Call 2021: Draft Project Summaries

Normative

Green Deal

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21NRM01 HiDyn

Support for the standardisation of luminance distribution measurements for assessing glare and obtrusive light using high-dynamic-range imaging systems

Overview

Luminance distribution measurements with high dynamic range (HDR) are required by various applications, e.g., measurement of new LED- or laser-based car headlights, obtrusive light and glare evaluation of indoor and outdoor scenes. Imaging luminance measurement devices (ILMD) and cost-effective RGB-based cameras are often used for such assessments. HDR measurements are achieved by post-processing image sequences, but standardization and uncertainty statements are usually absent. This JRP aims at developing procedures for providing with SI-traceability to HDR imaging measurement systems, a standardizing the determination of the instrument performance, including associated uncertainties, and at selecting an HDR algorithm adequate for SI-traceable luminance measurements.

Need

The complexity of the human visual system allows adaptation to extremely dark and bright lighting conditions. Due to its very large dynamic range for lightness perception (11 decades of luminance), we can safely and comfortably navigate the world, and perform tasks involving vision in lighting environments with very high luminance contrast. However, some lighting environments can be disturbing for some tasks, and it is convenient to adapt them for more adequate lighting. The evaluation of glare or obtrusive-light, and other visual aspects important for safety and comfort, rely on experiments presenting a high luminance contrast (luminance of glare sources at a few Mcd/m² beside the background of several mcd/m²). To characterize such scenes as displayed in proband studies requires measuring instruments specifically designed for these conditions. In the recent years, an increasing number of research fields and industry applications have been using high-dynamic-range (HDR) imaging technologies. However, there is currently no metrological certainty obtained with measurements performed using HDR imaging measurement systems, and glare and obtrusive light evaluations using such systems are not SI-traceable, which can lead to major shortcomings in safety and comfort for many visual activities.

It is necessary to make references available to characterize HDR imaging measurement systems, and to establish instruments requirements to guaranty traceable HDR luminance measurements as well as to demonstrate the comparability of the results. The latter includes the characterization of the stray light produced inside the camera. It is necessary to improve the estimation of the uncertainty by the proper evaluation of these sources of error. Present HDR algorithms need to be evaluated from a metrological point of view, in order to provide a recommendation, if not of a single HDR algorithm, at least of the requirements they need to fulfil for traceable luminance measurements and assessments of glare and obtrusive light.

Objectives

The overall goal of this project is to enable the traceability and characterization of HDR imaging luminance systems, and to support the standardisation of luminance distribution measurement methods, which are required for glare, light pollution, and other lighting assessments. This will involve developing HDR luminance standards required for the characterization of HDR imaging measurement systems and developing metrics and guidelines for the determination of the associated uncertainties.

The specific objectives of the project are:

1. To develop luminance standards with high dynamic contrast pattern (covering at least 6 orders of magnitude) in order to characterise the dynamic range and spectral mismatch for different types of commercial instruments that are available for luminance distribution measurements (e.g., ILMD, RGB matrix sensor cameras). This should be based on the recommendations stated in CIE 232:2019 [1].
2. To model and validate HDR luminance measurements (including non-linearity, internal stray-light, and lens flare), with the objective of reproducibly determining the input data required for

the models (average luminance, luminous surfaces, if required contrasts in the glare source, peripheral angle). To define the requirements for traceable instrumentation and to demonstrate the inter-comparability of HDR luminance measurements (in general and between different camera technologies), including the effect of its uncertainty on glare assessment.

3. To develop a harmonised metric (i.e. an algorithm) for (i) generating an HDR-luminance image from a sequence of multiple raw images and (ii) enabling traceability of relative images scaled to one or a few traceable spot measurements of the scene.
4. To develop guidelines on the determination of uncertainty budgets for HDR luminance imaging measurements of single pixels and integral values (e.g. evaluation region, illuminance) as well as glare evaluation, according to existing standards EN 17037:2019 [2], EN 13201-2:2015 [3] and EN 12464-1:2011 [4]. This should include a report on the relevance of existing quality indices and test methods regarding HDR imaging luminance systems.
5. To contribute to the standards development work of CIE TC 2-86, CIE TC 2-95, CIE TC3-57, CIE TC 4-58, TC 8-18, CEN/TC 169, IEC TC-34, and the resumption and continuation of the work of CIE TC2-59 and CIE TC4-33, to ensure that the outputs of the project are aligned with their needs, communicated quickly to those developing the standards and to those who will use them (e.g. manufacturers of RGB sensors and cameras), and in a form that can be incorporated into the standards at the earliest opportunity.

Progress beyond the state of the art and results

High contrast reference standard source of at least 6 decades (objective 1)

In this project a high contrast reference standard source of at least 6 decades of luminance will be developed, which will include several luminance levels, simultaneously presenting about 0.1 cd/m² to about 100 kcd/m² or more and in addition a light trap of <0.01cd/m². The luminance of the consisting sources will be determined with an expanded uncertainty no larger than 1 % for the brightest source and no larger than 2 % for the dimmest one. This standard source will cover the needs for testing and characterization of measurement systems with narrow and wide measurement fields via a modular design concept. It will be designed and developed to meet the requirements of luminance dynamic range for applications and measurement needs of the relevant standards and documents, like CIE 232:2019 [1], CIE 150:2017 [5].

Validation of HDR luminance measurements (objective 2)

Characterization procedures using the reference standard source and beyond will be developed. They will allow the validation of the assessment of glare and obtrusive light, and the metrological demonstration of the comparability of evaluations by different HDR imaging technologies. At least three types of HDR imaging measurement systems will be tested (ILMD, commercial DSLR, camera based on an RGB matrix sensor). The comparability of measurements by these device types will be investigated though laboratory and field tests using the characterized systems.

Harmonized HDR algorithm for traceable HDR luminance measurements (objective 3)

This project will go beyond the state of the art by developing a dedicated HDR algorithm which will include all the functionalities that are missing from existing algorithms and will serve the metrological needs of HDR imaging measurements, including the propagation of uncertainties. It will be implemented in source code that will be distributed under an open-source license.

Uncertainty estimation of HDR luminance measurements, propagation to glare and obtrusive light assessment, and relevance of existing quality indices (objective 4)

A model of the uncertainty propagation of luminance measurements and of glare and obtrusive light evaluation using HDR imaging systems will be developed in this project. It will be developed using data from the characterization of the investigated HDR imaging technologies and demonstrated with the newly developed reference standard source, and field measurements. The part of the model regarding the uncertainty propagation in glare and obtrusive light assessment will be validated using dedicated measurements in well documented lighting installations. The model will be directly implemented with the algorithm developed for HDR processing.

Contribution to standardization (objective 5)

An important progress beyond state of the art is the agreement of recommendations to scientific community. In this regard, this JRP will provide feedback for upcoming standardizations, to the chief stakeholder, CIE, by collaboration in several technical committees (e.g. CIE TC 2-62, TC 2-86, TC 2-95, TC3-57, TC 4-58, TC 8-18, JTC 12), and to other standardization bodies, such as the International Organization for Standardization (ISO), the Comité Européen de Normalisation (CEN) and the International Electrotechnical Commission (IEC).

Outcomes and Impact

Outcomes for industrial and other user communities4

HDR imaging measurement systems have been used in industry for more than 30 years for production monitoring and for the generation of ray data from luminance images. Due to the missing traceability, they were only used to analyse relative changes between consecutive HDR measurements made under the same conditions. Traceability would make HDR measurements from different measurement systems and varying conditions comparable. Industry would benefit from this traceability by a more flexible application of HDR measurement systems. Authorities currently do not assess photometric glare neither from streetlights nor from workplace lighting during daylight nor from façade shading systems, although citizens are often complaining about inappropriate installations which produce discomfort to pedestrians and disturbing glare within properties and dwellings. On-site glare and obtrusive light evaluation cannot be accomplished by relative measurement and without standard procedures and affordable measurement devices. With the results of the project, it will be possible for the first time to ensure the reproducibility and comparability of these kind of measurements, even for non-standardised measurement geometries on site.

Outcomes for the metrology and scientific communities

This project will provide tools, in the form of guidelines, open design guides and open-source software, which are all necessary for the realization of traceable measurements and for a proper assessment of uncertainty in the process of capturing, processing and combining a sequence of low dynamic range (LDR) images to an HDR luminance image, and of assessing glare and obtrusive light. These results will help NMIs to offer new characterization services for HDR imaging luminance measurement systems and to develop activities for in-situ measurements of scenes requiring a glare or obtrusive light evaluation.

The present research proposal will also, for the first time, provide a metrological basis for scientific results to be comparable and reliable, in the field of glare assessment, where there is a lack of metrological considerations. Thanks to the developed procedures and recommendations for measuring high luminance contrasts, scientists will have the tools to improve device characterization and to validate the traceability of their measurements. To support the adoption of these new tools, this project will provide examples and tutorials aimed to increase awareness of the need for reliable and traceable HDR luminance measurements as well as hands-on training in the correct handling of HDR imaging luminance meters.

Outcomes for standardization efforts

The results of this normative research project will provide the necessary conditions for the application of the latest CIE reports. Without this project, the comparison of glare evaluations based on luminance measurement using HDR luminance images is not possible. Research on glare and human vision strongly depends on the setup and characterization of test scenes with extremely high and very low luminance levels at the same time. These scenes can only be measured and quantified via imaging systems that offer HDR functionality, yet not standardized nor metrologically validated. The known deviations are too large at the moment and critically not covered by corresponding uncertainty contributions. Only a correct classification and limit definition of different camera systems based on an associated uncertainty assessment will close this serious gap. With the results of the project, it will be possible to reproducibly test the existing glare assessment models for the first time, and make recommendations for their application. This is an elementary step towards effectively combating discomfort glare. Several current TCs of CIE will benefit from the outcomes of this project and this is the reason for selecting CIE as the Chief Stakeholder. In addition, new TCs are expected to be proposed to exploit the scientific results of this project. For instance, the closed TC 4-33 (discomfort glare in road lighting) will be re-established in case the measurement procedure for average luminance and luminous area of a glare source is to be standardized.

Longer-term economic, social and environmental impact

Light pollution, obtrusive light and light emission are currently gaining enormous societal and political importance. The massive replacement of traditional lamps by LED-based light sources with much higher luminous efficacy often encounters rebound effects and, in the scope of obtrusive light, even backfires due to the enormous luminance of these new light sources. The massive insect mortality, the constantly increasing number of people suffering from low sleep quality, the climate protection-driven necessity to use light only where it is really needed - and to use high luminance points in connection with this - make indispensable a clear photometric characterisation of the outdoor lighting installations regarding their obtrusiveness and glare. However, this is only possible if a measurement technology exists for such situations to be evaluated on site. Traditional spot luminance meters are completely unsuitable for today's LED luminaires to fulfil this task since they cannot sample the complex angular distribution, plurality, and the temporal and spatial character of the outdoor light scenes. The results of this project will enable for the first time a metrologically-based field assessment of glare, which will make possible to mitigate the future risks of inadequate evaluations of glary and obtrusive situations, and therefore will have a major impact mainly on public safety but also concerning environmental protection, biodiversity and visual comfort.

21NRM02 Digital-IT

Metrology for digital substation instrumentation

Overview

Due to the wider use of decentralised renewable energy resources, future electrical power grids require real-time control and monitoring to ensure stability under more challenging conditions. Digital substation solutions according to IEC 61850 and 61869 are increasingly replacing analogue instrumentation approaching the end of their useful lifespan. To support the European electrical power industry, this project will provide yet missing solutions for calibration and timing of the new type of substation instrumentation. The project will specifically support IEC/CENELEC TC 38 in their work on revision of the related standards, with the specific aim on proposing solutions for more precise measurements.

Need

The decarbonisation of energy systems is causing significant changes in electrical power grids, due to the wide-scale connection of decentralised renewable energy resources. Future electrical power grids will require real-time capable control and monitoring systems to ensure stability under increasingly complex conditions, as well as metering systems, to ensure fair trading of electrical energy.

New standards in the IEC 61869 series address the digital communication of electronic instrument transformers, as well as stand-alone merging units (SAMUs, digitisers for analogue instrument transformers). The IEC 61850 standard series is also under constant evolution, adding new definitions for routable sampled values (SV) data to establish a truly real time wide area measurement system. These new standards boost the transition from traditional analogue instrumentation towards the new digital instrumentation technology, both on transmission and on distribution level. To support this change, relevant normative bodies are further developing their standardisation with metrological aspects in mind.

However, the calibration methodologies and metrological infrastructure for the new digital instrumentation are still missing, therefore new metrology-level facilities are needed to be able to test and to prove the performance of intelligent electronic devices (IEDs). Missing solutions for the higher sampling rates and PTP timing required by the new standards need to be developed.

Importance of the topic is highlighted in ENTSO-E new "*Research, Development & Innovation Roadmap 2020 – 2030*", where digitalisation is one of the four structural trends identified affecting the European power system of which '*digitally-enabled substations of the future*' are an important part. In addition, IEC TC 38 recognizes digital substation as one of the emerging trends related standardisation in their Strategic Business Plan. Further to this, the European Metrology Network for Smart Electricity Grids (EMN SEG) has identified digital substations in their strategic research agenda as one of the key priorities.

Objectives

The overall objective is to develop the metrology infrastructure for traceable calibration of sampled value (SV) enabled equipment such as merging units, digital instrument transformers and instrument transformer measuring bridges.

The specific objectives of the project are:

1. To **develop and calibrate reference systems (hardware) for calibration of sampled value (SV) enabled equipment**, covering the new requirements of recently released IEC standards. To develop new hardware for traceable measurement of new data rates up to 96000 samples per second, for the related measurement bandwidth up to ca. 40 kHz.
2. To **develop software for controlling the setups and handling of SV data streams** and develop new data processing and uncertainty estimation approaches for new data rates up to 96000 samples per second.
3. To **develop communication and timing networks**, in participating laboratories, by creating ethernet networks that will transmit SV data and PTP-based timing between commercial devices. To **establish traceable link between PTP timing and 1PPS reference pulse** with target uncertainty of 100 ns.
4. To provide the data, methods, guidelines and recommendations, which are necessary for the calibration of SV enabled equipment, to IEC TC 38 "Instrument Transformers". To integrate the plans for future research activities on the European Metrology Network for Smart Electricity Grids (EMN SEG).
5. To contribute to the standards development work of the technical committee IEC TC 38. Outputs will be in a form that can be incorporated into future standards at the earliest opportunity and will be communicated through a variety of media to the standards community and to end users (equipment manufacturers, transmission system operators, distribution system operators, and customers).

Progress beyond the state of the art and results

Primary reference systems for calibration of sampled value (SV) enabled equipment

Some steps towards capability to calibrate SV enabled equipment were taken in the FutureGrid II (17IND06) project. Basic calibrations of sampled value based equipment are now possible by some NMIs using their developed SAMUs, but only for basic measurements like RMS voltage and RMS current. Traceable services are limited mainly to low sampling rates (4 kSPS) using 1PPS timing protocol.

This project will extend traceable calibration services both to higher sampling (14.4 and 96 kSPS) and to equipment working on the PTP timing protocol, as required by the new standards will be provided. Services will also be introduced by partners that have not yet been able to calibrate digital ITs or SAMUs.

Control and analysis software solutions for handling of SV streams

Algorithms for calculating parameters – e.g. RMS value, ratio error or phase displacement – are typically implemented as proprietary solutions in digital substation instrumentation and related test sets. Their calibration methods have to rely on available SV data streams and separate reference algorithms, which are not available and not standardised for all parameters under non-synchronous conditions, or are not validated for new data rates up to 96 kSPS.

The work will progress in to develop new data processing schemes and algorithms to accurately characterise amplitudes, phases, and relevant power quality related parameters with complete system-wide uncertainty estimation, thus providing a firm basis for traceable calibrations. All software will be collected and documented in a reference software package that would support a comparison of developed data processing schemes and algorithms. This would enable all interested NMIs and calibration laboratories to serve the user needs in their transition to digital substations. The comparison results would further enable standardisation bodies to recommend best validated data processing schemes and algorithms for their intended use.

