metrology - National Standards Institute, leading to a linking of methods and a reduction in their dimensional uncertainty to less than 150 nm. Improved measurement strategies were derived and will be used to form the basis of a new dimensional diamond characterisation method.

Impact

SMD-ENS and instrumentation company AC Optomechanix are developing a new scanning contactless measurement head for the Zeiss F25 micro co-ordinate measurement machine routinely used to measure the facets of cut diamonds. Using well characterised reference diamonds and the project's improved measurement strategies, they have been able to optimise their measurement head during the design stage. It is anticipated that this improved head will achieve uncertainties of less than 150 nm for routine measurements, exceeding the expectations of the Belgium diamond industry, and paving the way for more accurate distinctions between the various diamond grades. When the new measurement head is introduced into routine measurements diamond purchasers will be able to have greater confidence in certified diamonds based on greater metrological rigour. This in turn will reduce challenges to a diamond's grading and further enhance the reputation of the Antwerp diamond market.

Metrology for the photonics industry

The EMRP project *Optical and tactile metrology for absolute form characterisation significantly* improved the absolute form measurement of optical components – ranging from flat surfaces to aspherical and free-form surfaces. Different physical probing principles were combined and compared to develop improved measurement techniques, tools and standards which support the accurate measurement of optical surfaces. These capabilities will lead to the design of better optical components and systems, which can be manufactured with less energy and waste, and help strengthen Europe's position in the global photonics market.

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New standards for nano-testing

Nanomaterials have a range of desirable properties such as increased strength, high elasticity and electrical conductivity making them desirable for use in a large range of applications. These properties are being used to develop the next generation of products in the transport, energy and manufacturing industries. However, while the properties of nanomaterials are attractive, they are not always well understood, and manufacturers need standardised methods to assess their performance.

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Challenge

Friction and wear in industrial processes waste energy and degrade materials. Durable engineered surfaces that reduce friction and wear, based on nanoscale surface coatings, can be used to develop high-performance products and improve process efficiency in transport, energy generation, manufacturing and mineral extraction.

Low-friction thin-film nanomaterial coatings are increasingly applied to components to protect their surfaces and extend in-service life by reducing wear due to friction - for example, thin diamond-like coatings are applied to drill bits to prevent material loss at the nanoscale.

The design and manufacture of improved components with nanomaterial coatings require a good understanding of the coatings mechanical properties and how well they adhere to the underlying bulk material. The current practice of using tests designed for performance testing of high friction materials such as those used in vehicle clutch and brake mechanisms can lead to inaccurate results for low-friction coating applications.

A number of new test methods have been developed to test the low friction properties of diamond-like coatings, for example, a ball in contact with a spinning disc can be used to assess resistance to movement by a surface. Another test method that enables durability testing of material surfaces under near in-service conditions is nano-scratch testing. This technique uses a sharp stylus to create a scratch on the material's surface. The resistance to this movement and the depth of the scratch produced indicate surface wear properties important for in-service performance. Currently there is a lack of written standards outlining how to robustly and consistently conduct these tests, placing industrial reliance on inappropriate and time consuming techniques designed for materials with vastly different friction and wear properties.

Solution

The EMRP project *Metrology to assess the durability and function of engineered surfaces* investigated methods to accurately measure the applied load during testing - a key parameter in determining a materials friction coefficient. It also investigated how these measurements experience small changes over time due to instrument drift. Extensive testing of nano-material coatings using both ball on spinning disc and nano-scratch testing has increased the understanding of these measurement methods for low-friction and wear measurements on engineered surfaces. This has enabled the project to propose good measurement practices for conducting these types of friction and wear testing which will contribute to increased industrial test accuracy.

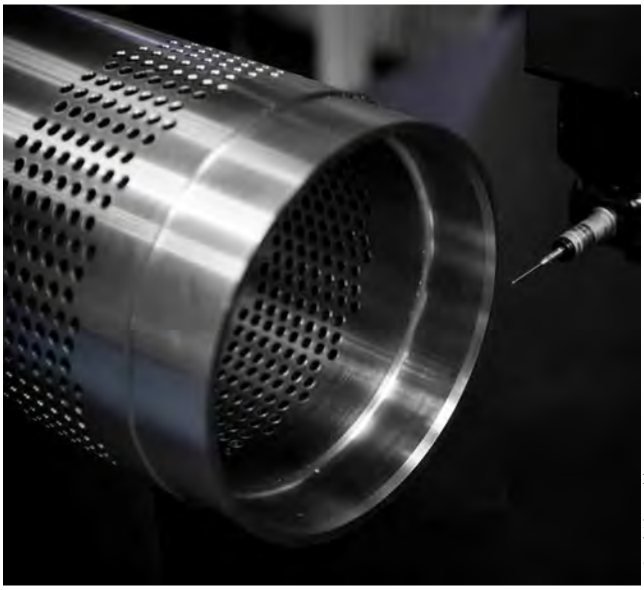
Impact

The project's good practice guidance on the ball-on-disc friction test method has contributed to a new international standard ISO 18535:2016: *Diamond-like carbon films - Determination of friction and wear characteristics of diamond-like carbon films by ball-on-disc method*. The guidance developed on nano-scratch testing will also be used in a new standard being developed by the CEN Technical Committee on Nanotechnologies.

Having these new documentary standards issued, specifically written for measurements of diamond like coatings and engineered surfaces will support European industry's wider efforts to improve the quality and harmonisation of measurements of nanomaterial properties. High-quality, comparable data will improve understanding of nanomaterial coatings and support the development of improved high-performance products, with longer lifetimes and greater efficiency. Transport, energy generation, manufacturing and mineral extraction are just some of the industrial users who will benefit from optimising the design of engineered surfaces as a result of standardised test methods.

Metrology for engineered surfaces

Companies relying on highly precise production tools and engineered surfaces need to understand how they wear. The EMRP project *Metrology to assess the durability and function of engineered surfaces* developed techniques for measuring nano-scale wear and localised heating, low-friction coating performance, and the mechanical degradation of tools. These techniques will enhance industrial competitiveness and reduce environmental impact by supporting the adoption of low-wear, low-friction surfaces in sectors including transport, energy generation, manufacturing and mineral extraction.



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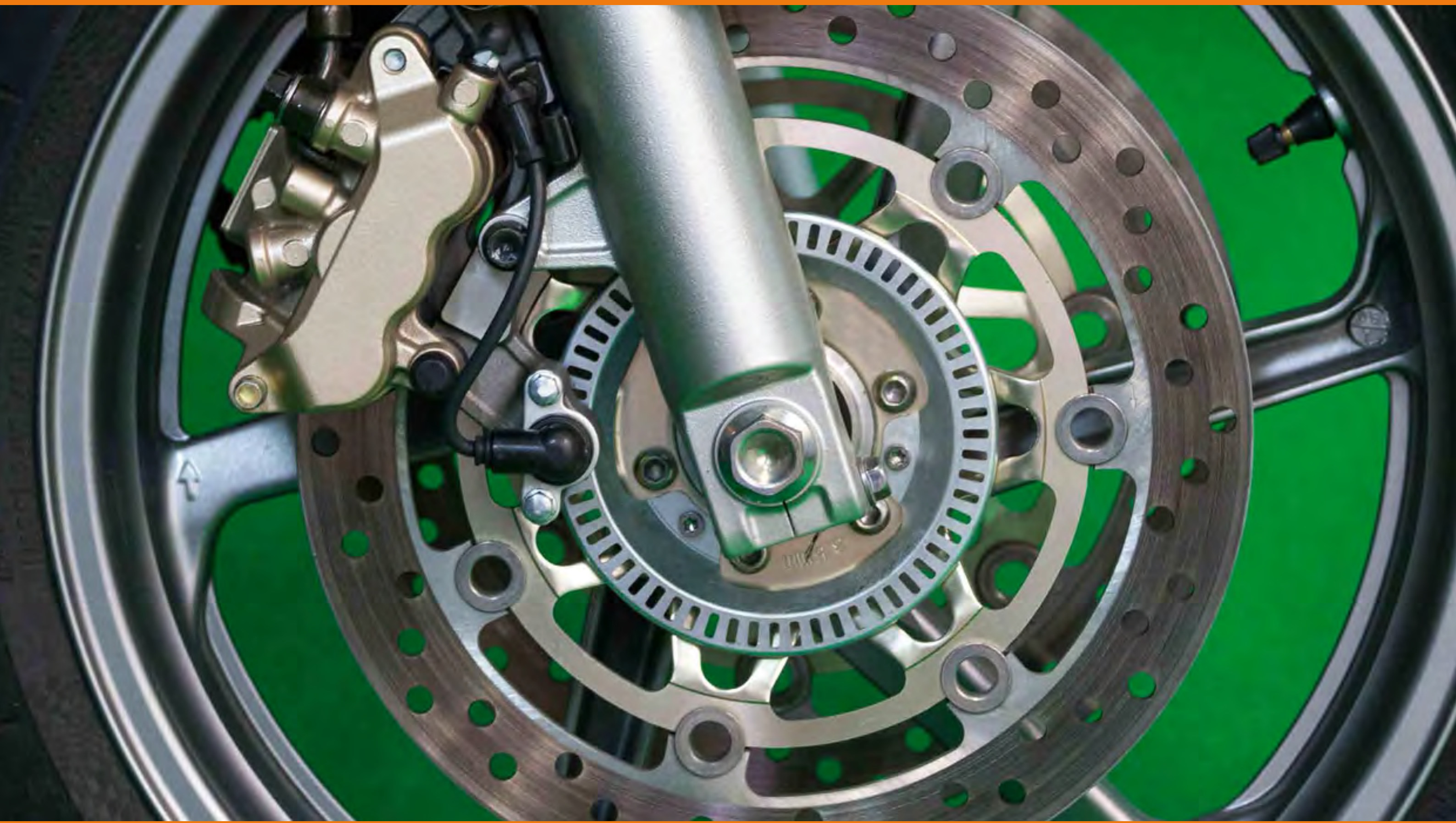

Temperature and friction testing

Understanding how engineered surfaces respond to friction is important in many applications where wear affects in-service performance. During friction measurements testing probes can create high temperatures at the point of contact with the material, affecting test accuracy. Developing ways to measure these temperatures will improve understanding of how friction affects surfaces in use, speeding the development of new products such as lighter weight vehicles and longer lasting mine drills.

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Challenge

Many engineering products, such as car clutch assemblies and machine tools, undergo high friction during their service life. New materials are constantly being investigated that will provide better performance and increased durability against friction or chemical degradation. Such products require rigorous testing to understand how they will perform in-service.

During the R&D process, these materials are subjected to frictions which simulate those they will undergo in-service. This process, known as tribology, involves a precision probe in contact with a moving surface.

One problem is that the probe creates high temperatures at the point of contact, affecting the reliability of measurements and even changing the material's mechanical properties. This temperature is not evenly distributed, so whilst the applied friction may raise the overall material temperature by 10 °C, points where friction is applied can raise by 400 °C. This is not captured by current measurements which look at the average temperature change of the bulk material.

It is important to know the exact temperature effects created by friction testing so corrections to friction measurements and calculations can be made. Therefore it is necessary to accurately measure the temperature at the specific point of contact as well as across the whole material.

Solution

The EMRP project *Metrology to assess the durability and function of engineered surfaces* developed a novel testing probe made of industrial ruby. When ruby is made to fluoresce using a laser, it creates a temperature sensitive response, which can be measured accurately to provide the exact temperature at the point of contact. This was verified by testing and comparison with other independent temperature measurement techniques as part of the project.

The ruby tip both supplies the test probe for generating friction, and a method of making surface temperature measurements. By incorporating both into a single probe, reliable temperature measurements can be taken at the point of contact allowing accurate corrections for temperature.

Impact

The ruby based temperature measurements developed by the project can now be incorporated into probe tips for measuring friction on engineered surfaces. This will provide *in-situ* temperature measurements, leading to greater accuracy in the study of the durability of new industrial components.

A patent application has been made by INRIM, Italy's national metrology institute, and two instrument manufacturers are keen to incorporate the ruby probe tip into their existing instruments.

It has been estimated that the UK economy alone loses £24 billion (1.6 per cent of the country's GDP) every year because of problems with friction, wear and lubrication in transport, manufacturing, energy and life sciences. The improved measurement capability will benefit a variety of industries through improved in-service life times of friction components reducing maintenance costs and in-service failure rates.

Metrology to assess the durability and function of engineered surfaces

Companies relying on highly precise production tools and engineered surfaces need to understand how they wear. The EMRP project *Metrology to assess the durability and function of engineered surfaces* developed techniques for measuring nano-scale wear and localised heating, low-friction coating performance, and the mechanical degradation of tools. These techniques will enhance industrial competitiveness and reduce environmental impact by supporting the adoption of low-wear, low-friction surfaces in sectors including transport, energy generation, manufacturing and mineral extraction.

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Nanoprecision positioning

The biomedical, semiconductor and robotics industries need precision positioning techniques to underpin the development and production of high-performance products. Positioning systems are driven by linear drives, which control the position and orientation of surgical or manufacturing tools or measurement devices with extreme precision. Improvements to the size, speed and accuracy of linear drives will support the development of new and improved techniques in many diverse applications.

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Challenge

Precise positioning of miniature components during the manufacture of hard disk drives and the movement of robots during delicate medical surgery all rely on the exact positioning provided by linear drives. Nano-positioning devices are used in the manufacture of hard disk drives where exact positioning of components is essential for operation. These linear positioning drives are required to be small, compact, and fast with extremely accurate positioning to fulfil these operations. Similar precision is also needed for some advanced microscopy sample positioning stages and nano-measurement probes for example those used to measure wear experienced by nano-coatings increasingly used in high performance engineered products.

Linear positioning drives are at the heart of these delicate positioning movements. Manufacturing these is complicated involving many components produced using complex processes working at design limits. Improvements both to component design and simplification of the manufacturing process is required to increase positioning precision and enable greater accuracy in the measurement of ever smaller features.

Solution

National measurement institutes often make measurements that require very specialised instruments working at the boundaries of what is possible. In this case, the EMRP project *Metrology to assess the durability and function of engineered surfaces* required an improved positioning system for precise re-positioning of a nano-measurement head over a test piece for repeat measurements of surface wear. Several prototypes of a positioning system based on optical interferometry were tested within the project, but meeting the exacting specification for the linear positioning drive using traditional manufacturing processes was difficult.

So TETRA GmbH Ilmenau, a developer of systems and components for sensors, robotics and automation, developed a novel optical sensor for the interferometers used in the project's nano-measurement instrument. To meet the exacting specifications, TETRA devised a new production method based on 3D printing and 5-axis machining technology. The resulting optical sensor is about the size of a sugar cube and capable of measuring metre-scale distances with nanometre precision, making it ideal for use in many applications where small measurement errors and speed are important such as robotics and precision laser cutting.

Impact

This new sensor will be incorporated into TETRA's high-end positioning systems, enabling a market-leading capability which has the potential to surpass the performance of other currently-available positioning systems. TETRA estimate that several million Euro's worth of business per annum could be generated from this novel new linear drive component when it is launched in 2017. The market for these positioning drives is expected to experience huge growth in coming years as other users in the semiconductor industry (global market worth $305 billion in 2013) and robotics industries (worth $32 billion in 2014) seek to benefit from improved positioning accuracy.

Increased positioning accuracy resulting from improvements to linear drives will enable a step-change in performance in many fields, such as the precise location of surgical tools used in eye-surgery, and the nano-positioning of micro-components becoming commonplace in manufacturing in the aerospace and automotive industries.

Metrology to assess the durability and function of engineered surfaces

Companies relying on highly precise production tools and engineered surfaces need to understand how they wear. The EMRP project *Metrology to assess the durability and function of engineered surfaces* developed techniques for measuring nano-scale wear and localised heating, low-friction coating performance, and the mechanical degradation of tools. These techniques will enhance industrial competitiveness and reduce environmental impact by supporting the adoption of low-wear, low-friction surfaces in sectors including transport, energy generation, manufacturing and mineral extraction.

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3D surface wear imaging

Precision manufacturing industries rely on highly precise cutting and milling tools - small chips or grooves in these can mean products fail to meet specification, leading to re-work costs and delays. Designing more durable tools requires an improved understanding of how surfaces wear in use. Accurate, non-contact measurement methods and 3D imaging will improve research into such surfaces, but these techniques require improved traceability to provide confidence in their use.

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Challenge

Milling and cutting tools, used in precision manufacturing, are subject to wear with use. Tools designed with specific profiles can develop worn surfaces or ridges. These micron-scale flaws affect performance, meaning tools do not produce products as intended. This leads to higher component rejection rates, higher costs and manufacturing delays.

Understanding how materials wear over time is important for developing wear resistant tools. Improved surface measurement methods and reliable 3D visualisations can help tool manufacturers study such surfaces and improve designs. However, current measurement methods have challenges. One technique involves rubbing the surface with radioactive materials and measuring the location of retained radioactivity, but this presents a hazard. Another uses a surface probe which scans across the surface, but this is time consuming and can cause further damage.

Very precise surface measurements can be taken using scanning electron microscopes (SEM), however these images are 2D. They can detect surface imperfections, but not the depth or height of the imperfection. Being able to combine multiple SEM measurements to form 3D visualisations with the SEM accuracy will help manufacturers better understand the profile of tool surfaces. This will help them research, develop and test more durable tools, limiting the impact of wear on advanced manufacturing processes.

Solution

The EMRP Project *Metrology to assess the durability and function of engineered surfaces*, developed a system for combining SEM images from different angles and an improved software model to give a 3D surface reconstruction and visualisation of surface wear features.

Extensive measurements were taken of samples before and after wear testing, giving data on surface changes introduced by wear. These were used to generate a range of simulated 2D SEM images of generalised features often found on surfaces which have undergone wear. These images were produced at a range of different angles, and were then used to further refine software for modelling 3D visualisations of wear surfaces. The testing has also helped improve the reliability of SEM surface reconstruction for small wear effects on engineered surfaces and coatings.

Impact

Alicona Imaging GmbH, a provider of optical 3D surface measurement solutions for lab based and production quality assurance, has improved confidence in a unique 3D measurement tool through its involvement with the project, delivering improved measurements to industries where surface roughness is important.

Alicona markets a standalone software package, MeX, which uses stereoscopic SEM images to produce 3D images of surface features, enabling roughness and volume analysis. Alicona was able to use the accurate images developed by the project to make comparisons and evaluate the performance of its MeX software. This has provided independent verification of MeX's accuracy and generated increased confidence in measurements of 3D features during component wear evaluations.

Alicona's customers include machine tool, steel and forensics companies. Access to this new software gives them more confidence in the measurement of surface features, aiding research into new products with improved surface properties.

Metrology to assess the durability and function of engineered surfaces

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Faster vacuums = faster production

Vacuum chambers are an important tool during the manufacture of many high-tech and high-value products, such as semiconductors, photovoltaics and LED lighting. Fast, accurate pressure measurements play an important role in process control as product quality and process efficiency depend on how quickly and how consistently a vacuum can be applied. Improved vacuum measurements will support Europe's precision manufacturing industries to develop more cost effective products and processes.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Semi-conductors are manufactured using precision instrumentation in a clean-room environment, as even a single speck of dust can lead to the failure of a high-value product. As components on semi-conductor processors get ever smaller and more sensitive to contamination, there is an increasing requirement to manufacture in a vacuum chamber – the ultimate clean-room.

The faster a high-quality vacuum can be established, the quicker manufacturing processes can begin, so faster cycling of air in and out of a vacuum chamber improves productivity. This not only requires accurate measurements of very low pressures at or near the vacuum, but also measurements of rapidly-changing pressures as air is pumped out. Until recently, vacuum measurement standards, used to calibrate industrial instrumentation, were only applicable in static pressure conditions, not the dynamic, rapidly-changing pressures used in high-value production processes.

Solution

The EMRP project *Vacuum metrology for production environments* developed a new vacuum gauge calibration facility capable of providing a well-defined rapid change in pressure, from 100 kPa down to 100 Pa in just 23 milliseconds. This exceeds even the most-demanding current industry requirements and is a huge technological advance. It is now possible, for the first time, to perform SI traceable dynamic pressure calibrations under conditions encountered by sensors in industrial applications.

Impact

INFICON, a Swiss manufacturer of world-class instruments for gas analysis, used the new facility to test the prototype of its innovative new gauge for measuring dynamic pressure. The facility enabled INFICON to demonstrate the gauge's high-speed reaction to rapidly-changing pressures. INFICON's new Stripe™ High-speed Capacitance Diaphragm Gauge has a response time twenty times faster than the previous model and the facility validated the manufacturer's claim that it is the 'fastest gauge in the world'.

Access to the new facility helped accelerate the development of the new gauge and contributed to three patent applications. It is estimated that several million Euro in increased sales will result from the introduction of this new vacuum gauge. The fast-response gauge enables rapid analysis of vacuum chambers and will enable INFICON's customers in the semi-conductor sector to improve productivity by evacuating vacuum chambers effectively and quickly. This will lead to reduced time between production runs while continuing to ensure product quality. INFICON expects to extend the market for these fast pressure gauges to its customers in industrial vacuum coating and solar panel and display manufacturing.

Vacuum metrology for industry

The EMRP project *Vacuum metrology for production environments* developed and extended the metrology capabilities for low pressures and vacuum. Dynamic vacuum pressures, partial pressure and outgassing rate measurements can now be made traceable for the first time. This addresses the need for more accurate measurements in industrial settings to assess, for example, the quality of vacuums used in high-tech manufacturing processes, the sources of contamination of vacuums and leak identification.

An image from a glass plasma coating process © EUROGLAS

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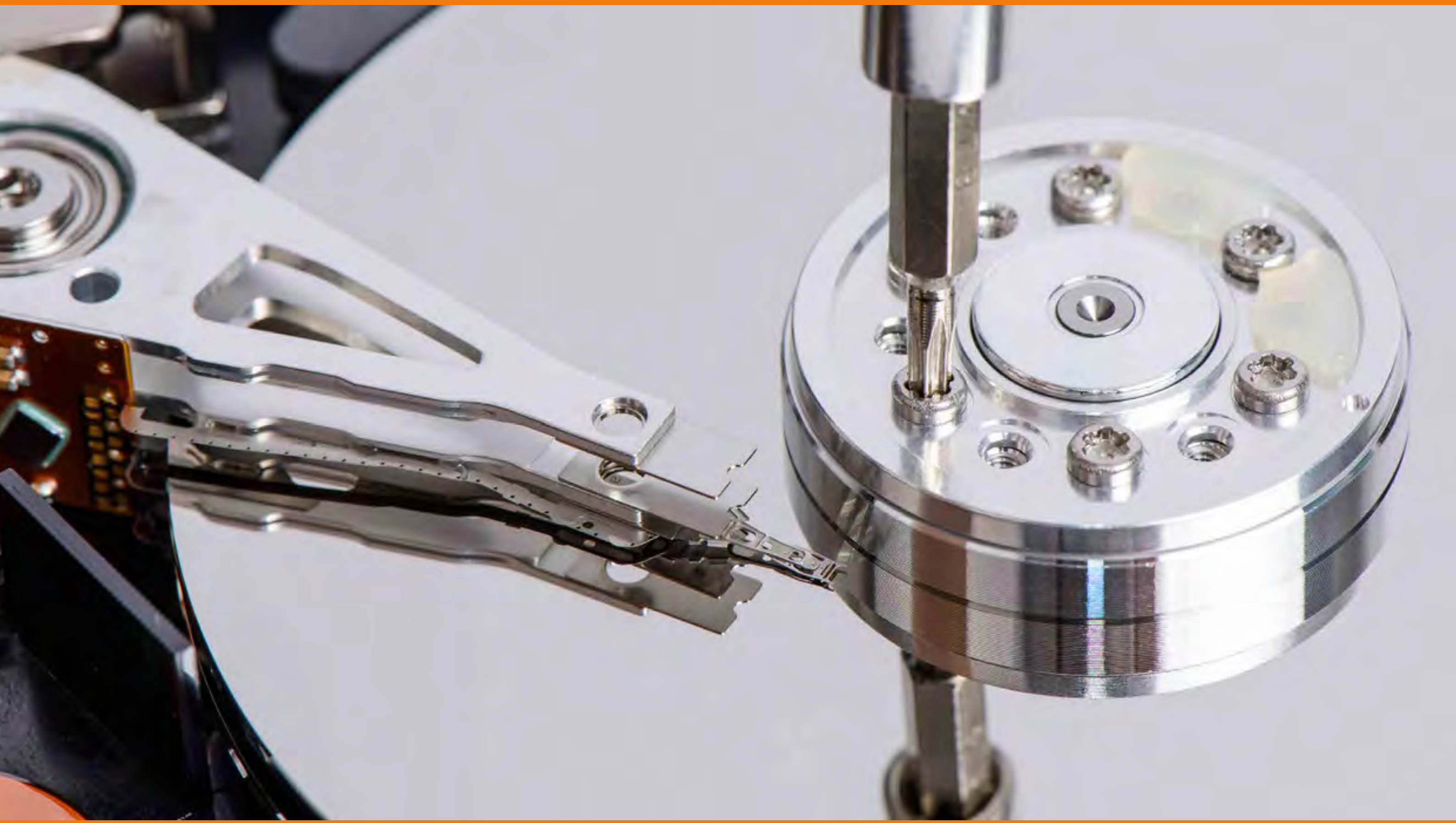

Ultra-sensitive temperature sensors

The world's leading manufacturing companies, from IT to aerospace, need ever smaller, more precise parts. A barrier to such innovation is that, at this level of precision, process control instrumentation can be affected by small variations in temperature effecting the specification of end-products. By measuring ambient temperatures with ultra-sensitive thermometers, manufacturers will be able to identify links between machine inaccuracies and temperature fluctuations, and develop compensation methods to offset them.

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Challenge

Cutting edge industries, such as semiconductors and nano-materials, rely on ultra-precision production techniques and sophisticated measurement instruments to meet design tolerances. As these industries develop ever smaller, more advanced products, ever greater precision and accuracy is needed.

One of the problems of working at such high precision, is that both the instruments and the products being produced can change with small variations in the surrounding temperature, leading to inaccuracies which affect the final product. Such instruments require regular re-calibration to compensate for temperature fluctuations, or must be maintained in costly temperature controlled labs.

High precision instruments are particularly effected by ambient temperature fluctuations. Accurate monitoring of small temperature variations found in most industrial environments is required to enable these instruments to continue to produce precision components.

Solution

The EMRP project *Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures* developed a prototype measurement system for ambient temperatures. This can be used to accurately assess how the performance of precision instruments change due to the small temperature fluctuations found in industrial environments.

The prototype utilises multiple, extremely sensitive contact thermometers, enabling accurate measurement of very small changes in ambient temperature. Manufacturers of precision instruments can use this to measure temperature variations at their facilities, and compare these to instrument responses. This can be used to understand the exact relationship between temperature and instrument performance, and so allow compensation methods to be developed to improve thermal stability.

Impact

MPro GmbH is exploiting the results to develop a commercial product. This expands MPro's own product line, and helps other measurement instrument manufacturers improve the temperature-stability of their instruments.