Timing networks and calibration method for 1PPS to/from PTP time protocol conversion

Some NMIs have recently developed calibration setups, where the device under calibration uses 1PPS as a timing source and the phase encoded into its SV stream can be compared to the 1PPS pulse front. The reference systems rely on determining the latency of reference device front-end electronics and compensating for it to produce a 1PPS aligned SV data stream. Similarly, commercial devices are required to do the same, as presented in IEC 61869-9 Annex 9B. Several methods exist for determining the required compensation parameters, and a robust implementation of reference and commercial systems already exist.

The 1PPS timing has been replaced by PTP timing protocol in the new versions of related standards. The project will develop best practices for calibration of PTP slave device timing and for verifying leap second insertion in the timing networks. As the PTP timing quality will ultimately depend on all networking components relaying timing packets, the focus will not only be on slave devices, but also by necessity on master clocks and network switches.

Outcomes and Impact

The results of the project will benefit the electrical power industry such as instrument manufacturers and grid operators and will contribute to standards especially within IEC/CENELEC TC 38 "Instrument transformers". The outcomes of the project will be disseminated to stakeholders, scientific and metrology communities as well as standardisation bodies.

Outcomes for industrial and other user communities

The project will improve, and extend, electrical power and energy metrology infrastructure to cover instrumentation with digital output for successful further innovation in development and improvement of the electrical distribution and transmission grid. Industrial end-users and stakeholders will benefit from project outputs, such as new test systems for the dynamic characterisation of instrument transformers for PQ measurements, a metrological infrastructure for calibration of stand-alone merging units, for test systems for measuring instruments based on the IEC 61850-9-2, like energy meters and all-digital PMU and from enhanced capabilities for time dissemination.

Outcomes for the metrology and scientific communities

The project will develop new and demanding measuring techniques including several important additions and extensions to CMC statements. The power systems scientific community will benefit from these new or enhanced measurement capabilities in areas where scientific information has been scant or lacking. Major scientific impact will be provided via the publication of the key project results in peer review journals and via presentations at key conferences. The project will also host two workshops which are targeted to standardisation bodies (IEC, CENELEC) and the industrial stakeholders, to foster implementation standards and grid applications in the future. Close cooperation between the partners from research institutes, instrument manufacturers and NMIs will also support this. The project outcomes will also be shared with the rest of the NMI community through dissemination activities within EURAMET technical committees for electricity and magnetism (TC-EM) and time and frequency (TC-TF). Further knowledge dissemination to the metrology community will be arranged via workshops and presentations specifically in the EURAMET TC-EM "Power and Energy" subcommittee.

Outcomes for relevant standards

This project will generate results that will be very valuable to standardisation work within IEC, CENELEC and IETF/IEEE. Liaison will be accomplished by members of the project, who are active within the respective committees. The partners who are members of corresponding technical committees will inform them about the results of this project and will endeavour to ensure they are incorporated in any updates to the standards or guidelines-

Longer-term economic, social and environmental impacts

This project supports the transition of the grid from analogue to digital control, which probably needs decades to accomplish, as large-scale replacement of equipment is necessary. The use of the new next-generation ITs and PMUs equipped substations is the prerequisite for successful integration of wide-scale connection of decentralised renewable energy sources in the high voltage distribution and transmission grid and for ensuring stability of the highly vulnerable European power grid under these increasingly complex and challenging conditions. The work will directly impact the competitiveness of European industry in their endeavours on the international market for electricity supply, by providing them with the metrology tools to unambiguously prove the quality of their equipment. This quality is one of their prime selling arguments giving European industry a decisive competitive advantage with respect to low-cost low-quality non-European manufacturers. To meet these requirements for a substantial impact in the long-term sense, the following project outputs will provide benefits to industrial end-users and stakeholder:

- Enhanced measurement capabilities to support procurement of new systems or components for the digital instrumentation in high-voltage substations. Target beneficiary groups will be transmission and distribution system operators (TSO, DSO) and major equipment manufacturers.
- A metrological infrastructure for steady state and dynamic measurements on digital substation instrumentation by providing proper calibration services. Beneficiaries will be manufacturers and purchasers of such equipment.

- Reference measuring systems for stand-alone merging units with time synchronisation and test systems for digital energy and PQ meters will be available. Target beneficiary groups will be transmission and distribution system operators (TSO, DSO) and major equipment manufacturers.
- Improved standardisation by providing recommendations for uncertainty requirements for digital low power instrument transformers to the relevant IEC TC 38 / IEEE TC39 working group.
- Improved knowledge and expertise in the European Metrology landscape in the field of testing new digital instrument transformer technology.

21NRM03 MEWS

Metrology for Emerging Wireless Standards

Overview

Key emerging wireless standardisation processes are required for Internet-of-Things (IoT), fifth-generation (5G) and sixth-generation (6G) mobile networks due to the industrial adoption of complex emerging wireless technologies. New radio (NR) signals, systems, environments and exposures need to be investigated in order to support the competitiveness of European industry. Current challenges include the lack of accurate, fast, low-cost, and traceable methods for NR high-volume product verifications against wireless standards. This project aims to develop practical and efficient metrology required by the emerging wireless standards for overthe-air (OTA) testing, for wireless channels up to sub-THz, and for radio frequency (RF) exposure assessment.

Need

The European Digital Agenda has driven the need to better exploit Information and Communication Technologies (ICTs) in order to foster innovation and economic growth. The European telecommunications industry is playing a crucial role in the development of emerging wireless technologies for IoT, 5G and 6G mobile networks. The rollout of 5G/6G networks and large-scale deployments of cellular IoT will lead to fundamental changes to our society, impacting not only consumer service but also industries embarking on digital transformations. Metrology has a pivotal role to ensure product quality and end-user confidence, and ultimately to improve the competitiveness of European Industry.

With the industrial adoption of complex NR signals and large-scale multi-antenna technologies at different radio frequency (RF) bands in emerging wireless systems, their product verifications have become very time consuming and involve complicated procedures and equipment, leading to high cost. Several international standards bodies (e.g. ETSI, 3GPP), industries, and research communities are now actively seeking improved process control on NR OTA methods (Objective 1). Also, Sub-THz wireless radio propagation channel characterisation (Objective 2) is currently an active topic being studied by ITU and IEEE standards but there is currently a lack of real-world empirical measurement data to support its R&D advancement toward 6G definitions and new product development. Furthermore, there is no reliable method to measure the RF exposure of 5G NR systems. Importantly, CENELEC, IEC and IEEE international standards are actively seeking improved process control for addressing the time-burden issue when using current RF exposure assessment methods (Objective 3). Hence, there is an immediate need for NMI-level metrology research to improve measurement capabilities to provide underpinning metrology to input to the relevant standards in order to support the competitiveness of European industry. The work proposed in this project aligns with broader European visions, as outlined in the European Commission Strategy – e.g. “Digital Single Market”.

Objectives

The overall goal of this proposed project is to support standardisation in wireless processes and R&D for the IoT and for 5G and 6G mobile networks. This JRP will establish a European portfolio of metrology capabilities with new underpinning metrology developed to meet the need on achieving internationally harmonised emerging wireless standards.

The specific objectives of the proposed project, which fully match the SRT-n06 objectives, are:

1. **To develop practical cost-effective and time-efficient NR OTA metrological methods** for multi-antenna systems (e.g. NR MIMO terminals, MU-MIMO, massive-MIMO) for sub-6 GHz and mm-wave bands. Focus will be given to the development of accurate correction techniques for practical measurement setups enabling trade-offs between measurement efficiency, and facility cost. The relevant traceability and uncertainty quantification would be established, taking into account ETSI TR 38.827, TR 38.810, and TS 38.141-2. 2.
2. **To characterise the complex real-world wide-bandwidth radio propagation channel** for practical realisation for 5G/6G communications. The experimental and numerical characterisation of sub-THz radio propagation channel and the use of band stitching techniques for wideband channel sounding will be covered as well as their traceability, channel modelling and validation. Recommendations on THz and mm-wave measurements will be made to relevant standardisation bodies and industry groups (e.g. IEEE 802.15 SC THz and ETSI Industry Specification Group on Millimetre Wave Transmission (ISG mWT)).

3. **To develop metrological methods for traceable and efficient NR RF exposure assessment** applicable to specific absorption rate (SAR) and power density (PD). Advanced methods, such as machine learning and statistical approaches will be used, respectively, at sub-6GHz and the mm-wave bands for application to versatile emerging wireless systems, to reduce cost, time and human Page 8 of 72 n06 JRP protocol P1.0 compliance tests. Recommendations on NR RF exposure assessment will be made to relevant standardisation bodies (e.g. CENELEC CLC/TC 106x, IEC TC106 MT3, ITU-T SG5).

4. **To contribute to the standards development work of the technical committees**, e.g. CENELEC CLC/TC 106X, IEEE 802.15 SC THz, 3GPP and ETSI ISG mWT, to ensure that the outputs of the project are aligned with their measurement needs, communicated quickly to those developing the standards and to those who will use them (e.g. the telecommunications industry), and in a form that can be incorporated into the standards at the earliest opportunity.

Progress beyond the state of the art and results

Operating at a higher RF is a route to achieve the promise of higher data bandwidth. A raft of NR emerging wireless technologies for IoT, 5G and beyond are becoming available. Although some key validation methodologies have been discussed in the standardisation process for production verification in emerging wireless systems their development and implementation are hampered by the lack of accurate, fast, low-cost, and traceable methods for the verification of NR beam reconfigurable products. Given the current rapid increase in their product complexity and implementation into today's wireless environment, this situation represents a serious lack of metrological support provision by the NMI community to stakeholders, i.e. standard bodies, end-users in industry and academia.

Traceable cost-effective NR OTA measurements to 30 GHz (Objective 1)

Current standard metrology for OTA radiated testing of RF conformance metrics and end-to-end performance metrics of NR systems are time-consuming, expensive and complicated. Here, this project aims to develop efficient and cost-effective OTA radiated testing metrology for RF conformance metrics and end-to-end performance metrics of NR systems at both sub-6GHz and mm-Wave bands. This project will also extend the state of the art by putting in place traceability and quantify the associated uncertainties for 5G NR conformance measurement and end-to-end performance testing. This complements the work carried out in the previous EMRP IND51 MORSE (2013 to 2016) and EMPIR 14IND10 MET5G (2015 – 2018) that included some preliminary 4G OTA studies at sub-6GHz and 5G NR signals at 30 GHz, respectively.

Traceable sub-THz wide-bandwidth radio propagation channel measurements to 750 GHz (Objective 2)

The current state of the art for THz channel sounding is up to 330 GHz and limited to measurement scenarios with a very short measurement range. There is still a lack of measurement-based knowledge of characteristics of many typical real-world deployment scenarios at different sub-THz and mm-wave frequencies. This project will extend the state of the art by putting in place THz channel sounding up to 750 GHz for both indoor and outdoor environments. This enables the industry to characterise propagation channels at these very high frequencies. This complements the work carried out in the previous EMPR IND16 Ultrafast (2011 to 2014) that include some preliminary study on indoor propagation channel between 50 GHz and 325 GHz. Novel approaches using band stitching techniques and optical cable solutions will also be explored as well as subTHz channel modelling and validation.

Traceable and efficient NR RF exposure measurements to 40 GHz (Objective 3)

The current state of the art for NR RF exposure is up to 6 GHz. This project will extend the state of the art by putting in place traceability for RF exposure measurements up to 26 GHz for NR base station, and for Absorbed Power Density (APD) measurements up to 40 GHz for mobile phone. This complements the work carrying out in the current EMPIR Support for Impact (SIP) 18SIP02 5GRFEX (2019 – 2021) that included experimentbased RF exposure study of stochastic nature of massive MIMO (mMIMO) system at sub-6GHz and EMPIR Vector SAR 16NRM07 (2017-2020) that dealt with vector array-based SAR assessment, up to 6 GHz.

Outcomes and Impact

Outcomes for industrial and other user communities

This project will enable efficient, accurate, and traceable measurements covering all aspects from the NR signals, systems, antennas, propagation environments and their exposure at a wide range of frequencies up to sub-THz. This will have a direct impact on wireless communications and electronics industries on ensuring product quality and end-user confidence. Notable examples include virtual and augmented reality, autonomous driving, remote surgery, artificial intelligence, smart manufacturing, unmanned aerial vehicles (UAV), IoT, and vehicle-to-everything (V2X).

The establishment of measurement traceability and improvement of measurement accuracy will enable the manufacturers to provide confidence in their specifications. This plays a key role in the customer/supplier relationships, for which products need to be demonstrated as 'meeting specification', regardless of who is carrying out the test or when/where the test is being performed. The outcomes of this project will allow emerging wireless product manufacturers to specify their products more precisely, leading to systems with Page 9 of 72 n06 JRP protocol P1.0 better performance. This in turn will boost the product yields for the manufacturers and potentially reduce prices for customers as well as enhancing user experiences.

This project will achieve new measurement capabilities by extending the current measurement capabilities of the participating NMIs, to 750 GHz for radio propagation, to 30 GHz for NR OTA measurements and to 40 GHz for NR RF exposure measurements. This will lead to greatly improved access to, and dissemination of, measurement traceability for European NMIs, accredited testing and calibration laboratories and the manufacturers of test instrumentation. This will be beneficial for all end-users, including customers and suppliers of emerging wireless devices and systems.

The project's outcomes will be disseminated to stakeholders and industrial end-users through:

(i) A Technical & Stakeholder Advisory Group (T&SAG), formed of members from end-user industry, standard bodies, public sector, regulator, and metrology communities. Such direct interaction will ensure the project aligns with industrial other user communities' needs and will help foster the transfer to industry of the knowledge and the developed metrological outcomes throughout the project lifetime and beyond;
(ii) Papers published in scientific conferences, and journals (including trade journals), contributions as Technical documents (e.g. Word documents, slides presentations, etc.) to standardization bodies, reporting on the research outputs from the project;
(iii) Database of sub-THz empirical channel sounding measurement data for various practical real-world scenarios made available online (which contribute new knowledge over complex real-world radio propagation channel for wide bandwidth communications);
(iv) Workshops and professional training courses focusing on measurement and traceability issues for emerging wireless technologies.

These activities will boost end-user industrial and other user communities' uptake, exploit and use of the research outputs from this project. Note that seven companies – all good representatives of the industry – will participate in this project as Unfunded Partners, demonstrating the great potential impact and relevance of the work in this project.

Outcomes for the metrology and scientific communities

Developing the emerging wireless technologies for future generation mobile communication infrastructure is a global-scale research effort. It is fully recognised that no single NMI has, or will have, the capability to deliver all the work in this project. The strategy in this project is to bring together EU-leading NMI's, industries and academics' capability in this area in order to build capability across all the partners that fully aligns with the stakeholder and standardisation measurement needs. This approach aligns with the scope of the European Partnership on Metrology, i.e. to promote collaborative research in the most demanding fields of industrial metrology going beyond the state of the art.

This project will involve five European NMIs (of these five NMIs, four can be considered as well-established NMIs with world-leading capabilities, i.e. NPL, METAS, LNE, and RISE, and one can be considered as developing NMI, i.e. CMI), which will synergise the national metrology research programmes of these five nations, along with five world-leading academic, and with seven key industry unfunded partners, who bring in their specific knowledge, and measurement instrumentation in this emerging technology for all the technical WPs. Together these provide a strong coherent consortium that will be involved in the JRP in several ways to enhance the quality of the research outputs, and, maximise the overall impact from the project. The objective is to propose changes to NMI calibration and measurement capabilities to provide the underpinning metrology that supports the European emerging wireless technology research effort and keeps the focus within Europe. During the lifetime of this project, preparatory tasks will be undertaken to subsequently establish a coordinated network of NMIs that will provide comprehensive measurement capability based on the scientific activities in this project, and, in earlier and current European projects (specifically, the EMRP projects – MORSE, Ultrafast, and EMPIR projects, MET5G, 5GRFEX, and Vector SAR).

Outcomes for relevant standards

This project will make substantial contributions to the following international standards and related documents:

(i) International standards developed by ETSI/3GPP: TS 38.141-2, TS 38.151, TS 38.161, TS 38.521-1, TS 521-2, TS 521-4
(ii) International standards developed by IEEE: IEEE 802.15.3d, IEEE 1720
(iii) International standards developed by IEC: IEC TC106 MT3 and JWG12
(iv) International standards developed by CENELEC: CLC/TC 106X
(v) International standards developed by ITU: ITU-R IMT-2020, ITU-R SM.2352, ITU-T SG5

This project will also make indirect impact on European standards being developed by European Telecommunications Standards Institute (ETSI) through 3GPP. These include 3GPP TR 38.827, 3GPP TR 38.810, 3GPP TR 37.842, 3GPP TS 38.101-1, 3GPP TS 38.101-2, 3GPP TS 38.101-4, 3GPP TS 38.104, 3GPP TS 38.141-2, ETSI EN 302 686, and ETSI EN 302 550. Progress and output from this project will be disseminated to the above standard bodies and committees, via representatives in the project consortium who are involved in these standards bodies.

Longer-term economic, social and environmental impacts

Economic: The digital economy and high bandwidth mobile communication are essential tools for wealth creation in Europe. The measurement science generated by this project will pave the way for development of emerging applications using future generation wireless network including virtual and augmented reality, autonomous driving, remote surgery, smart manufacturing, UAV, IoT, V2X and security imaging. This will enable European businesses to move into these areas with confidence and will ensure a strong competitive advantage over organisations outside the European region and attract business from global markets.

Health and Social Care: The impact of emerging wireless technologies will extend well beyond telecommunications and is increasingly underpinning all aspects of health and social care activities. This will lead to fundamental changes to our society, impacting not only consumer service but also industries embarking on digital transformations. It is envisaged to provide a universal communication environment that enables us to address the wider societal challenges, such as transport, automotive, safety, employment, health, environment, energy, manufacturing and food production. Furthermore, rigorous scientific evidence on RF exposure issues will enable effective wireless system deployment to be supported that balances user experience and public safety.

Environment: Space radiometers play a key role in Earth monitoring, which provides information about global climate change and weather forecasting. This project will facilitate more accurate and traceable measurements at millimetre-wave and terahertz frequencies, yielding radiometers with better performance. The energy efficiency of systems will also be improved as a result of more accurate measurements. The average electromagnetic radiation intensity has been steadily increasing, fuelled by the evolution of wireless communications for applications like IoT, 5G and beyond. To reduce the impact of electromagnetic fields on the environment, it is therefore important to decrease the transmitted power of wireless communication systems and to measure power density as precise as possible, which this project will underpin.

21NRM04 Biomethane

Protocol for SI-traceable validation of methods for biomethane conformity assessment

Overview

The conformity assessment of biomethane requires further standardisation in order to support Europe's green energy future. This project will deliver **accessible traceability** by developing efficient and cost-effective methods for the preparation of **traceable gas transfer standards** for the performance evaluation of biomethane monitoring systems. Using these, a robust **performance evaluation protocol** will be developed and validated to benchmark and characterise analytical systems. The outputs, including trial applications, will be directly fed into **standardisation development**. It will bridge the gap between previously developed primary standards and the industry need for accessible, traceable performance evaluation against a validated protocol.

Need

Biomethane is already used widely within Europe as a means to **sustainably displace fossil fuels** and its usage is projected to increase significantly (doubling by 2030) [i] as a result of European green energy targets [ii]. Biomethane quality monitoring is essential to prevent damage to gas infrastructure and end user appliances caused by harmful impurities that are required to be kept below limit thresholds (as specified in EN 16723 for gas grids [iii] and vehicles [iv]).

Reliable and traceable purity measurements can only be obtained with equipment of **known performance**, from which the sensitivity, selectivity, precision and bias have been traceably evaluated (as required under e.g. ISO/IEC 17025 §7.2 [v]). Instrument manufacturers and end users require a **standardised protocol** in order to meaningfully demonstrate instrument performance in both laboratory and field settings. Despite similar approaches existing for other green fuels e.g. hydrogen in the form of ISO 21087 [vi], such an evaluation protocol suitable for biomethane **does not yet exist**.

An additional challenge is **bias prevention**, as existing measurements methods (e.g. as developed in 16ENG05) have not been traceably tested for cross-interference bias caused by gas matrix and impurity variation. This type of selectivity evaluation is essential to prevent bias in reported results, **prevent interruptions in the supply** of biomethane into European gas infrastructure (caused by over-reporting), and **prevent damage to infrastructure** (caused by under-reporting).

To deliver this on a practical level, cost effective transfer standards are required to **disseminate traceability** from primary standards in an accessible format for the biomethane industry, which includes many small-scale producers. These transfer standards have to be fit-for-purpose in terms of measurement uncertainty (≤10 %) and shelf life (≥12 months). Improving accessibility to gas standards and a validated protocol for their application will allow for a safe and effective expansion of the biomethane industry within Europe.

Objectives

The main goal of the project is to support the development of standardisation and to provide the traceability, reliability and characterisation necessary for the conformity assessment of biomethane.

The specific objectives of the project are:

1. **To develop cost-effective gas transfer standards, for the impurities specified in EN 16723 for use in biomethane conformity assessment with uncertainties of 1 % - 10 %.** Novel standards will also be prepared for the evaluation of **cross-interferences** caused by impurities and a variable biomethane gas matrix to quantify bias. This will enable metrological traceability to be transferred from the primary standards to test laboratories and field measurements at the required limit thresholds.
2. **To develop a protocol for the sampling, analysis and performance evaluation of the gas analysers that are used for biomethane conformity assessment**. The protocol will be validated using lab-based analysers, sampling and test methods developed in previous EMPIR projects. In addition, the validation will determine the repeatability, reproducibility, limit of detection, selectivity and uncertainty. It will include the evaluation of bias caused by cross-interference due to gas matrix and impurities (specified in EN 16723).
3. **To use the protocol, developed in objective 2, to evaluate the performance of different types of relevant industrial gas analysers**, based on e.g. spectroscopy and gas chromatography, which are currently employed for laboratory and field-based biomethane conformity assessment. The application of the protocol at various sites will be reviewed to produce a best practice guide for its usage.
4. **To collaborate with the technical committee ISO/TC193/SC1/WG25 "Biomethane", and the users of the standards they develop** to ensure that the outputs of the project are aligned with their needs, including the protocol for the evaluation of the performance of gas analysers and recommendations for incorporation of this information into future standards at the earliest opportunity.

Progress beyond the state of the art and results

Methods for the preparation of cost-effective gas transfer standards (Objective 1)

This project will develop novel, cost effective solutions in the form of multi-component gas standards and improved dynamic methods for the preparation of gas transfer standards, with a focus on the impurities and limit levels specified in EN 16723. This cost-effective approach will allow laboratories to perform verification, validation and quality control as required by, e.g., ISO/IEC 17025 with reduced and affordable costs, increasing the accessibility of traceability to industry. These standards will also resolve the issue of some standards not being available for field use on biomethane sites due to their complexity, non-portability and cost.

Novel cost-effective standards will also be developed for the evaluation of the effects of the variable biomethane gas matrix and cross-interferences caused by impurities simultaneously present in biomethane. This JRP is the first research project addressing this issue in full and the project output will help to secure reliability of the analytical measurements of the impurities in biomethane, avoiding biases that are commonplace (e.g. terpenes/siloxane interferences via certain GC methods and methane interference with certain spectroscopic methods).

Protocol for the sampling, analysis and performance evaluation of the gas analysers (Objective 2)

Currently, gas analysers for biogas and biomethane applications cannot be reliably evaluated for performance. ISO 10723 [vii] describes the performance evaluation for analytical systems for natural gas composition, and ISO 21087 is in place for hydrogen applications, however, methods and protocols for biogas and biomethane applications still need to be developed. The project will develop a robust protocol for the sampling, analysis and performance evaluation of gas analysers that are used for biomethane conformity assessment. The protocol will be designed in a way to make it suitable for current and future measurement techniques.

Use of protocol for the sampling, analysis and performance evaluation of the gas analysers (Objective 3)

The protocol will be validated using lab-based analysers, with traceably validated methods previously developed as part of targeted research (e.g. ENG54, 16ENG05). The application of protocol will then be expanded to industrial analysers and a review undertaken of the results of its application, comparing the variables of location, analyte and technique to produce a best practice guide for the repeatable and accurate implementation of the protocol. Such a comparison has not been undertaken for the biomethane industry and the results will provide a valuable route for more solutions to enter the market and for stakeholder knowledge to be enhanced.

Outcomes and Impact

Outcomes for industrial and other user communities

- The project outputs will enable fit-for-purpose biomethane measurement services for industries, testing laboratories, research organisations and other end-users. Such services will include: a) calibration gas mixtures b) calibration and measurement facilities and services c) performance evaluation of gas analysers; d) direct characterisation of biomethane quality in the field; e) proficiency testing; f) consultancy and g) training. Accreditation can be sought against e.g. ISO 17025.
- Instrument and sensor manufacturers will receive access to a protocol by which they can benchmark their products and use during the product development process as a means of quality control. Their customers will be able to utilise the protocol for their own quality control checks when e.g. developing and characterising methods.
- Biomethane producers will be able to use protocol in combination with transfer standards and training material outputs to repeatably and accurately quantify analyser performance, which will reduce the opportunity for measurement bias and improve efficiency of biomethane production.

Outcomes for the metrology and scientific communities

- Laboratories, research organisations and academia will be able to use the standards and protocol developed within this project to perform further research within the biomethane purity area to support development of new biomethane measurement technologies, of which performance can be traceably quantified.
- Metrology institutes will have new capability in the form of gas standards and a protocol by which to evaluate further techniques and methods they wish to develop within the biomethane area for research and delivery of measurement services to industry.

Outcomes for relevant standards

- The project's outputs will provide direct input to ISO/TC193/SC1/WG25 "Biomethane" on a validated protocol for the sampling, analysis and performance evaluation of the gas analysers. The results of the performance evaluation of the industrial gas analysers will give a realistic overview of (industrial) measurement capabilities, which will allow for standards to be tailored to the real needs of industry and promote their widespread uptake. The protocol and method developed for the performance evaluation of the gas analysers will be submitted to ISO/TC193/SC1/WG25 for consideration as a new ISO standard (in the form of a New Work Item Proposal (NWIP) and draft ISO standard text). The results obtained from the project will also be disseminated to CEN to enable it under its mandate M/475 to update EN 16723.

The following ISO standards, NWIP's and technical reports from ISO TC 193 and CEN TC 408 include measurements that will be studied in this project, and can be improved through this project, during the next revision:

- ISO/DTS 2610 'Analysis of natural gas -Biomethane — Determination of amines content'
- ISO/CD 2611-1 'Analysis of natural gas — Biomethane determination of halogenated compounds — Part 1: HCl and HF content by ion chromatography'
- ISO/CD 2612 'Analysis of natural gas — Biomethane -- Determination of ammonia content by Tuneable Diode Laser Absorption Spectroscopy'
- ISO/CD 2613-1 'Analysis of natural gas — Silicon content of biomethane — Part 1: Determination of total silicon content by AAS'
- ISO/CD 2613-2 'Analysis of natural gas — Silicon content of biomethane — Part 2: Determination of siloxane content by Gas Chromatography Ion Mobility Spectrometry'
- ISO/CD 2614 'Analysis of natural gas — Analysis of biomethane — Determination of terpenes' content by micro gas chromatography'
- NWIP – 'Analysis of natural gas — Analysis of biomethane - Determination of biogenic methane content'
- NWIP - 'Analysis of natural gas — Analysis of biomethane - Determination of compressor oil content'
- CEN/TR 17238, Proposed limit values for contaminants in biomethane based on health assessment criteria

- The project will also provide input to the activities of other committees, such as ISO/TC158, CEN/TC408, BIPM CCQM Gas Analysis Working Group (GAWG), Euramet/Metchem SC-GAS, and national working groups and mirror committees. The project outputs will also be introduced into the European Metrology Network for Energy Gases.

Longer-term economic, social and environmental impacts

The project outputs will enable fit-for-purpose services to industries, testing laboratories, research organizations and other end-users, such services will include: a) calibration gas mixtures (transfer standards); b) calibration and measurement facilities and services; c) performance evaluation of gas analysers; d) direct characterisations of biomethane quality in the field; e) proficiency testing; f) consultancy and g) training. These service receivers will be able to undertake e.g. SI-traceable calibrations of equipment and the calibration of gas mixtures, to improve the quality of their measurement results, and they will be able to use traceable and cost-effective gas transfer standards for measuring impurities in biogas and biomethane.

The accurate measurement of trace-level toxic impurities will ensure that regulations limiting the contents of these compounds to levels below that at which they affect health can be enforced robustly.

This project will accelerate the increased use of biomethane and upgraded biogas and enrich the European natural gas supply chains. Therefore, it will also help to reduce Europe's dependence on natural gas import and promote the EU target on Renewable Energy to be realised.

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[i] EBA "European Biogas Association Statistical Report: 2019 European Overview". Brussels, Belgium, January **2020**.

[ii] European Commission, A European Green Deal. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en., **2019**

[iii] EN 16723-1 - Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network - Part 1: Specifications for biomethane for injection in the natural gas network, **2016**

[iv] EN 16723-2 - Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network - Part 2: Automotive fuel specifications, **2017**

[v] ISO/IEC 17025, Testing and Calibration Laboratories, **2017**

[vi] ISO 21087 - Gas analysis — Analytical methods for hydrogen fuel — Proton exchange membrane (PEM) fuel cell applications for road vehicles, **2019**

[vii] ISO 10723, Natural gas — Performance evaluation for analytical systems, **2012**

21XXX01 OpMetBat

In operando metrology for energy storage materials

Overview

The development of new battery materials is key to improving the performance, liftetime, safety and cost of energy storage technologies like Li-ion batteries for electric vehicles. However, innovation is hampered by the inability of industry to reliably characterise their structure and chemistry in an operating environment. This project will build a metrological framework supporting traceable *operando* characterisation of state-of-the-art battery materials under dynamic charge / discharge conditions. This includes advancement and validation of *ex situ* methods, establishing new protocols, cells and best practice for *operando* approaches and developing new instrumentation enabling hybrid, multiparameter measurement to inform new materials development.

Need

The European Green Deal targets net zero CO_2 emissions of greenhouse gases in Europe by 2050, specifying zero emissions from new cars by 2035. Electrification of the automotive industry is key to meeting these goals, but rapid advances in energy storage technologies such as lithium-ion batteries are required to realise this. Many new materials combinations for battery electrodes are emerging that can begin to address performance targets, but lifetime issues remain problematic. Hence, there is an urgent need for traceable analytical techniques to decipher structure-behaviour relationships and elucidate degradation and failure mechanisms to improve battery performance by design, rather than empirically.

Quantification of elemental composition, and determination of oxidation and chemical binding states, coordination and phase structure are crucial for an enhanced understanding of battery electrode degradation. Moreover, investigations must be conducted in real-time, allowing aging mechanisms to be linked to battery state of charge (SoC) and state of health (SoH). Currently, degradation studies are performed *post mortem*, using *ex situ* methods where the cell is disassembled, leading to chemical modification which can distort the result. To avoid that, *operando* methods, where electrode materials are characterized simultaneously during cell charge-discharge, are needed. Whilst some *operando* methods are available, they are not sufficiently reliable or quantitative to allow confident data interpretation. Moreover, there is a need for new hybrid *operando* methods, where multiple measurands are synchronously probed during electrochemical cycling, to establish causal links between materials properties and their impact on cell performance. Such advanced measurements bring new challenges as they require special sample environments such as dedicated electrochemical cells with thin probing windows, while ensuring that the electrochemical behaviour remains unperturbed. Hence, there is a need for establishing a robust, validated metrological framework for *operando* metrology, that can be transferred to battery developers and demonstrated through industrial case studies.