One such manufacturer is SIOS Messtechnik. The prototype allowed them to monitor temperature changes at their facility, a typical industrial environment, to understand their instruments' thermal stability. Using this data, they have improved an ultra-precise dimensional measurement instrument by eliminating small uncertainties related to temperature fluctuations. This will allow their customers to measure small components such as microelectronic, micromechanical or optical objects, to sub-nanometre precision, without the need for highly controlled environments.

In addition, Magnicon, who supplied a low noise amplifier to the project, have identified a completely new application for their technology through collaboration in the project. They are now developing the amplifier into a new instrument for measuring low voltages associated with temperature measurement.

More widely, the project is helping precision instrument manufacturers improve the reliability of precision instrumentation where temperatures change over time can effect performance. This will deliver increased accuracy to advanced manufacturing industries who are producing ever smaller and more advanced products for exciting new applications.

Metrology for precision engineering

The EMRP project *Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures* developed metrological tools and methods to support optimised thermal stability of ultra-precision engineering measurement and production tools over timescales of weeks to months. Methods were developed for assessing and modelling instrument dimensional stability on the nanometre scale, and also tools for stable temperature measurement with mK uncertainties.

The outputs of the project will support improved accuracy in precision engineering, which is crucial to the development of high-performance products in industries including electronics and aerospace.

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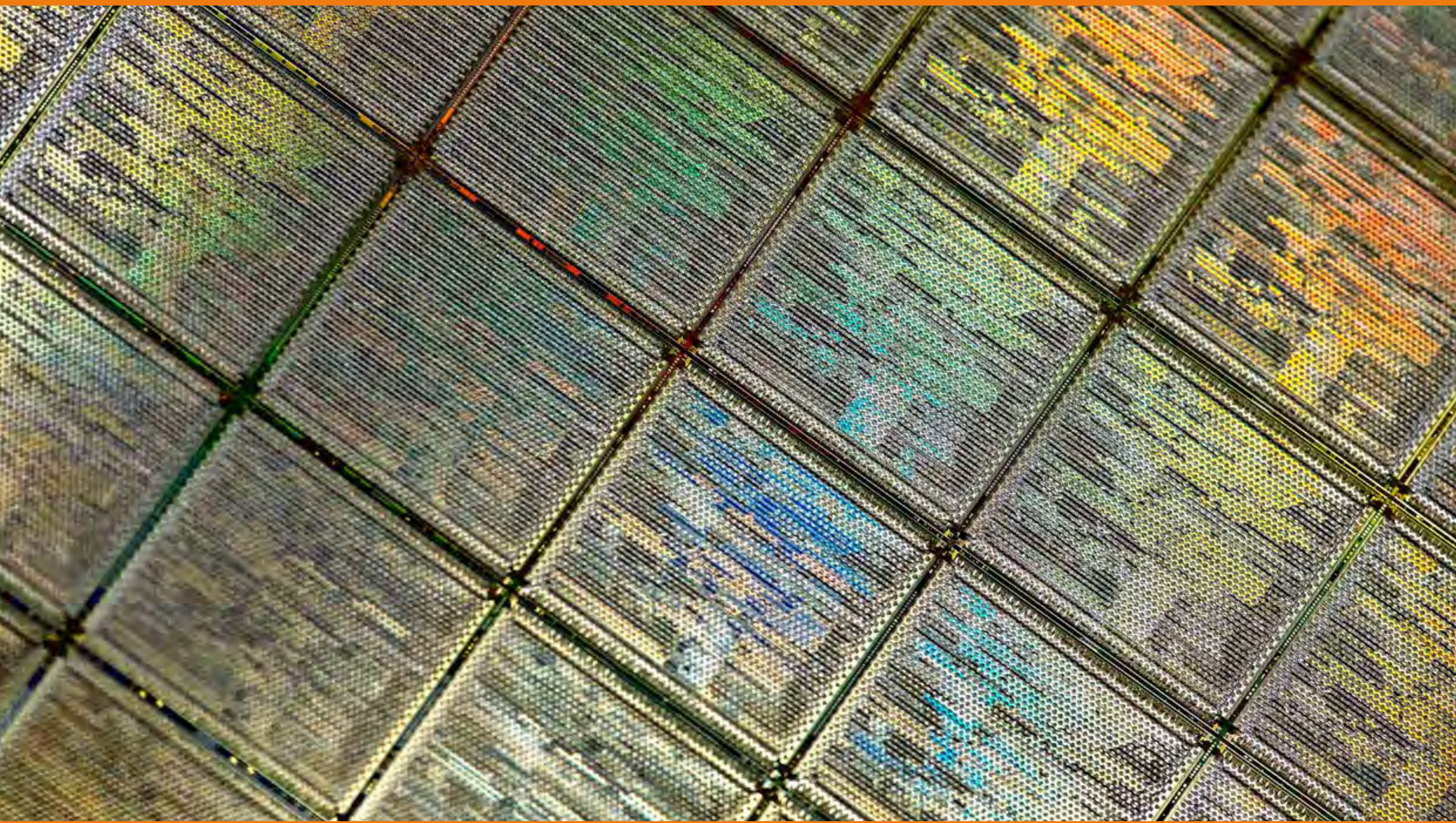

Non-destructive surface measurements

Materials and chemical producers require detailed knowledge of surface chemistry for research into new products. One way to understand a surface without damaging it is to bombard it with an electron beam, causing its atoms to emit characteristic X-rays enabling identification. The measurement of these must be precise as many elements emissions are close in energy – traceable reference materials will ensure instruments using this technique are stable and accurate.

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Challenge

Many companies are developing products that require a detailed understanding of surface chemistry, such as new catalytic exhaust systems to reduce car emissions, and new coatings to improve optical and functional properties of microelectronics.

Such innovations need very precise non-destructive measurement techniques to study materials or check for surface contamination. Catalyst development for example requires chemical analysis measurements throughout the process to understand how tweaking properties affects functionality.

A suitable technique is Electron Probe Micro Analysis (EPMA) by Energy Dispersive X-Ray Spectroscopy (EDS). EPMA bombards a surface with electrons, which causes surface atoms to emit X-rays. Every atom emits different characteristic X-ray lines, creating a unique fingerprint. EDS measures these X-ray lines and identifies which atoms are present, without causing any changes to the surface. These technologies are widely used – a study of the ISO technical committee "Microbeam analysis" estimated 40 million of samples are analysed annually using EDS and similar techniques.

Until now EDS techniques have lacked traceable reference materials and users have had to rely on in house verification. Universal reference materials certified to a high degree of accuracy and traceable to the SI will improve the cost effectiveness, accuracy and provide greater confidence in EDS use.

Solution

The EMRP Project *Traceable Quantitative Surface Chemical Analysis for Industrial Applications* has developed new certified reference materials (CRMs) for EDS with well-defined surface chemistries, composition, and structure. These enable EDS users to verify their measurements against universally agreed standards.

The CRM is a silicon wafer containing four pure elements, enabling EDS to be characterised for a broad range of different chemical species. Each element's spectra was rigorously measured using a range of different devices, providing very accurate data to define values for its unique elemental fingerprint. The project certified these values, creating a new universal reference material, which is traceable to the SI and can be used to accurately calibrate EDS instruments.

Impact

The reference material has now been taken up by EDS manufacturers, including project partner Bruker Nano Analytics, which has developed a new improved instrument as a result of the project.

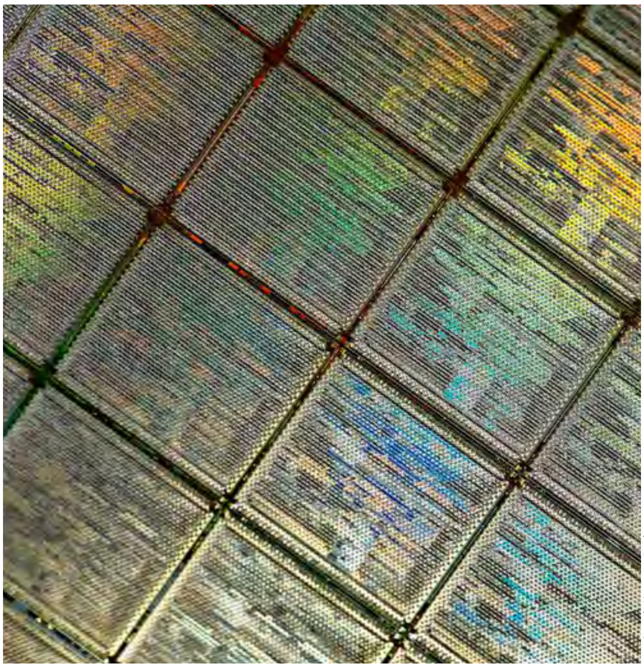
Bruker has now tested its instruments at much higher levels of accuracy than were previously possible and identified opportunities for improvement. This has enabled Bruker to develop a new more accurate XFlash© 6 silicon drift detector series.

The improved accuracy of new and existing instruments gives greater confidence in performance, and is proving a valuable selling point helping Bruker stay competitive and preserve its market share. The new instrument will help Bruker's customers in the semiconductor, automotive, steel and mining industries to improve R&D and quality assurance for new cutting edge products and chemicals.

Traceable quantitative surface chemical analysis for industrial applications

Surface chemical measurements have provided a foundation for the development of products in many sectors including chemicals, fuels, semiconductor devices and biomedical devices. However, an improved metrological infrastructure is needed for continued product development and quality control by European manufacturers.

The EMRP project *Traceable Quantitative Surface Chemical Analysis for Industrial Applications* has addressed this by developing new certified reference materials and methods to improve analytical instrumentation traceability. As a result of the project, instrument manufacturers and researchers can have greater confidence in the comparability of surface chemical analysis results. This will speed the introduction of complex measurement techniques such as EPMA EDS, the use of Argon cluster sputtering for the analysis of layered organic films and the use of TofSIMS to perform multiple species analyses in a single biological sample measurement.



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Measuring organic layers

Many innovative products - from touchscreens to solar panels to pharmaceuticals – utilise multiple organic layers to create complex functionality. New techniques have been developed to remove and measure layers individually enabling improved product development and assisting with quality assurance. However, manufacturers cannot be certain of the depth of layer being removed and new reference materials for these techniques are needed to increase uptake, and remove a major barrier to innovation.

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Challenge

Many next generation technologies have multiple layers of organic materials with complex surface chemistries. For example, in mobile phones these layers provide visual displays, touch response and protection. Organic solar cells require multiple layers to turn light into electricity. Drug delivery systems are designed to break down in very specific ways to deliver the correct dose over the prescribed time.

Innovation in such technologies requires an understanding of how surfaces, interfaces and thin layers behave at the molecular level, and how this effects performance in the final product.

Measuring these multiple organic layers requires surface layers to be individually removed without damage to the freshly exposed surface. Instruments that can do this accurately will speed innovation through enabling a better understanding of how molecules are distributed, thereby providing confidence in the performance and reliability of new products. However it is currently hard to be certain of the depth being removed, making it difficult for manufacturers to be confident in which layer they are measuring.

In order for these techniques to deliver their potential, and support innovation in organic thin film chemistry, it is necessary to develop methods which provide users with certainty about the depth of material being removed.

Solution

The EMRP project *Traceable quantitative surface chemical analysis for industrial applications* developed two certified organic reference materials for depth analysis of layered organic materials. The reference materials consist of stacked layers of different organic molecules with different mixtures and accurate layer thicknesses. These were validated using X-ray Reflectometry, an existing traceable measurement technique.

The organic reference materials now enable calibration of a range of depth profiling technologies for organic materials. This holds huge potential for manufacturers in many industries, who require reliable ways to measure surface chemistry of organic layers, improving both quality assurance and R&D.

Impact

The new reference standards have generated widespread interest from surface analysis instrumentation suppliers. Kratos Analytical Ltd, makers of state-of-the-art spectrometers for surface and biochemical analysis, is one of several early users of these reference materials. Kratos has improved their X-ray photoelectron spectroscopy (XPS) technology, which incorporates a technique for removing layers one at a time using a stream of argon cluster ions, each cluster containing hundreds or thousands of argon atoms and measuring the freshly exposed surface by electron spectroscopy.

Kratos was keen to introduce reference materials to demonstrate the viability of XPS for analysing individual organic layers. The standards developed by this project mean they can better characterise their instrument performance, and provide confidence to customers. This will facilitate XPS acceptance in a number of industries, and increase the potential market for Kratos's instruments.

The improved ability to use techniques such as XPS to determine the chemical composition of organic layers using depth profiling is making a significant contribution to research and product improvement in this area. This brings important benefits to manufacturers of complex layered organic materials such as display screens and solar panels, including Kratos's customers.

Traceable quantitative surface chemical analysis for industrial applications

Surface chemical measurements have provided a foundation for the development of products in many sectors including chemicals, fuels, semiconductor devices and biomedical devices. However, an improved metrological infrastructure is now needed for continued product development and quality control by European manufacturers.

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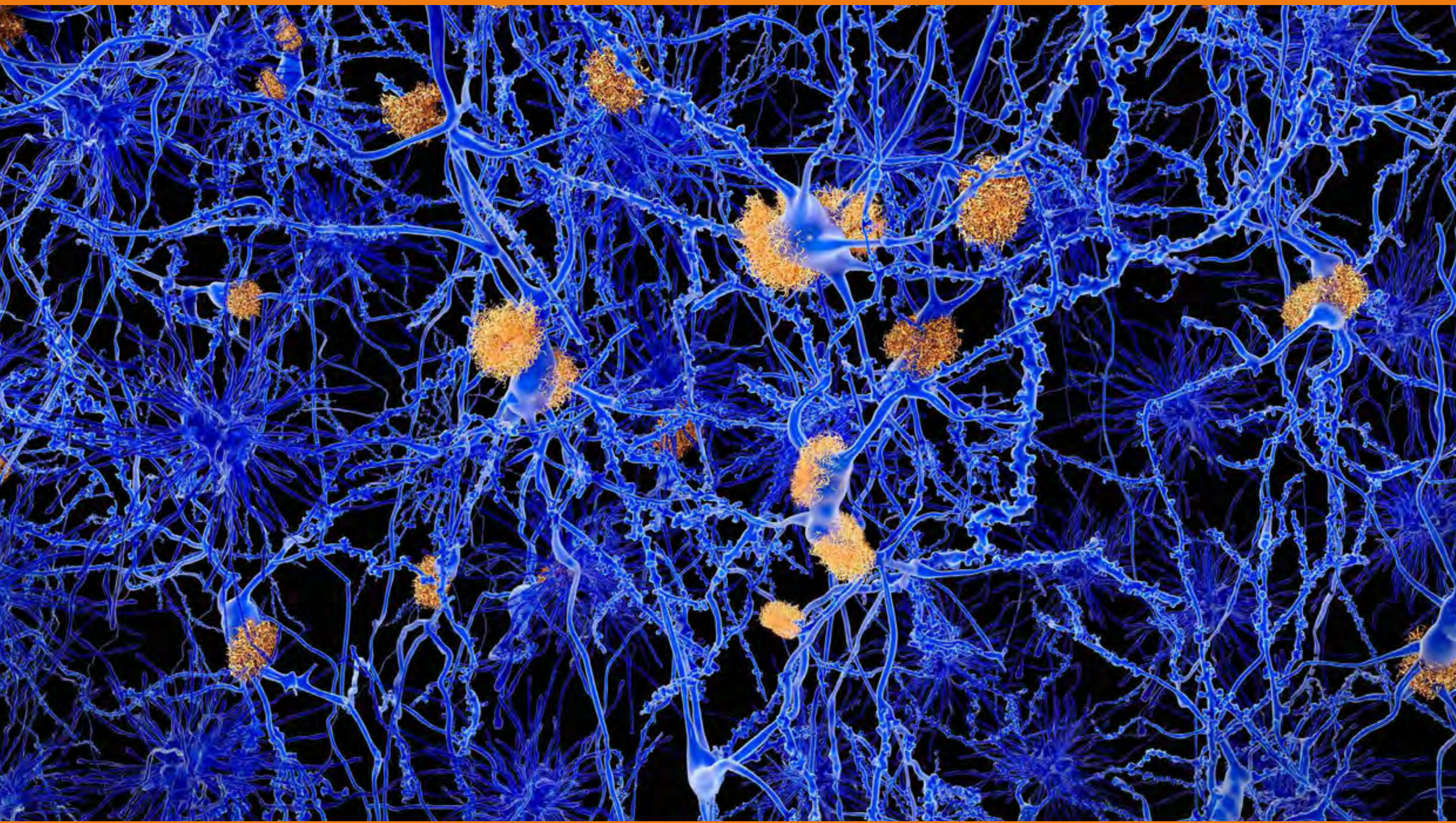

Surface analysis for Alzheimer's

Modifying or controlling surface chemistry is important in new product development, quality control and research. This is particularly true where functionality of surfaces, thin films and interfaces are key to the application, such as organic solar cells and devices for medical diagnostics.
Surface chemical analysis aims to provide quantitative elemental, chemical state and functional group information from the surface of materials, but requires comparable test data and improved measurement traceability.

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Challenge

There are many different methods to analyse surfaces and interfaces, each with advantages and disadvantages. Imaging plays a key role in medical research and drug discovery, identifying the spatial distribution of particles, locating drug targets, and assessing drug distribution. This type of analysis depends on reliable comparison between different techniques, and developments here can result in more data, gathered more quickly, and in some cases analysis that was not previously possible.

One of these surface analytical techniques, time-of-flight secondary ion mass spectrometry (ToF-SIMS), has advantages including high sensitivity and the ability to achieve high spatial resolution. However, ToF-SIMS generally cannot be used to produce quantitative analyses and traceability is not well-established. This hinders its wider use in understanding the causes of diseases and drug uptake within the body. Being able to traceably apply ToF-SIMS to biological samples would improve confidence in results and support a broad range of research, including into Alzheimer's disease.

Solution

The EMRP project *Traceable quantitative surface chemical analysis for industrial applications* worked on the identification of low concentrations of surface peptides or proteins using liposomes. This involved the introduction of a new diagnostic tissue labelling method for ToF-SIMS, which was traceably linked to an established fluorescent analysis technique.

ToF-SIMS can quantitatively identify different proteins and peptides in a single analysis by using biological labels. Liposomes have enabled ToF-SIMS to be used to simultaneously measure multiple surface sites in a single analysis, introducing the possibility of screening for many different functional entities - proteins, peptides, and DNA in each measurement. Mapping the position of specific peptides simultaneously with other molecules that cannot be located using conventional protein marker imaging, provides information about lipid-protein interactions which are key in understanding the mechanisms of neurodegeneration associated with Alzheimer's disease.

The benefits of ToF-SIMS, including its superior spatial resolution and the use of samples that are freeze-dried without the need for complex and time consuming preparation, can now be deployed traceably and with confidence for quantitative analysis to identify the location of specific entities on a sample's surface.

Impact

SP Technical Research Institute of Sweden was one of the first to use this technique in determining the amount and location of specific liposome sites on tissue sample surfaces. This is part of their investigations into the formation of Alzheimer's plaques and tangles. Plaques occur in brain regions where nerve degeneration has occurred due to the disease, and mapping these regions promotes understanding of the mechanisms involved. Studying these characteristic features of Alzheimer's with greater confidence, and particularly focussing on the spatial localisation of specific peptide deposits will aid research into causes of this disease.

Analysing a single sample to simultaneously look for multiple features means more samples can be studied in greater detail. Samples can now generate more data faster than previously possible, speeding up tissue sample analysis, and reducing costs. Medical researchers can now have greater confidence in using comparable ToF-SIMS data to support their research, contributing to understanding the causes of diseases and drug uptake within the body.

Traceable quantitative surface chemical analysis for industrial applications

Surface chemical measurements have provided a foundation for the development of products in many sectors including chemicals, fuels, semiconductor devices and biomedical devices. However, an improved metrological infrastructure is now needed for continued product development and quality control by European manufacturers.

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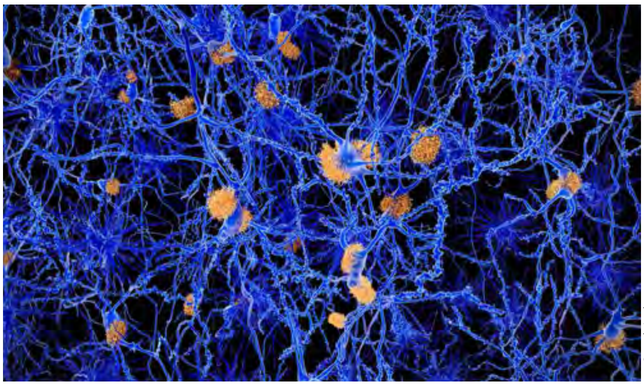

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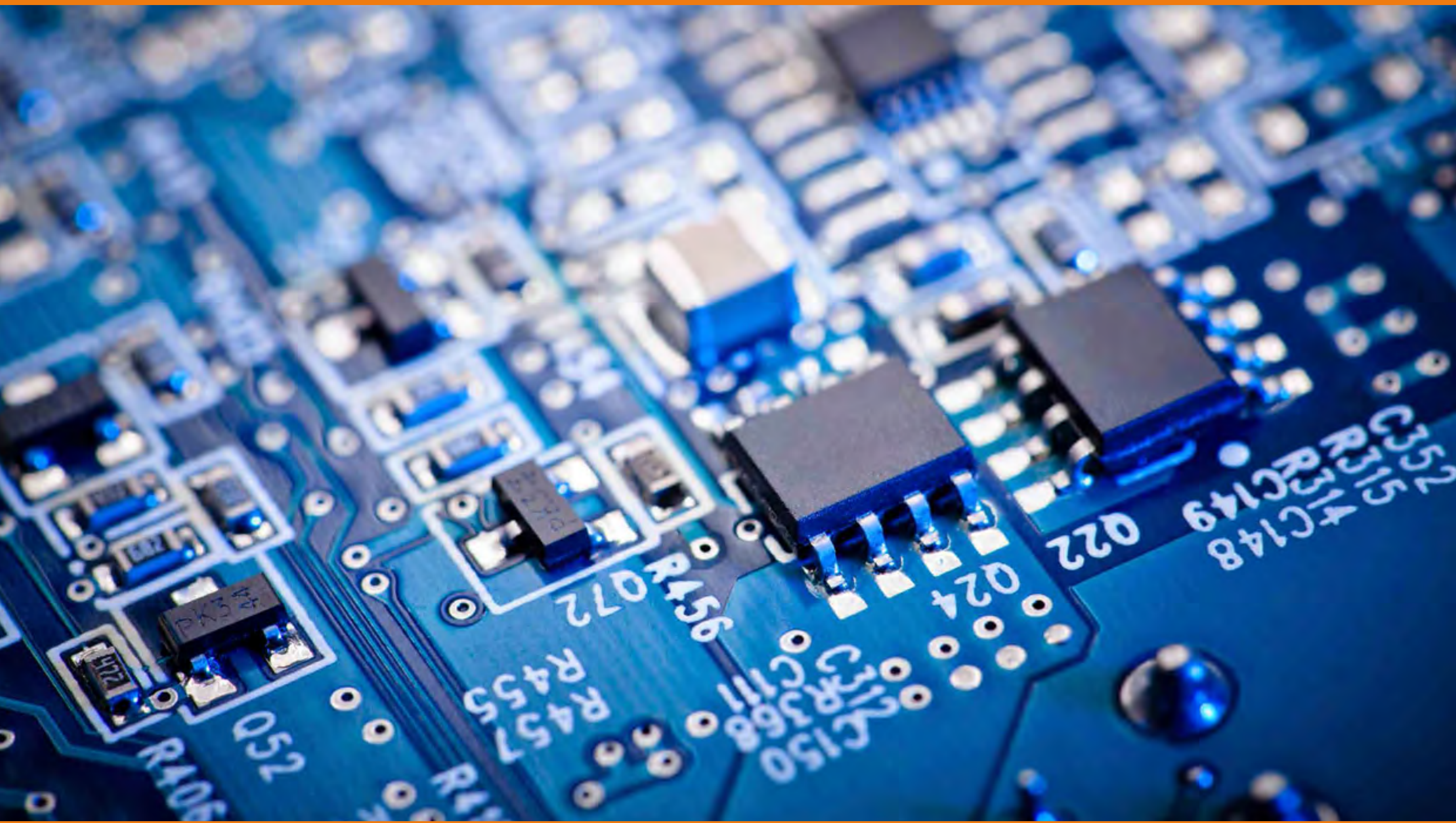

Semiconductor measurements

To stay competitive, electronics manufacturers are constantly developing smaller microchips, requiring greater manufacturing precision. Accurate measurement techniques for the nanoscale exist, but they are slow and unsuitable for manufacturing environments. Scatterometry offers fast nanoscale routine measurements, but lacks suitable reference materials. Developing new standards to link scatterometry to established measurement techniques will improve accuracy, supporting the development of smaller electronics.

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Challenge

Semiconductor devices - the foundation of modern electronics - continue to get smaller and more complex. *The International Technology Roadmap for Semiconductors* expects them to halve in size over the next six years.

Working at the nanoscale requires the production of sub-micrometre structures to build up sophisticated electronic circuits on silicon wafers. Other industries operating at micro- and nanometre scales, such as optics, medicine and biotech, face similar challenges.

Structures must be produced to extremely high accuracies, requiring small scale measurements which are hard to make. Techniques do exist to measure nano-structures, such as Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM), but they are relatively slow or require ultra-high vacuums, making them costly (SEM) or even unsuitable (AFM) for routine measurement.

Scatterometry, which illuminates a surface and detects the scattered light in reflections from it, provides an ideal way to measure small structures in a production environment. However, its adoption is held back by a lack of standards. Providing standards which link scatterometry to established techniques such as SEM and AFM would reduce uncertainties, provide confidence in measurements, and so make the technique viable for routine nanometre industrial measurements.

Solution

The EMRP project *Metrology of small structures for the manufacturing of electronic and optical devices*, has developed new reference materials to accurately calibrate scatterometry instruments.

Scatterometric systems were systematically investigated and compared to other techniques to assess relative performance. A scatterometry reference standard was designed and specified, which was then validated using trusted measurement techniques. These included existing microscopic methods such as AFM and SEM, which have established calibration routes for measuring critical dimensions at nanoscale. The reference standard can now be used to calibrate scatterometry systems.

The final reference standards and a corresponding calibration service based on the methods used are now available for scatterometry instruments. This improves traceability and accuracy of scatterometry by making it comparable to other trusted measurement methods, enabling its use for routine measurements of sub-micrometre features.

Impact

Advanced Mask Technology Center (AMTC) a joint venture of GLOBALFOUNDRIES and Toppan Photomask is developing EUV photomasks to accurately expose circuitry onto silicon wafers. A specific goal is supporting its parent companies - to enable 7 nm technology and below for next generation silicon chips. Access to advanced photomasks is key to achieving this.

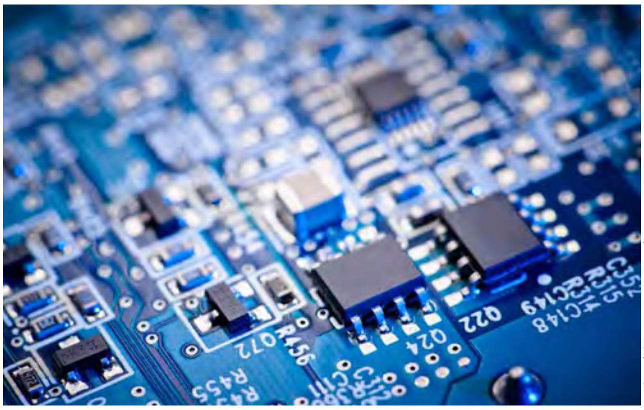
Through the project, AMTC is now able to accurately certify dimensions and uncertainties of their reference photomasks. Using these internal reference photomasks, and calculations developed in the project, they will be enabled to calibrate their metrology systems.