Objectives

The JRP aims to develop *operando* techniques and hybrid (multi-modal) instrumentation, supported by quantitative and validated *ex situ* analysis and electrochemical measurements, to enable beyond state-of-the-art materials characterisation for high-capacity energy storage technologies.

The specific objectives are:

1. To develop traceable chemical, physical and structural analysis methods for ex-situ characterisation of high-capacity energy storage materials and components with a focus on x-ray spectroscopic techniques, and including the fabrication and qualification of calibration samples and verification by interlaboratory studies.
2. To establish Best Practice Guides for current and emerging in operando spectroscopy methods including X-ray spectroscopy and vibrational spectroscopy, validated by ex-situ analysis and round robin activities, in order to improve experimental repeatability and accuracy. To understand the influence of cell geometry, electrode configuration, and measurement parameters on observable phenomena, and to assess the extent and influence of vacuum ultra-violet (VUV) or X-ray radiation damage.
3. To develop novel dynamic electrochemical approaches combined with in operando spectroscopy and dimensional metrology for the correlative assessment of the relationships between material structure and cell performances.
4. Based on the results of Objectives 1-3, to develop novel in operando instrumentation and hybrid methodologies for multi-parameter spectro-electrochemical characterisation of high-capacity energy storage materials and components. To investigate the causal relationship between electronic/molecular- and microstructure information and charge carrier dynamics as measured with electroanalytical methods, to gain information on the state of health and state of charge.
5. To facilitate – in cooperation with the EMPIR 20NET01 Clean Energy – the take up of the data and measurement infrastructure developed in the project by the measurement supply chain (NMIs, DIs, calibration laboratories), standards developing organisations (e.g. ISO/TC 201) and key end users (materials suppliers and battery manufacturers). To promote technology transfer of the project outputs as lab-based alternatives to synchrotron radiation-based methods, towards industry and manufacturers.

Progress beyond the state of the art and results

Despite a variety of existing approaches to *operando* characterisation of energy storage materials based on X-ray spectrometry, vibrational spectroscopy and X-ray diffraction, practices vary substantially across academia and industry. There is little agreement and consistency in terms of electrochemical cell geometry, materials handling methods and measurement protocols, leading to a lack of confidence in data comparison.

This project aims to make progress beyond state of the art by establishing a foundation for *traceable* and quantitative *operando* measurement built on *ex situ* methods that are validated by adopting appropriate reference materials. This includes development of new, more reliable, sample transfer protocols that minimise the likelihood of chemical changes as a result of cell disassembly in *post mortem* studies. Advanced analytical techniques such as X-ray photoelectron spectroscopy (XPS) and secondary ion mass spectrometry (SIMS) will be employed which improve upon current approaches in terms of sensitivity, accuracy and spatial resolution, and new reference data will be generated to support widespread and reliable comparison.

For the first time, this project will develop and disseminate best practice in the application of operando X-ray and optical techniques. This will be achieved by developing cells and protocols validated by physical modelling, performing parametric studies to optimise experimental conditions, and undertaking interlaboratory comparisons to establish the root of uncertainties in order to improve experimental repeatability.

We will develop a completely new and innovative approach to electrochemical impedance spectroscopy (EIS) which can be implemented during galvanostatic cycling. Conventional EIS typically requires cell equilibration which precludes this kind of dynamic measurement, but the new approach to frequency-dependent analysis will for the first time allow EIS to be performed simultaneously alongside operando spectroscopic materials characterisation to uncover the connection between materials property changes and cell performance loss.

Finally, the new knowledge generated throughout the project will be built upon to develop novel *operando* instrumentation and methodologies that further extend the state of the art by: (i) improving sensitivity compared to current approaches by developing new *operando* cell windows; (ii) allowing advanced X-ray methods normally confined to synchrotrons to be transferred to laboratory-based instrumentation; and (iii) enabling simultaneous, *hybrid*, multiparameter measurement to allow causal links between materials property changes to be established, and their links to cell performance loss to be identified unequivocally.

The new framework for *operando* metrology will be demonstrated by way of industrial case studies, in which the tools developed will be combined to deconvolute some of the most challenging degradation mechanisms currently observed by battery developers and that cannot be resolved by current ex situ characterisation techniques. For this reason the battery manufacturer Johnson Matthey (JM) and the Fiat Research Center S.C.p.A. (CRF) associated with the large automotive manufacturer Stellantis proposed three industrial impact case studies that will demonstrate how *operando* and *hybrid* chacterisation techniques can overcome these issues. From an industrial perspective regarding both R&D and quality management the intended demonstration of transferability from large-scale facilities into the laboratory is highly desirable.

Outcomes and Impact

Outcomes for industrial and other user communities

Through various dissemination activities, the protocols and best practice guidance established for the implementation of *operando* X-ray spectroscopy (XRS), Raman spectroscopy and X-ray diffraction (XRD) for energy storage materials characterisation will be adopted by battery manufacturers and user communities in Europe. The uptake of best practice by battery and materials developers will add value to their materials characterisation by improving the fidelity of *operando* approaches and increasing confidence in data interpretation. The improved depth of time-resolved information gleaned by operando techniques compared to more conventional analytical methods will stimulate innovation, leading to more rapid and efficient materials development for established battery technologies such as Li-ion as well as for emerging chemistries such as lithium-sulphur (Li-S). The uptake of the new know-how will deliver a lasting impact of improving battery performance, durability and safety as fade and failure mechanisms become better understood.

The transfer of synchrotron-based methods to equipment that can be used in a laboratory will have an enormous impact on industrial and other user communities, since the availability of synchrotron beam time is highly limited. Sophisticated lab-based systems can, therefore, be used as standard characterisation methods for battery cells by industrial cell producers.

As quality control in the industry is typically performed with galvanostatic charge/discharge, the EIS measurement protocol and analysis algorithm will be an ideal tool to access valuable information about processes in operating industrial cells, at low cost. The immense output of data will benefit from the use of novel machine learning algorithms to better estimate battery SoH and improve lifetime prediction. Moreover, the dynamic nature of this innovative approach will allow EIS to be performed simultaneously alongside *operando* spectroscopy, enabling much more confident analysis of degradation mechanisms.

Ex situ characterisation continues to be important in battery failure analysis. However, the requirement for cell disassembly and removal of liquid components limits the modes of failure that can be assessed. The project will validate and clarify the limitations of *ex situ* methods and will serve as guidance to industry analysts and increase confidence in ex situ characterisation by providing reliable reference data. This improved metrology framework will accelerate the development of better performing batteries with longer lifetime.

Outcomes for the metrology and scientific communities

The best practice guidance developed will benefit the scientific community by improving reliability, repeatability/reproducibility and fidelity of *operando* measurements. By encouraging the uptake of a common set of methods and measurement protocols, the comparability of data across the academic literature will be greatly improved, allowing more conclusive links between materials chemistry/structure and behaviour. The consortium will develop cells for *operando* and *hybrid* (multi-dimensional or multimodal) spectroscopy, which benefits both communities as they can integrate the outputs in their systems and workflows. The project will pioneer *operando* metrology for battery research at several European synchrotron radiation facilities and the transfer into laboratories to support industry and researchers. The provision of accurate atomic fundamental parameters is of substantial interest for the scientific community using X-ray techniques. Electrochemical assessment of capacity fade in battery systems will gain from the novel EIS measurement protocol. As it can be performed in parallel, it opens additional information regarding e.g. charge transfer evolution and solution resistances. The scientific community will benefit from protocols for performing microchemical analysis of batteries in fixed states which will allow for studies of the internal solid-liquid interfaces to obtain mechanistic insights. Such results will further support the interpretation of *operando* spectroscopies widely in the metrological community.

Outcomes for relevant standards

The NMI partners are involved in key international organisations (ISO, BIPM, EURAMET). Many of the techniques to be developed are too immature to consider standardisation at this stage, however activities to support the future development of relevant standards are planned. To achieve this, partners will disseminate project outputs to committees and lead discussions on *operando*-specific challenges. The consortium will also communicate the battery industry's needs to the respective committees to help identify target methods of future standardisation activities.

The most relevant standards committee is ISO TC201, which focuses on surface chemical analysis and includes many of the analytical techniques used in the project. The project will provide input into: Working Group 5 on optical interface analysis (e.g. Raman spectroscopy); subcommittee 6 on SIMS; subcommittee 7 on XPS; subcommittee 10 on X-ray reflectivity (XRR) and X-ray fluorescence (XRF) spectroscopy; subcommittee 2 on general procedures for surface chemical analysis; and subcommittee 1 on terminology. In ISO TC201 SC10 input related to physically traceable XRF methods will be generated. The consortium will also engage with VAMAS on the topics of Raman spectroscopy (technical working area 42) and surface chemical analysis (technical working area 2) in order to establish a foundation for pre-normative interlaboratory comparison activities. This will establish the current level of repeatability and comparability and provide the basis for future standardisation. Several committees associated specifically with batteries will also be targeted to ensure that the importance of standardisation at the materials level is represented.

Longer-term economic, social and environmental impacts

The transition to hybrid electric vehicles is essential to reduce human impact on air pollution, global warming and their effects on public health. Improved confidence in measurement is key to the development of next generation energy storage materials with sufficient performance and lifetime for automotive applications, and therefore underpins this energy transition. The improved measurement capabilities and robust traceability chain to be developed in this project will facilitate the required understanding to develop electrochemical viability to meet this rapidly growing need. The improved battery lifetime that results will not only improve the commercial viability of these technologies for use in the automotive sector but moreover bring down their cost, which is one of the most prohibitive challenges preventing more widespread adoption of electric vehicles.

Reducing the cost of electric vehicles will improve their competitiveness against conventional combustion engine vehicles, thus stimulating market growth. Reduced costs will also improve public perception of electric vehicles, further augmenting their uptake within society. More broadly this will lead to significant economic benefits across the EU, with automotive companies prospering, generating wealth and jobs

The metrology framework and tools developed will support rational materials design concepts in the energy storage sector and more broadly, which will in future pave the way to more efficient development of functional material chemistries with improved sustainability, and smaller CO_2 footprint. Of major concern in the battery industry is reliance on critical raw materials such as cobalt and lithium. These materials are available currently, but a supply risk has been identified and in the long term a fully electrified society will require alternative materials and chemistries. By developing new and advanced tools and methodologies for the reliable *operando* characterisation of these materials, we are empowering scientists and industry to develop next generation materials based on more abundant (and therefore cheaper) resources that can also be more easily recycled.

Finally, this project will bring substantial societal benefits. Decarbonisation of the automotive sector will significantly improve air quality whilst reducing noise pollution in urbanised areas, thus improving the overall quality of life of inhabitants as well as their physical and mental health. The latter aspects will decrease pressure on health services, therefore improving wellbeing for wider society.

21XXX02 BIOSPHERE

Metrology for Earth Biosphere: Cosmic rays, ultraviolet radiation and fragility of ozone shield

Overview

This project addresses one of the most significant–yet unexplored–ecological challenges facing EU member states and beyond: evaluating how the increasing atmospheric ionization caused by extraterrestrial radiation (cosmic rays and solar UV radiation) and boosted by anthropogenic emissions impacts human and ecological health. This project aims to develop the necessary tools, methodologies and measurement infrastructure to evaluate the mutual impact of cosmic rays and biologically active UV radiation on the Earth's biosphere, and to support EU policy makers with scientific assessments that can substantially improve policies on climate, health and anthropogenic activities.

Need

Over millennia, living organisms have been continuously exposed to cosmic rays and solar UV radiation. Biological actions of many kinds have evolved to deal with such exposures and a balance between beneficial and harmful effects of these radiation fields has been established. In the recent years, however, this balance is being disturbed due to anthropogenic emissions and environmental pollution. Therefore, there is an urgent need to combine ground-breaking observations by modern satellite technologies and ground-based in situ/remote sensing with scientific expertise in biology, chemistry, environment, and radiation protection to study how such combined radiation fields can shape our natural habitat, affect the evolution of the biosphere, and impact our health status.

Since the mid-1970s, human activities have been changing the chemistry of the atmosphere such that cosmic rays now can act as an agent that mediates depletion of the ozone layer [1-3]. As ozone shields the Earth from harmful UV radiation from the Sun, its depletion would lead to an overexposure to UV radiation flux with serious acute and chronic health effects to humans, mammalian and plant species. These concerns prompt the need not only to address health safety issues related to combined radiation exposure, but also to examine the relationship between cosmic rays and the thickness of the ozone layer and their effect on the atmospheric chemistry. Both cosmic rays and terrestrial solar UV radiation are monitored in well-established global surface-based networks. Side-by-side high-accuracy measurements of these quantities needed to quantify the effect of the cosmic rays on the ozone layer have not been done so far.

Ionization of the biosphere by cosmic rays is known to correlate significantly with disease prevalence, infectious disease mortality, and overall mortality [4,5]. Genomic, epigenetic, transcriptomic, and metabolomic changes that may be responsible for cellular radiosensitivity and possible long-term dysfunction remain, however, largely unknown. The lack of understanding of these effects is exacerbated further by ozone depletion-induced overexposure to UV radiation and its implications for cellular defence mechanisms. Therefore, monitoring, modelling, and correlating cosmic rays, terrestrial solar radiation, and ozone thickness is critical not only to understand the radiological sensitivity of cells, but also to make informed decisions regarding the global challenges facing our society.

Objectives

The overall aim of this project is the development of novel metrological methodologies to establish the correlations between cosmic rays, solar UV radiation and ozone layer thickness, for evaluating their mutual impact on the Earth's biosphere.

The specific objectives of this project are:

1. To upgrade the measurement capabilities of existing mobile Secondary Cosmic Ray (SCR) detectors and LIght Detection and Ranging (LIDAR) systems, such as by development of new metrological methods to determine the dependence of SCR flux to the ground on Primary Cosmic Radiation (PCR) and various atmospheric profiling parameters (e.g., temperature, density, aerosol concentration).
2. To quantify the correlation between PCR and solar UV radiation on the ground including their dependence on anthropogenic gas emissions with the help of simultaneous modelling and traceable measurements of (i) ground-level muon and neutron fluxes, (ii) terrestrial solar UV-irradiance, and (iii) total ozone column.

3. To determine the effects of slow electrons produced by PCR and SCR on the chemical processes in the atmosphere, in particular those impacting the ozone layer. This should include the quantification of molecular ionisation and production rate of charged molecular fragments due to the interaction between low-energy electrons and atmospheric gases of both natural and anthropogenic origin with the help of table-top experiments.
4. To assess the impact of combined SCR and UV irradiation on human health by determining the effect of mixed radiation fields on human primary and plant cells under various experimental conditions. This should include investigation of genetic, epigenetic and transcriptomic changes in cells using established radiation effect models and systems biology approaches.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs and DIs, atmospheric monitoring networks) standards developing organisations (BIPM Consultative Committee for Photometry and Radiometry, CIE Division 2, WMO) and end users (e.g. health and environment regulatory bodies, research institutions focused on environment, climate, medicine and biology, and radiological protection, and instrument manufacturers).

Progress beyond the state of the art and results

Determining the dependence of SCR on PCR and atmospheric parameters

This project will develop for the first time metrological methods to quantify the correlation between PCR and SCR using atmospheric profile parameters measured by LIDAR(s). Since SCR generation and absorption depend strongly on atmospheric conditions such as air density and temperature, this project will go beyond the state of the art by incorporating inhomogeneities of air density/temperature in the troposphere and the lower part of the stratosphere (up to about 15 km), including peaks caused by clouds in the troposphere, into the framework that links PCR and SCR.

Identifying and quantifying the relationship between cosmic radiation, UV radiation and anthropogenic emission

Side-by-side measurement of the terrestrial solar UV spectrum, total atmospheric ozone, and SCR flux rate have never been attempted so far due to the lack of the proper measurement infrastructure. This project will provide such measurement capabilities for the first time and will go beyond the state of the art not only by measuring these parameters simultaneously, but also by supporting the ground-based measurements with satellite measurements such as satellite observations of energetic electron, proton and Helium-ion fluxes at low Earth polar orbit (PROBA-V satellite), satellite observations of energetic electron and proton fluxes at geostationary orbit (GOES satellites), continual monitoring air quality in Europe and around the world using satellite and ground-based observations and advanced numerical models (Copernicus Atmosphere Monitoring Service), and tools such as The Space Environment Information System (SPENVIS) an ESA operational software developed and maintained by our partner BIRA-IASB since 1996, providing a web-based interface for assessing the space environment.