Being able to confidently use calibrated metrology systems will help AMTC to successfully produce EUV masks for 7 nm technology and beyond with features down to ~10nm on the next generation of silicon wafer circuits. They aim to make these technology available by mid-2018. This will play an important role in reducing the size of semiconductor devices, keeping the *International Technology Roadmap for Semiconductors* size reduction schedule on track, and improving the competitiveness of the semiconductor industry.

Metrology for manufacturing electronic and optical devices

The development of miniaturised optical and semiconductor components to meet the International Technology Roadmap for Semiconductors requires accurate dimensional measurement of micro-structures. Scatterometry measurements are relatively fast compared to the traditional methods of Atomic Force Microscopy and Scanning Electron Microscopy, but poor traceability and problems in handling the vast data sets is hampering uptake.

The EMRP project *Metrology of small structures for the manufacturing of electronic and optical devices* developed validated reference standards for all three measurement methods. For the first time, scatterometery calibrations can be compared to those of the other more established dimension measurement techniques. The new data handling methods and improved uncertainty analysis developed are making scatterometry a viable technique for use in the semi-conductor and optics industries where accurate micro-structure measurements are essential.



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Modelling small surface features

The precise production of geometric features on nano-electronic devices becomes more challenging as they get ever smaller. Scatterometry, which measures light scattering, could be a fast, simple technique for verifying that these features meet design, but it produces huge datasets, which are slow to process using current methods. A modelling technique, Finite Element Analysis, could provide faster calculations and make scatterometry measurements viable, but investigation and validation are needed.

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Challenge

The semiconductor and optical industries create ever smaller components, whose functionality depends on sub-micron features. Highly accurate measurement methods are required in the production of photomasks - tools for depositing circuitry onto silicon wafers - as well as for measurements of the chips themselves.

Scatterometry, which illuminates a surface and detects the scattered light in reflections from it, could provide an ideal way to measure small structures in a production environment, but the time needed to process the data generated is hampering uptake.

Interpretation of light reflections requires fast, accurate, and rigorous modelling of the interactions between light and surface features. The current approach compares measurements to a library of pre-computed look-up tables, which is time consuming for the large data sets created by scatterometry.

Improved software is required to process these large and complex data sets in workable time frames. One method that offers potential is Finite Element Analysis (FEA), a mathematical technique which creates models of interactions at boundaries of complex geometries by subdividing them into simpler parts. FEA is used for predictive modelling of physical structures, and could be effectively applied to processing scatterometry data. Doing so will make measurements using scatterometry faster to run and easier to use.

Solution

The project *Metrology of small structures for the manufacturing of electronic and optical devices*, developed new models for processing scatterometric data to provide accurate measurement results of sub-micron 3D surface structures.

The project took extensive dimensional measurements of features on silicon wafers and photomasks using trusted scatterometry techniques in the optical to X-ray spectral range. This enabled the determination of errors, such as edge roughness, spot and structure size effects, which can all cause dimensional measurement inaccuracies. Using this data, mathematical models were created which can be used to evaluate and correct scatterometry measurements, including compensating for these effects. This approach enables fast, reliable 3D re-constructions of surface features from scatterometry measurements.

Impact

JCMwave, a developer of FEA software used in nano-optic design, carried out research as part of the project. In doing so, it was able to advance its FEA software for use in scatterometry measurements.

JCMwave evolved their existing FEA mathematical models to be suitable for use in scatterometric measurements, and developed its JCMsuite software to make it viable for this purpose. By comparing its FEA method to surface feature measurement and models developed by the project, JCMwave validated its own approach.

This independent validation gives JCMwave and its customer's confidence in the use of JCMsuite, and FEA more generally for scatterometry measurements. Involvement in the project has helped the company gain new expertise in using FEA for processing optical measurement data, which has helped JCMwave improve its surface feature modelling capability.

As a result of software improvements, manufacturers of scatterometry instruments can ensure the accuracy of measurements of complex surface features and now have a method for handling the large data sets produced. This provides the electronics industry with a new technique for fast accurate surface measurements in a production environment, speeding the development of new, smaller electronics.

Metrology for manufacturing electronic and optical devices

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Supporting mobile network expansion

From e-banking to social media, high quality satellite, fibre, and mobile communications are an essential part of modern life. As networks expand to meet rising demand, safety concerns over non-ionising radiation emitted by mobile phone base stations need to be addressed. One way to do so is to confirm that the power transmitted does not exceed regulatory limits. This requires reliable on-site measurements with robust links to SI units.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Our increasing use of mobile phones for accessing the internet, checking train times, and transferring money online, relies on communication networks that can match our rising expectations. Good quality signals, data transmission speeds, and network coverage are essential for reliable network operation, and in rural areas connectivity must improve to provide the service network users anticipate. One solution is to increase the number of mobile phone masts, but there are growing concerns over potential risks associated with exposure to the non-ionising radiation they emit. Environmental regulations set strict limits for the maximum transmission power of radio masts, and require network operators to make on-site measurements to demonstrate compliance.

Changing volumes of mobile calls, texts, and online service usage causes mobile phone mast signal strength to vary significantly throughout the day making assessments of it difficult. Networks send engineers to measure mast radio frequency transmission strengths using handheld probes, which require robust links to lab-based calibrations to ensure accuracy on-site – a prerequisite for determining any non-ionising radiation exposure hazard.

Solution

The EMRP project *Metrology for optical and RF communication systems* developed an improved calibration setup for hand-held radio frequency probes and a statistical method for calculating the maximum transmission power of mobile phone masts. To link the on-going performance of probes on site to lab calibrations, the project has introduced the use of radio mast signals broadcast at constant power for connecting mobile phones to networks. Coupled with the project's statistical approaches for determining total radio signal power, engineers using handheld probes can now accurately determine signal strengths as these fluctuate over time. Project developments provide laboratories certifying hand-held probes with robust links to SI units, and their users with a reliable and straightforward statistical method for determining whether a mobile base station's transmission power is within regulatory limits.

Impact

NED-TECH GmbH, a Swiss company providing transmission power measurement services for communication network masts, has been one of the first to use the project's new calibration setup and statistical method for determining maximum transmission power. This has enabled NED-TECH to more accurately and reliably measure emitted radiation from mobile network masts.

By providing robust tools and techniques for measuring radiated signal strength, those monitoring mobile phone mast transmission powers can now have greater confidence in their measurements. In turn, this supports efforts to ensure that radio frequency signals from mobile network communication masts do not exceed environmental radiation emission regulations. In Switzerland network operators could demonstrate that masts operating at 2G and 3G did not exceed the most stringent regulations in Europe. Now they have the tools to demonstrate that masts with 4G also comply to these limits. In helping to address concerns over non-ionising radiation emission that could impact planning considerations for phone masts, the results from this project will promote the effective and safe expansion of the mobile communications infrastructure.

Measurements for 5G communication technologies

The EMRP project *Metrology for optical and RF communication systems* increased the accuracy of lab-based instrument calibrations and also that of the compact test set-ups used for characterising antenna transmission power, where signals may be reduced due to the presence of quiet zones. Best measurement practice guidance, developed in the project, now enables manufacturers and suppliers to have greater confidence that components match specification and are compatible when assembled into very high bandwidth products - an essential requirement for achieving greater overall system transmission speeds. Introducing communication system upgrades to achieve widespread 5G performance could be cost effectively achieved by greater accuracy in component specifications and their increased compatibility.

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European Metrology Research Programme
Delivering Impact

Measuring sparkle

The colour or sparkly finish of cars effects how well they sell. Paint effects using metal or mica flakes that shimmer like stars in the sky are an eye-catching effect. Achieving a uniform finish over the entire car is a production challenge due to the variety of materials used. Manufacturers need reliable measurement methods to assess complex paint effects but currently these do not exist.

Europe's National Measurement Institutes working together

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Challenge

Sparkle – an effect created by small flakes of mica, glass or aluminium in paint to produce a glistening finish, is important in the automotive, printing and cosmetic industries where visual appearance directly influences sales.

Our perception of colour and sparkle varies depending on lighting conditions, as demonstrated by changes in a car's appearance between bright sunshine and a cloudy day. Understanding these changes and being able to accurately measure surface effects during development and quality control as cars leave the production line is essential for optimising sales. Measuring complex visual effects achieved on a variety of materials – metals, plastics and composites is extremely difficult. It involves illuminating components from different angles in sequence and recording the strength of the reflections created. This data is then fed into complex models to predict our perception of colour and sparkle. To ensure that perception models match the effect we see, light booths are used to compare results from expert consumer panels and instrumentation viewing the same samples under the same lighting conditions.

Ensuring that pigment suppliers and their industrial customers make comparable measurements is essential if product quality is to be maintained. Currently there are no standard procedures or instrument calibration methods to provide confidence in result accuracy. Perception models, originally designed for solid colours, are not suitable for complex effects like sparkle and require further development. New standardised approaches to measurement methods, calibrations for complex effects, and models to link these to human perception are all needed to enable comparable measurements.

Solution

The EMRP project, *Multidimensional reflectometry for industry*, characterised sparkle paint samples, provided by coatings manufacturer BASF, and used these to investigate how instrument measurements using many different light positions could be simplified without losing accuracy. The project team also upgraded light booths to improve the accuracy of links between perception based instrument measurements and panels of experts viewing samples for sparkle and other complex effects.

Impact

X-Rite, producers of precision colour measurement instruments for product design, formulation and production, was one of the first to use the image based measurement equipment characterised within the project to confirm the sparkle attributes of samples with effect pigments. This confirmed the performance of their measurement instruments and provides both X-Rite and their customers with greater confidence in the results these generate.

Car manufacturer, Audi uses complex paint coatings across its range that must appear uniform no matter to which material they are applied. Audi were early users of project validated light booths set-up for sparkle measurements. This enabled them to identify a mismatch between expert panel assessments of colour samples and the perception models they use with instrumentation results.

As a result of growing industrial concerns over measurement comparability and the validation of perception models for sparkle effects, the international commission on illumination, the CIE, has set up a new working group to investigate these complex visual effects. Representatives from across the European supply chain will work towards a harmonised approach for determining complex visual effects and reliable perception models to increase confidence in new surface finish measurements which are important for product quality assurance.

Measuring complex visual effects reliably

The EMRP project *Multidimensional reflectometry for industry*, increased the accuracy of 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. Reliably linking visual effect perception of complex finishes such as gloss, sparkle and texture to those made by instruments has the potential to increase product sales, prevent un-necessary re-working of nearly perfect components and enable QA automation. These types of measurements are essential for ensuring continued success in industries where visual attributes are key to economic success such as in the automotive, printing and cosmetic sectors.

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European Metrology Research Programme
Delivering Impact

EURAMET

Atomic clocks for satellites

Navigation, from phone-based maps to shipping routes, depends on global positioning satellites and their on-board atomic clocks. Several bulky clocks are installed in each satellite, so if one fails another can continue to provide reliable time keeping. This redundancy significantly increases launch costs. Europe's satellite positioning system, Galileo, is spurring atomic clock innovations to create a new generation of smaller, more robust clocks with potential applications in other industries.

Europe's National Measurement Institutes working together

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Challenge

Europe is launching 22 satellites as its new global positioning system Galileo expands. This will provide robust, secure location and timing signals to European users, removing reliance on other countries, and opening new markets for high performance products that require precision time and frequency signals.

Satellite positioning systems rely on accurate timing from atomic clocks. Knowing how long their signal takes to arrive is key to calculating the position it came from. These positioning signals can also provide accurate synchronisation for other applications, such as high-speed data transmission in telecommunications or time stamping banking transactions.

The most accurate atomic clocks, based at national measurement institutes (NMI), are large complex devices requiring expert maintenance to provide the highly accurate frequency signal used for timekeeping. Many industrial users of atomic clocks, need their own frequency standards, which must be linked to NMI atomic timekeeping, but do not require the same level of accuracy. Simpler and more compact atomic clocks that use less energy, are needed to provide robust time and frequency accuracy for existing and emerging industrial applications.

Solution

The EMRP project, *Compact and high-performing microwave clocks for industrial applications,* improved a compact prototype atomic clock based on a technique called pulsed optical pumping (POP) to make it more suitable for industrial uptake. POP, one of many types of atomic clock being developed, was identified as having potential for miniaturisation. These atomic clocks have three parts: a module containing vapour cells of rubidium or caesium atoms, a laser to excite the atoms so that they produce microwave radiation at very precise frequencies, and electronics to generate the frequency signal used to confirm the performance of timing devices. The project developed a simpler laser system, improved the vapour cell and upgraded the clocks electronics, to generate a more compact prototype better suited for space-based applications.

Impact

Leonardo, a global player in the Aerospace, Defence and Security sector, already supplies Galileo satellites with atomic clocks. Through co-funding with ASI within ESA Technology program GSTP, it is now further developing the project's prototype POP clock to make it a viable candidate for next generation Galileo 2 satellites.

Leonardo is exploring ways to make this POP clock lighter and more robust for use in space by adding magnetic and thermal shielding. The company aims to produce a simpler and more robust atomic clock for satellite navigation systems by reducing component complexity. The investment in a new rubidium vapour cell production facility has enabled Leonardo to produce the majority of the required clock technologies in-house, so reducing dependence on external suppliers.

More compact clocks will provide European telecommunications, navigation and commerce with accurate and reliable frequency and synchronisation tools for use in-house or on-board satellites. The development of new timing standards for the European satellite navigation system, Galileo, is increasing the resilience, and improving the reliability of frequency standards used in European industries and assisting innovation that relies on location and timing services.

Compact, high-performance timing

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 and industrial users. The project worked with three prototype atomic clock technologies – POP, CPT and a Rubiclock to make them more compact, stable and suitable for use in space. This was made possible by an intensive and extensive collaboration between leading European atomic clock experts from National Measurement Institutes and academia. As a result of this project, atomic clock prototypes have been demonstrated that are suitable for commercialisation and will enable users to benefit from their own in-house time and frequency standards.

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Transportable atomic clocks

Atomic timekeeping provides communication systems relaying information with very precise timestamping, and navigation systems with the ability to exactly pinpoint locations. The most accurate atomic clocks rely on expert staff maintaining complex operating conditions to ensure their performance. As applications requiring precise timekeeping increase, simpler yet highly accurate atomic clocks, suitable for use without expert supervision, are needed to supply the accuracy needed by industry and commerce.

Europe's National Measurement Institutes working together

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Challenge

Banks and internet companies need very accurate time and date stamps to send information and process high frequency transactions. As the technology used gets faster, greater timing precision is required. Atomic timekeeping, provided by National Measurement Institutes, supplies the highest timing accuracy, but these clocks are bulky and require very precise operating conditions and exceedingly low temperatures making them difficult to maintain. Technology and finance companies need on-site clocks that offer comparable levels of accuracy, but which are simpler to look after and operate.

Compact, and more portable, rubidium vapour clocks are being developed for industrial uses. In this type of atomic clock, lasers excite rubidium atoms under very tightly controlled temperature and magnetic conditions to produce and control the specific microwave frequencies used in timekeeping – the clocks 'ticks'. Variations in manufacturing processes can create very small changes to the clock's cavity that produces the microwaves, and hence can effect its performance. This makes a standardised frequency difficult to reliably reproduce between clocks from the same production process.

Reliable on-site atomic timekeeping has the potential to create innovations in financial transactions and internet based communications provided greater compactness and reliability can be achieved. Making clocks smaller, more robust and improving reliability will increase the spread of these highly accurate frequency standards.

Solution

The EMRP project *Compact and high-performing microwave clocks for industrial applications,* improved an existing prototype rubidium clock – the Rubiclock – to make it suitable for industrial applications.

The project made design changes to the clock's cavity, and improved understanding of how to make adjustments to its magnetic field and temperature. This allowed improved tuning of the frequency output, enabling greater optimisation of clock performance. Advances were validated against highly stable hydrogen maser atomic clocks.

The project's revised rubidium clock was further tested during zero-gravity flights in the earth's upper atmosphere. Removing gravity extends the clocks signal generation time, allowing more accurate confirmation of performance.

Impact

Muquans, a spinout company from the Institut d'Optique and Observatoire de Paris, built on Rubiclock technologies advanced in the project to develop and commercialise the clock for industrial applications. Project developments have enabled the Rubiclock's advanced prototype to be made more compact and provided better fine tuning for the clock's microwave cavity. This has significantly improved clock performance by reducing cavity size differences resulting from the manufacturing process. Now commercially available as the Muclock, it offers comparable on-site accuracy to NMI clocks, whilst being much more compact and easier to maintain.

Easy to use atomic clocks, such as the Muclock, will provide European financial, telecommunications, navigation and research organisations with accurate and reliable frequency and synchronisation tools for use in-house and on-site.

Compact, high-performance timing

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 and industrial users. The project worked with three prototype atomic clock technologies and a Rubiclock to make them more compact, stable and suitable for use in space. This was made possible by an intensive and extensive collaboration between leading European atomic clock experts from National Measurement Institutes and academia. As a result of this project, atomic clock prototypes have been demonstrated that are suitable for commercialisation and will enable users to benefit from their own in-house time and frequency standards.

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European Metrology Research Programme
Delivering Impact

EURAMET

Ensuring medical implant safety

Manufacturing complex layered structures for 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, are essential for patient safety.

Europe's National Measurement Institutes working together

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Challenge

Thin films and complex surfaces can introduce formidable surface chemistry challenges in high volume manufacturing, such as electronics, and medical implant production. Multiple chemical layers are often engineered to give specific functionalities during use. The quality and completeness of these functional layers needs to be confirmed during production. In addition, surface cleanliness must be monitored to ensure it is contamination free. In the medical sector this is especially important for patient safety during surgery and for long-term medical implants, where manufacturers must have confidence that potentially toxic cleaning agents have been completely removed.

Advanced high vacuum measurement techniques are frequently used to analyse medical implants and surgical instruments to ensure they meet stringent quality requirements. These techniques need better characterisation to be able to reliably identify the chemicals present, whether these are part of functional surfaces, such as drug layers on implants, or, potential contamination from the production process. To increase the accuracy of these techniques, well characterised materials simulating real world functional layers are needed to provide greater measurement reliability and robust links to SI units.

Solution

The EMRP Project, *Chemical metrology tools to support the manufacture of advanced biomaterials in the medical device industry,* investigated high vacuum techniques, such as X-ray photo-electron spectroscopy (XPS) and 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 accuracy of both techniques, also increasing links to SI units.

Project knowledge and best practice have been published and now provide a resource to aid medical device manufacturers in selecting the most appropriate analysis methods for determining whether functional layers meet stringent specifications and that process procedures have been rigorously followed.

Impact

Smith and Nephew manufacture and supply medical products, such as dressing systems for advanced wound management, surgical instruments and long-term medical implants, globally. Ensuring that these meet stringent quality control procedures is essential to ensure patient safety. Having confidence that production procedures are rigorously followed relies on understanding all process steps and being able to quickly identify and rectify non-conformance. Contamination caused by deviating from procedures has the potential to cause lost production, scrap-age and needing to replace expensive equipment. This type of occurrence can cost tens of million euro in the medical device industry.

Using the project's ToF SIMS measurement technique, Smith and Nephew were able to quickly identify that production line equipment had not suffered contamination when operators raised concerns about a potential contaminant. By rapidly and categorically determining that production line plant contamination had not occurred, Smith and Nephew were able to avoid the huge costs associated with replacing it.

As a result of this project, industries that rely on accurate detection of chemical traces at surfaces, or in near surface layers now have access to advanced and reliable analytical tools underpinned by robust links to SI units. This is an essential requirement in the medical device industry where effective drug delivery and patient safety are overriding considerations.

Chemical tools support medical industry

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 implant coatings and investigated optical techniques such as vibrational spectroscopy for potential application in surgical implant manufacturing environments. This project has had an immediate and lasting impact on the global competitiveness of the European medical implant industry by providing a suite of advanced analytical techniques validated using appropriate reference materials derived from real medical devices. Using the project's analytical techniques has enabled the development of new medical devices, such as urinary catheters with novel coatings, prostheses with improved performance, and improved assessments of implant corrosion.

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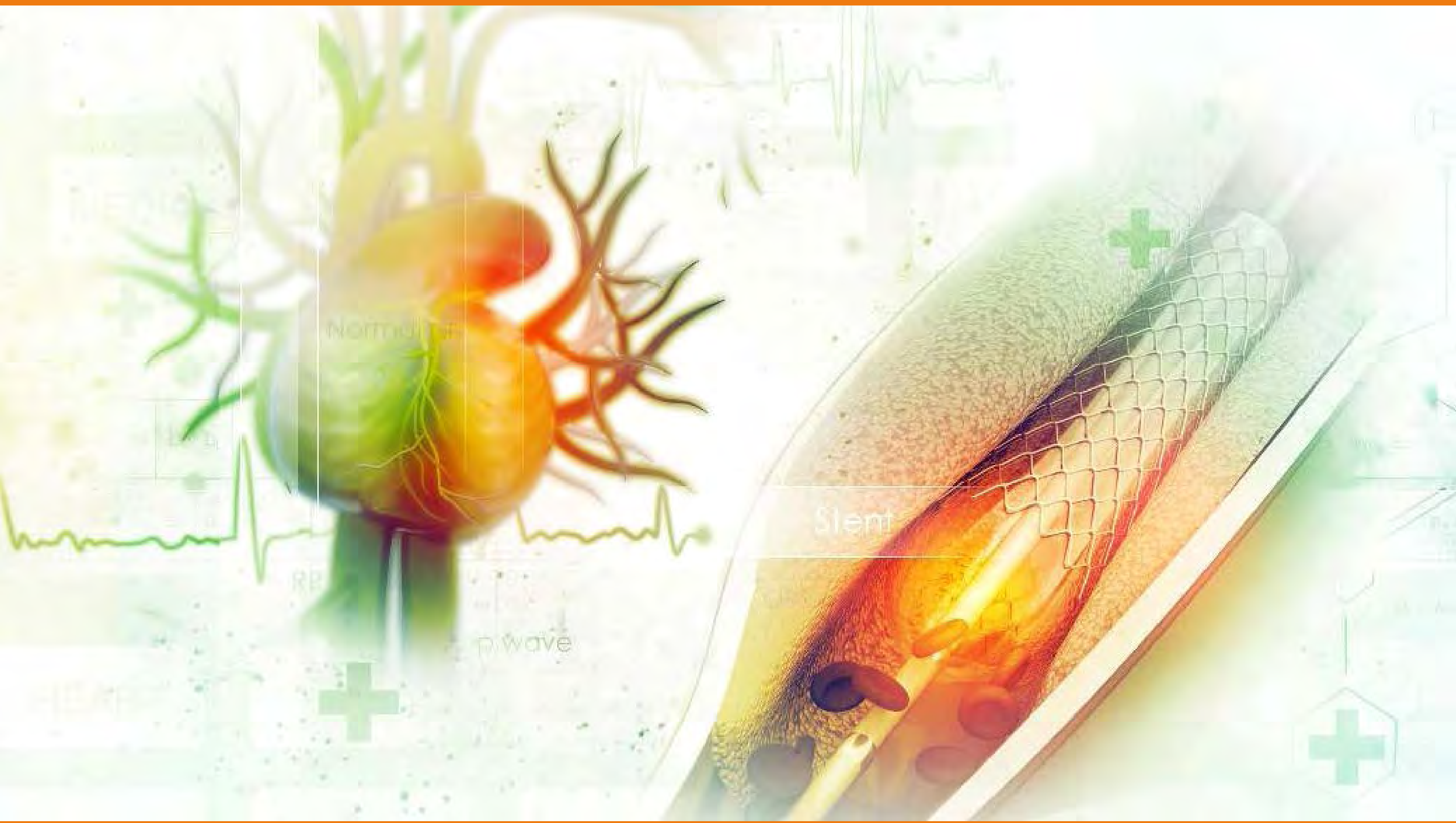

Precision for complex drug layers

Manufacturing complex layered structures, for example 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 finished products. Complex functional layers are used in long-term medical implants but to optimise patient outcomes greater accuracy for analysis methods is needed.

Europe's National Measurement Institutes working together

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Challenge

Films and coatings with complex layers often introduce formidable surface chemistry challenges in advanced manufacturing processes, such as constructing electronics based on non-silicon semiconductors or in drug delivering layers used in medical implants. Biochemical surface interactions have particular importance for patient wellbeing during surgery and afterwards while the body acclimatises to a new implanted device.

To avoid rejection of an implant, its surface layers are designed to release anti-inflammatory and antibiotic drugs over time. Precise control of its near surface chemistry is essential to ensure the reliability and effectiveness of drug delivery. Manufacturers are looking for exact methods that will reliably map surface layers in 2-D and 3-D to obtain a better understanding of how drugs are distributed in implant layers. With this knowledge devising optimised drug layer release rates will offer them the potential to tailor implants to individual patient requirements. A first step towards this goal is improving the accuracy of measurements made using advanced analytical instruments. This requires the development of robust reference materials that match both the types of chemicals and substrates used in implants to confirm instrument performance.

Solution

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 analytical techniques including Time of Flight Secondary Ion Mass Spectrometry (ToF SIMS) to characterise chemical layers used in medical device manufacture. This technique is based on the removal of thin layers from a coating surface using a focused analytical ion beam followed by mass spectrometry analysis to accurately determine how chemical layers change with depth below the materials surface.

Samples of flat implant materials were carefully prepared with known chemical properties and these were used to characterise the task specific measurement capabilities of the Tof SIMS technique in the project. Once the team were confident that results matched the samples known chemistry, the technique was extended to the more complex geometries of real world medical devices.

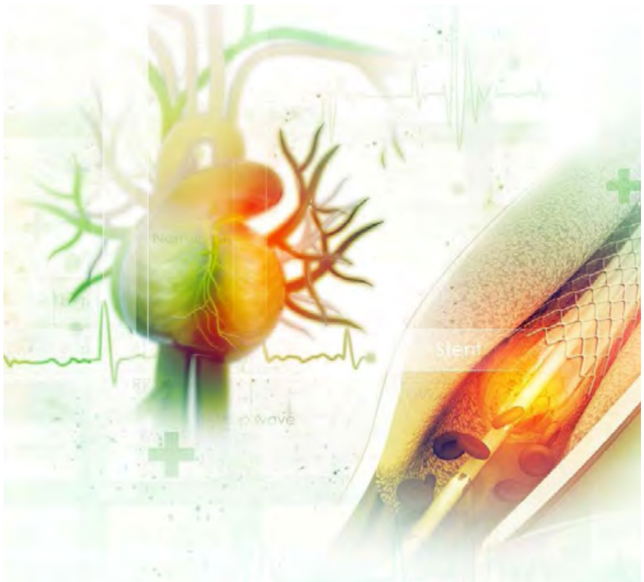
Impact

B. Braun Melsungen AG is a leading manufacturer of a wide range of healthcare products worldwide, including stents used to support and widen narrowed arteries in patients. Some 2.2.million stents are used globally every year in surgical procedures. These consist of a wire mesh coated with thin layers of anti-inflammatory and antibacterial drugs to ensure improved patient acceptance of these life saving devices. Optimising drug delivery directly into coronary arteries is now a possibility thanks to the project's new Tof SIMS method.

B.Braun are keen to use the new Tof SIMS capability in research on how drug concentrations can be varied with depth in stent chemical layers to enable the rapid release of higher concentrations immediately after implantation with amounts reducing over time as the body adapts to the implant. This opens the possibility for developing the next generation of arterial stents with drug layers tailored to individual patient requirements. Greater accuracy in determining the chemical composition of surface layers will contribute to increased European competiveness in the global medical device market estimated to be worth 70 billion euro to the EU economy annually.

Chemical tools support medical industry

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, and investigated optical techniques such as vibrational spectroscopy for potential application in surgical implant manufacturing environments. This project has had an immediate and lasting impact on the global competitiveness of the European medical implant industry by providing a suite of advanced analytical techniques validated using appropriate reference materials derived from real medical devices. Using the project's analytical techniques has enabled the development of new medical devices, such as urinary catheters with novel coatings, prostheses with improved performance, and improved assessments of implant corrosion.



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Delivering Impact

Nanoscale surface mapping

Manufacturers of nano-materials, such as those used in semiconductors and solar cells, need accurate tools for quality control. Knowing precisely where on a sample's surface measurements are being made and having confidence in the results achieved are key to reliably characterising material properties. Atomic force microscopy has great potential for use in material science, but problems associated with extended measurement run times and instrument drift need to be overcome.

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Challenge

Advanced manufacturers of nanotechnologies, semiconductors and solar cells are increasingly innovating with multifunctional materials and this requires the accurate characterisation of very small features. Atomic Force Microscopy (AFM) allows very precise sub-nanometre measurements of surface features and could in the future provide manufacturers with the highest accuracy levels for production process quality assurance (QA).

AFM probe tips scan the surface of materials measuring atomic scale interactions and this information can be used to construct 3D images of surface features, as well as for characterising the materials electrical properties. Current AFM topography scans creating maps of surface features are time consuming. Taking large numbers of measurements at regular intervals across a material's surface generates huge amounts of data for processing and the length of time needed creates problems. AFM tips experience wear and slight operating temperature changes can lead to minor drifts over time, both of which compromise measurement accuracy. Overcoming these accuracy limitations is essential to enable greater uptake of AFM as a quality assessment tool.

Solution

The EMRP project, *Metrology for movement and positioning in six degrees of freedom*, developed a new adaptive scanning approach for AFM measurements, allowing users to concentrate measurements on areas of interest, and reducing the number of data points accumulated over a measurement scan. This helps minimise tip wear and speeds scans so reducing the likelihood of temperature drift. The project also investigated factors affecting AFM performance and developed an improved statistical model for determining measurement uncertainties and minimising measurement errors. This knowledge has been incorporated into freely available software (Gwyddion), which enables AFM users to preselect the instrument's measurement pattern removing reliance on conventional equi-spaced data points. The new software, backed by an open data library of test parameters provides optimised AFM scanning, reducing tip wear and measurement time.

Impact

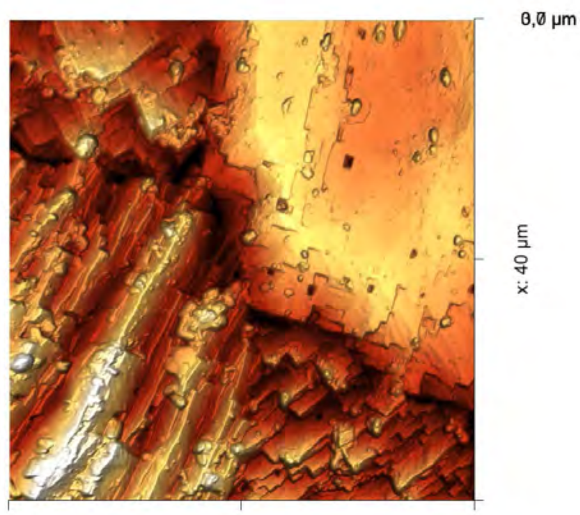
NenoVision s.r.o, a Brno University of Technology spinout, markets the Litescope, an AFM accessory for scanning electron microscopes aimed at researchers in the materials science, nanotechnology, semiconductor and solar cell markets worldwide. The Litescope extends the capabilities of electron microscopy machines used for surface imaging to the analysis of a material's mechanical, electrical and magnetic properties. NenoVision were one of the first to incorporate the project's AFM software into its product. Using the free release software saved them the time, money and risk of developing a similar software themselves.

For routine industrial measurements, such as in quality assurance, it is not necessary to measure entire surfaces, just specific features. The Litescope, with project software, now brings adaptive AFM scanning to the market, reducing the number of measurements and time needed to analyse samples. This speeds processing time whilst mitigating the problems of AFM tip wear and drift.

More flexibility and faster scans allow AFM measurements to be applied to a wider range of nanoscale research applications, and opens its use for more routine manufacturing measurements such as QA. This could save time and money in R&D and create a highly accurate measurement tool for innovative nanoscale technologies, improving product quality and reducing waste.

Accurate positioning in three dimensions

The EMRP project *Metrology for movement and positioning in six degrees of freedom*, has increased the accuracy for determining machine tool and 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 for characterising the motion of precision machine tools, and strategies to decrease the effects of tip wear and instrument drift during extended or rapid scanning of surface features using atomic force microscopy. Traceable nanometre measurements of position, angle and straightness, are essential in many industries and research fields, for example the precise positioning stages used in semiconductor manufacture or for manipulating samples during analysis using electron microscopy.



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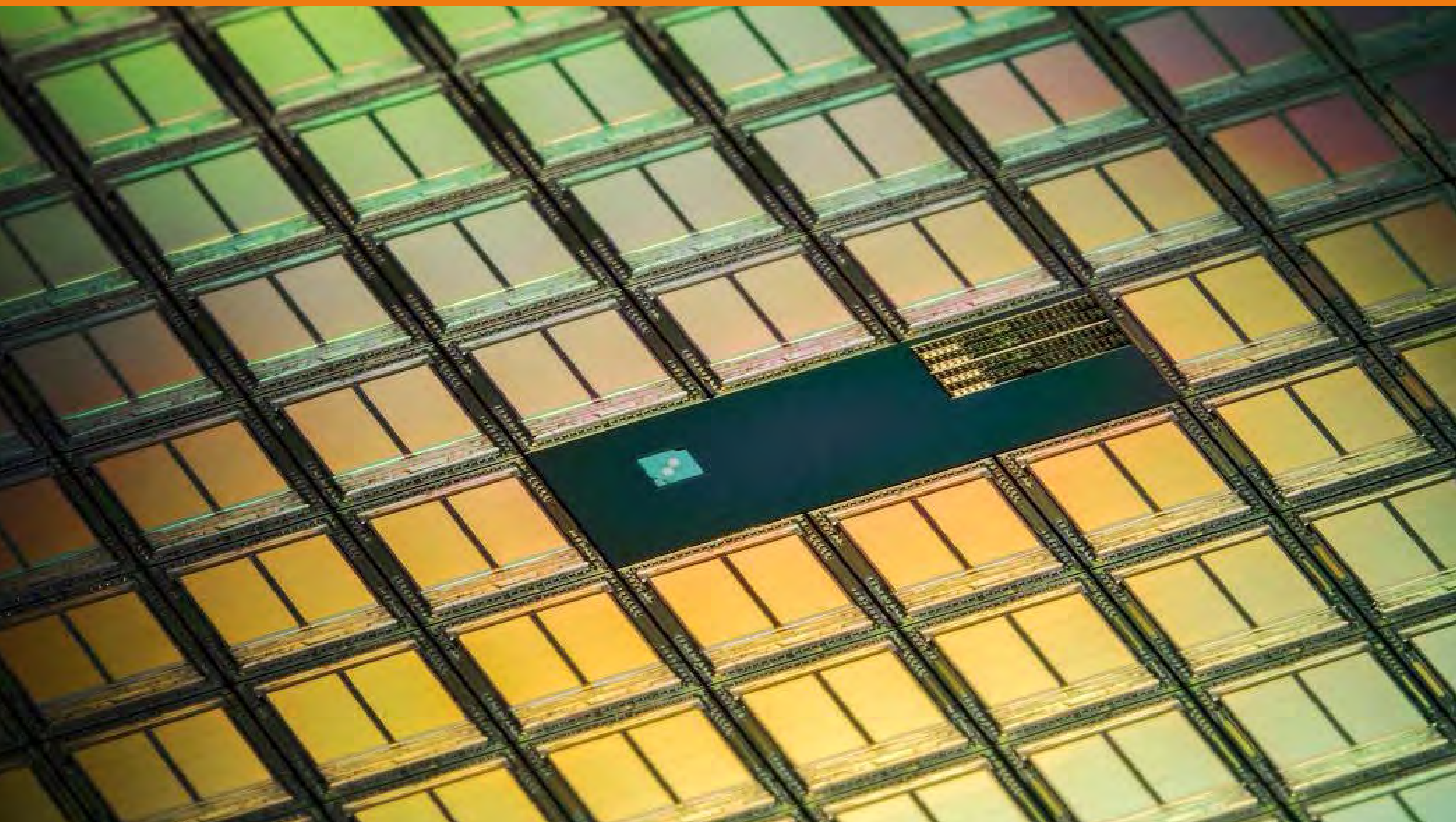

Precision positioning for electronics

Europe is aiming to capture 20% of the global silicon wafer production market, with an estimated value of 11.5 billion euro by 2025. To do so, it needs to develop innovative manufacturing techniques for producing the next generation of larger silicon wafers with increased numbers of electronic circuits. Efficient production methods are needed to boost EU manufacturing productivity and create low cost electronics.

Europe's National Measurement Institutes working together

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Challenge

Producing circuits on silicon wafers relies on high-precision manufacturing processes that assemble electronic components to form multiple complete circuits on a single wafer. These are later separated into individual units for device assembly. To improve productivity and efficiency, wafer manufacturers are investigating methods to increase circuit production by fabricating more circuits on larger wafers.

During manufacture, positioning stages move wafers in 3D inside a vacuum chamber, as tiny details are etched or deposited onto them, to build-up electronic circuits. Achieving the high levels of position control required relies on accurate movement sensing techniques able to operate in challenging industrial environments. As more features are added to wafers, the distance between individual components shrinks and ever greater control over the stage's nanometre movement are essential.

Interferometry is a laser-based technique for precisely determining distances in a single direction. It is based on splitting a laser beam into two, one beam travels to and is reflected back from a target on the item that moves, while the other acts as a reference. Recombining the two creates an interference pattern that can be used to accurately determine position changes. Currently multiple lasers are needed to generate information for movements in 3D, adding complexity and introducing significant measurement errors. To overcome these problems more powerful lasers able to generate multiple intense beams for 3D measurements, coupled with system simplification, are needed to enable industrial users to benefit from highly accurate interferometry measurements.

Solution

The EMRP Project, *Metrology for movement and positioning in six degrees of freedom,* developed a powerful infrared laser, suitable for making 3D interferometry measurements.

The new laser, which was characterised in the project, is 10 times more powerful than lasers currently used in measurement applications. This increased power allows a single laser light source to be split into multiple beams of sufficient intensity for use in simultaneously determining movements in 3D.

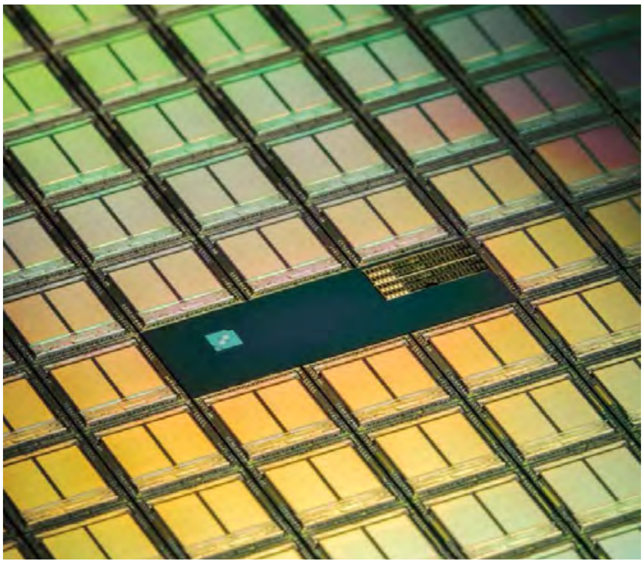
Impact

TESCAN, a Czech company manufacturing scanning electron microscopes and advanced analysis instrumentation, is upgrading the laser technology demonstrated in the project, for incorporation into a new wafer manufacturing system they are developing for electronic circuit production. Tescan's system will incorporate a positioning stage, based on their existing technology, to provide the highly controlled nanoscale movements for silicon wafer production. Determining the precise position of the stage will be achieved using the project evaluated high powered laser and an interferometry system capable of operation in 3D.

New innovations in positioning technology, such as the extension of interferometry for use in 3D, are vital for improving production speed and efficiency in many industries. Increasing the precision of nano-positioning is supporting the development of a new European silicon wafer production capability and has the potential to reduce European industrial reliance on external suppliers as the demand for more sophisticated electronics grows.

Accurate positioning in three dimensions

The EMRP project *Metrology for movement and positioning in six degrees of freedom*, has increased the accuracy for 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 for characterising the motion of precision machine tools, and strategies to decrease the effects of tip wear and instrument drift during extended or rapid scanning of surface features using atomic force microscopy. Traceable nanometre measurements of position, angle and straightness, are essential in many industries and research fields, for example the precise positioning stages used in semiconductor manufacture or for manipulating samples during analysis using electron microscopy.



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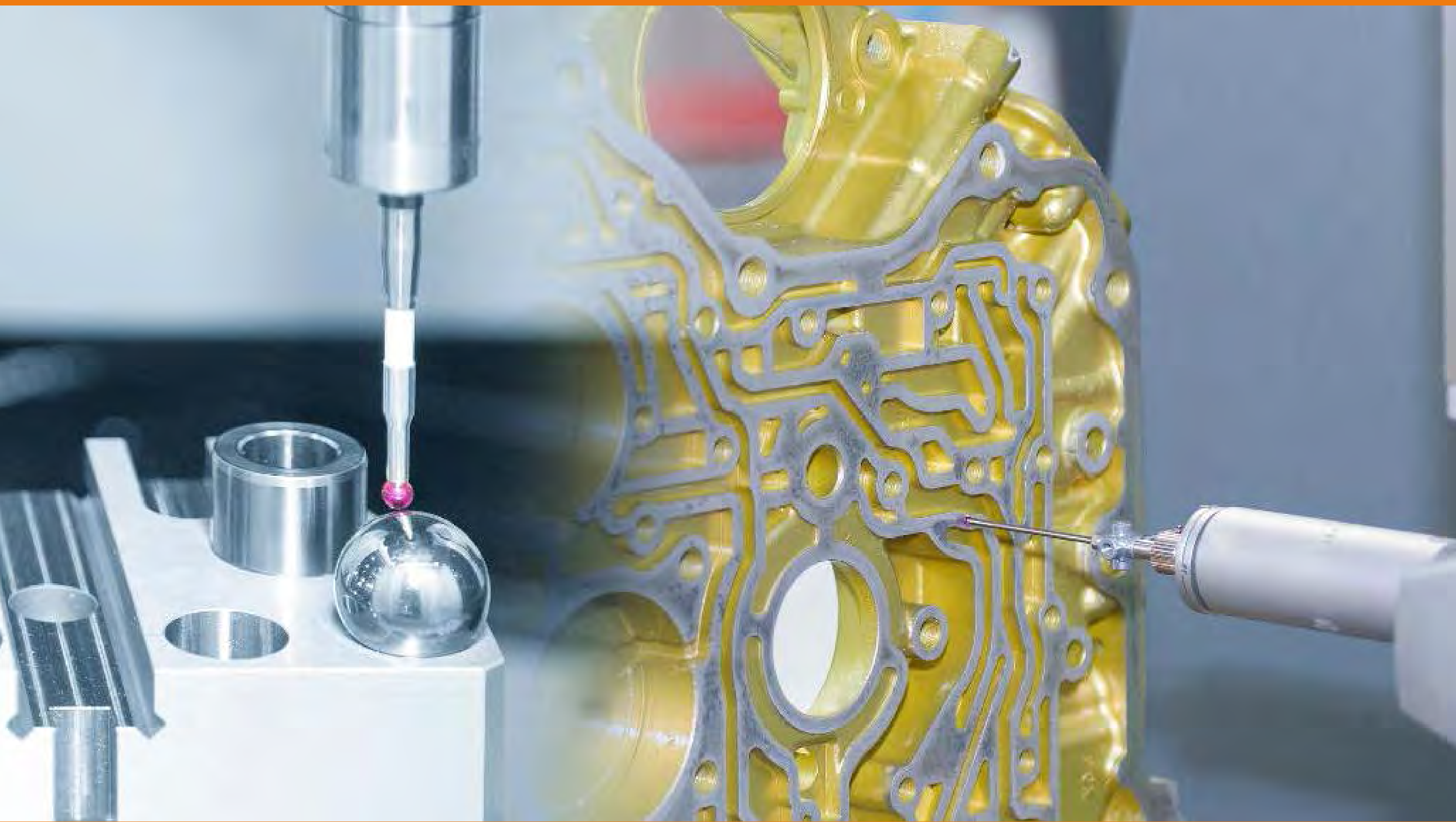

Ensuring precision component quality

The automotive and aerospace industries, worth billions of Euro, use precision engineering production processes in which robotic arms carrying machine tools make complex small-scale movements in 3D. Ensuring that the parts made meet specification relies on confirming their dimensions and also that machine tools precisely follow pre-set moves. Automation, based on identifying movement errors early, has the potential to increase precision engineering productivity and so boost European competitiveness.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Ever smaller components in high value manufacturing industries, such as automotive and aerospace, require highly accurate machine tools to produce very precise features, sometimes at the nanoscale. Such tools make small, complex movements in a 3D space, known as 'six degrees of freedom'. But their accuracy can drift due to temperature variations in production environments, so manufacturers need to check these tools regularly to ensure they are operating with the required precision.

In the past, this would be done by stopping production, mounting the component away from the production line, and measuring it with a coordinate measurement machine to confirm the machine tool is working correctly. This creates production downtime and costs. If a fault is found, whole batches may need to be scrapped.

New measurement technologies are needed to ensure that machine tool movements are precise without halting the production process. Introducing automated quality control measurements and implementing immediate changes if machines drift, has great potential for improving component precision and reducing machining errors.

Solution

The EMRP Project, *Metrology for movement and positioning in six degrees of freedom*, upgraded an existing one-dimensional interferometry-based measurement technique to be suitable for 3D measurements.

Interferometry can be used to determine exact distances and precise movements by attaching reflective targets to objects that move, such as precision machine tool robotic arms. It works by splitting light beams in two, one beam is used as a reference and the other travels to and is reflected back from targets on the machine tool. Recombining the beams creates an interference pattern that is processed to determine the small changes in a machine tool's position in a specific direction during use.

The project combined three interferometers, into a single system for determining locations in 3D. The system was made easier to use by the addition of a camera to capture interference patterns, so enabling digital image analysis. The interferometry systems stability to air turbulence and temperature changes, common in precision engineering workshops, was assessed during the project and its accuracy reliably confirmed against existing measurement methods.

Impact

Mpro GmbH, a precision measurement instrument start-up company, is developing a prototype micro coordinate measurement machine using the project's 3D interferometry system to supply its vital positioning accuracy. To increase the system's suitability for use, Mpro is making it more compact and looking at ways to increase its operating speed. A feedback system is being added to instigate corrections to tool positioning in real time, improving the reliability of quality control and eliminating the need to shut down production to perform measurements. The new Mpro micro coordinate measurement machine will allow in-process verification of nanoscale 3D movements made by production machine tools.

Innovation in machine tool position detection has the potential to increase product quality and manufacturing efficiency in the electronics, aerospace and automotive industries. This will assist in maintaining Europe's reputation for quality products and has the potential to contribute towards future economic growth.

Accurate positioning in three dimensions

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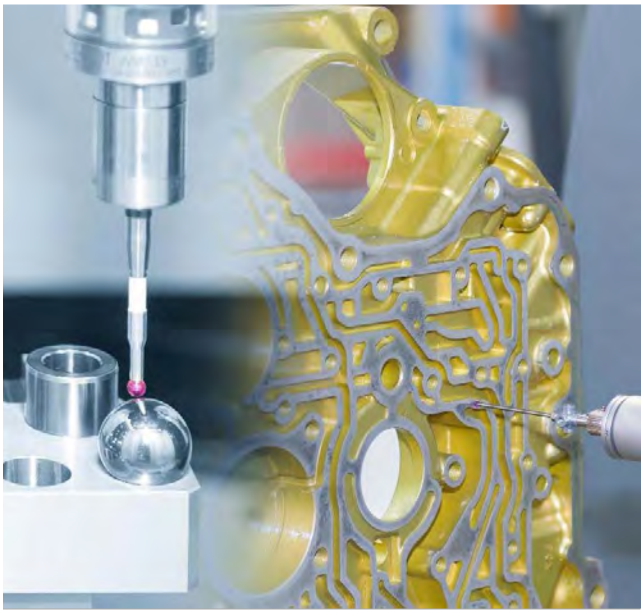

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Measuring lens implants accurately

Reducing micropart size allows new functionality in smaller spaces, but confirming the accuracy of tiny dimensions is extremely challenging. Often simple shapes are used to calibrate instruments measuring miniscule features, increasing the match between these shapes and the real measurement would improve accuracy. One area where this is critical is for instruments used to measure the eyes corneal curvature to aid lens implant selection during sight restoration after cataract surgery.

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Challenge

Cataract surgery saves millions of people from blindness and is one of the most common surgical procedures in the EU, with 4.2 million operations performed a year. To restore sight surgeons replace the eye's lens with a synthetic replica, but to achieve the best possible outcome this must be carefully matched to the dimensions of the patient's eye.

Advanced manufacturing processes, such as those producing medical devices or telecommunication components, rely on ever smaller and more complex parts to introduce new functionality to their products. The instruments used to measure these parts must do so accurately, but confirming measurement performance routinely uses simple objects like spheres, which do not reflect the complexity of the items to be measured. This undermines confidence in the quality of complex shaped parts. Without calibration artefacts resembling the features to be measured, it is hard to know if measurement parameters are being correctly determined. New ways need to be developed to precisely characterise the dimensions of complex reference shapes, so that these can be used to confirm the accuracy of industrial and medical measurement instruments assessing small scale size variations.

Solution

The EMRP project, *Multi-sensor metrology for microparts in innovative industrial products,* improved the accuracy with which complex shapes can be measured and developed robust links between different measurement techniques.

The project developed new smaller probes for surface scanning techniques used to map surface features and measure unusual or hard to reach component features. Researchers compared surface scanning and light-based measurements to create better ties between the techniques. Through these activities they also acquired a greater understanding of measurement error sources for both techniques.

These advances have enabled Swiss Federal Institute of Metrology (METAS) to launch a new service for confirming the dimensions of complex reference components for use as 'gold standard' artefacts, which enable the accuracy of measurements made by industrial instruments to be robustly linked to the international system of units - the SI.

Impact

Haag-Streit, a leading manufacturer of precision instrumentation for eye care professionals and researchers, was one of the first to benefit from using the improved measurement service resulting from the project. Haag-Streit have been able to confirm the accuracy of EYESTAR 900, an innovative new instrument for improved eye curvature measurements, used by surgeons to select the best lens implant to restore sight during cataract surgery.

Calibration of their instrument relies on an accurately characterised meniscus-shaped object, with curvatures matched to the shape of the eye. This now forms a 'gold standard' reference replacing the simpler glass sphere Haag-Streit previously used. The new instrument uses a laser imaging technology called Optical Coherence Tomography to measure both the front and back surfaces of the eye's cornea and lens, giving more information about how light is focussed on the retina to surgeons performing cataract operations. Armed with this information and assisted by the on-board lens implant database, the surgeon can now more easily select candidate implants from the shortlist the system provides.

The ability to transfer measurement accuracy to instruments via high quality well characterised artefacts is key when assessing complex microparts, greater accuracy in this area will help spur innovations in European industry and healthcare.

Multi-sensor measurement for innovation

The EMRP project *Multi-sensor metrology for microparts in innovative industrial products* developed a reliable framework by linking data from tactile probes and optical sensors using reference artefacts with complex shapes to increase 3D measurement accuracy. To support the greater use of X-ray computed tomography (CT) for determining inaccessible dimensions the project developed a simulation to identify systematic measurement errors. This has resulted in a 50 % increase in the accuracy of determining dimensions using CT.

The precise manufacture of miniscule parts is essential for the smooth operation of a wide range of small mechanisms in the automotive, medical and telecommunications industries. Products, such as micro gears, fuel injection and drug delivery systems, all rely on accurate and reliable measurements in 3D.

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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 essential in the automotive and medical device industries. Product innovation to improve performance often involves new designs for ever smaller components. As parts shrink, confirming that nanoscale dimensions meet specifications requires improvements to measurement methods used for quality assurance.

Europe's National Measurement Institutes working together

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Challenge

Car fuel injection systems, medical pumps and high-end watches are all examples of applications where smaller mechanisms have supplied improved performance and enhanced customer satisfaction. In advanced products, reducing the size of mechanical parts and introducing greater manufacturing precision improves reliability, durability and increases efficiency, whilst minimising size and weight.

Ultra-precise machining is used to create parts with miniscule holes, recesses and complex curves that must conform to tight tolerances to ensure that the final mechanism runs smoothly. The advent of new materials and the introduction of processes from the semiconductor industry is revolutionising micropart production. These techniques provide increased manufacturing accuracy, greater design freedom and enable higher manufacturing volumes to be achieved. However, measurement methods for verifying that microparts meet specifications need to be upgraded to keep up with manufacturing developments.

One approach for examining these small components uses tactile probes integrated into high-precision Micro-CMM machines for traceable and precise measurement of small dimensions. However very small parts can have features that are inaccessible to existing probes, so optical and X-ray computed tomography (CT) measurement methods are used in production quality assurance. Improved links between the tactile, optical and CT measurement methods are needed to improve quality control for micropart mechanisms.

Solution

The EMRP project, *Multi-sensor metrology for microparts in innovative industrial products,* developed new smaller tactile probes and improved links between different measurement techniques to reduce discrepancies. The project developed a new tactile probe manufacturing method, based on electro-eroding tungsten carbide rods to produce shafts with tips half the size of current probes. These enable smaller features to be accurately measured as well as strengthening the probe-tip joints. Project researchers also used software to simulate the response of a micro-CMM when using the new probes to separate different sources of measurement error and therefore improve accuracy.

With smaller probes and greater measurement accuracy, project partner METAS, the Swiss Federal Institute of Metrology, now offers an improved precision measurement service for calibrating small and complex shapes used to transfer measurement accuracy to industrial micro-CMM used for production quality assurance.