Molecular processes affecting ozone depletion and atmospheric dynamics

This project will produce for the first time a complete data base of collision cross sections for natural atmospheric and anthropogenic gases relevant for ozone layer chemistry. This also includes the quantification of molecular ionization and production rates of charged molecular fragments and other reactive species going beyond present-day models which restrict to ionization and a nonspecific energy loss value per produced ion pair. Implementation of these data in simulation codes that propagate space radiation through the atmosphere allows refined radical, ion, and slow electron production rates to be obtained.

Effects of combined SCR and UV radiation fields on biological systems

Understanding the mutual impact of cosmic and ultraviolet radiation on human health is important not only for humans, but for all mammalian and plant species and the entire living ecosystem. This project will go beyond the state of the art by creating, for the first time, a database of results from irradiated and non-irradiated biological samples such as lung and primary skin fibroblasts, cerebral microvascular endothelial cells from the brain, and healthy blood monocytes. The use of different human cells from different tissues will help to compare the possible role of inherent parameters in relation to tissue or culture conditions. Through advanced bioinformatics and systems biology methodologies, a complex network of molecular changes related to cell death, DNA damage and genomic instability, adhesion and proliferation, and expression profile of stress genes will be established.

Outcomes and Impact

Outcomes for industrial and other user communities

The project's data on the combined SCR and UV irradiation of human primary cell lines (such as primary skin fibroblasts, blood monocytes, brain cerebral microvascular endothelial cells) can be used to provide key information on a plethora of biological effects such as DNA damage, genome instability, cell death, oxidative stress, subtle structural changes and transcriptomic changes. This information is crucial for assessing the impact of such radiation fields on human health. Therefore, European health groups and organization such as ECCO (European Cancer Organisation), EORTC (European Organisation for Research and Treatment of Cancer), ESMO (European Society for Medical Oncology), and more globally World Health Organization (WHO) will benefit from this project.

Cosmic ray-induced low energy electrons and solar UV radiation are major drivers for atmospheric chemistry. For quantitative description of atmospheric ionization, collision and chemical processes involving ozone, reliable cross-sections for the interactions of gases in the stratosphere with low energy electrons as well as solar UV radiation and the production of reactive species by those interactions are required. This project will determine for the first time the medium to low-energy electrons cross sections for ionization and fragmentation-ion production of atmospheric constituents such as N_2, O_2, NO, NO_2, selected chlorofluorocarbons (CFCs), halogenated molecules (such as HCl, HF, HBr, SF6), as well as aromatic and nitrogenated molecules (such as pyridines whose cations facilitate aerosol formation).

The cross-section data produced in this project will support "ACSO" ("Absorption Cross Sections of Ozone") Committees involving Global Atmosphere Watch (GAW) of the World Meteorological Organization (WMO) and the International Ozone Commission IO3C) of the International Association of Meteorology and Atmospheric Sciences (IAMAS). Quantification of molecular ionization and production rates of charged molecular fragments and other reactive species goes beyond present-day models which restrict to ionization and a nonspecific energy loss value required to produce an ion pair. These data can also be used in chemistry-climate models (CCM) such as SOCOL (SOlar Climate Ozone Links) [6], MEZON (Model for the Evaluation of Ozone Trends) [7], MA-ECHAM5 model [8], and CRAC:CRII [9] designed to study the impact of different external factors such as galactic cosmic rays (GCR) and solar proton events (SPE) on the Earth climate system and the ozone layer.

Cosmic rays, along with UV radiation and the Earth's natural radioactivity, are one of the main sources of atmospheric ionization, contributing to atmospheric cooling and warming, and thus to the overall climate system [10]. Attempts to quantify the changes they cause in climate processes (e.g., cloud formation and thunderstorms), however, are debated and remain poorly understood [11]. Traceable metrological data on cosmic ray fluxes, solar UV spectra, and the total ozone column generated by this project are key to assessing the role of cosmic rays as climate drivers. Quantifying the correlations between these three observables will contribute to new approaches to chemistry-climate models that will help clarify the ambiguities in the scientific community.

Outcomes for the metrology and scientific communities

This project will develop, for the first time, a new metrological method for determining the dependence of the secondary cosmic ray flux to the ground on primary cosmic rays and atmospheric profile parameters. This will greatly improve the prediction accuracy of the SCR rate at ground stations as a function of pressure and temperature, which is particularly needed during intercomparisons of environmental monitors. This would also lead to better quantification of ground level enhancements (GLE) and subsequent radiation dose assessments. A report summarizing this new metrological methodology will be submitted to EURAMET and will be made available to end users.

The metrology infrastructure and methods developed in this project will help estimate the on-ground magnitude of cosmic events such as SPEs and Gamma Ray Bursts (GRB) and will provide information for designing biomedical studies for assessing the impact of radiation exposure on human health, in relation to radiation dose and dose rates.

In addition, quantifying the dependence of SCR on atmospheric profile parameters such as temperature would enable mobile SCR detectors to be used as middle-atmosphere temperature sensors for tracking short-term atmosphere dynamics such as Sudden Stratospheric Warmings [12] and geoscience applications such as characterizing the density structure of volcanoes [13]. Members of the consortium will present these results to the European Geosciences Union (EGU) and the European Space Weather Community at their annual meetings.

This project will create for a first time a comprehensive database of collision cross sections for natural atmospheric and anthropogenic gases. The database will be in an open format and can be used by modelers, developers and users from NMIs, public health and environmental agencies, research institutions focusing on the environment, climate, medicine and biology, and radiation protection and equipment manufacturers.

The project will also produce, for the first time, a database with results of irradiated and non-irradiated biological samples used in this project and processed for various types of tests (cryopreserved cells, cells prepared for DNA/RNA extraction, cell lysates, culture supernatants, cells prepared for immunofluorescence and transmission electron microscopy). The database will be in an open format and can be used by modelers, developers and users from NMIs, public health and environmental agencies, research institutions focusing on the environment, climate, medicine and biology, and radiation protection and equipment manufacturers.

Outcomes for relevant standards

The project will provide guidance for stakeholders and input to international standardisation bodies (ISO, IEC), as far as ionizing and non-ionizing radiation protection is concerned. The project will provide input to international standardisation bodies and members of the consortium are involved in the following committees: IEC/TC45 (Nuclear Instrumentation, SC45B Radiation protection instruments, WG9 Detectors and systems), CENELEC/TC 45B (Radiation Protection Instrumentation), EURAMET Technical Committee for Ionising Radiation (TC-IR), European Radiation Dosimetry Group (EURADOS) [WG2-Harmonisation of individual monitoring , WG3-Environmental dosimetry, WG11-High energy radiation fields], BIPM CCRI (Section I: x- and gamma rays, charged particles) and CCRI (Section II: Measurement of radionuclides) and ESA Space Weather Working Team. Thus, the project will support the harmonisation of procedures and methods for the measurement of cosmic rays and solar UV radiation in the environment and hence their inclusion into European and international standardisation.

Longer-term economic, social and environmental impacts

This project will provide data that will help assess the contribution of cosmic rays and UV radiation exposure in the risk for developing chronic diseases and cancer. Thus, cellular studies in well-controlled radiation fields that better mimic the “real world” will help identifying biomarkers of exposure as well as new therapeutic targets and strategies to counteract the deleterious effects of radiation exposure, in the benefit of the general population and of the exposed professionals, including astronauts. The data and methods ensuing from the current project will be useful for ecological correlative studies, providing a first glimpse of some of the possible unexplored interactions between the environment and the human health. Such findings will have significant economic implications, particularly in terms of public health, agricultural production and food security on a global scale.

21XXX03 PaRaMetriC

Metrological framework for passive radiative cooling technologies

Overview

Cooling systems account for nearly 20% of electricity consumption and 10% of greenhouse gas emissions, globally. With demand for cooling expected to grow tenfold by 2050, and the increasing frequency of extreme heat waves, improving the efficiency of cooling systems plays a critical role in addressing the global climate challenge. Passive Radiative Cooling (PRC) materials that can dissipate heat as infrared radiation, have recently emerged. The overall aim of this project is to define the figures of merit and testing conditions enabling the standardized evaluation of their cooling performance and potential energy saving that could derive from such technologies.

Need

To date, the annual cost of heat-related issues is estimated at about $2.4 trillion, with cooling systems costs estimated around $300 billion and producing 1Gt of CO_2 per year. Within 2050, the additional energy needs related to cooling are expected to surpass the total electricity use of China and India today, combined. This is often referred to as one of the most critical blind spots in today’s energy debate, given that the rising demand will add an enormous strain on the electricity systems of many countries, driving up emissions and triggering a self-aggravating feedback loop.

PRC materials can dissipate heat through the infrared transparency window (8 - 13 µm) without using any electricity, using outer space as a cold and renewable thermal energy sink to reach sub-ambient temperatures even under direct sunlight owing to their tailored optical and infrared photonic properties.

Despite hundreds of promising PRC coatings and devices demonstrated in the literature in the past few years, reliable testing protocols to evaluate their cooling performance have not been established yet, which is a major obstacle hindering the further development and commercialization of this new technology. Typical tests up to now are limited to measuring either a temperature drop or a cooling power with a heater, using improvised testing rigs with inconsistent insulation and shielding properties, unspecified thermal loads and under different atmospheric conditions, altitudes, ambient temperatures, etc.

Defining standardized figures and testing protocols requires a highly multidisciplinary approach improving the characterization of emissivity and reflectance properties of thin coatings over a broad wavelength range, the realization of model systems with known properties, the calibration of portable instruments for on-site monitoring, accounting for the impact of atmospheric and geoclimatic conditions on the expected cooling potential and the design of standardized testing apparatuses with known thermal loads and insulation.

Objectives

The overall goal of this project is to establish a metrological framework for the evaluation of passive radiative cooling technologies in order to enable their comparison. This will require the identification of suitable figures of merit per performance indicators, as well as the definition of standardized testing conditions and protocols. The specific objectives of the project are:

1. **To develop a metrological framework for the classification and comparison of passive coolers** based on key performance indicators (KPIs) for appropriate categories of passive cooler architectures. For this:
    a. laboratory test methods should be surveyed, and boundary conditions identified for the measurements to ensure comparability in the determination of the KPIs under appropriate conditions
    b. benchmark materials need to be selected (e.g. SiO_2 microspheres) exhibiting reproducible passive daytime radiative cooling performance, to develop micro and nano-structured model systems with well-defined thermal and optical properties.
2. **To develop and validate modelling methods** to correlate the cooling performance of model systems with the thermal and optical properties of their components, and to establish the materials' specifications and associated tolerances for quality control. To carry out the thermal infrared spectral modelling of the transmission and emission of the atmosphere at different zenith angles. Additionally, to evaluate the impact on energy savings and heat-island effect for urban environments in different geographic regions on a year-to-year basis under different atmospheric conditions (e.g. humidity, cloud cover).
3. **To perform an interlaboratory characterisation and comparison of the reflectance and emittance of benchmark passive cooling materials** over a broad spectral range (200 – 50 000 nm) encompassing the solar spectrum and the infrared transparency window of the atmosphere (8 – 13 μm). To develop and validate methods to convert measured infrared radiometric quantities (e.g. total near-normal or near-grazing emissivity) into a usable form for simulations and heat-balance calculations. In addition, to develop best practice guidelines for the conversion of directional to hemispherical emissivity, based on measurements obtained using commercial instruments.
4. **To design a testing setup and validate protocols for testing KPIs** (e.g. tracking solar irradiance, humidity and wind speed) of candidate passive cooling materials for both indoor and outdoor use and to perform a systematic error analysis, validating the determination of important KPIs at 10 % uncertainty level.
5. **To produce a good practice guide on the on-site determination of the performance of passive cooling solutions and their degradation with time and ageing** in terms of the above KPIs. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (testing laboratories), standards developing organisations (CEN/TC 89) and end users in the commercial, residential, and photovoltaic sectors.

Progress beyond the state of the art and results

Figures of merit tailored to passive radiative cooling materials and reproducible model systems

To date, figures of merit to evaluate the cooling performance of a PRC coating are either based on intrinsic material properties, the temperature difference between the substrate and ambient air, or the cooling power of the radiator at ambient temperature. All these quantities are severely affected by ambient, atmospheric and geoclimatic conditions, failing to predict cooling performances under different solar irradiance or relative humidity, or to differentiate between broadband and selective emitters. Other parameters typically used for traditional cool-roof applications, such as the Solar Reflectance Index, suffer from similar shortcomings as they were designed for a different class of materials. Within this project, tailored performance indicators will be designed to predict how external parameters affect the cooling power of PRC materials. Similarly, the reproducible benchmarking of PRC materials is hindered by the lack of established model systems, with comparisons often made against generic white or black substrates. During this project, several candidate materials will be characterized in terms of their performance to identify stable and reproducible coatings with a measurable net cooling power.

Multi-scale modelling of PRC composite materials

Modelling of PRC materials is a complex task involving several disciplines, length scales and numerical tools, requiring research efforts beyond the reach of single institutes. Moreover, high-performing PRC materials are often hierarchical disordered materials. This is particularly challenging for numerical approaches which are often limited to 2D approximations. This project aims at overcoming this limitation by resorting to heterogeneous computing and multi-scale modelling techniques. Additionally, the project will cast a connection between the composition and temperature of the atmosphere and its transparency/emissivity, leading to more realistic radiative balance calculations.

Optical and thermal characterization of thin, composite materials

Thermal characterization of sub-mm composite coatings is particularly challenging for state-of-the-art methods used to measure thermal conductivity, such as the Guarded Hot Plate or Heat Flux Meter. More flexible, transient methods need to be examined and validated for this purpose. Similarly, routinely used methods to measure the emissivity of building materials relies on commercial instruments measuring directional emissivity values. However, heat balance calculations relevant to PRC materials require the total hemispherical emissivity, which must be either measured directly or extrapolated from directional measurements using validated methods. Similarly, the angular dependence of the emissivity of PRC devices needs to be evaluated to determine the best relative orientation between the radiating panels and the sky.

Testing protocols to assess the performance and energy savings deriving from PRC materials

The cooling performance of PRC materials is typically measured using improvised testing rigs under shielding and thermal insulation conditions that are difficult to reproduce and not relevant for real applications, where realistic thermal loads and direct exposure to ambient conditions should be considered. Furthermore, testing of PRC materials should include intense heat conditions and monitoring campaigns spanning over months rather than hours/days, which is rarely the case in the literature. In this project, realistic use conditions will be accounted for when designing the testing apparatus and protocol for the evaluation of the cooling performance of PRC materials, filling this critical gap in the current state of the art.

Outcomes and Impact

Outcomes for industrial and other user communities

This project will establish a shared framework for passive radiative cooling technologies fostering the development of new energy-saving materials and providing a competitive advantage to EU companies in this emerging field. Companies in the building sector will be able to review their product portfolio in terms of the radiative cooling performance and to develop improved materials and coats based on well defined figures of merit and standardized protocols for their evaluation. Similarly, industries in the HVAC sector will be able to quantify the expected performance boost and energy savings deriving from the synergic combination of active and passive cooling technologies. End users in both communities will further benefit from the guidelines developed within the project for the validation of emissivity measurements with portable instruments and from the definition of model systems exhibiting near unity emissivity for the calibration of such devices. Expected benefits extend beyond the cooling of residential and commercial spaces, including also applications in the industrial sector such as in power plants or large-scale data centers, both of which have high cooling demands but also large roof areas which could be covered with PRC panels providing net cooling power via non-evaporative methods, thus reducing water withdrawals and thermal discharges in the environment. Notably, industrial processes represent an ideal application area for the large-scale deployment of PRC cooling appliances as in this case there is no need to avoid or reduce potential overcooling effects.

Outcomes for the metrology and scientific communities

In the past few years, the scientific community has called multiple times for the need to develop and define standardized testing conditions to assess the cooling performances of emerging PRC materials. Several critical points will be addressed within the scope of this project, including the need to account for different atmospheric conditions, different/extreme geoclimatic regions, and the lack of established figures of merit. By developing validated testing protocols and the expertise to evaluate PRC materials, the metrological community will be able to fulfil the needs of researchers in the scientific community seeking for standardized testing and facilities to benchmark the performances of their proposed materials in an objective and reproducible way, against well-characterized model systems. Additional outcomes relevant for the scientific community and our fundamental understanding of this emerging technology regard outstanding open questions in the field. For instance, the role of spectrally selective emissivity as a necessary condition to achieve sub-ambient cooling is still unclear to date depending on other external factors. This is a key point to clarify to understand whether PRC materials can contribute not just to local cooling needs, by dumping heat to the atmosphere, but to terrestrial cooling as well, by effectively discharging heat to outer space. Finally, a relevant scientific and technological outcome of the project will be the identification of the main bottlenecks limiting the performance of PRC materials, which require a multidisciplinary modelling effort beyond the capabilities of single institutes.

Outcomes for relevant standards

The output of the project will represent a widely shared basis for standardization improvement in the field of energy performance of building standards. The whole set of standards, starting from EN ISO 52000 “Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures” and those dealing with the performances of the building envelope developed under EC Mandate M/480 will be analysed and a list of possible adjustments, amendments, integrations will be proposed to the relevant CEN/TCs to foster the introduction of PRC technologies within the EPBD framework. Input to TCs engaged in several fields such as energy performance of building, thermal insulation, thermal performance and energy efficiency will also be provided, including CEN/WS 107 on “Mitigation of Urban Heat Island effects with cool materials”, developed by CEN under AFNOR and ECRC leadership, whose CEN Workshop Agreement will be further analysed as pre-normative document aiming at the integration based on the emerging PRC technologies.

Longer-term economic, social and environmental impacts

This project aims at promoting the introduction of validated methods to evaluate the expected performances, costs and benefits deriving from the large-scale applications of PRC materials. Due to the energy intensive nature of cooling (which is responsible for 20% of electricity consumption and 10% greenhouse gas emissions globally), any technology optimizing its efficiency is posed to play several long-term economic, social and environmental impacts. Energy savings reported up to date in the US range between 20% and 80%, depending on the climates, which is particularly attractive in the EU due to the higher average electricity costs compared to the US. PRC coatings are well suited to all applications using water as a coolant, to support the efficiency and lifespan of PV modules, and for thermal management of electronic devices and vehicles.

Regarding social and health aspects, heat-related stress is known to affect human well-being and mortality with an associated risk that escalates rapidly with temperature. Especially in urban environments, increasing the albedo of buildings and roofs with PRC coatings can help curb the heat-island effect. The length, frequency and intensity of heat extremes is constantly increasing, causing tens of thousands of premature deaths in Europe each year, especially in vulnerable population groups. The emerging role of space-cooling as a new basic need is an important factor that could exacerbate energy poverty, especially for low-income households, while the advent of inherently passive, all-day, electricity-free nature of sub-ambient radiative cooling offers opportunities for off-grid access to cooling power, thermo-electric generation and daytime solar water harvesting and purification.

On the environmental side, in addition to the often prospected benefits deriving from reduced freshwater and electricity consumption, this project aims at tackling also less explored but equally relevant aspects related to the introduction of new materials. Especially in the case of PRC coatings, which come in a multitude of heterogeneous architectures, components and constituent materials, it will be important to perform a life-cycle assessment of the different alternatives, as well as to evaluate their sustainability and durability to weathering agents (which is especially relevant due to their inherently outdoor application).

21XXX04 isoMET

Metrology for European emissions verification on methane isotopes

Overview

Atmospheric observations provide a reality check on the true efficacy of climate change mitigation policy. Methane is a potent greenhouse gas (GHG) with multiple complex sources and stable isotope ratios provide a fingerprint needed to verify emissions by source type. This proposal seeks to improve 1) ambient air monitoring capabilities; 2) the quality of source signature information; and 3) the modelling information necessary to direct the measurement strategy and make top-down emissions estimates.

Need

Methane is a GHG with anthropogenic and natural sources. Its anthropogenic contribution to climate change is only second in importance after carbon dioxide (CO_2) in terms of its radiative forcing and current emission rates (IPCC, 2021). It also contributes to air quality problems through its role in tropospheric ozone formation. Key source categories for anthropogenic CH_4 emissions in Europe estimated with ‘bottom-up’ methods suggest a breakdown as: Agricultural sector (~50%), waste (~22%), and energy (~15%). These three sectors account for up to 95% of global anthropogenic CH_4 emissions and are therefore the focus of mitigation action within the EU through the European Green Deal, and the EU Methane Strategy that describes stronger actions to address CH_4 emissions in each sector. Verifying the efficacy of mitigation policy related to each sector’s influence on total CH_4 emissions is not yet possible, yet the measurement and modelling technologies exist. Metrology research is the missing link to bring isotope ratio measurements into operational use for top-down emissions estimation by source category. ICOS is the foremost GHG monitoring network for tracking Europe’s GHG composition, however, currently formal protocols for measurements and calibration of deployed laser spectrometers do not exist, in turn limiting end-users' confidence to operate such instruments and collaborate as a network of sensors (objective 1). The source signature information needed to interpret atmospheric isotope ratio measurements is lacking. Defined measurement methods are needed that are dependent on the source under study and a centralised system to accrue and disseminate the measurements is needed (objective 2). Further, highly promising new ‘clumped’ isotope measurements could provide additional observables yet metrology research in Europe in this area is yet to begin. For isotope ratio measurements to have impact on policy and for the measurement strategy to be based on evidence, atmospheric transport modelling activities also need to be stepped up. Understanding the gaps and requirements in measurement for emissions estimation requires a collaboration between metrologists and modellers (objective 3).

Objectives

1. To develop a harmonised in-situ CH_4 isotope dataset of ambient air in Europe with improved compatibility for measurements of $\delta^{13}C(CH_4)$ and $\delta^{2}H(CH_4)$. This harmonisation should include a) improved methodologies and procedures for comparability of independent in situ analyses of ambient air CH_4 for $\delta^{13}C(CH_4)$ and $\delta^{2}H(CH_4)$ by OIRS to the VPDB and VSMOW scales and b) IRMS and OIRS methodologies validated through interlaboratory comparisons in Europe using WMO goals.

2. To develop a sustainable metrological infrastructure for a digitised dataset for $\delta^{13}C(CH_4)$ and $\delta^{2}H(CH_4)$-emissions source measurements in Europe and to evaluate the potential for source apportionment through clumped isotopes. This will include developing the analytical protocols for measurements of sources, especially those underrepresented in current databases, and the data analysis and uncertainty estimates for input of new and existing source signature data into inverse modelling for emissions estimation.

3. Use atmospheric chemistry transport modelling to inform objectives 1 and 2, creating estimates of the minimum measurement requirements for existing sites and informing where new measurements in Europe would be beneficial (optimal spatial and temporal frequency of sampling in order to reduce overall emission estimate uncertainties).

4. To facilitate – in cooperation with the EMN for Climate and Ocean Observation and the EMPIR project 20NET03 POLMO – the take up of the data and measurement infrastructure developed in

the proposal by key stakeholders such as the global monitoring networks WMO GAW and ICOS and the inclusion in the ICOS and MEMENTO databases.

Progress beyond the state of the art and results

Next generation of in situ network monitoring capability for $\delta^{13}C(CH_4)$ and $\delta^{2}H(CH_4)$ – objective 1. Following the success of GHG mixing ratio determination using OIRS, the development of precise real time, in-situ field measurements is at hand. The calibration procedures, reference materials and analysis protocols, however, are not sufficiently developed to allow efficient harmonisation of measurements to provide the network of compatible datasets needed for input in atmospheric transport models. For the first time we will develop such a framework and allow isotope ratio measurements to be used as a complete dataset over a significant spatial and temporal range.

Developing the source signature datasets for methane stable isotope ratios, including the development of clumped isotope measurements by OIRS – objective 2. For scientific interpretation of ambient air measurements from objective 1, improvements in source signature information is needed. Several studies have looked at sources across Europe, however, the approaches often entail use of different sampling, measurements and data analysis techniques. Improvements are needed in standardisation of measurements, including full uncertainty analyses, and the methods to curate and disseminate results. Attempts have been made at the global level and this project will look to create a more detailed European domain-based database. As with analysis of $\delta^{13}C(CH_4)$ and $\delta^{2}H(CH_4)$, OIRS techniques offer another route towards more routine and robust measurements of the rarer isotopologues. This area of research is in its infancy, however, progress in the fundamental metrology behind spectroscopic measurement of these rare ratios will help accelerate advancement and lead to discovery of potentially powerful new observables for source identification.

Using atmospheric transport models to direct monitoring strategy and improvements – objective 3. Uniquely we will use state-of-the-art atmospheric chemistry transport modelling techniques to help understand our measurement requirements and plot the course of future expansion. Atmospheric modelling is a prerequisite to translating amount fraction and isotope ratio measurements into policy relevant information. Not all measurements are equal in value for use in a modelling framework. Likewise, the uncertainty requirements on measurements can be relaxed in certain instances (where a measurement site is particularly sensitive to emissions) or required to be improved (e.g. for clean air sites that are needed to constrain the amount of CH_4 already present in the atmosphere before additional regional influences). We will use more than one model to quantify where model uncertainty is an important factor to consider in interpretation – the first such detailed study for CH_4 isotope ratios.

Outcomes and Impact

Outcomes for industrial and other user communities

This project will lead to confident uptake of the new methods, from using the calibration and measurement protocols to inform how instruments are developed and calibrated by manufacturers, through to the confident use of atmospheric flux estimates by governments and other communities. In development of the protocols for pushing the limits of precision and accuracy of measurement we will define the limitation of current instrumentation, therefore finding the most efficient and practical lines for improvement by manufacturers. Instrument manufacturers will also benefit from the supply of the next generation of accurate calibration standards for isotopic composition, which will enable their instruments to be traceable and provide valid data for atmospheric monitoring. The IPCC has set out the best practises for use of top-down emissions estimates to verify emissions estimates and their reporting to the UNFCCC . For these aims governments need to use data established confidently in networks that are linked internationally. The work of this project will inform the practises of such networks based on metrological principles (see following section on outcomes for the scientific communities). Other organisations aiming to help governments and industry will be very interested in both the details of our work (they themselves make measurements) through to the longer-term outcomes (improved top-down emissions estimates will help direct their mitigation efforts and monitoring strategies (e.g. EDF and CCAC).

Outcomes for the metrology and scientific communities

The CCQM strategy document (2021-2030) is aligned to the aims of this project including for 2022-2023 ‘developing an extended global GHG measurement system’ and beyond 2023 ‘interfacing with and providing technical solutions to global stakeholder communities’. We will extend the remit of ICOS to measurement of isotope ratios of CH_4 and create the solutions required by the stakeholder community through our focus on using atmospheric transport modelling. We will therefore be able to realise the aims of the CCQM strategy within the timeframe of this project and include the contribution to standards as set out in B3.c.

Through this effort other scientific groups will have the confidence to operate more instruments, thus bringing more measurements to a combined dataset, ultimately improving the quantity of high quality in situ observations which are critical scientific research and for eventual routine top-down assessment of CH_4 emissions. There is also a wider isotope ratio measurement community looking to use OIRS techniques for measurement of GHGs and other species. Stable isotope ratios and radioactive isotope ratios across other GHGs (name CO_2 and N_2O) also hold significant value for understand the carbon and nitrogen cycles and the sources of emissions. Many of the techniques and approaches we will develop for CH_4 isotopes could be adapted across other measurement systems.

Outcomes for relevant standards

The project will have a strong impact in the CCQM and also stakeholder-led standardisation activities (e.g. the reports from outputs of the GGMT meetings or the ICOS MSA). In terms of standardisation our project is broad, ranging from the preparation of gas standards to the methods of emissions estimation. The ISO technical committees targeted will be ISO/TC 158 (Gas Analysis), ISO/TC146 (Air quality) and ISO/TC207 (Environmental management). JRP partners that have connections via their institute or direct memberships of these committees will ensure that the knowledge developed within the project is fed into the committee meetings. For example, the representatives on the corresponding committee or working group from the project partners will jointly ask the chairperson to include a point in the agenda to present the outputs of the project related to the working group activities and ask for comments to the other committee / working group members. Where appropriate a written report will be submitted for consideration by the committee or working group.

Longer-term economic, social and environmental impacts

Economic

An increasingly rapid policy response will be vital to enhance responsiveness on the move towards net zero in under 30 years while ensuring any possible negative economic costs are minimised. The EU 2030 climate target plan Impact Assessment suggests an accelerated effort to tackle CH_4 emissions: A requirement of 35% to 37% CH_4 emission reductions by 2030 compared to 2005 – a significant step up for effectiveness of policy action. With binding emission targets being set accounting for emission changes is now inherently linked with decision making regarding the wider economy. Issues of trade-offs e.g. in policies that might limit CH_4 emissions but increase CO_2 emissions and perverse incentives (for example in the biogas industry) are further detailed economy-related reasons to improve the transparency behind emissions reported, including top-down verification. Air pollution can also considerably benefit from mitigation of CH_4 emissions (being a major cause of ground-level ozone pollution), affecting health, including both mortality and morbidity, and agricultural productivity. This has knock-on effects for the economy and the welfare costs from premature deaths and pain and suffering are quantitatively assessed.

Environmental

Methane makes up a significant part of the anthropogenic radiative forcing that is driving the global rise in temperature (now around ~1°C above preindustrial). The IPCC have reported that maintaining a temperature rise this century to 1.5°C could avoid the most harmful effects of climate change, which include huge changes to the environment and loss of biodiversity in terrestrial ecosystems (Masson-Delmotte et al., 2018), above this threshold and the chances of loss of unique and already threatened ecosystems becomes very likely. Threats to other areas of the planet are already under significant strain from rising temperatures due to the rising total of global anthropogenic GHG emissions. Europe therefore has a role to play in limiting these global environmental problems – leading the way in climate mitigation action. Other environmental questions to be taken into account include that benefits from grazing ruminants especially in terms of carbon sequestration and biodiversity in grassland and pastures that could be lost if these traditional farming methods were removed. objective measurement and understanding of these issues can help to make the right balance of decisions to protect the environment.

Social

Climate change mitigation policy is also an opportunity to address societal equity, ensuring that emissions mitigation measures to not burden the most vulnerable through fair and just policies. Direct GHG emissions mitigation measures will complement other developments for policies aimed at the agriculture sector and rural areas, in particular an expected societal shift to more balanced diets, with less red and processed meat, more fruits, vegetables and plant-based protein sources, in line with the EU Farm to Fork Strategy.

21XXX05 Met4H2

Metrology for the hydrogen supply chain

Overview

As one of the measures to reduce greenhouse gas emissions, the use of hydrogen should increase. To achieve this goal, the metrological infrastructure for hydrogen needs to cover all supply lines. This project provides novel and improved standards for the safe application of hydrogen, flow measurement, hydrogen quality assessment and custody transfer. Together with outcomes from previous projects, an infrastructure is established that provides measurement data that are fit for demonstrating compliance with regulations and contracts. They ramping up the use of hydrogen and society to adapt itself to using hydrogen to replace fossil fuels.

Need

The report from the Intergovernmental Panel for Climate Change of 2021 underlined once more the urgency of reducing greenhouse gas emissions to mitigate climate change due to greenhouse gas emissions. The European Commission developed the European Green Deal (EGD) to decarbonise the energy use, shifting from fossil fuels to renewable fuels. One of the pillars is a phased approach to the introduction of hydrogen to replace fossil fuels in electrical power generation, transport, industry and the built environment. To apply hydrogen safely, traceable measurements for leak testing, material compatibility, sensors for monitoring processes and odorization are required to demonstrate compliances with legislation. Traceable flow measurement and hydrogen quality assessment are necessary for custody transfer and fair trade. Demonstrating compliance with hydrogen quality specifications, such as ISO 14687, and legal metrology requirements, such as OIML R140 and OIML R137, for metrological type approval and for assessing the performance of measuring systems, is therefore essential. Hydrogen sampling methods for applications below 20 MPa, such as gas grids, need to be developed and validated, to ensure metrological traceability and reliability of data obtained using those methods.