Impact

Nivarox, a member of the Swatch Group makes many of the parts used in their watch mechanisms. It needs to be confident that these complex microparts meet specifications to maintain the Swiss watchmaker's reputation for quality.

Nivarox was one of the first to have the dimensions of complex microparts precisely determined using a new measurement facility, developed in the project. These artefacts are now used for quality assurance, to provide robust confirmation that Nivarox's tactile and optical measurement systems are operating correctly. This gives Nivarox greater confidence in their ability to identify machine drift's that edge manufactured components nearer to product specification limits. By spotting this early, corrections can quickly be made before parts fail tolerances, so reducing waste and improving production efficiency.

European precision engineering companies, such as Swatch, rely on accurately measuring complex microparts to ensure product quality. Reliable dimension measurements underpin mechanism innovations, helping them remain world leaders in very competitive industries. As a result of this project, companies can have improved confidence in the quality of microparts and the smooth operation of complex mechanisms. This has the potential to increase innovation and help European industries remain cost-effective and competitive on a global stage.

Multi-sensor collaboration

The EMRP project *Multi-sensor metrology for microparts in innovative industrial products* developed a reliable framework by linking data from tactile probes and optical sensors using reference artefacts with complex shapes to increase 3D measurement accuracy. To support the greater use of X-ray computed tomography (CT) for determining inaccessible dimensions the project developed a simulation to identify systematic measurement errors. This has resulted in a 50% increase in the accuracy of determining dimensions using CT.

The precise manufacture of miniscule parts is essential for the smooth operation of a wide range of small mechanisms in the automotive, medical and telecommunications industries. Products, such as micro gears, fuel injection and drug delivery systems, all rely on accurate and reliable measurements in 3D.

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X-ray measurement smooths insulin flow

Drug delivery systems and fuel injection nozzles are examples of applications where microparts with inaccessible yet critical dimensions are used. Reliable quality assurance is essential during their manufacture to ensure assembled systems function as designed. X-ray Computed Tomography (CT), commonly used in medical imaging and in identifying defects in castings, is a technique with great potential for reliably assessing internal dimensions, but it requires better characterisation before it can be introduced.

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Challenge

In Europe, there are 60 million diabetics requiring insulin injections several times a day using single use needles. Making frequent injections is painful, but discomfort can be reduced by using smaller needles with internal dimensions close to the diameter of a human hair. Ensuring an even insulin flow through the needle relies on a smooth and uniform bore, which is not easily measureable with conventional measurement probes or optical techniques.

X-ray Computed Tomography (CT) is routinely used in medical imaging and also in industry for for detecting defects in cast components. This technique also has the potential to reveal the shape and smoothness of a needles internal walls, factors that are important in the delivery of drugs to patients undergoing therapies. Before CT can be reliably used to determine the characteristics of needle bores it needs improved links to other well defined measurement techniques to ensure measurement methods are aligned and factors effecting accuracy are fully quantified.

Solution

The EMRP project, *Multi-sensor metrology for microparts in innovative industrial products*, investigated the many complex factors that contribute and influence dimension measurements made using X-ray CT and developed improved links to existing measurement techniques that use probes or light and have robust links to SI units.

The project developed new industrial reference standards by making careful and repeated measurements of micro-components using various techniques to improve the accuracy of quality assurance assessments. Accurately determining the shape and smoothness of the bore of very fine tubes using X-ray CT was one type of 'real world' micropart that the project precisely characterised.

Impact

Global healthcare company NovoNordisk supplies nearly 30 million patients worldwide with single use insulin needles. As a direct result of this project, they now have a 'gold standard' reference needle providing improved links to the SI units for their in-house measurement methods, including X-ray CT used for research into new needle designs.

Implementation of improved CT scanning in prototyping new needles has reduced testing time and increased bore accuracy as a single measurement uncertainty calculation now covers all needles measured at the same time. This helps to identify the best designs for new needles more quickly and therefore accelerates new product development.

However, to utilise CT measurements for quality control of needles in mass production, the US Food and Drug Administration (FDA) requires that the method is validated. A follow-on EMPIR project is now underway to further increase the use of CT measurements for medical device quality assurance and therefore to support companies working within this field to fulfil the FDA requirements.

Multi-sensor measurement for innovation

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The precise manufacture of miniscule parts is essential for the smooth operation of a wide range of small mechanisms in the automotive, medical and telecommunications industries. Products, such as micro gears, fuel injection and drug delivery systems, all rely on accurate and reliable measurements in 3D.

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European Metrology Research Programme
Delivering Impact

EURAMET

Mains adapter boosts competitiveness

The European electrical industry produces 700 billion euros worth of goods annually and employs four million people, making it one the EU's largest industries. This sector has an excellent reputation for high quality and reliable products underpinned by compliance with the EU's Electromagnetic Compatibility Directive. An accreditation scheme enables labs to demonstrate compliance with the directive's requirements but validating their testing requires improved methods to reliably confirm performance.

Europe's National Measurement Institutes working together

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Challenge

The electrical and electronic engineering industry is a major contributor to the EU economy and directly supports over 4 million manufacturing jobs. All mains-operated electrical devices made or used in Europe must comply with the EU's Electromagnetic Compatibility (EMC) Directive. This requires that electrical items or components do not cause interference that might damage or compromise performance in products, or other devices nearby. From initial product design to commercial production, quality assessments ensure products comply with the directive. EMC testing must be undertaken by laboratories that are members of accreditation schemes. These require that member labs can demonstrate robust links to the SI and that international quality standards for measurement procedures are rigorously applied. However, EMC testing is complex and there are few recognised measurement standards so accredited labs work to the general quality standard ISO17025.

Conductive EMC testing assesses interference in the form of electricity spikes or frequency changes induced in the appliance under test via its power cable, which can cause loss of performance in other devices on the supply system. Many devices are available for performing EMC testing, but individual test set-ups can radically affect results. Ensuring appliances are isolated from any mains interference during testing is essential for determining their compatibility with other electrical items. Greater standardisation of test methods and increased testing reliability is needed to ensure European electrical goods remain competitive in this global market.

Solution

The EMRP project, *Improved EMC test methods in industrial environments,* investigated the properties required for mains isolation test devices used in EMC testing, then designed, developed and characterised a new mains isolation adapter to improve the accuracy and reliability of conductive EMC measurements.

The characteristics of the new adapter were fully modelled using the properties of the materials used to ensure that the assembled device would meet EMC test requirements. Its performance was then confirmed by extensive testing with robust links to the International System of Units (SI).

Based on the project's results, AFNOR the French national standards organisation has submitted a Green paper on conductive EMC testing to the relevant committee on radio interference of the International Electromechanical Commission (IEC) – a first step towards a new international documentary standard in this area.

Impact

Trescal, a Danish accredited lab with customers across Europe, were one of the first to use the Project's mains adapter in customer EMC compliance testing. The new adapters well characterised performance and rigorously determined correction factors mean that Trescal have increased confidence in meeting their customers' expectations for rigorous EMC testing with good traceability to the SI system underpinned by robust quality assurance procedures.

The ability to perform EMC testing with greater accuracy underpinned by documentary standards and greater testing harmonisation will help industry, especially SMEs, to more reliably evaluate their products during the design stage. This will ultimately allow companies to have confidence that their prototypes and new products conform to the EMC directive and can successfully enter the marketplace. Improved standards for EMC testing support the competitiveness of EU industries in a global market where quality is key.

Ensuring electromagnetic compatibility

The EMPR project, *Improved EMC test methods in industrial environments* developed equipment, methods and improved accuracy for different types of testing performed to demonstrate compliance to the EU's Electromagnetic Compliance (EMC) Directive. A key aspect of the project was developing EMC testing methods and introducing them via on-site demonstrations to industrial users. The project's test device and mains isolation adapter are assisting accreditation schemes and member labs to demonstrate that test results are comparable, performed to ISO 17025 requirements and compliant with the EMC Directive

The EU supplies 21 % of the world's electrical engineering production, and has a reputation for quality underpinned by rigorous component and product test results that demonstrate compliance with the EMC Directive has been achieved.

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European Metrology Research Programme
Delivering Impact

Increasing power turbine efficiency

Lost turbine performance, forced outages and repairs cost the power industry 200 million euros per year. Harsh operating conditions, where high speed particles at elevated temperatures collide with gas turbine blades, creates wear that reduces turbine efficiency and hence electricity production. Developing more erosion resistant materials requires an improved understanding of the degradation process and better linking of material testing to in-service conditions.

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Challenge

Natural gas power plants burn fuel to turn turbines, which generates electricity. The burning creates high temperatures and high speed particles which collide with turbine blades, eroding surfaces and reducing efficiency. Lost performance, forced outages and repairs caused by erosion costs the power industry around 200 million euro per annum.

To have confidence that new materials will deliver performance improvements, relies on testing being carried out under in service conditions. This involves bombarding the material's surface with millions of particles at speeds of up to 300 m/s, in order to determine erosion rates. Few facilities can offer such testing, and those that do are limited in terms of the particle speeds and temperature conditions they can create. New test facilities for characterising a materials erosion resistance under in service conditions are needed to generate reliable data for predictive modelling, used to relate test results to in service component wear and turbine efficiency.

Solution

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 and models to improve predictions of how materials will perform in service. The modelling approach is now being patented prior to commercialisation.

An imaging system that uses LED illumination and a CCD camera, developed in the project to determine particle size and speed, enables test facilities to confirm that in service conditions are being reliably matched during testing. This has been incorporated into a new testing facility, commissioned during the project, bringing the number available in Europe to three out of the seven worldwide.

Impact

PyroOptic, a small university spin-out company specialising in precise imaging measurements, has validated its LED technology for measuring particle speeds, as a result of engagement with the project team. Their system uses a LED light source with pulses down to 23 ns to provide an illumination and also to trigger a particle imaging camera that takes two images in rapid succession. The information collected is transmitted for processing in milliseconds and the system resets in readiness for the next image. The new PyroOptic imaging has been refined to ensure it meets safety standards, and an easy to use software package has been introduced to manipulate the data collected.

This new imaging system has created interest for use in a range of applications where measuring particle or fluid droplet behaviour in motion is important. Other potential applications include power plant gas discharge cleaning systems or flowing liquids in bio- and life- science research.

Introducing new measurement methods suitable for use in harsh environments and improving the knowledge of how materials perform under these conditions will help provide the basis for greater power plant efficiency and improved environmental monitoring. The project's contribution to improving the reliability of material's research will enable manufacturers supplying power plant infrastructure, such as turbines, to have greater confidence in the long term performance of components. Improving turbine power output and reducing sudden blade failures has the potential to increase gas power plant efficiency by 10 %. This equates to an extra 800MW for the same fuel burn and potential savings of 250,000 tonnes in CO_2 emissions per individual plant.

Improving high temperature turbine efficiency

The EMRP project *Metrology to enable high temperature erosion testing,* investigated parameters affecting material erosion testing, devised measurement methods for determining test particle speed and developed a probability based predictive model for linking material testing data to likely in service performance. A new European facility for erosion testing has been commissioned as a result of the project, bringing the number available in the EU to three out of seven worldwide. Engineers working to improve turbine efficiency, whether for power generation or aircraft propulsion, can now have greater confidence in predicting a materials in service performance. This will help improve turbine operating efficiency, reduce fuel consumption and cut CO_2 emissions.

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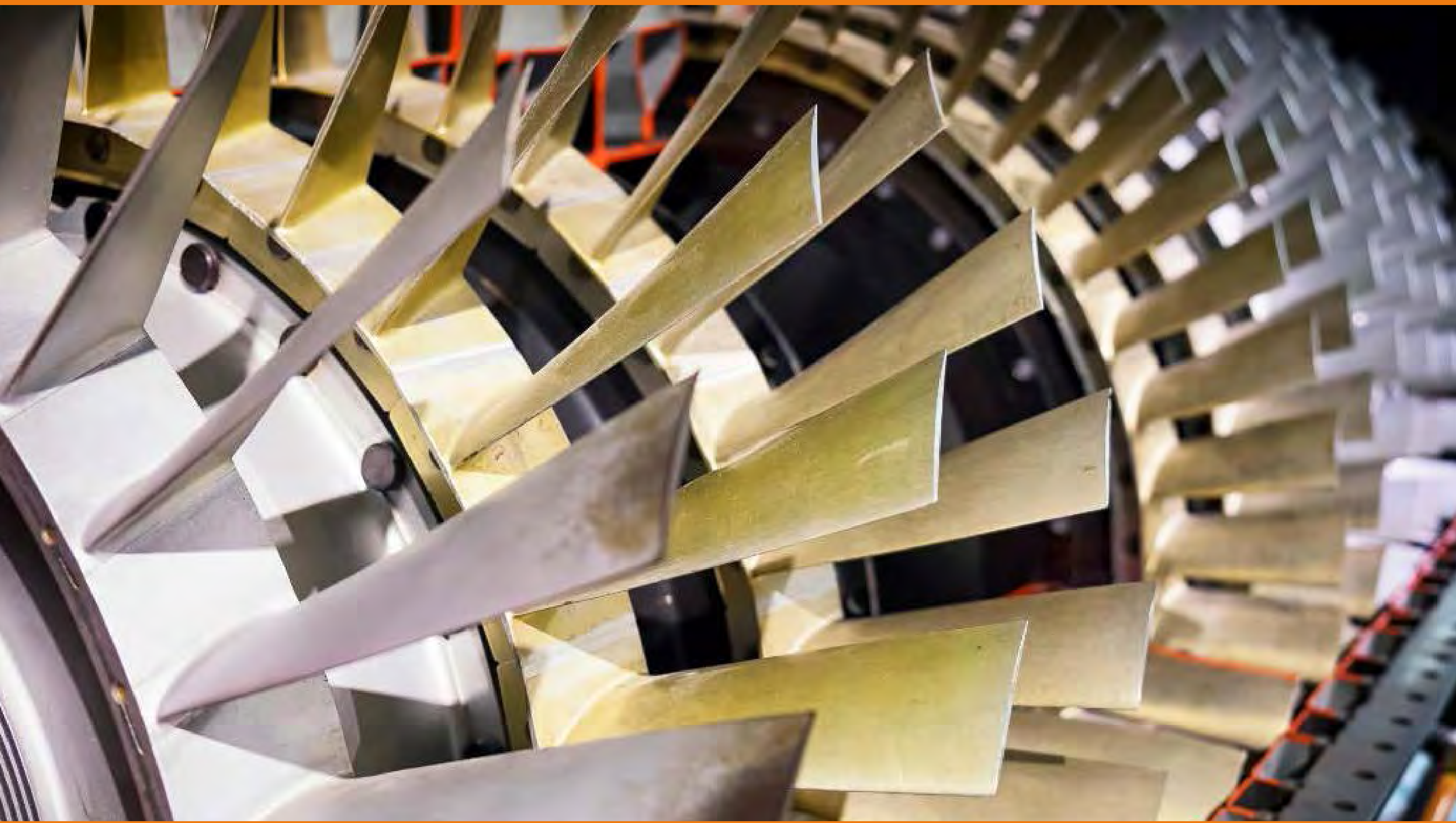

Coatings for gas turbines

Harsh operating conditions in gas fired power plants erode turbine blades, costing the power industry 200 million euros per year in downtime and lost efficiency. New coatings can reduce heat transfer from hot gases to cooled components and protect against erosion, improving turbine efficiency and helping plants meet EU CO_2 emission directives. Developing and having confidence in new coatings relies on testing under in-service conditions, which are challenging to reproduce.

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Challenge

Gas fired power plants use burning gases to drive turbines and create electricity. The efficiency of converting the heat and speed of gas streams into turbine blade motion determines how much energy is produced per ton of gas burnt. Hot gas streams pick up particles and corrosion scales from interior surfaces of combustion chambers and transition ducts, which later collide with turbine blades causing erosion. This compromises operating efficiency and sometimes leads to expensive unscheduled emergency power plant shut downs.

To reduce heat loss from the gas stream to the turbine, manufacturers use ceramic thermal barrier coatings to protect turbine blades. Improving the performance of these coatings has a direct benefit for power plant operation – increased efficiency, reduced gas burn per megawatt produced and reduced carbon-emissions as required in EU directives. But thermal barrier coatings, especially new low thermal conductivity ones, can be less erosion resistant than more traditional coatings.

Therefore, when new blade coatings are being developed, confidence in their erosion resistance to the millions of particles moving at speeds close to 300 metres per second at temperatures of up to 900 °C is required. Testing new barrier coatings using in-service conditions relies on being able to measure experimental parameters accurately.

Solution

The EMRP project, *Metrology to enable high temperature erosion testing*, investigated key parameters in erosion testing. They developed methods to determine particle shape and size using X-ray computed tomography and ways to accurately measure particle speeds in test rigs. This has generated a better understanding of the differences between test and real particles in gas streams and methods to relate these to the erosion caused.

One of the European centres with erosion test facilities, RSE, collaborated in the project, and is now applying project knowhow to better tailor testing to in-service conditions. Getting test conditions correct using fewer attempts reduces the number of wasted samples and speeds facility set-up, whilst improved measurement techniques provide greater assurance that testing closely matches in-service conditions.

Impact

Ansaldo Energia, manufactures gas turbines for the power industry and has supplied turbine installations worldwide that produce 33,400 MWh of electricity. Today, Ansaldo Energia is performing research to develop new turbine coatings to further increase overall turbine efficiency and in-service operating life. Ansaldo Energia is therefore very keen to gain the benefits that can come from testing performed at the improved RSE facility. As a result of project upgrades, Ansaldo Energia will have increased confidence that their new turbine coatings have been rigorously tested using the in-service conditions they specified.

As a result of this project, turbine manufacturers, such as Ansaldo Energia, can now have increased confidence that coatings will perform as expected in-service as a result of faster and more efficient material testing. Improvements to turbine blade erosion resistance will help gas power plants reduce unplanned downtime and improve efficiency, thereby reducing their CO_2 emissions and helping with EU carbon emission reduction directive compliance.

Improving high temperature turbine efficiency

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11326/0618 - IND61 17082

European Metrology
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Delivering Impact

Precision in paper production

Finland is a major exporter of paper, with pulp and paper contributing two billion euro to their economy. Paper manufacturers are continually striving to increase quality, and production efficiency, whilst reducing manufacturing costs. Ensuring paper quality meets production tolerances is key to maintaining competiveness. Finnish paper producers require improved measurement reliability to maintain this important national industry.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Paper manufacturers must produce paper to consistent standards to stay competitive, since uniform paper thickness reduces ink use, saving their customers money. To produce paper, large round rollers turn pulp into sheets of defined thickness. These rollers develop scratches and dents over time, so are periodically reground to give them a good surface finish. Very smooth rollers are required since small variations in roller profile affects paper quality.

Ensuring the regrinding process produces a perfect surface is important, and in-process measurement probes are used to confirm the quality of a roller's surface as it is repaired. These probes must be periodically sent to calibration labs to ensure they measure correctly, but this risks damage during transit and has the potential to introduce errors after reinstallation on the roller's spindle.

Reference artefacts that can be installed on the grinding machine would allow the performance of measurement probes to be verified on the machine itself, giving paper manufacturer's greater confidence that once returned to the production process rollers will produce paper of the required quality.

Solution

The EMRP Project, *Traceable in-process dimensional measurement* developed a number of well characterised artefacts, with complex shapes and geometries, for use as industrial reference standards. One of these is a reference disc suitable for confirming the measurement accuracy of probes used to assess re-ground paper roller surfaces. Mounted on the roller's spindle alongside the probe, the disc is used to compare probe results to previous precise measurements of the standard, so verifying the installed probe performance.

The project also investigated factors that contribute to confidence in achieving a true measured value for paper roller surface smoothness, and developed recommendations on how best to determine this. The project derived factors have now been incorporated into written ISO standards to assist with determining measurement uncertainties.

Impact

RollResearch, a Finnish manufacturer of high-tech roll measuring and re-grinding control systems for paper and steel milling, is launching a new calibration service for roller maintenance, as a result of the project.

RollResearch has a four point measuring system that can evaluate wobbles and dimples in rollers as they are being reground, ensuring an optimised surface finish. It uses one of the project reference artefacts, a round disc suitable for in-situ calibration of its measurement instruments. Staff have received training, developed in the project, on determining measurement uncertainties in accordance with the recently updated ISO standards. As a result, Rollresearch can now confidently confirm the 'roundness' of rollers as they are being reground, and can now provide customers with a test report for the rollers performance after remedial work has finished.

The new RollResearch calibration service will provide reliable in situ calibration of roll measurement probes to the paper industry. This will improve accuracy and allow corrections to be made during regrinding to reduce roller variations, leading to greater paper uniformity. RollResearch's customers in the Finnish paper industry, as well as across the EU, Asia and USA, will now have an advanced tool to improve paper quality, helping them to stay ahead of the game in a very competitive market.

On machine in-process dimension measurement

The EMRP project, *Traceable in-process dimensional measurement,* developed new reference artefacts with well characterised and complex geometries to confirm the performance of measurement and positioning systems used in industry. The project also investigated the sources of in-process measurement errors and developed guidance and training to transfer measurement best practice to industry. Ensuring the accuracy of in-process dimension measurements by early identification of drifts towards production tolerances has the potential to increase the productivity, and hence competiveness of European manufacturing and machine tool industries by 20%.

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European Metrology Research Programme

Delivering Impact

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 strictly controlled. As components shrink and production becomes more susceptible to extremely low contamination levels, improved monitoring methods are needed to reliably detect changes in air quality.

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Challenge

Manufacturing semiconductors and high power LEDs relies on cleanroom processes where chemicals such as hydrogen fluoride, hydrogen chloride and ammonia are used to create features on printed circuits. But if these same chemicals are inadvertently released as tiny traces into the cleanroom air, interactions can ruin entire production batches. It is crucial that air quality is reliably monitored for contamination at the parts per billion level to reduce wastage and ensure manufacturing efficiency.

Most conventional cleanroom air quality monitors were not envisaged for part per billion contamination detection and are beginning to be replaced. Newer monitors use individual lasers, with wavelengths carefully matched to specific process chemicals, shining through samples of cleanroom air to identify and quantify any contamination present.

However, one of the challenges faced by existing laser based technologies is their size. Current lasers fill an airplane cabin bag but smaller versions nearer shoe box size are needed, without reduction to the laser beam's intensity. Highly sensitive compact monitoring systems able to detect a range of process chemical contaminants simultaneously are needed to reduce waste in high cost industrial production environments, such as cleanrooms.

Solution

The EMRP project *Metrology for airborne molecular contamination in manufacturing environments* developed a compact tuneable laser system able to produce different light wavelengths and incorporated it into a highly sensitive prototype cleanroom monitoring system.

By studying existing lasers, the team identified design improvements and used these to create a more compact light source which uses less power. This incorporates a novel feature that enables the laser to be tuned to different wavelengths – opening up the potential to use a single instrument to detect multiple cleanroom contaminants. Project testing demonstrated the system's ability to detect ammonia at the parts per billion level of cleanroom contamination.

Impact

HC Photonics, an SME specialising in laser wavelength conversion technologies, improved their understanding of laser light source design and development, as a result of interacting with project partner VSL. This knowhow has been used to develop a new infra-red laser light source that has broad wavelength tuneability and sharp spectral resolution. Compact and significantly cheaper than existing infra-red light sources, HC Photonics new laser is suitable for a number of applications, such as cleanroom monitoring for multiple contaminants, atmospheric pollution sensing and medical diagnostic technologies.

The projects contribution to understanding how these tuneable lasers work is important for creating innovations that have the potential to extend laser technology uses to meet the emerging demands of many different industrial and medical sectors. Lasers with the capability to produce different specific wavelengths and high output power have the potential to create innovation in medical diagnostic imaging of brain lesions, breast cancer or determining oxygen levels in the blood.

Monitoring airborne contaminants in cleanrooms

The EMRP project, *Metrology for airborne molecular contamination in manufacturing environments*, developed advanced instruments for detecting part-per-billion (ppb) airborne contamination in manufacturing cleanrooms and dynamic gas reference standards suitable for calibrating cleanroom air monitors. Many electronics devices such as mobile phones, flash drives, or digital cameras are underpinned by technologies fabricated under cleanroom conditions where reductions in air quality can detrimentally affect the production process. As a result of this project, these and other industries reliant on the rapid identification of trace contamination in air can now have greater confidence in installed monitoring systems for air quality.

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Keeping cleanrooms clean

Semiconductor production relies on precise control during cleanroom manufacturing processes. Chemical spills can contaminate the air and reduce the effectiveness of these highly sensitive industrial processes, leading to parts being scrapped. As semiconductors become smaller, improved detection of extremely low levels of contamination in real time is needed to quickly identify traces of airborne chemicals and allow remedial action to sustain production efficiency and yield.

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Challenge

Semiconductor manufacturing requires tiny details to be etched onto silicon wafers using precision chemical processes. These are performed in cleanrooms to avoid contamination. However, chemicals from other stages in the production process, most importantly, ammonia or hydrofluoric acid, can occasionally spill producing traces in the air. Even at very low levels, this chemical contamination can compromise etching, and introduce production faults resulting in lowered process yields.

Most cleanrooms currently employ ion mobility spectrometry to detect specific chemical traces in the air and alert staff, so that remedial action can be taken. It may take time for these monitors to reliably respond to the very tiny chemical traces and this delays production stoppage, leading to wasted components. In many cases the monitors are not able to robustly identify molecules such as acids or bases in a contaminated air stream.

As semiconductors become smaller, miniscule traces of contamination have even greater potential to disrupt production, therefore, new highly sensitive monitoring methods capable of detecting key airborne contaminants in real-time are needed to maintain production efficiency.

Solution

The EMRP project *Metrology for airborne molecular contamination in manufacturing environments* developed a new instantaneous method for generating low concentration reference gas mixtures used to calibrate highly sensitive cleanroom monitors at close to in-service contamination levels. These gas standards were used to confirm the feasibility of developing optical monitoring techniques for cleanroom use, based on laser spectroscopy principles. Photoacoustic spectroscopy (PAS) was found to have good potential for development into a new type of cleanroom contamination monitor. This technology uses a laser to excite contaminant atoms in the instrument's measurement cell, then detects and measures the small pressure pulses created as they relax. Each chemical has its own specific response enabling different chemicals to be detected simultaneously using a single instrument.

Impact

As a result of the project, Optoseven Oy, a manufacturer of gas and liquid analyser systems, is now confident that PAS spectroscopy is suitable for cleanroom use. Optoseven has developed a prototype contamination monitoring system for detecting ammonia and hydrofluoric acid in cleanroom air. Optoseven were one of the first users of the improved cleanroom monitoring calibration service resulting from the EMRP project. This enabled them to characterise their prototype and gave their staff the opportunity to gain additional measurement expertise.

To establish the prototype's suitability for industrial cleanroom operation it was trialled in the VTT cleanroom facility – the largest cleanroom facilities in the Nordic countries. The trials of the PAS contamination analysis system under operating conditions, have demonstrated that Optoseven's prototype is suitable for real-time analysis of multiple cleanroom contaminants, and that it matches the sensitivity levels needed for semiconductor manufacturing. Optoseven are actively exhibiting the instrument in Asia, the world's largest region of semiconductor production to promote sales whilst also investigating extending the technology to detect the higher contaminant concentrations encountered in industrial process monitoring.