Metrological traceability and accuracy already developed need to be deployed to onsite measurement systems, so that robust and comparable results are obtained that support their use beyond monitoring processes. Finally, there is a need to improve and expand documentary standards for totalisation of quantity and energy used for custody transfer, such as OIML R140, ISO 15112 and EN 1776, to make them fit for purpose for use with hydrogen-enriched natural gas and hydrogen and to cover the totalisation of impurity content.

Objectives

The overall objective of the project is to further develop and integrate the metrology necessary to support the entire supply chain of hydrogen, from production to storage and end use.

The specific objectives of the project are:

1. To develop calibration and measurement methods to support reliable, traceable, and accurate measurements of hydrogen in production processes and end-user applications, in view of safety, process efficiency and environmental issues, such as for purity, leak detection, odorisation, and materials performance, ensuring that online measurement instruments and sensors are operating within their specifications (ISO 14687, OIML R139, and OIML R140) (WP1).
2. To develop measurement standards to enable calibration and validation of flow metering equipment under actual conditions (pressure, temperature), used to accurately quantify flow rates of hydrogen (including blended hydrogen) through the hydrogen supply chain, and to ensure compliance with respect to, e.g., OIML R137, OIML R139, OIML R140, and the Measurement Instruments Directive (WP2).
3. To develop and improve measurement standards and methods to enable traceable validation and performance evaluation of gas quality measurement methods, to thus improve on the current lack of equivalence for e.g. oxygen, hydrogen sulphide, moisture content, and for

reactive components such as hydrogen chloride and chlorine. To develop and improve analysers for critical impurities for online monitoring changes in gas quality, through the supply chain and processing equipment, to ensure the gas quality is meeting the required specifications (ISO 14687) (WP3).

4. To develop novel methods for the evaluation of measurement uncertainty along the supply chain as a whole, namely with regard to the measurement of quantity, and energy and impurity content of hydrogen and hydrogen blends (WP4).
5. To facilitate, in cooperation with the European Metrology Network Energy Gases, the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrumentation manufacturers for hydrogen), standards developing organisations (ISO, OIML) and end users (ammonia production, oil refining) (WP5).

Progress beyond the state of the art and results

The project will deliver novel standards and methods for **leak flow measurement, material compatibility testing, and odorization** of hydrogen-enriched natural gas (HENG) and hydrogen. These standards and methods build forth on previous projects, such as 20IND10 regarding leaks, and ENG01 and ENG54 regarding odorization standards, which focused on other gas media. To support calibration, validating and verifying sensors, rigs and methods are being developed, so that sensors can generate traceable results with a defined uncertainty. This work builds forth on the work done in, e.g., 16ENG01 and 19ENG04.

This project will collate and analyse the results from previous projects regarding **flow metering** (e.g., 16ENG01, 18NMR06, 19ENG03, 19ENG04, 20IND10, 20IND11, and 20IND13) to combine these and improve their accessibility and therefore their uptake. Primary standards for flow metering developed in, e.g., 18NMR06 will be improved and assessed for equivalence in support of calibration and measurement capabilities (CMCs) of European NMIs. For small-scale gas meters, novel calibration facilities are developed for use with HENG and hydrogen. With these facilities, open access data will be generated showing how an impurity content of 2% affects meter performance. Finally, for gas meters above 0.2 kg/min, metrological traceability chains will be designed and matched with ongoing developments of calibration facilities to understand better the need for calibrations for these gas meters.

The framework for **hydrogen quality assessment** developed in, e.g., 16ENG01 and 19ENG04 will be expanded to cover chlorine, one of the impurities listed in ISO 14687 for which accurate measurement standards and methods are lacking. Furthermore, sampling methods will be developed and validated for applications below 20 MPa, e.g., for electrolysers and gas grids, supplementing those from 16ENG01 and 19ENG04 for hydrogen refuelling stations. The capabilities for analysing trace levels of sulfur will be improved and expanded, focussing on equivalence between facilities in measuring the total sulfur amount fraction around the specification of 4 nmol/mol. Improved spectroscopic methods will be developed for ammonia in hydrogen. Stability studies for moisture and hydrogen chloride in static standards will be performed to generate data for the provision of gas standards with defined stability. Measurement standards for water dew/frost point will be developed or adapted to work with HENG and hydrogen up to 6 MPa, a pressure relevant for transmission grids. Developments in, e.g., ENG01, ENG54 and 20IND06 will be taken up to achieve this outcome. Finally, the metrological traceability chains to onsite measurements are demonstrated and validated.

The models for **calculating the total quantity, energy** from, e.g., OIML R140 and EN 1776 will be improved to address correlations in the results used to calculate these totals, dynamic effects in gas grids due to varying flow rate and gas composition to avoid underrating the measurement uncertainty. A model for the calibration for the totalisation of impurity content (purity exposure) is developed to facilitate calculating this parameter which is critical for appliances that are sensitive to the presence of a particular impurity.

Outcomes and Impact

Outcomes for industrial and other user communities

This project is supporting the industry involved in the hydrogen supply chain from hydrogen production to transport and end use.

Novel measurement standards for hydrogen leak rate measurement enable industry to have reliable devices used to monitor the integrity of gas grids, thereby ensuring safety when feeding hydrogen into these grids. The methods and standards for material compatibility assessment enable universities, research institutes and industry to assess materials for their suitability to be used with hydrogen, ensuring that potential hazardous situations are recognised at an early stage. The odorization standards enable, e.g., gas grid operators confirming that the odorant level in HENG and hydrogen meets the specifications, thereby ensuring the safe distribution of these gases to the built environment. They also enable research institutes and other bodies to assess the olfactometric properties of these odorants with hydrogen-containing energy gases.

The rigs for the calibration and evaluation of hydrogen quality sensors enable users and producers of these sensors to have them assessed, so that the results of these sensors have a known performance, and the results are metrologically traceable. This traceability in turn enables the parties using the sensors to use them beyond the monitoring of processes, thereby avoiding the need to measure again for, e.g., assessment of compliance with specifications.

The validated primary standards for flow metering of hydrogen-containing energy gases enable custody transfer for these gases, in combination with the methods for sampling and hydrogen quality assessment, and the improved methods for totalisation and the associated measurement uncertainty evaluation.

The hydrogen quality measurements performed at two industrial sites, electrolyser plant and gas pipeline, will demonstrate to the industry how metrological traceability and accuracy can be delivered in real-life situation. These demonstrations and the good practice guidelines derived from them, will create a close link with the hydrogen production and transport sector as well as with the measurement system manufacturers and therefore, ensure a swift take up of project outcome.

Outcomes for the metrology and scientific communities

In order to facilitate the take up of hydrogen in Europe and worldwide, a well- established measurement infrastructure is a must. This project will focus on developing, optimising and comparing traceable measurement standards and methods, so that this infrastructure is created.

The novel flow measurement standards enable NMIs, DIs and calibration laboratories to provide measurement services for the hydrogen supply chain and industry to have their instruments calibrated . These in turn enable research into the development of gas meters for HENG and hydrogen. The sampling methods, standards and methods for hydrogen quality assessment enable providing services by the gas industry in the form of secondary and working gas standards and measurements and provide research groups with the necessary tools to make their measurement results metrologically traceable, so that conclusions from their work can directly be taken up by others.

The improved methods for hydrogen quality assessment enable disseminating metrological traceability to laboratories, which in turn can seek accreditation based on ISO/IEC 17025 for their services related to ISO 14687, including sampling. Research groups benefit from these capabilities in that they can assess improvements in processes along the supply chain with the necessary standards for calibrating their equipment.

Legal metrology organisations and their national bodies benefit from the work related to especially OIML R137 and OIML R140, as well as the calibration and measurement services enabling assessing the performance of measurement equipment supporting conformity assessment and type approval.

Outcomes for relevant standards

The project provides enhanced guidance for calculating the total quantity, energy and impurity exposure of supplied or received gas and good practices in taking into account the dynamics of the gas grid and gas properties in the uncertainty evaluation to OIML R140 and ISO 15112. The work on flow measurements provides evidence that OIML R137 this recommendation can also be applied to metering and custody transfer of hydrogen and HENG. Material compatibility testing is covered in standards like ISO 15105 and ISO 2782; this project contributes approaches for increasing the sensitivity of the measurement and set-up adjustments allowing for extension of the parameter range in terms of the boundary conditions. The results in WP3 will demonstrate that the scope of ISO 21087 can extended to other supply chains than only PEM fuel cells. The materials compatibility overview for calibration gas mixtures in ISO 16664 can be updated based on the stability study data for static gas standards with, e.g., hydrogen chloride and moisture.

Longer-term economic, social and environmental impacts

As natural gas is the primary fuel source for heating in Europe, the market is approximately 550 billion cubic metres per year. The introduction of hydrogen in this part of the gas supply relieves the pressure on the electrical grids. This project provides the tools to adapt the measurement infrastructure to distributing HENG in the first instance, and hydrogen at a later stage. Using HENG comes with relatively small changes for end-users, thus a very economical measure to decarbonise the gas supply in the short term. It is also far less disruptive than requesting end-users to switch from gas to electricity for these purposes.

The outcomes support the safe application of hydrogen in gas transmission and distribution systems, as well as charging end-users and industry for their gas use in accordance with current requirements. Thereby it facilitates the transition from fossil fuels to net-zero carbon dioxide emission renewable fuels. Feeding in hydrogen enables end-users and industry to gradually adapt to this future, with as little disruption as necessary. In the coming years, feeding in green hydrogen in the natural gas grids leads to a reduction of carbon dioxide emissions, thereby contributing to meeting intermittent goals of the EU Green Deal.

21XXX06 MetCCUS

Metrology Support for Carbon Capture Utilisation and Storage

Overview

Europe must make reductions in CO_2 emissions in order to meet stringent reduction targets related to **global warming**. Carbon capture utilisation and storage (CCUS) can be used to remove CO_2 produced from industrial processes to be **stored either underground or locked in an alternative material**. It is versatile, in the sense that the CO_2 removal step can complement any process e.g. **production of power, fuels, chemicals and heating**. There are key measurement challenges related to **flow metering, emissions monitoring, chemical metrology and physical properties** that must be addressed before this technology can be used efficiently and safely across Europe.

Need

The European Union set a target to **reduce greenhouse gas emissions by 55 % by 2030** and become **carbon neutral by 2050**. To support meeting these ambitious targets the Green Deal[1] was introduced which specifically states that "**priority areas include clean hydrogen, fuel cells and other alternative fuels, energy storage, and carbon capture, storage and utilisation**." As of the end of 2020, several European countries including **Czech Republic, Finland, France, Germany, Portugal, the Netherlands, Denmark and the UK** had included CCUS as part of their national strategies. The European Commission has acknowledged the role that CCUS plays in meeting this target but have also stated that "**the environmental integrity of CCUS is their overriding concern**."[2] Monitoring of carbon dioxide through flow metering within the delivery system and through leak monitoring outside the system is key to quantifying real amounts of carbon dioxide captured. Directive 2009/31/EC on the geological storage of carbon dioxide stated a **requirement of a regulatory framework for monitoring CO_2 leakage** which was established through the Emissions Trading System. Additionally, as highlighted by the EMN for Energy Gases in their annual Strategic Research Agenda[3] and an energy transition report on CCUS measurement challenges[4] authored by NPL with contributions from NEL, new requirements for measurement solutions were identified for **CO_2 quality assurance, physical properties, and material testing such as pipeline corrosion and capture solvent degradation**. The reports were written following direct consultation with **over 300 stakeholders** from European industry including the key players within the CCUS field. This will be the **first metrology for CCUS project** that will solve the key metrology challenges for CCUS identified by industry and provide as outputs the Primary Standards, methods, good practice guides and literature reviews that they require to successfully grow a CCUS industry in Europe.

Objectives

1. To develop the metrology infrastructure required for monitoring CO_2 produced and lost within an industrial process through the development of new traceable facilities, including primary flow standards to enable calibration of flow meters for liquid and gaseous-phase of CO_2 with uncertainties of 1.5 % - 2.5 %, as well as validation of systems capable of quantifying CO_2 leaks from pipelines, transport (e.g. shipping) or storage sites.

2. To develop primary standards, sampling, analytical methods and models required to support industry in specifying operational conditions and to perform required measurements within CO_2 capture, transport and storage. To develop methods for CO_2 purity analysis (ISO/TR 27921), data verified models to predict physical properties (e.g. phase equilibria, density and viscosity) and testing methods to produce validated data for pipeline corrosion, capture material

degradation, chemical reactions, purification and CO_2 storage. In addition, to develop and qualify instrumentation for monitoring phase behaviour and composition.

3. To develop and provide metrology facilities to support industry in the development of new technologies for capture, transport, utilisation and storage of CO_2 and in performance testing of new capture techniques, purification systems and sensors in order to facilitate rapid uptake of carbon capture in Europe.
4. To develop validated analytical methods and primary standards for the use of captured CO2 that meet the technical specifications of European manufacturers (e.g. food industry). Additionally, to develop metrological methods to measure the degradation of products, assess their lifetime and quantify actual loss of CO_2 to the atmosphere over time.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrument manufacturers), standards developing organisations (ISO TC 265) and end users (CCUS industry).

Progress beyond the state of the art and results

This is the first project that will focus on metrology to support the CCUS industry. Some of the key progress will be:

- New traceable flow calibration facilities and primary standards to evaluate performance of various flow meter types when used with gaseous and liquified carbon dioxide including assessment of lowest uncertainties.
- Guidance on calibrating these meters with alternative fluids that are common in existing traceable laboratories.
- New capability to simulate precise CO_2 leaks from pipelines to test and validate commercial new leak monitors. Further, methods will be developed to monitor largescale CO_2 leaks from on-shore and sub-sea storage sites using state-of-the-art gas detection techniques such as LIDAR and other spectroscopic methods.
- This project will identify the gas analysis methods that require traceability when performing purity measurements and provide new PRMs and validated analytical methods to support industry. Furthermore, a primary humidity generator will be developed to provide humidity values in CO_2 for calibrating hygrometers.
- Improve best practice for sampling CO_2 including how to perform sampling accurately and selection of suitable sampling vessels.
- One work package in the project will be dedicated to physical property measurements, which includes experimental work to provide traceability for a physical property (density, viscosity and heat) at a specific gas composition (made traceable through preparation of binary mixtures). Furthermore, activities will be focused on developing new equations of state models and uncertainty evaluation.
- The project will focus on developing and validating online instruments and sensors for monitoring flow rate, phase behaviour and gas composition in real-time. Air Liquide will provide their CCS industrial site to test instruments in a real scenario following NMIs performing rigorous testing of devices against traceable primary standards.
- The project will develop a testing rig capable of subjecting capture solvents to high temperatures under controlled CO_2 atmospheres (containing varying levels of impurities). This facility will allow CO_2 capture cycling to monitor degradation and presence of impurities from the material.
- The PRMs and analytical methods developed in the project can be used by industry to test CO_2 purifiers and online gas monitoring devices. Furthermore, a materials testing rig will be developed that can screen materials to assess their ability to purify CO_2.
- A materials testing facility will be developed that is capable of measuring amount of carbon dioxide uptake and released during capture cycles against traceable standards.
- This project will develop PRMs, gas analysis methods and a good practice for sampling that will support accurate purity measurements of CO_2 intended for utilisation rather than storage. The selected impurities will be based on literature reviews and discussion with stakeholders.

- A method will be developed using the materials testing facility to measure amount of CO_2 released from, for example, $CaCO_3$ over several cycles at temperature.

A more comprehensive overview of the progress that will be made in this project to improve state of the art can be found in Section B2d.