Laser spectroscopy is an innovative field of new technologies which allows multiple cleanroom contaminants to be detected in real time, giving manufactures immediate notification of problems and reducing the number of parts compromised by contaminated environments. This has the potential to reduce waste and speed time to market for cutting-edge semiconductors and nano-technologies.

Monitoring airborne contaminants in cleanrooms

The EMRP project, *Metrology for airborne molecular contamination in manufacturing environments,* developed advanced instruments for detecting part-per-billion airborne contamination in manufacturing cleanrooms and dynamic gas reference standards suitable for calibrating cleanroom air monitors. Many electronics devices such as mobile phones, flash drives, or digital cameras are underpinned by technologies fabricated under cleanroom conditions where reductions in air quality can detrimentally effect the production process. As a result of this project, these and other industries reliant on the rapid identification of trace contamination in air can now have greater confidence in installed monitoring systems for air quality.

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Innovation in 3D analysis

Many industrial sectors need to understand and control the structures, and chemistries of organic materials at the very smallest scale. New materials are expected to find uses in diverse applications, such as replacing silicon in next generation semiconductors, or as coatings to control drug release rates. For nano-structured organic materials to find their way into commercial applications, new techniques for measuring organic properties layer by layer are needed.

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Challenge

The electronics industry aims to develop ever smaller, more powerful and efficient devices, and is keen to use new organic materials alongside conventional components. Existing measurement methods – designed for silicon based electronics – are unsuitable for these organic materials. Therefore, in order to accurately specify the performance of organic components, new traceable 3D nanoscale chemical, and electrical imaging methods need to be developed.

Secondary ion mass spectrometry, a technique that measures the chemistry of surfaces, can now use newly developed argon cluster sputtering to gently remove surface layers, and produce ions for analysis. This generates information on a layers chemistry and structure, but it lacks the procedures needed to make measurements reliable.

Solution

The EMRP project *Traceable characterisation of nanostructured devices,* investigated the use of this new 3D analysis tool for organic materials based on argon cluster sputtering and mass spectrometry. Using reference materials from the EMRP project *Surface Chem,* the team derived a universal equation which allows an important measurement parameter to be deduced from the ion beam energy, and the number of atoms in the cluster. This approach enables robust and reliable measurements of how the chemistry, and structure of organic samples change below their surface.

Subsequent research in a UK government funded project *3D OrbiSIMS* enabled the project team to apply the 'universal equation' to a new innovative mass spectrometry instrument, improving control of the analysis beam. The innovative *3D OrbiSIMS* instrument has the highest simultaneous spatial and mass resolving power for organic materials achieved to date. This is an important development in mass spectrometry analysis, and will enable greater accuracy in the characterisation of complex sub-surface organic nanolayer chemistry.

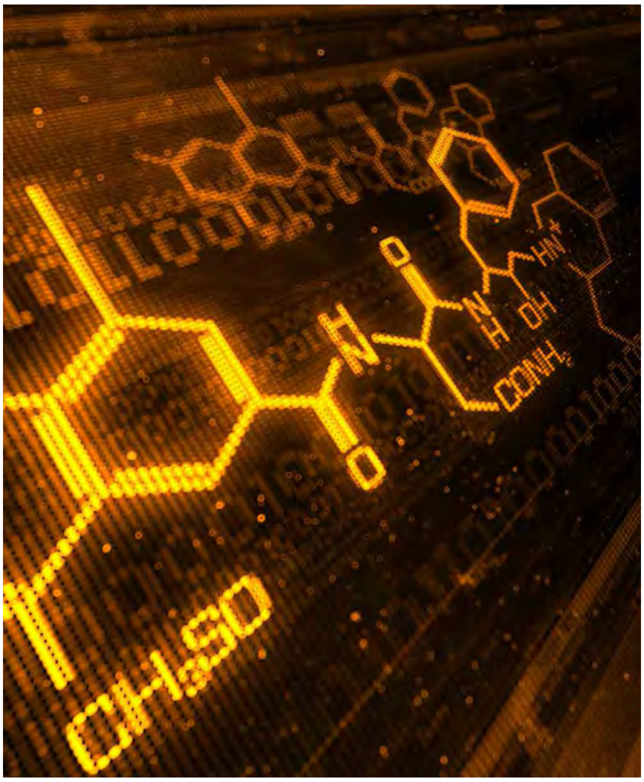
Impact

Global pharmaceutical company, GSK, has gone on to use the *3D OrbiSIMS* in drug release studies, and as a result, has gained a better understanding of how drugs are taken up in the body after administration. The GSK research discovered that the way drugs enter the circulation after administration can differ between species in pre-clinical testing. An important finding for drug efficiency studies, made possible by the development of this innovative new analysis technique, and the understanding of its applications.

Andy West, Head of ex-vivo Bioimaging GSK UK, says "Studying how compounds are distributed, and the effects they have within tissues and cells is key. For a drug to be effective it must reach its target at the right time, and at a sufficient concentration. We can now create 3D images of drug molecules in tissues at better than cellular resolutions. This means we can monitor the uptake of drugs into target cells enabling changes to maximise effective drug adsorption."

Traceable characterisation of nanostructured devices

As new organic materials and multi-layer films are developed to be used alongside or replace traditional silicon based technologies, new material analysis and characterisation methods are needed to ensure material performance can be accurately determined. The EMRP project *Traceable characterisation of nanostructured devices*, developed robust chemical analytical methods for characterising nanolayers and demonstrated 2D photoelectric mapping of nanostructures. The project's visualisation tool that extracts 3D nano-electrical information from 2D mapping data has potential for enabling new direct 3D measurement methods. These developments are assisting in the accurate characterisation of novel organic materials, and provide the confidence in material performance needed to speed their implementation into new applications.



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Smart meter reliability

Over 280 million smart meters are being installed in Europe giving consumers greater control over energy use. Accurate metering is based on testing small numbers from large production batches both pre and post installation. Complex computer modelling is used by regulators to set the re-test frequency, so minimising costs to energy suppliers and customers. Ensuring this retest system is fair requires improved optimised models for these new energy meters.

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Challenge

Electricity meters measure how much energy consumers use so they can be accurately billed. If they measure incorrectly it is bad news for the consumer; either they are charged more individually, or they are undercharged leading energy companies to raise prices. Smart meters are being manufactured in large batches and introduced with the aim of helping consumers manage their energy consumption more intelligently. National Energy Regulators are responsible for ensuring fairness to both the supplier and the consumer.

Recognising that a meters performance can change over time, regulators require that testing is performed before installation, then periodically to ensure ongoing accurate energy metering. This relies on an optimised testing schedule using small numbers of meters from individual production batches to determine if batch performance is within the expected accuracy. Reducing the numbers of meters tested based on statistical approaches minimises customer inconvenience and supplier costs without compromising decisions on batch performance.

The regulator's role is to find the right balance between the risk of incurring consumer costs due to erroneous metering, and that of suppliers bearing additional costs from increased meter re-test frequency and unnecessary early replacement of conforming meters. Current conformity assessments, on which testing regimes are based, consider failure rates but not associated costs and risks.

Solution

The EMRP Project, *Novel mathematical and statistical approaches to uncertainty evaluation,* developed a new probability based approach to model the performance of meter batches.

The project applied the 'bath-tub reliability curve', which has a similar shape to a bath's profile, to model meter batch failure rates over their life-time and developed a combined model showing how consumer risks increase with measurement errors. This new model assigns a quality score to the meter batch and can predict when it will fail specification enabling energy supply companies to plan cost effective meter replacement.

Impact

The project findings were used to develop recommendations for a new regulatory testing regime reducing the total costs of measurement using a risk assessment of meters measuring incorrectly. This is now being considered by the Surveillance Department in the Norwegian Metrology Service, and has potential to make assessing installed meter performance more cost effective.

The project models and insight form part of a growing body of knowledge which suggests that better statistical evaluations of consumer and supplier risks from faulty meters will provide a more robust approach to decision making on meter retesting, and could indicate the need to make more or less frequent testing.

Appling statistical approaches using historic data from previous products and associated costs to generate assessments for the testing frequency of new mass produced items is an innovative use of probability in risk managements.

Novel approaches to uncertainty evaluation

The EMRP Project *Novel mathematical & statistical approaches to uncertainty evaluation,* developed new robust methods to assess uncertainties for situations that are not currently covered by the *Guide to the expression of uncertainty in measurement* (GUM). Rigorous application of statistical and mathematical techniques generated 'smart' sampling to reduce computational times for processing extended data sets, and new accurate uncertainty approaches based on probability, risk assessment and decision making. Worked examples for improved product testing, safety regulations, medical diagnosis and drug testing will provide input for future GUM revisions.

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Accuracy for installed flow meters

Monitoring fluids flowing through pipes is vital to the efficiency and safety of many systems, from transporting hot water around buildings to transporting oil across continents. Accurately measuring these rates allows for detection of leaks, helps optimise the system for energy efficiency, and is used for correct taxation/billing where the fluid attracts a duty. Methods for confirming installed flow meters are operating correctly are required to ensure ongoing system performance.

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Challenge

Understanding how fluids move around pipes is vital for improving efficiency and safety – whether in manufacturing processes or in the transport of commodities such as oil and gas. But fluid flow in pipes is variable which makes measuring it hard. Better models are needed to understand how bends in pipes influence fluid flow, so that reliable corrections can be made to the flow meters used to make these important measurements.

Flow meters, which measure this fluid flow, are calibrated before installation on test benches. However once installed in a system, two challenges arise. Firstly, fluid flow characteristics in complex pipe networks such as district heating systems is very different to the ideal conditions used for calibration, as for example, pipe bends cause different fluid flow rate distributions across the diameter of the pipe. Secondly, it is not easy to remove a flow meter for recalibration.

A correction factor is applied to the flow meter measurement to offset flow irregularities. This is calculated using flow simulation models, which estimate the effects of pipe direction changes, but current simulation methods involve computationally expensive processes and lack accuracy. Better methods for understanding non-uniform flow rates would allow the reliable checking and recalibration of flow meters, improving measurements, and enabling performance optimisation.

Solution

The EMRP project *Novel mathematical and statistical approaches to uncertainty evaluation* developed new statistical models to better estimate the effect of flow disturbance on meter measurements.

Parameters such as operating pressure, temperature and pipe layout, were measured and input into fluid flow models to generate data sets. This new and faster method provides accurate estimates of system flow rates with related uncertainties using less computer processing capacity and without compromising quality.

Impact

Optolution Messtechnik GmbH, which specialises in calibrating district heating system flow meters, has used models developed in the project to create an effective calibration tool for installed flow meters. It measures fluid flow speeds by passing laser beams through a window in the pipe near the system's flow meter and measuring light interference caused by the fluid flow at the crossing point. By moving the beams you can scan flow speeds at different points across the pipe bore and generate the data on which fluid flow speed calculations are performed.

Using adapted versions of the project's fluid flow rate model in their software, Optolution have determined system flow rates under the disturbed flow conditions that installed gauges routinely experience, without interrupting the systems operation. The results their lasers generate are related to the installed gauge's measurements forming a calibration method for the installed gauge.

The introduction of the model gave Optolution sufficient confidence to apply for accreditation from DAkkS, Germany's accreditation body and enables them to offer a certified calibration service for flow meters. Once granted, Optolution expects to expand their customer base, both in Europe and to countries around the world where heated water supply systems and district heating systems are commonplace.

Novel mathematical & statistical approaches to uncertainty evaluation

The EMRP Project *Novel mathematical & statistical approaches to uncertainty evaluation* developed new robust methods to assess uncertainties for situations that are not currently covered by the GUM. Rigorous application of statistical and mathematical techniques generated 'smart' sampling to reduce computational times for processing extended data sets, and new accurate uncertainty approaches based on probability, risk assessment and decision making. Worked examples for improved product testing, safety regulations, medical diagnosis and drug testing will provide input for future GUM revisions.

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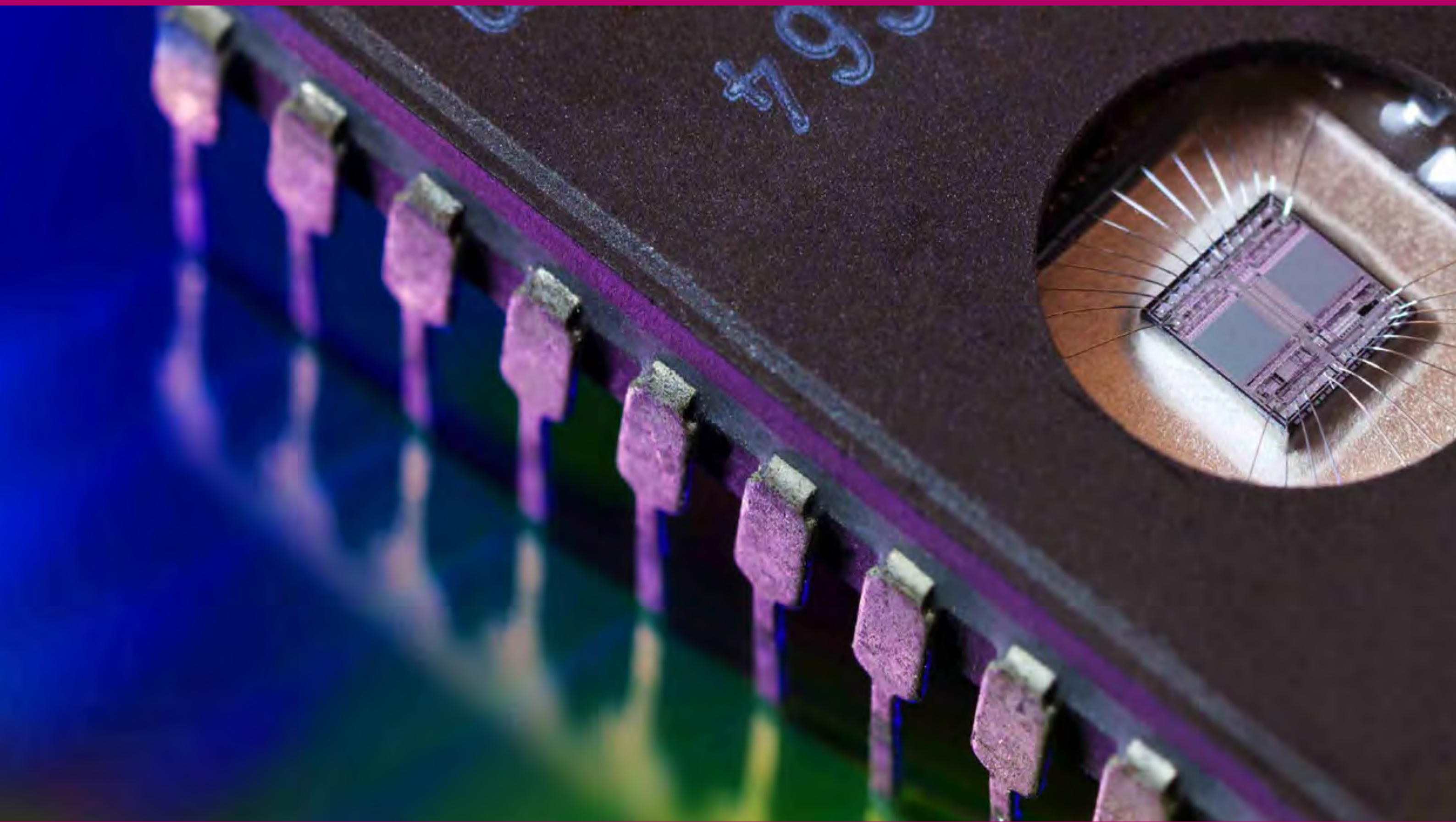

Nano-material properties

Nano materials are inspiring a new generation of products; chains of molecules acting as wires in ever smaller electronics, nano-films creating future flexible unbreakable phones, membranes with nano-holes filtering sea water into drinking water. However, their small scale means they behave in a fundamentally different way to the bulk material. To reap the benefits of new innovations, methods are needed for measuring nano-scale material properties.

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Challenge

Introducing innovative products such as novel optoelectronics based on quantum dots, nanowires and nanorods or wear resistant coating using new nanostructures relies on having confidence in how these materials behave at the nano-scale.

Understanding the strength of materials at the nano-scale as opposed to in bulk is essential. Atomic interactions may dominate nano-scale properties and being only a few atoms thick may make a material very delicate to handle. Before the world's most innovative manufacturers can start using nano-materials, they need to reliably measure nano-scale material properties.

Miniaturised materials and objects need miniaturised test methods. Atomic Force Microscopy (AFM) is a popular method for measuring nano-properties such as elasticity. It works by applying a load to a probe tip and measuring how much it sinks into the material. The tip is held in place by a tiny piece of material called a cantilever. Unfortunately cantilevers flex and compromise measurements by reducing the applied force. Greater accuracy in measuring cantilever stiffness and determining how much of the applied load is transferred to the test material are needed for calibrations of AFM used for measuring nano-material properties.

Solution

The EMRP project, *Traceable measurement of mechanical properties of nano-objects*, looked at methods for determining cantilever stiffness.

The project developed well defined nano-objects with known response to loads and used these to compare different AFM calibration methods, determining which factors have the greatest effect on measurement accuracy and how improvements can be made. Cantilever vibrations were analysed to simplify their contributions to complex calculations of the forces applied during AFM testing. The acquired measurement data was then compared to precise computer models. This allowed verification of proposed new corrections and the achievement of greater calibration accuracy for AFM measurements of nanoscale material strength.

Impact

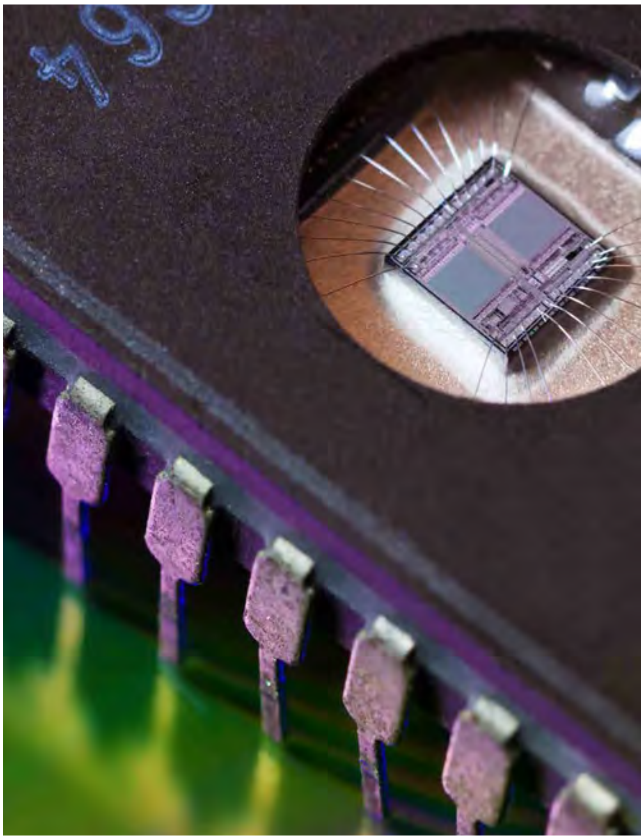
NanoWorld AG, a leading manufacturer of high quality probe tips for AFM and similar measurement technologies, used the cantilever stiffness calibration method developed by the project to bring traceability to their own CalibLever reference cantilevers.

NanoWorld's certified cantilever enables SI traceability for their own in house calibration methods, confirming the stiffness uncertainty of their commercially available AFM cantilevers, and allowing them to offer a calibration service to users. As a result, NanoWorld has increased sales of cantilevers with measured force constants to customers around the world.

Improved robustness for AFM measurements of elasticity at the nanoscale is increasing our understanding of nanomaterial behaviour in situ, so providing greater confidence in the use of nano-wires and other nano-structure innovations in new products.

Introducing traceability for nano-mechanical properties

Conventional bulk material measurement techniques cannot be used to assess nano-material properties, and existing nano-scale measurement methods lack rigour impeding uptake of novel nano-materials into new innovative products. The EMRP project *Traceable measurement of mechanical properties of nano-objects* developed methods for nano-sized specimen preparation and compared existing and novel nano-measurement techniques leading to increased traceability for nano-material mechanical properties. As a result atomic force microscopy can be confidently used to determine the strength of nano-materials and a new scanning electron microscopy tool enables users to view sub-nano mechanical testing as it's performed.



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Validating 3D measurement software

Engineering projects – from the world's tallest skyscrapers to new transport infrastructure – use complex 3D models to assess safety, efficiency and cost effectiveness. Running millions of survey data points through complex computational simulations to create these models introduces opportunity for error. To provide the confidence needed by such safety critical industries, 3D simulation software developers need standardised methods for checking programming accuracy.

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Challenge

Computer aided measurements are an essential part of engineering projects. From predicting if building components can access sites, to having confidence in the structural integrity of walls and containers, reliable 3D models are needed for critical decisions on safety, appearance, and investment.

Computer simulations turn millions of survey data points, collected from measuring these structures, into reliable models. These models rely on many different and complex subroutines. Users making decisions based on these models must trust that the programmes correctly interpret and process the input data. Mistakes can be very costly in these industries, so users need confidence that these models are performing correctly.

Developers often send their software for independent testing. Whilst this increases the chances of programing errors being spotted, there is no coherent framework for testing measurement software - developers must rely on ad hoc approaches, with no way of demonstrating that such methods provide correct results.

An independently validated, standardised method to demonstrate performance of modelling software would reduce errors and give confidence to the many engineers and manufacturers who rely on 3D structural models.

Solution

The EMRP project *Traceability for computationally-intensive metrology* has developed a validation process to prove the correctness of calculations using complex, numerical algorithms implemented in measurement software. 3D measurement software is a typical application that would benefit from this approach.

This project applies the calibration principle used for measurement instruments – using a well understood reference object to calibrate software, with the reference object being replaced by data sets.

The project developed a range of 'golden data sets' – standardised data sets and routines that match the required accuracy needed for software conformance testing. The project's TraCIM system evaluates and compares the results from the software being tested to idealised values, providing a performance certification process to confirm that test software runs properly and does not produce errors. The system is cloud based and so can be used by the software developer on their own system, making it quicker than previous third party approaches, as well as more reliable.

Impact

Technodigit, part of Hexagon AB, specialises in point cloud processing for various applications such as surveying, digital terrain modelling and civil engineering. The company has validated a new software model as a result of the project, creating a more efficient way to check the integrity of fuel or oil storage tanks at ports and airports.

Technodigit's 3DReshaper is used to ensure site safety through fuel tank storage integrity checking. This process currently requires two days of manual measurements and data manipulation. Recognising the frustrations in this process, Technodigit developed a new software module which can automatically generate the test report in two hours with minimal human intervention.

Demonstrating that the data points have been correctly analysed has been difficult, undermining confidence in a product, which customers are otherwise keen to embrace. With the TraCIM system, Technodigit has been able to check its software algorithms and receive a test report confirming these are fit for purpose.

This gives 3DReshaper user's confidence in the results and that the inspection has been appropriately carried out, speeding take-up of the software. The TraCIM system is also being used to continually assess its own in-house testing systems and software components, making it a key part of Technodigit's new product development and ensuring confidence from day one.

Novel mathematical & statistical approaches to uncertainty evaluation

Developers of software implementing complex calculations increasingly require independent testing to demonstrate that results are accurate. The EMRP project *Traceability for computationally-intensive metrology* identified calculations for a number of priority metrology applications and developed approaches and associated test data to assess the performance of software implementing these calculations. A system, TraCIM, was developed that allows mathematical software to be tested using the internet. Software developers now have a recognised route for independent product verification reducing risks associated with errors, while customers benefit from increased confidence in the software's ability to produce reliable results.

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www.euramet.org/project-NEW06

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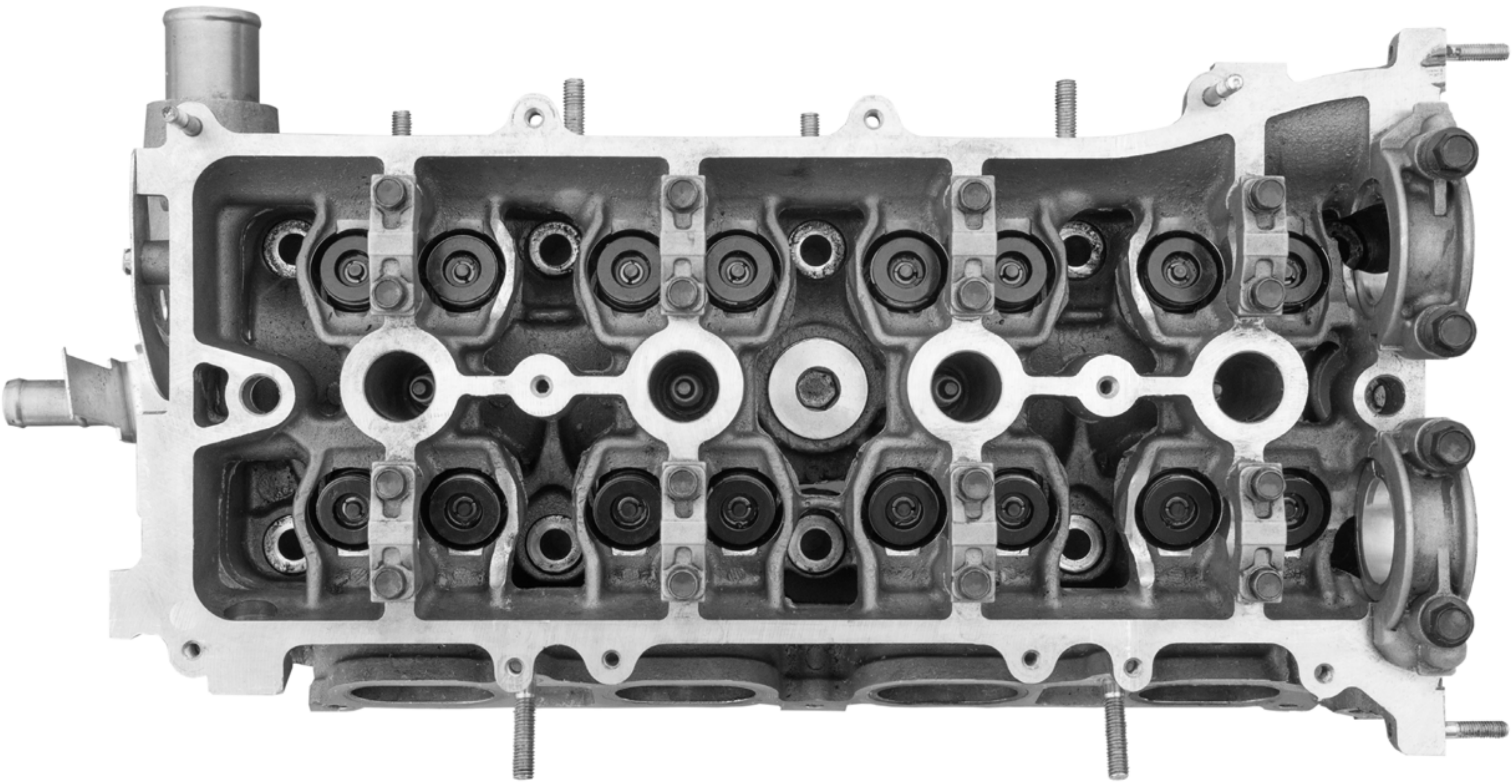


Trusting complex software

Complex software is key to analysing measurements used to assess quality. It turns huge measurement datasets into the information needed to check products, from cars to microchips, have been manufactured correctly. But such software contains vast amounts of complex code, so confirming it works as intended is extremely challenging. As products become more complex, manufacturers need greater confidence in measurement accuracy and new independent methods to verify software are required.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Modern cars must be manufactured with great precision to ensure they meet design specification. Grooves in the pistons or ripples on body surfaces affect the car's performance and appearance. Most engineering industries face similar issues, as ever greater accuracy is required to produce more precisely engineered parts.

Co-ordinate measuring machines (CMMs) measure components to check they correspond to design. A CMM runs a probe along the surface, and the machine's software turns the miniscule movements of this probe into detailed three dimensional information which can be used to determine the dimensions of the product. Manufacturers rely on software to accurately process and analyse that data.

The software is hugely complex and runs numerous statistical analyses, using multiple subroutines, to generate results. Small errors in the code can cause problems. But the complexity of the software means checking every line of code is extremely difficult. Manufacturers of CMMs – and the customers who rely on them - need new robust procedures to ensure that software works as expected.

Solution

The EMRP project *Traceability for computationally-intensive metrology (TraCIM)* has developed an internet-enabled system for verifying mathematical software; such as that used within CMMs.

This project applied the verification approach used for measurement instruments – using a certified reference object to check performance - to software calibration, with the certified object being replaced by data sets.

The project developed a range of 'golden' data sets and corresponding 'known' results to enable software validation. The data sets were created using ideal measurement results to generate accurate input data. Using these, the internet based *TraCIM Software Verification System (TraCIM SVS)* was created. This compares results generated by software under test to 'known' results and issues a test report on the degree of agreement. Users of complex measurement software now have a new tool for validating its performance or identifying routines that need improvement.

Impact

Mitutoyo, the world's leading manufacturer of precision measuring equipment, used the *TraCIM SVS* system for an independent evaluation of its co-ordinate measuring machine software.

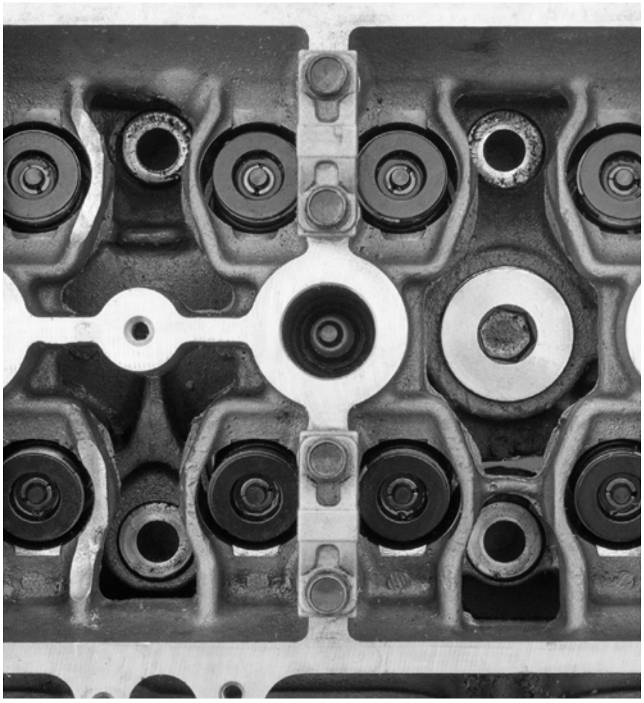
Mitutoyo has in-house methods for testing the performance of software but independent assessment is highly prized as it enables the company to demonstrate via a test report that their software is fit for use and will not generate inaccurate dimension measurements.

One of the first users of the *TraCIM SVS*, Mitutoyo downloaded the system's golden data sets and used its software to analyse them. The results were submitted for comparison with the corresponding 'ideal' results and a test report generated giving the degree of agreement between the results. The report provides independent verification of Mitutoyo's software and enables both Mitutoyo and its customers to have increased confidence in the results generated. The test report can now be used by Mitutoyo to demonstrate to customers that its software is fit for purpose.

Test reports confirming software performance provide much needed confidence to manufacturers that their products match specification, an increasingly important issue as more complex products require ever greater precision and smaller tolerances.

Improved traceability for complex measurement software

Developers of software implementing complex calculations increasingly require independent testing to demonstrate that results are accurate. The EMRP project *Traceability for computationally-intensive metrology (TraCIM)* identified calculations in a number of metrology applications and developed approaches and associated test data to assess the performance of software implementing these calculations. The *TraCIM Software Verification System*, that allows mathematical software to be verified using the internet, was developed. Software developers now have a recognised route for independent product verification reducing risks associated with errors, while customers benefit from increased confidence in the software's ability to produce reliable results.



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Safe airport scanners

Safer air travel relies on smarter security scanning to identify hidden weapons. Terahertz radiation offers high resolution detection, but demonstrating its safety to both operators and passengers is slowing wide spread adoption. Proving terahertz scanners are harmless relies on accurate power measurements and showing scans create minimal heating effects in the body. Reliable calibrations for terahertz detectors are needed to bring accuracy to risk assessments and help ensure travel security.

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Challenge

Terahertz (THz) lasers are finding new uses in non-destructive material testing and security scanning. The long wavelength radiation these lasers emit is ideal for both applications as it can pick-up near surface defects or substances hidden under clothes which pose security risks. Manufacturers of materials are keen to embrace non-invasive and non-contact detection methods that offer higher spatial resolution than existing radio frequency techniques, whilst increasing security at airports requires new imaging technology to provide more reliable passengers scans.

Devices using terahertz radiation have great potential for use in security scanning but their implementation relies on accurate assessment of any risks the radiation may pose to either operators or passengers. Relating the terahertz power to potential heating of skin is key to assessing scanner safety and relies on accurately knowing the radiation's intensity. Improved laser detector calibration and reliable ways to transfer this to the scanner production line form the first step towards ensuring terahertz scanning is safe.

Solution

The EMRP Project, *Microwave and terahertz metrology for homeland security* developed a range of complementary methods and facilities for calibrating microwave and terahertz detectors and used a modelling approach to demonstrate that the skin heating induced by microwave and terahertz radiation is not hazardous.

One method developed to calibrate units on the scanner production line uses pyroelectric detectors which give a reliable response across the entire terahertz range. Unlike other detectors these are not effected by humidity or temperature so can be operated with confidence in many different environments. This makes pyroelectric detectors suitable for taking laboratory based power calibrations to laser manufacturer's in-house equipment.

To determine any potential harmful effects from THz radiation, the project developed a modelling approach and tested its findings experimentally using gels which simulate the skin. These measurements confirmed the model's predictions of skin heating and demonstrated that terahertz radiation is safe for use.

Impact

SLT Sensor- und Lasertechnik GmbH supplies laser measurement products and manufactures the pyroelectric detector characterised in the project for use as a calibration transfer instrument. Because of using the new terahertz calibration facilities, SLT's customers can now have confidence in the accuracy of their in-house lasers power. This enables their terahertz radiation products to be accurately measured and accurate risk assessments for their use to be made. The importance of this detector was recognised through an AMA Association for Sensors and Measurement innovation award for outstanding research and development work in sensor and measuring technology. SLT are current making further upgrades to improve the pyroelectric detectors usability.

For the first time, it is possible to accurately measure terahertz laser power and ensure measurements are comparable. Access to calibrated detectors and validated models allows manufacturers of terahertz imaging technologies to demonstrate the safety of operators and the public through a traceable measurement chain. Being able to demonstrate that terahertz radiation is safe, and having confidence in the performance of lasers, will spur greater adoption of terahertz technology in security applications, health imaging and process quality control.

Terahertz traceability for security scanners

Remote sensing techniques using terahertz and millimetre waves are important for security applications such as personnel scanners and spectrometers for the detection of illegal or hazardous substances. But the development and use of these devices has been hampered by an inability to reliably measure important performance properties. The EMRP project *Microwave and terahertz metrology for homeland security* developed methods to calibrate microwave and terahertz instrumentation against SI unit definitions, and validated an approach for assessing the safety of this type of radiation. The project's techniques are being used to develop the next generation of security scanners, offering dramatically improved, fast, safe and non-invasive scanning.

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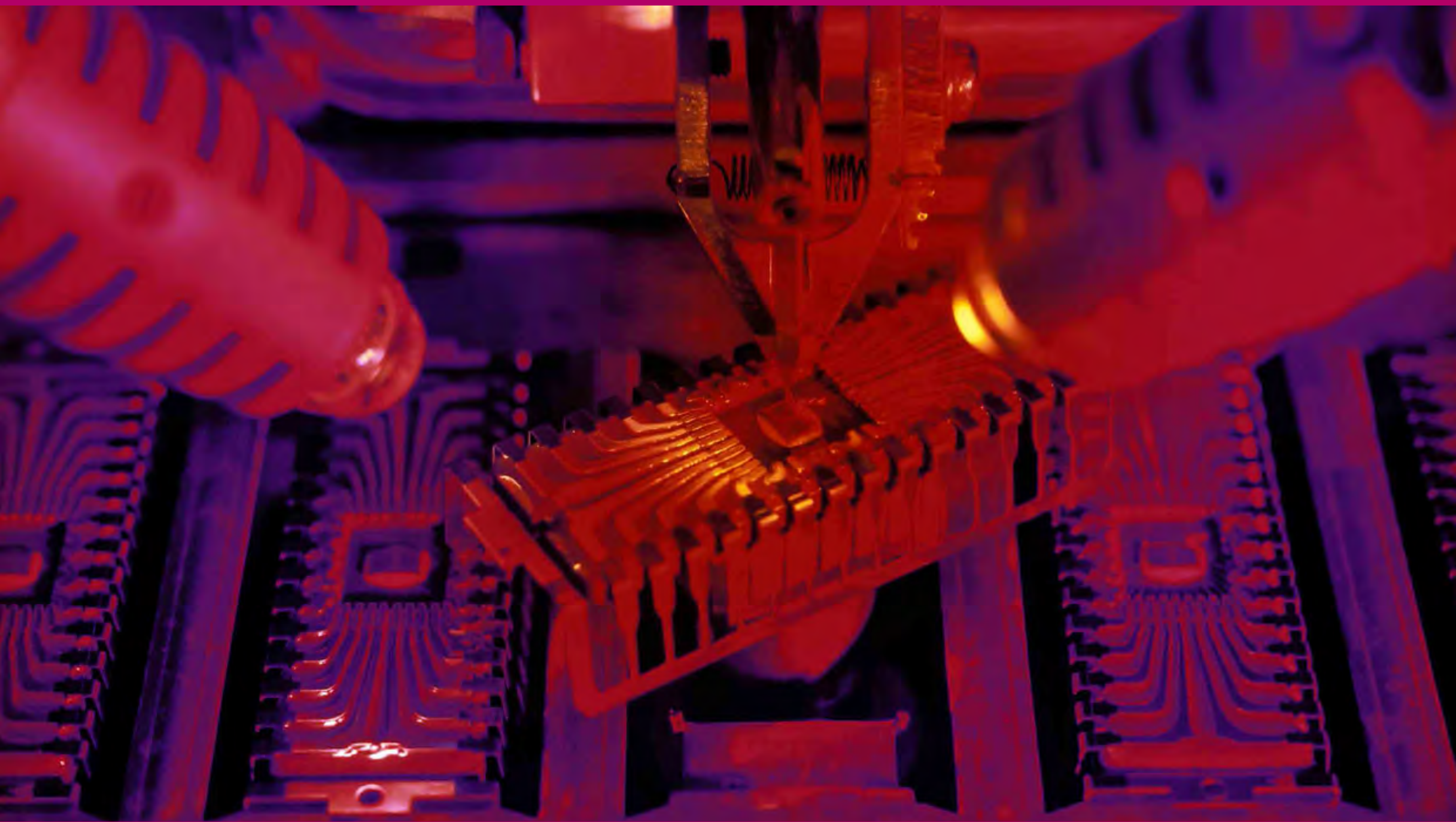

Piezoelectric innovation

Piezoelectric materials– which turn movement into electricity and vice versa – need to be able to operate at high temperatures to make new products possible such as sensors for engine testing. Incorporating new high temperature piezoelectric materials into innovative product designs relies on accurate material data underpinned by reliable methods. Developing test methods for these materials and demonstrating their accuracy is essential for increasing uptake of advanced materials into new technologies.

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Challenge

Piezoelectric materials, which convert movement into electrical signals and vice versa, are used in a wide range of applications such as gyro-sensors, and micro switches in miniaturised electronic devices. In addition, their unique characteristics make them suitable for sensing operations where continuous remote monitoring of real time systems is needed.

Many of these sensing applications require devices to perform in high temperature environments, where established piezoelectric materials lose performance. However, innovative new piezoelectric materials could offer greater precision and sustained functionality at high temperatures, but these need to be well understood before they can be used in commercial products.

For designers to confidently incorporate new piezoelectric materials into high temperature sensors they must have confidence in the devices ability to perform to specification. Accurate and robust test methods are needed to provide the rigorous piezoelectric test data that forms the basis for reliable sensor specifications.

Solution

The EMRP Project *Metrology of electrothermal coupling for new functional materials technology*, evaluated different compositions of piezoelectric materials with the aim of developing high temperature piezoelectric reference materials. One of the compositions, supplied by Leeds University, was optimised, and characterised at temperatures up to 380 °C without losing performance. This demonstrated its viability as a reference grade material suitable for use in developing new test methods and for validating the ongoing performance of material testing instruments and enables testing to higher temperatures than previously possible.

Impact

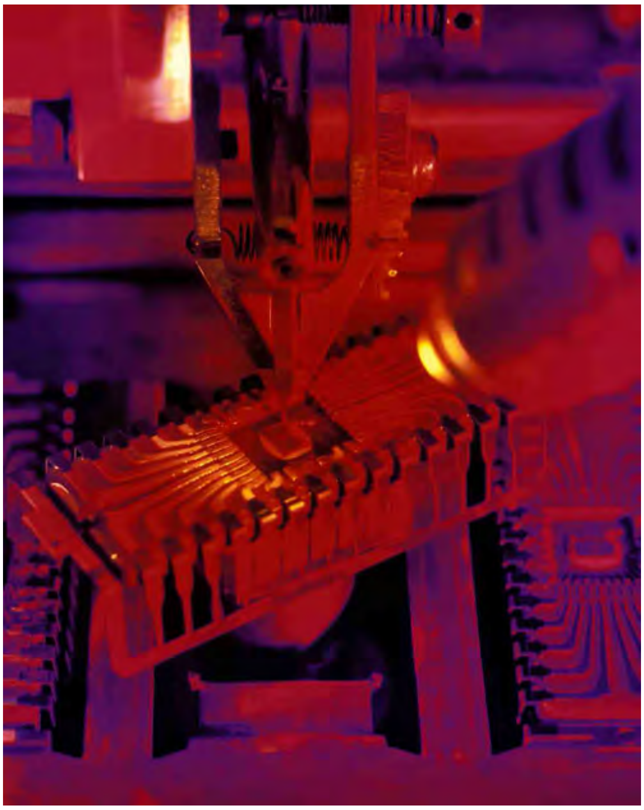
AixACCT Systems GmbH, a leading manufacturer of instruments for testing the electrical properties of materials, has improved its aixPES Piezoelectric Evaluation system as a result of using the new piezoelectric reference materials. The aixPES system's ability to measure piezo-materials across a wider temperature range was improved and AixACCT Systems now have an easy way to determine that their machines are correctly set up and measuring accurately.

The resulting accuracy improvements, and demonstration of performance at higher temperatures than previously possible, gives greater confidence in piezoelectric materials testing using the aixPES system. AixACCT's customers – testing materials for applications such as gyro-sensors, microphones and miniature speakers – will now have more reliable data to use for material specifications.

Greater certainty in how piezoelectric materials behave and increased confidence in their performance at elevated temperatures will enable product designers to confidently create new devices. Ultimately, this will enable increased uptake of piezoelectric materials into advanced devices and sensors, bringing new and improved functionality to these innovative high-tech applications.

Traceable characterisation for novel materials

Piezoelectric materials have potential applications as high temperature sensors in industrial processes whilst electro-caloric material could be used for magnetic refrigeration, so reducing reliance on propellant gas cooling in industry. The EMRP project *Metrology of electrothermal coupling for new functional materials technology* developed methods to improve thermal, mechanical and electrical property traceability for these materials at high temperatures (up to 1000 °C) or in strong electric fields (up to 5 kV/mm). Understanding how these materials will perform once installed into processes based on traceable material characterisation is a pre-requisite for the development of next generation products such as fuel flow in aero-engines or solid state cooling in the electronics industry.



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Installed sensing for power plant

Unexpected pipe failures in power plants mean unplanned shutdowns and huge costs. Installed sensors could provide ongoing information on integrity during operations, so parts can be replaced before they fail. Piezoelectric materials which turn sound waves into electrical signals make ideal sensors, but struggle at the high temperatures seen in some power plants. New well characterised materials are needed to underpin the next generation of high temperature sensors.

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Challenge

Power plant operators must reliably monitor structural integrity to ensure safety. For example, high pressure, high temperature steam can degrade and corrode the pipes that carry it. If these crack during operation, the damage and lost power generation from unscheduled shutdowns can cost millions of Euros.

Networks of sensors could be used to monitor plant degradation so damaged parts can be scheduled for replacement long before they fail. Piezoelectric materials make excellent sensors, since they produce an electric current in response to movements, such as the pressure from a sound wave. Using these materials in installed sensors could determine the extent of degradation to the pipe and enable better maintenance scheduling.

However existing piezoelectric materials lose performance above 200 °C, so when measuring hot surfaces, such as steam pipes, it is necessary to set them back from the pipe or use cooling techniques so reducing measurement accuracy. There is a need for new piezoelectric material that can operate effectively at higher temperatures, and better characterisation methods to demonstrate the viability of such materials for power plant sensing; an application where complete confidence is required before new technologies are embraced.

Solution

The EMRP Project *Metrology of electrothermal coupling for new functional materials technology*, evaluated many different new piezo-electric materials. One supplied by Leeds University, was shown to have great potential for high temperature measurements. This was further developed, tested and characterised in the project, demonstrating its suitability up to at least 380 °C without losing performance. The characterisation demonstrated its viability both as a reference grade material and also for use in installed sensors that operate at high temperatures.

Impact

As a result of the project, IONIX, a company setup to commercialise these new piezoelectric materials, has had the materials properties confirmed by the project and now has the accurate data sheet needed to prove performance.

IONIX has developed these high temperature piezoelectric materials into a new line of ultrasonic sensors for use in extreme environments which extend beyond the capabilities of existing piezoelectric materials.

An accurate material property data sheet is vital for making the commercial case to sensor customers in power plants, where the introduction of new sensors requires the demonstration of 100% reliability. IONIX can now progress to the next step in sensor commercialisation; the extensive testing of prototypes needed to obtain a licence for use in power plants.

Once licensed, the sensor will be available for monitoring power plant integrity during operation. Improved operational sensing should save considerable costs by preventing unscheduled power plant shutdowns for repair as a result of failure. The sensors also have potential for use in other hostile environments such as oil wells, reducing reliance on manual inspections in hazardous locations to identify components that need changing.

Traceable characterisation of novel materials

Piezo electric and electro-caloric materials have potential application as new high temperature sensors in industrial processes or for reducing reliance on propellant gas cooling in the electronics or automotive industries. But uptake is hampered by a lack of a traceable measurements. The EMRP project *Metrology of electrothermal coupling for new functional materials technology* developed the required capability to improve thermal, mechanical and electrical property traceability for these materials at high temperatures (up to 1000 °C) or in high electric fields (up to 5kVmm-1). Understanding how these materials will perform once installed into processes based on traceable characterisation techniques will help the development of next generation products.

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Better industrial insulation materials

Insulation materials play a vital role in reducing heat loss in high temperature processes, such as steel production and oil refining. Energy use can represent up to 75 % of costs for some petrochemical processes, so keeping heat in the system is vital to cost saving, energy efficiency and competitiveness. To ensure the best materials are selected for the job, there is a need for increased rigour in demonstrating thermal performance.

Challenge

Many production industries, such as steel and glass manufacture and petrochemical refining, run processes at high temperatures, requiring high energy consumption. Insulation materials are needed to minimise heat loss throughout the system.

All such materials need certification to confirm their insulation properties. Certification is underpinned by testing in authorised laboratories, which use rigorous quality assurance criteria laid out by the EN ISO/IEC 17025 standard. The assessment of the thermal performance is carried out using a Guarded Hot Plate method, where material is heated from one side and thermometers measure the temperature difference through its thickness under steady-state conditions. Conventional insulation materials can then gain a CE mark, confirming they meet harmonised European standards in this area, and new materials such as polymers and aerogels which are not covered by the CE mark scheme, can demonstrate performance specifications through reliable data.

Comparison exercises show measurement variation between laboratories of up to 15 %. This is down to two major sources of error: a lack of homogenous reference materials to make comparisons, and the tendency of rigid samples under test to bow as a result of heating. Improved reference materials and testing approaches would bring certainty to accreditation labs across Europe, and ensure confidence in the properties of insulating materials.

Solution

The EMRP project, *Metrology for thermal protection materials*, investigated sources of measurement error during insulation testing, and devised new approaches to improve thermal measurements.

A new testing regime was developed which overcame the bowing issue by using smaller samples which all stay in contact with the hot plates. The project identified and characterised calcium silicate as a suitable reference material, with stability up to 650 °C. Fifteen identical samples were developed and used in a comparison exercise of Guarded Hot Plate apparatus performance between different laboratories to identify and remediate sources of variation.

Impact

Forschungsinstitut für Wärmeschutz e.V. München (FIW), an accredited German testing and certification body for thermal insulation products with clients around the world, participated in the project comparison. Using the project reference materials FIW could internally compare its Guarded Hot Plate apparatuses, identifying and eliminating uncertainties, and ensuring all delivered the same measurements with robust links to the SI.

This gives its customers greater confidence in FIW's test reports and certificates, which are used to gain the CE mark for some classes of insulation material. For manufacturers of new materials, they receive greater confidence in the specified properties of the material, helping them develop and assess new insulating products.

All of which brings greater confidence around how by conventional and innovative insulating materials will perform in service. This will help bring new products to market and help manufactures make informed choices to reduce heat loss, and therefore energy use and associated costs, for high temperature processes.

Meeting EU regulations on thermal insulation

Advances in thermal insulation offer industries working at high temperatures such as petrochemical or steel production a range of engineering improvements, including greater energy efficiency, but to confidently introduce new insultation materials more accurate characterisation methods are needed.

The EMRP project *Metrology for thermal protection materials*, investigated the routinely used "guarded hot plate" method for measuring thermal conductivity, and extended the traceability of the temperature range covered by this method to 650 °C. The project also validated a new reference material for use in instrument calibration and investigated materials used in constructing guarded hot-pates, the performance of associated sensors and the test sample set-ups used. This resulted in best practice guidance for improving thermal insulation material measurement accuracy and supports manufacturers demonstrating products comply with the European Construction Products Regulation.

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Seeing the light

Many sensors in ICT, earth observation and healthcare applications rely on photodiodes to measure light. Europe is one of the world's largest photodiode producers, providing precision sensing capabilities to these cutting-edge industries in a global market projected to double in value to 766 m€ by 2026. To maintain Europe's leading position, advances in photodiode technologies are needed to support their uptake into new applications requiring greater precision in light measurements.

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Challenge

The European Commission has identified optics as a 'key enabling technology' essential for supporting a wide range of advanced research and cutting-edge technical industries. ICT and healthcare applications are amongst those requiring more sensitive light measurements as existing approaches reach their physical limits. Photodiodes convert incoming light into an electrical signal which can be easily measured and are critical for many applications, from adjusting display screen brightness as lighting levels change, to X-ray imaging for security and healthcare, to satellite earth observation measurements supporting climate studies.

Photodiodes are also used in research where accurately assessing light intensity is important, including experimental setups for realising the candela, the SI unit of luminous intensity. Further advances in these methods are needed to improve its transfer to users needing highly accurate calibrations optical instruments.

Silicon photodiodes, commonly used in research and industry, are reaching their efficiency limits, so new design approaches are being explored to improve sensitivity to small changes in light intensity. Currently only 60-80 % of light is captured by the diode and converted into a useful signal, the rest is lost as reflections from its surface. For Europe to continue to be a leading player in this area of optics, it must investigate and develop new photodiode technologies to remain competitive.

Solution

The EMRP project *New primary standards and traceability for radiometry* developed a new 'black silicon photodiode' which captures almost all incoming light, providing much more accurate light to electrical signal conversion.

Building on a highly efficient photodiode developed in a previous project, researchers devised a three-dimensional treatment which effectively does not reflect incident light. As a result, the photodiode now captures and convert 96 % of light arriving at the surface into electrical current across a wide range of wavelengths. Its high sensitivity makes it viable for constructing a Predictable Quantum Efficiency Detector needed for improving experimental set-ups for realising the candela. A patent has since been granted for the black silicon photodiode, which is considered a breakthrough in light detection.

Impact

ElFys Oy, a new spinout from Aalto University in Finland, is now commercialising the black silicon photodiode, which was launched in 2018 and has already won early customers in airport X-ray security imaging. The company is run by researchers from the project who have extensive experience in developing photodiode technology, including the black photodiode itself.

ElFys is able to tailor the photodiode to different customer requirements and anticipates significant interest in many other areas. The company has received development funding from the national Finnish support program for SMEs, and from the European Space Agency. The latter is interested in its potential for improving the resolution of satellite imaging, for example those used to measure light reflected from the sea, a major metric for assessing the impact of climate change.

The photodiode, an innovation in measurement science, is set to have significant commercial potential in a wide range of cutting-edge industries and research applications. Its commercialisation will play a key role in ensuring Europe remains a leading global player in optical technologies, and support the many industries that rely on them.

Improving SI links for light intensity measurements

The EMRP project, *New primary standards and traceability for radiometry*, developed and validated two new primary standards for radiometry, one that operates at cryogenic temperatures with very high accuracy, and a second for use at room temperature that can, for the first time, be easily used by calibration and testing laboratories. This was used to calibrate industrial light intensity sensors and achieved the required 100 ppm uncertainty goal for significantly shortening the traceability chain to the Candela for this type of device. Project research will help the European photo-sensor industry grow its global lead, in an industrial sector where it contributes 30% of light measurement devices in a total global market worth €23 billion.

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www.euramet.org/project-SIB57

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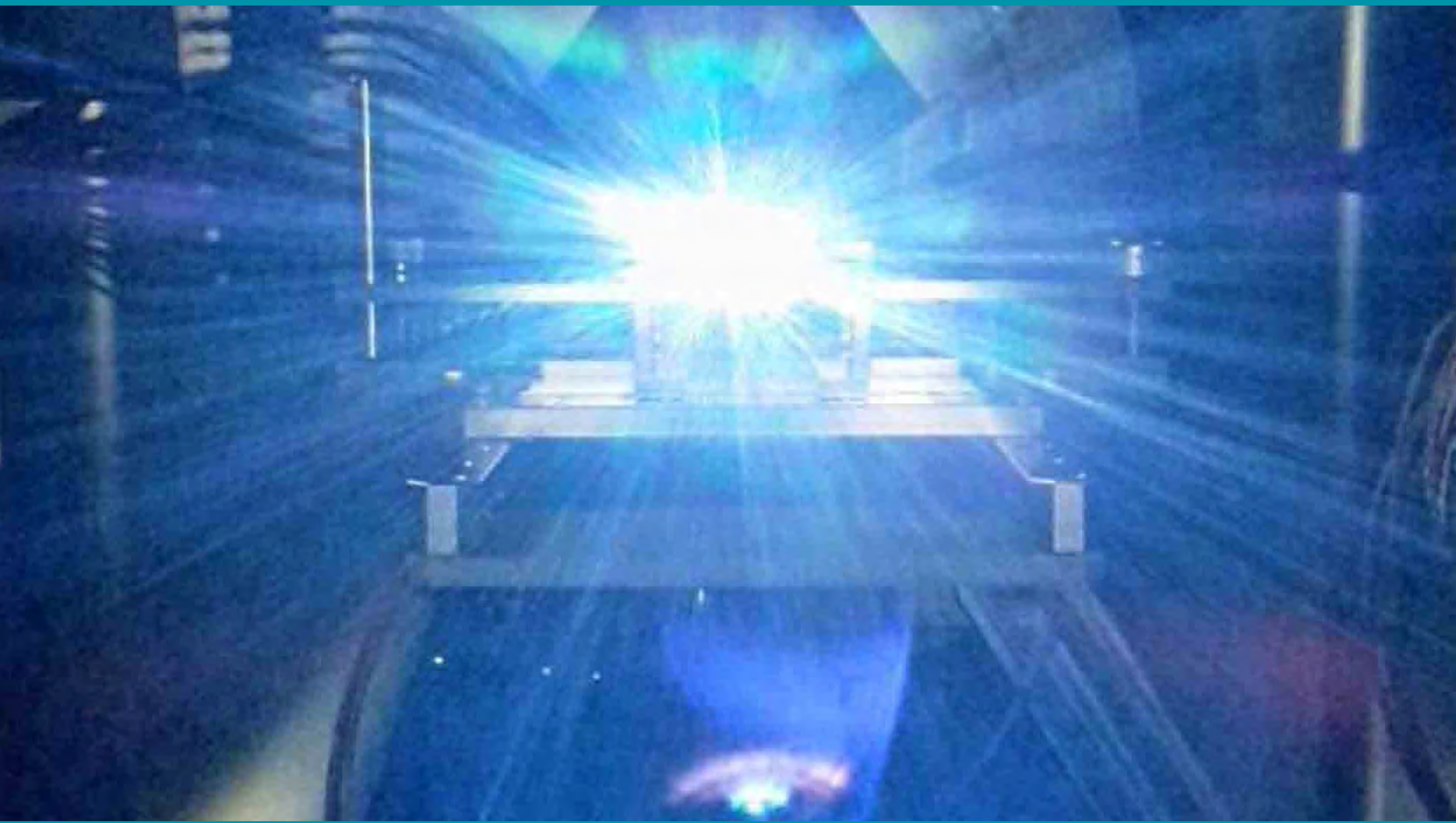

Assessing complex optic performance

To understand the properties of new materials, from medicines to nano-electronics, high energy photon beams are used to probe their molecular structure and atomic interactions. For meaningful results, photon beams must be accurately focused and controlled. This requires precisely curved optics and mirrors with perfectly smooth surfaces – pushing manufacturing processes to their limit. To verify these optical surfaces are free from nanoscale errors, measurement capability limits must be extended.

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Challenge

Academic or industrial researchers studying new materials and chemicals – such as those for pharmaceuticals and next generation solar panel films – are allocated beamtime at synchrotron or Free Electron Laser (FEL) research facilities where high intensity, focused infrared, ultraviolet, and X-ray beams can probe a material to generate knowledge on its structure and properties.

To provide images or an absorption spectrum while studying new materials, live-cells or chemicals, photon beams must be very precisely manipulated using complex optical components. Labour intensive and time consuming to produce, these must operate at the limits of existing manufacturing and measurement capability. Assembled from multiple parts, precisely aligned and highly polished, optical components must not contain any imperfections larger than 1nm or optical distortion will occur affecting research results. This is equivalent to having a 40 km road with no bumps larger than the diameter of a human hair.

Confirming that these optics meet specification relies on facilities performing highly precise acceptance test measurements where the required accuracy is close to the error margins of instruments used. Nearly 30 % of tested components fail these exacting tests. Autocollimators are optical instruments which measure angular displacements of reflecting surfaces and are frequently used to identify nanoscale irregularities in complex optic components. Improving the accuracy with which these instruments can measure tiny defects will help ensure research beamlines operate as designed.

Solution

The EMRP project *Angle Metrology* developed a new centering device, ACenD, for precisely positioning small apertures with respect to the autocollimator's optical axis during calibration and measurement. This ensures that calibration values can be used to correct autocollimator measurement results obtained with the same aperture setting. The project also investigated the use of a 'shearing method' – a mathematical analysis approach – that significantly improves error determination and compensation for autocollimators. These developments have increased autocollimator measurement accuracy, an important requirement in the assessment of complex optical components used in research beam lines.

Impact

MÖLLER-WEDEL OPTICAL (MWO), part of HAAG-STREIT, manufactures advanced optical testing instruments suitable for assessing the complex components used in research beamlines, and is commercialising the project's ACenD aperture centering device. One of the first users of this device was the Helmholtz Zentrum Berlin (HZB). This institute is responsible for acceptance testing of near-perfect optical components, including the world's most precise mirror for the new European X-ray Free Electron Laser Facility (XFEL) in Hamburg, Germany in addition to their regular work on their own beamlines.

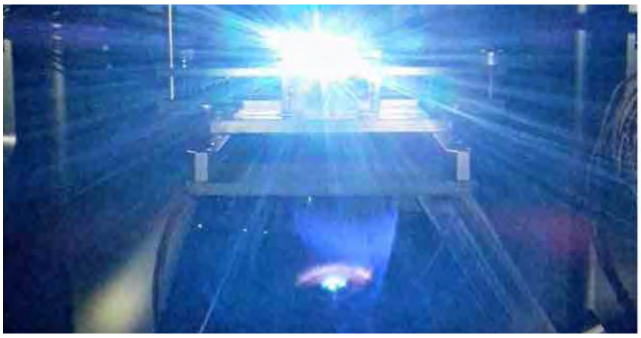
Another early user of the ACenD device is the Diamond Light Source, which operates the UKs national synchrotron light source to provide high intensity X-rays for applied and fundamental research. They conduct their own acceptance testing of optical components and have also introduced the project's 'shearing method' for assessing the performance of their new nano-angle generating device and for calibration of autocollimators used to investigate complex optic components. This improves confidence that beamline components can fulfil their extremely demanding requirements.

Project improvements to accuracy and calibration help instrument manufacturers, such as MWO, to supply the highly precise measurement tools and their users at advanced facilities to reliably assess complex and expensive beamline components against onerous specifications. This is key for generating reproducible results in fundamental beamline material research as well as improving their capabilities.

Improving precision angle measurements for x-ray optical components

The EMRP project *Angle Metrology* improved the precision of angle measurements and developed devices for checking the quality of complex optical components used in fundamental research at Synchrotron and Free Electron Laser (FEL) facilities and also the angle encoders that control industrial robotics and automated machine tool movements.

Project results include new calibration methods now published in two EURAMET calibration guides; one on angle encoder calibrations important for robotics, and another on autocollimators performing surface profile measurements. For the first time 2D autocollimator calibrations are possible that meet requirements for inspecting highly curved optical surfaces. Whilst project investigations into angle encoder performance produced a self-calibration method for the fast and precise in-situ calibration of multi-head encoders so improving robotic machine tools movements.



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Precision robotic movements

Manufacturers of cars and planes rely on automated industrial robots to assemble parts with great precision. The EU produces 30 % of these robots - an industry which generates 140 billion euro and employs 2 million people. To stay competitive, as manufacturers develop smaller and more precise parts, the robotics industry needs to measure 3D movements with increasing accuracy in order to develop more precise motion control.

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Challenge

Precision manufacturing industries, such as aerospace, mechanical engineering, and automotive all rely on automation to produce quality products. Industrial robots making complex movements in 3D follow engineering designs to manufacture and assemble parts on the production line.

Robots are fitted with angle encoders, devices used to convert the angular position of a rotating shaft into an electrical signal. To ensure correct assembly, robotic arms must move through pre-described angles around rotating shafts, in a three-dimensional environment. Software delivers the required instructions according to the design need, as a series of small electrical signals. These signals are processed by controllers and matched with angle encoder's, to drive the motors that translate them into the precision robotic movement required.

As manufacturing requires ever greater automation precision, angle encoder design and calibration must also develop greater accuracy. A particular challenge for angle encoders is that their angle measurement performance is heavily influenced by the rotation errors of the mechanisms that they are fitted to during calibration and use. An understanding of this and other sources of potential errors would improve measurement practices and support the development of the greater angle encoder precision demanded by the robotics and automation industry.

Solution

The EMRP project, *Angle metrology,* investigated performance and sources of measurement error for angle encoders to increase knowledge on the factors that affect calibration and operation, thereby improving traceability to the SI unit for angles – the 'radian'.

This included a focus on emerging multiple scanning head angle encoders and the development of a self-calibration method for the fast and precise in-situ calibration of multi-head encoders with optimised numbers of reading heads. This method was validated using computer simulations and does not rely on external reference standards. The project also investigated various methods for calibrating angle encoders and identifying sources of measurement error. The measurement best practice information generated is now available to users as a EURAMET calibration guide for angle encoder calibration.

Impact

Fagor Automation, a manufacturer of machine automation technologies – in a collaboration with non-profit technology centre IK4-Tekniker – has used project knowledge and understanding to design and commission a new angle encoder assessment machine fitted with a special multiple reading head angle encoder. This new test machine acts as a reference device and uses the project derived self-calibration principle to achieve more precise calibrations for Fagor Automation's angle encoders. Fagor Automation have also developed new software for assessing calibration result spread therefore increasing confidence in measurement results.

With these improved assessment tools, Fagor's R&D department can better evaluate the performance of new and improved prototype encoders. This is enabling the company to develop angle encoders with increased accuracy and improved repeatability, leading to a 100 % improvement in product performance. These advances in angle encoder precision will allow robotics companies to develop the more precise 3D movement capabilities needed to underpin the next generation of automated machine tools. Providing greater precision for robotic arms carrying process tools, such as those used for cutting, drilling, welding, or spraying paint, has the potential to boost the competitiveness of Europe's major manufacturing industries.

Improving precision angle measurements for industrial applications

The EMRP project *Angle metrology* improved the precision of angle measurements and developed devices for checking the quality of complex optical components used in fundamental research at Synchrotron and Free Electron Laser (FEL) facilities and also the angle encoders that control industrial robotics and automated machine tool movements.

Project results include new calibration methods now published in two EURAMET calibration guides; one on angle encoder calibrations important for robotics, and another on autocollimators performing surface profile measurements. For the first time 2D autocollimator calibrations are possible that meet requirements for inspecting highly curved optical surfaces. Whilst project investigations into angle encoder performance produced a self-calibration method for the fast and precise in-situ calibration of multi-head encoders so improving robotic machine tools movements.

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European Metrology Research Programme
Delivering Impact

Improving sub-nanometre accuracy

Semiconductors, bio-materials and other nanoscale innovations rely on the precise production of miniscule features. Verifying that these have been reliably reproduced requires advanced analytical instruments and highly accurate microscopes working at the forefront of measurement capabilities – an area where Europe is world leading. To maintain Europe's competitive edge, as features get even smaller, new sub-nanoscale reference standards are needed to demonstrate the accuracy of current and next generation instruments.

Europe's National Measurement Institutes working together

The European Metrology Research Programme (EMRP) brings together National Measurement Institutes in 23 countries to address key measurement challenges at a European level. It supports collaborative research to ensure that measurement science meets the future needs of industry and wider society.

Challenge

Innovations in nanotechnology are producing novel materials with unique properties, such as the functionalised surfaces that are spurring the development of a new generation of electronics. Verifying that these nanoscale innovations perform as designed relies on measuring their features with sub-nanometre accuracy.

Ultra-high-resolution Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM) and optical techniques such as confocal microscopy and interferometry are used to assess height changes across surfaces and distances between features with nanometre accuracy. Calibrating these instruments and confirming their performance currently relies on using reference standards with physically machined ridges, but these can only be manufactured with steps down to 6 nm. This is fine for now, but existing machining techniques cannot produce ridges small or precise enough to confirm the further advances in microscope precision that will be available in next generation nano-technologies.

New reference standards are needed based on sub-nanometre length standards to characterise microscopes with this level of precision. Using the fundamental properties of crystals, such as the distance between atoms, could provide reliable measurement standards at this scale. However, constructing such standards requires the development of reliable production and rigorous characterisation methods.

Solution

The EMRP project, *Crystalline surfaces, self-assembled structures, and nano-origami as length standards in (nano)metrology,* investigated different types of materials and assembly methods for creating sub-nanometre structures and prototype dimension standards.

This was achieved by taking advantage of fundamental properties of nature that create regular, predictable crystalline structures. In creating these standards, project researchers focussed on extending the use of low-cost production methods based on technologies routine in the semiconductor industry. By using silicon crystals, and controlling environmental conditions during crystal formation, they created small regular steps of less than 0.3 nm spacing.

The so-called 'staircase' standards are 20 times smaller and 10 times more accurate than existing reference standards. These will now undergo evaluation by the international measurement community to confirm their links to SI units, and assess their suitability for industrial use.

Impact

Sensofar, develops high-end optical measurement instruments, and was one of the first users of the project's novel step height dimension standard. The company used the staircase standard to explore the limits of its current microscopes and to support R&D for new ones.

This will help Sensofar future-proof their business, demonstrating that their products exceed client expectations, whilst also helping them create and validate a new generation of ultra-high resolution measurement tools for emerging nano-technologies. Once the staircase standard has been validated for wider industrial use, other instrument manufacturers will also benefit from being able to accurately characterise more precise instruments.

The resulting improvements in sub-nanoscale measurements will support the development of ever smaller innovations in electronics and other nanoscale applications, such as the creation of nanoparticles and carbon nanotubes, which are of great interest to the environmental and health sectors.

Improving dimensional measurement accuracy at the nanoscale

The advanced electronics industry continues to push the limits of component miniaturisation, but assessing production quality at the nanoscale requires well-calibrated test equipment capable of performing measurements accurately.

The EMRP project *Crystalline surfaces, self-assembled structures, and nano-origami as length standards in (nano)metrology* developed novel dimensional reference standards, based on self-organizing crystalline and molecular structures, for the calibration of instruments used to measure the dimensions of advanced nanoscale electronic components.

Nanostructures formed from silicon crystal lattices, polymer chains or DNA sequences were investigated, their regular lateral and step height features exploitable as nano-dimensional standards. Once fully approved for calibration purposes, manufacturers of test equipment for the electronics industry will be able to offer improved measurement accuracy at the nanoscale.

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Delivering Impact

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Demonstrating building material safety

Materials used in buildings and bridges need to withstand extremely large loads, whilst being subject to design and cost constraints. This relies on demonstrating that materials meet anticipated in-service loading within a required safety margin. Testing conducted at high loads confirms this, but improved accuracy with robust links to SI units and methods for monitoring that loads have been reliably transferred to test samples are needed to underpin public safety.

Europe's National Measurement Institutes working together

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Challenge

The safety and stability of buildings, bridges, and wind turbines relies on having confidence in the strength of the construction materials used. At the same time, materials are subject to cost and design constraints, which introduce the need for performance testing using similar loads to those likely to be experienced in-service. Demonstrating material strength and stability under these conditions relies on testing machines capable of applying extremely high loads. These large non-transportable test machines are permanently installed in industrial laboratories but require robust links to the SI units. Consequently, there is a need for a 'transfer device' able to relay SI unit links from calibration facilities at National Measurement Institutes to industrial users of installed and non-transportable high load testing machines.

Transfer devices based on several transducers – devices which convert force to an electrical signal – require individual calibration up to their maximum operating load. However, when used together in transfer devices they may operate beyond this range. Therefore, a good understanding of their performance when loading limits are exceeded is needed. In addition, NMI calibration conditions are tightly controlled unlike operational conditions in industry, where greater temperature and humidity fluctuations can occur and effect transducer accuracy.

Solution

The EMRP project *Force traceability within the meganewton range* investigated how transducer performance is affected by varying environmental conditions, such as ambient humidity and temperature. Using these results, the project generated statistical models to predict transducer behaviour. Software was also developed to allow transducer users to apply environmental corrections to measurements. In gaining a better understanding of transducer performance, the project was able to develop better high-load transfer device calibrations and to establish best practice for their use.

To further improve high-load testing for construction materials, the project also investigated different transducer designs to understand how these affect performance and load-limit. This led to the discovery that the most accurate transducers are compact in both size and shape.

Impact

GTM Testing and Metrology GmbH, a company that manufactures transducers for a range of engineering and testing industries, have used developments from the project to improve their transducer designs, reducing their diameter and weight to make them more suitable for use in high load measurement systems. GTM were also able to integrate project knowhow into the transfer devices they manufacture for customers requiring high load testing. As a consequence, GTM customers can have increased confidence in reliably monitoring the performance of their high load testing systems with improved links to SI units.

The project results are helping to improve construction material testing and strengthen industry confidence that materials will perform as expected in service. This will support improved building stability and integrity during extreme loading events, such as high winds. By providing a better understanding of the load carrying capability of materials, this project is also enabling industries to improve designs and reduce costs without comprising on safety standards.

Improving accuracy for high load measurements for industry

Large-scale structures, from high-rise buildings to wind turbines, must often withstand considerable loads, with EU directives on structural integrity and construction material testing designed to ensure safety under all conditions. Large material testing machines use "build-up systems" for calibration at the highest loads. Extension to the operating range and performance investigation for transducers used in these transfer standards is needed to ensure accuracy at the meganewton loads used.

The EMRP project *Force traceability in the meganewton range* investigated various build-up systems – including a novel hexapod design – and their component transducers, enabling the introduction of calibration improvements and extending the loading range to 50 meganewtons. For industries subject to EU Directives on construction materials, users of high load material testing machines can now benefit from greater measurement accuracy when required to demonstrate compliance for safety.

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Testing for safer suspension systems

Spring-loaded mechanisms used to dampen unwanted movement are used in civil engineering and transportation. For example, devices are often used in rail carriages to provide smooth travel at high speeds. To confirm spring-loaded mechanisms are fit for purpose and meet European safety standards, they must be tested with high loads that simulate in-service conditions. Improved testing methods are needed to provide the reliable measurements that underpin public safety.

Europe's National Measurement Institutes working together

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Challenge

Many civil engineering and transportation projects require devices that can dampen vibrations and absorb shocks. Spring mechanisms can be used for this purpose and are commonly found in applications ranging from high-rise buildings to car suspension systems. Railway carriages, for example, have spring damper systems placed between the axle and the undercarriage. These allow the entire train to travel smoothly at high speeds and also ensures passenger safety by maintaining contact between the carriage's wheels and track.

Mechanisms used to limit unwanted movements, whether preventing buildings swaying during earthquakes or carriages moving at speed along tracks, play a vital role in ensuring public safety and must be tested for their ability to withstand the considerable forces experienced in service. A problem with testing springs is the distortion caused to their shape as they are squashed. This can significantly change the way test loads are applied leading to inaccurate results. Any mis-alignment of the test machine is amplified by spring distortion during testing. This creates a major source of measurement error. Reliably assessing spring performance requires improved methods for monitoring test machine alignment.

Large machines capable of providing testing at the extremely high loads anticipated in use cannot be moved to calibration labs for performance confirmation, so devices are required to transfer links to the SI units to them. Greater accuracy in the calibration of these devices and ways to assess any machine mis-alignments are needed to ensure high load testing provides reliable results to underpin safety assessments.

Solution

The EMRP project *Force traceability in the meganewton range* developed a novel high-load measurement device based on six transducers, instruments that convert force to an electrical output, arranged to record all the forces that operate during spring testing. To establish robust links to SI units, this hexapod's performance was validated by comparison to another well-characterised high-load measurement transfer device. By using the hexapod it is now possible to check the alignment of machines used for high load testing and to measure forces acting in other directions to that applied by the machine during spring testing.

Impact

EasyDur Italiana, manufactures high load test machines for assessing the performance of springs used in the automotive and rail transport sectors. They are already preparing the hexapod for commercialisation to give their customers a reliable method for confirming test machine alignment and calibrations on an ongoing basis. For the first time it is now possible to reliably assess the effect of the side loading experienced by springs in service. As a result there is now a method for manufacturers of springs used in rail carriages and the train operators that provide a public service to rigorously demonstrate that their springs conform to European safety standards for suspension systems.

Many areas of civil engineering and transportation rely on spring loaded mechanisms to dampen movements. These will now be able to demonstrate that device and material performance meet the safety standards required by EU Directives so helping to sustain Europe's impressive safety record.

Improving accuracy for high load measurements for industry

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Accuracy for moisture measurements

Many industries need to measure and manage moisture content in their products, examples include paper, food and pharmaceuticals. In the paper industry, quality is governed by water content and therefore drying processes must be accurately controlled. In Finland, over 20 % of their economic output comes from forestry industry products, so therefore developing greater accuracy for measurements of moisture content during production is important.

Europe's National Measurement Institutes working together

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Challenge

Measuring the moisture of many different products, such as pulp, board and paper, is vital for manufacturing a quality product. Moisture content in paper effects ink uptake during printing, whilst in the production process drying consumes large amounts of energy. Paper industry products are commonly sold by weight, and therefore, their water content can lead to trade disagreements. Getting the moisture content right in this valuable Finnish export relies on reliable measurements to ensure consistent product quality.

Online sensors are used to measure moisture levels during the paper drying process. Calibrating their performance relies on comparing individual sensor results to laboratory measurements often made using the 'Loss on Drying Method'. This is a well-established method defined by international standards, where a sample is weighed, and then heated until there is no further weight loss. The difference between sample weights is assumed to reflect the evaporated water content.

However, this standardised method lacks traceability due to uncertainty around how well moisture is extracted by the evaporation process. Industry needs robust links to SI units for both the loss on drying method and for the online measurement sensors calibrated using it.

Solution

The EMRP project, *Metrology for Moisture in Materials*, developed and validated four highly accurate laboratory methods for determining moisture based on existing techniques available at National Measurement Institute laboratories – top level calibration facilities. One method uses chemical analysis (titration) and three others are based on mass and humidity measurements to determine water removal from a sample by heating. Reference materials suitable for use in diverse industries where characterised using the project measurement methods to help transfer SI links to laboratories performing routine industrial measurements using the standard loss on drying method. This is a key step in spreading measurement accuracy to industrial users.

Impact

JMK Instruments Oy, provides the Finnish paper industry with moisture measurement calibrations and, as a result of participation in a laboratory comparison exercise organised by project team member VTT, the Finnish NMI, were able to link their loss on drying method to SI units. Building on project knowledge of how to select and transport moisture samples and using VTT's improved measurement accuracy, JMK Instruments identified improvements to its sampling methods and analysis routines. As a result, JMK Instruments has achieved very reliable results and has been able to become a member of the Finnish accreditation scheme for performing moisture measurements on pulp, paper and board. Their customers will now be able to receive certificates for sensor calibrations that have international status, robust links to SI units and carrying the Finnish accreditation scheme logo.

Increasing the type of calibrations covered by accreditation schemes and introducing improved measurement traceability to SI units is important for ensuring product quality and helping to avoid costly trade disputes.

Improving moisture measurement accuracy for industry

Moisture content critically affects the quality of industrial products ranging from foodstuffs to fuels, but measurements for this parameter have lacked the traceability needed to improve accuracy.

The EMRP project, *Metrology for Moisture in Materials*, developed new techniques and reference materials to make industrial moisture measurements more accurate and provide robust traceability to SI units.

Several measurement methods and a spectroscopy-based calibration system were developed, as well as a model to investigate water absorption and transport in materials. To provide calibration laboratories with traceability to National Measurement Institutes, well-defined reference materials were also developed. Two best practice guides are now available, with end-users in sectors such as biofuels and agriculture set to benefit from the project's results.

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Improving biofuel moisture assessments

Replacing fossil fuels with biofuels, like wood chips, for district heating and electricity generation helps countries to become carbon neutral. But moisture in wood, which changes with tree species and the season, leads to weight differences and affects combustion efficiency. Inconsistencies between moisture content measurements made by suppliers and consumers can lead to trade disputes. Reducing these requires greater measurement accuracy to help increase the use of this sustainable fuel.

Europe's National Measurement Institutes working together

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Challenge

Wood chips produced from sustainable forestry are a carbon neutral source of energy for district heating and other biofuel power generation plants. Denmark is embracing this approach and aims for woody biomass to supply 100 % of district heating by 2035, as part of its goal to be independent of fossil fuels by 2050.

Wood type and seasonal weather affect the moisture content of wood chips. Buyers, who pay by the kilogram, don't want to be charged for the added weight of moisture, which also reduces energy efficiency on burning. When truckloads of chips arrive, they assess moisture content to confirm the price for each truck load is fair.

Moisture content assessment often use a the 'Loss on Drying' method, where a sample is taken to a laboratory to be weighed, heated to evaporate water, then re-weighed to establish its water content. This takes 16 - 24 hours and results can be inconsistent between different laboratories, leading to disputes between suppliers and consumers.

To establish a fair and trustworthy trade in wood chips, greater accuracy and comparability between different loss on drying laboratory measurements is needed. Longer term, methods that are rapid yet simple to use are required to accurately determine wood chip moisture content on delivery.

Solution

The EMRP project, *Metrology for Moisture in Materials,* improved the traceability of the loss on drying method by developing highly accurate techniques for determining moisture content, traceable to the SI, and then using them to characterise different reference materials. These materials were used to investigate sources of measurement error and make comparisons between highly accurate NMI methods and the loss on drying methods routinely used in the forestry industry.

DTI, the Danish Designated Metrology Institute for moisture measurements, participated in the project, and used the project developed reference materials to improve their own highly accurate moisture measurement methods. These are now available for confirming the performance of probes and laboratory methods routinely used to assess the moisture content of wood chips and other products.

Impact

HedeDenmark has sustainable forestry management contracts across Denmark and the Baltic countries and is a large supplier of wood chips for Danish district heating plants. It uses the time-consuming loss on drying method to assess moisture content and set prices. Hededenmark is now benefitting from the new reference methods available through the DTI, which create more reliable measurements and greater comparability between the moisture measurements made by different laboratories. Improving confidence in moisture content determined by the loss on drying method is key to reducing arguments between suppliers and consumers of the wood pellets used as biofuels.

The Danish Energy Agency has now granted funding for a new project investigating faster methods to assess moisture in wood chips, which will build on knowledge and reference methods developed by this EMRP project. These will ultimately allow district heating plants and other biofuel energy generators to make fast assessments of wood chip moisture content as they are delivered, confirming they are as described by suppliers, such as HedeDenmark. This will reduce delays in payments whilst disputes are settled, thereby supporting an emerging industry which is helping countries become carbon neutral.

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