Outcomes and Impact

Impact on industrial and other user communities:

- CCS operators will be able to perform flow metering and leak monitoring of CO_2 to accurately quantify amount of CO_2 capture, transported, stored and lost in their process. This is required to operate the facilities safely, but also to quantify CO_2 capture and losses when reporting.
- CCS operators and CO_2 suppliers will be able to determine suitable conditions and materials (e.g. pipelines) and monitor these conditions through purity and physical property measurements to ensure safe and efficient operation.

Impact on the metrology and scientific communities:

- NMIs and DIs will develop Primary Standards for flow metering, gas analysis, physical property measurement and leak detections specifically which can be used to develop new Calibration and Measurement Capability (CMCs) to support national traceability for these measurements in CCUS. Furthermore, these new capabilities can be utilised by other measurement or calibration laboratories to provide their own calibration services for the CCUS community.
- Laboratories, research organisations and academia will be able to use new capabilities developed by NMIs, DIs and other research partners of this project to perform high quality research within the CCUS area where measurements are traceable to the SI and suitably accurate to obtain results that support development of new CCUS technologies.
- The project will perform fundamental scientific work in the development and uncertainty evaluation of equations of state for CCS conditions

Impact on relevant standards:

The following ISO standards and New Work Item Proposals from ISO TC 265 include measurements that will be studied in this project, and can be improved through this project, during the next revision:

- ISO 27913:2016 - Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems
- ISO 27914:2017 - Carbon dioxide capture, transportation and geological storage — Geological storage
- ISO/TR 27915:2017 - Carbon dioxide capture, transportation and geological storage — Quantification and verification
- ISO/TR 27921:2020 - Carbon dioxide capture, transportation, and geological storage — Cross Cutting Issues — CO_2 stream composition
- ISO/TR 27922:2021 - Carbon dioxide capture — Overview of carbon dioxide capture technologies in the cement industry
- NWIP (approved June 2021) - Performance Index and Standard Test Method of Absorbent Performance for CO_2 Capture

Longer-term economic, social and environmental impacts:

<u>Economic impact</u>

- Flow metering of carbon dioxide is required for monitoring emissions for CCS processes according to the EU ETS. Inaccuracies could lead to errors in the calculations, which could either lead to overcharging of carbon emission costs or fines for providing inaccurate information.
- The work of this project will support monitoring of leaks in pipelines; early identification of leaks will reduce risk of extensive damage/loss of CO_2.
- Impurities in carbon dioxide if not monitored can provide problems to the CCUS operator through unintended toxic releases, and corrosion or damage to pipelines, equipment and storage sites. These incidents can be costly by firstly requiring the operator to stop operation,

but there would also be considerable costs for maintenance, repair and equipment replacement.

- Impure carbon dioxide in CCS processes (e.g. inert gases at volume percent level) can increase energy requirements (for compression) which would inherently increase the cost of operation.
- Inaccurate equations of state model (or lack of one) may lead to issues with meeting CCUS operator conditions by not being able to monitor real physical properties. This could lead to dangerous scenarios for operation such as over-pressurisation or even cases where pure hydrogen could bubble out from the CO_2 and come into contact with pipelines.

Social impact

- Developing new capability to monitor for carbon dioxide leaks is imperative for ensuring health and safety in the gas industry and will protect citizens.
- A focus will be made to educate new players (e.g., laboratories and instrument manufacturers) entering the CCUS market on the importance of laboratory accreditation and showing competency through comparisons, either for purity analysis or performance of online analysers. This will be a principle aim of the impact work package.
- Several technical workshop will be hosted by the partners to disseminate the newly developed standards and methodologies to allow fast uptake by commercial laboratories and organisations.
- Several countries across Europe are running their own independent projects implementing CCUS technologies; however, this project will be the first time relevant industrial stakeholders from across Europe will join together in a collaborative effort to progress this topic.
- The project, through hosting a website, organising workshops, presenting at conferences and running a stakeholder advisory board will inherently support better networking between gas distribution networks, and the relevant laboratories and instrument manufacturers.

Environmental impact

CCS contributes to reductions of carbon dioxide emissions which support countries to meet targets set by the Climate Change Act.[5] The activities within this project would not only support CCS for decarbonising gas, but all CCS processes including those used in tandem with power production and direct extraction of carbon dioxide from the air.[6] Many of the measurement requirements specified in this proposal originate from mandatory legislation, such as the EU ETS or national legislation (that may reference International Standards). Where legislation has not yet been developed, this project will support its development by ensuring the relevant measurement capability is already available.[7]

The direct environmental impact from this project is as follows:

- The entire project is focused on supporting the success of European companies in implementing CCUS technologies; doing so will support the significant decrease in CO_2 emissions from industrial and energy processes or by direct air capture.

Companies will have the ability to accurately measure carbon dioxide in CCS processes to track their carbon dioxide emissions in accordance with EU ETS.

21XXX07 PlasticTrace

Metrological traceability of measurement data from nano to small-microplastics for a greener environment and food safety

Overview

The PlasticTrace project aims to address the urgent need for development and harmonisation of methods for the chemical identification, physical characterisation and quantification of released small micro/nanoplastics (SMPs/NPs) in drinking water, food and environmental matrices as required by the EU's Circular Economy Action Plan (CEAP). In this context, hyphenated and complementary analytical approaches will be developed, optimised, compared and harmonised, leading to the establishment of metrological traceability of measurements through robust validation studies. Novel and environmentally relevant SMP/NP reference materials will be developed within the project. International cooperation with key stakeholders globally will be achieved in an integrated manner, being the basis of a European Metrology platform.

Need

Plastic pollution is recognised as a severe anthropogenic issue globally, where complex physico-chemical transformation processes such as aging, degradation and fragmentation produce MPs and subsequently NPs. These processes occur during production, consumer use, waste processing and through environmental process after emission. Several studies have reported the occurrence, analytical methods and toxicity of larger MPs in the environment and food matrices; conversely, MPs that <100 μm in size (SMPs) and NPs (<0.1 μm) in natural systems have been overlooked, primarily due to significant methodological challenges associated with their nano-specific properties. Even though the presence of SMPs/NPs in environmental and food samples, including, water, biota and soil samples is hypothesised, there is limited data to conclusively demonstrate this and quantify the amounts. There is an urgent need for such harmonised and standardised analytical procedures to be developed and utilised.

In this respect, the European Commission (EC) initiated a study focused on understanding the potential ecotoxicological impacts of SMPs, encouraging research aimed at a better characterisation of both materials and exposure conditions. Furthermore, the EC adopted the new CEAP in March 2020, which encourages sustainable consumption and aims to prevent plastic waste. To reduce plastic contamination, however, methods for the identification, characterisation and quantification of SMPs and NPs in food and environmental matrices are needed to support the CEAP. Such methods need to be metrologically validated using appropriate reference materials, so that Europe can establish harmonised and traceable measurements of SMPs and NPs.

End users of the procedures to be developed within PlasticTrace are public organisations concerned with environmental and food monitoring, regulatory bodies responsible for the control of environmental pollution and food safety, and industries that may be responsible directly or indirectly by potential MP emissions into the environment or the human food chain. Furthermore, the need for efficient and reliable measurement infrastructure is required in support of ECHA's proposed restriction targeting intentionally added MPs in consumer products and the new Drinking Water Directive (EU) 2020/2184 that explicitly mentions microplastics and which is due for revision in 2024.

Objectives

The overall aim is to develop international metrological capacity that enables the traceable measurement and characterisation of SMPs and NPs in environmental and food samples and the production of suitable reference materials, according to the metrological requirements.

The specific objectives are:

1. **To produce SMP (0.1 μm –100 μm) and NP (<0.1 μm) reference materials** with clearly defined and realistic particle size distributions, irregular morphologies and mass fractions for the validation of analytical procedures and the establishment of a metrological traceability**.** The SMP/NP reference materials will include both pristine particles and those more representative of the partially degraded/naturally aged SMPs/NPs expected to be present in the environment and food products.
2. **To develop accurate and efficient sample preparation methods for the measurement of SMPs and NPs in complex food and environmental matrices** (e.g. drinking and surface water, sewage sludge and milk). The sample preparation methods must also demonstrate a negligible effect on the particle characteristics and polymer compositions of samples.
3. **To develop accurate and robust traceable methods for the characterisation of SMPs/NPs in complex matrices -** (i) chemical identity of the SMPs/NPs polymer type; (ii) physical particle characterisation and quantification, size distribution and particle morphologies; and (iii) quantification of the mass fraction.

4. **To demonstrate the validity and applicability of the methods and reference materials developed in Objectives 1-3 via an interlaboratory comparison**. As part of the comparison, best practice guidance on the traceable measurement and characterisation of both neat SMPs/NPs and SMPs/NPs in food and environmental matrices will be developed.
5. **To facilitate the take up of the technology and measurement infrastructure** developed in PlasticTrace by the measurement supply chain (national metrology institutes, accredited laboratories), standard development organisations (CEN, ISO) and end users (e.g. food and drink producers, environmental monitoring programmes and health experts).

Progress beyond the state of the art and results

SMPs/NPs resulting from the fragmentation/wearing of plastics are expected to have different properties than the synthesised monodisperse spherical SMPs/NPs typically studied to date, questioning the representativeness of synthetic plastic particles used in many experiments. SMP/NP reference materials representative of partially degraded/naturally aged samples are currently not available and will be developed and provided by PlasticTrace. Various SMPs/NPs with realistic polydisperse size distributions and irregular shapes will be considered for the representative environmental and food media chosen for use in the project. The composition of SMPs/NPs and environmental/food matrices are related to literature knowledge and will be adapted during the project to new insights. The selected environmental and food matrices will include examples that are strongly suspected or known as SMPs/NPs entry pathways (drinking and surface water) and other less investigated matrices (sewage sludge and milk). In this approach, different environmental and food media are represented and the specific properties of these media are considered, including expected amounts, particle size and mass loads, as well as the various organic and inorganic content in complex matrices.

The identification and the analysis of SMPs/NPs in complex media is very challenging due to the inability to readily distinguish SMPs/NPs from other types of particles in the same size range (dissolved and particulate organic matter) and due to the need for pre-concentrating samples to meet the detection limits for their identification. The existing procedures for sample preparation are often critical in terms of the stability of very small and aged particles, as well as very time consuming. PlasticTrace will cover the application and harmonise these procedures, including the application of state of the art digestion protocols for complex organic media, the selection of specific enrichment procedures suitable for each analytical approach, the development of filters in the sub-micron/nanometer range for SMPs/NPs filtration, and the application of different types of innovative fractionation steps for size separation. This will give the opportunity to further develop online and offline methods for particle size distribution analysis and stability evaluation, polymer identification by spectroscopic tools and mass fraction quantification by thermoanalytical techniques.

Given the challenge of characterising SMPs/NPs in complex matrices, PlasticTrace will primarily focus on the development and harmonisation of routine/established analytical methods for the measurement of SMPs (100-10 µm) and on the development of innovative hyphenated, complementary and correlative analytical approaches for the measurement of SMPs/NPs (<10 µm) in complex samples.

In particular, the following beyond state measurement capabilities will be developed and optimised:

(i) Light scattering methods for the characterisation of size distribution and particle number with hyphenated approaches based on fractionation techniques;

(ii) Innovative micro-spectroscopy methods for fast automation and data processing for large scale plastic particle monitoring and a new online hyphenated prototype based on fractionation-sizing-quantification and chemical characterisation;
(iii) Mass spectrometry-based methods for the characterisation of mass concentration, number and chemical identification with hyphenated approaches based on fractionation techniques;
(iv) High-resolution, correlative and automated microscopy methods for the characterisation of size distribution, shape and chemical identification performed on fractionated or filtered samples.

Outcomes and Impact

Outcomes for industrial and other user communities

The project will provide application-oriented analysis tools and an infrastructure for SMPs/NPs measurement across various fields. The establishment of a traceable measurement chain with the provision of new reference materials and associated methods will improve the reliability and accuracy of SMPs/NPs characterisation, supporting utilisation of the results by end users that include accredited commercial laboratories, national environmental institutes and monitoring agencies. Together with tools for quality control and proficiency testing, the traceability will guarantee standardisation and comparability of the results, which is currently lacking for SMPs and especially NPs. The outcome of the project will enable comparable and traceable monitoring to support decision-making and effective assessment of mitigation measures implemented by the EUs Plastic Strategy.

This interest is particularly evident from the letters of support for PlasticTrace from plastics and food industries, international/national food and environmental monitoring agencies, instrument producers, institutional and commercial laboratories. These provides strong evidence of the importance of the project and indicates the direct impact across a wide range of stakeholders. All stakeholders are committed to support implementation of the results through joining the stakeholder committee. Direct use of the results and alignment with industry and monitoring agencies is assured by the direct involvement of key actors, from SMEs (Postnova, SmartMembranes), to globally leading instrument producers (ThermoScientific, Horiba and Agilent), commercial laboratories (EUROFINS), leading food producers (Nestlè Waters, Barilla and Parmalat) and national or international environmental agencies (Norwegian Environment Agency, AMAP, UNESCO).

Outcomes for the metrology and scientific communities

PlasticTrace will provide validated SI-traceable measurement capabilities for the integral quantification of SMPs/NPs derived from the most common polymers, which are currently not available. The project will provide efficient sample preparation SOPs for relevant complex environmental and food samples, which will support both the measurement infrastructure aimed at routine laboratories and also the academic scientific community and several EU projects. New technological developments in innovative hyphenated systems and their standardisation represent major outcomes for PlasticTrace and we expect them to be quickly adopted into common use by metrological, research and scientific communities. Through organisation of workshops, and presenting project outcomes at symposia, conferences, exhibitions and trade shows, dissemination of the developed technologies and methods to core stakeholders in different sectors will be assured.

The partners in the project have strong connections to all existing EU projects related to plastic in the environment and are in close contact with both the European Commission’s General Directorate for Health, Consumers & Reference Materials and the Consumer Products Safety Unit within the Joint Research Centre (JRC). In total, consortium partners are participating or in contact through the European Research Executive Agency (REA) Cluster meetings with more than 20 ongoing EU projects and one COST action. The majority of the projects will need harmonised methods for the detection of SMPs or NPs in complex samples, including human samples. In addition, several partners participate in the construction of the European infrastructure for promoting metrology in food and nutrition METROFOOD-RI, the European Metrological Network on food (FoodMetNet) and pollutants (POLMO), and the NORMAN network WG micro and nano plastics, assuring a solid anchoring in the European research community. To ensure projects connection internationally, several international experts from China, Australia, USA, South Africa, Korea, Japan and Brazil have expressed their interest to be part of the PlasticTrace international scientist board.

Outcomes for relevant standards

Several project partners are represented internationally in several ISO/CEN committees and working groups in VAMAS and BIPM, as well as national standardisation organisations (DIN, AFNOR, SFS, Standard Norway). This will guarantee the implementation of the project results in standardised methods both at a national and international level. In turn, this will build capacity for European environmental, food and drinking water monitoring programmes on SMP/NPs. The produced reference materials will support long-term quality control of analytical methods used for this purpose. This is in line with the EU's long-term strategy formulated in the European Green Deal. More specifically, 'The Zero Pollution Action Plan' is asking for compliance with end-of-pipe technologies, while the 'The Farm to Fork Strategy' requires minimisation and control of SMP/NPs and 'The Plastic Strategy' calls for the reduction of litter (including MP). The results of PlasticTrace represent a crucial contribution towards achieving the objectives of these action plans on the restriction and especially control of SMP/NPs.

Longer-term economic, social and environmental impacts

PlasticTrace will address major societal needs defined in the Priority Themes of the EU Framework Programme for Research and Innovation 2021–2027, particularly in Horizon Europe Cluster 6, and by the CEAP, which highlights the severe impact of chemical pollutants and MPs on the health of water bodies and the need to develop harmonised measurement methods for unintentionally released of SMPs/NPs to close existing gaps in the scientific knowledge related to the risk occurrence of SMPs/NPs in the environment, drinking water and foods.

Achieving reliable SMPs/NPs analytical determination is a prerequisite for addressing these major knowledge gaps, for providing a framework for science-based risk assessment and for consequent adoption of measures tackling plastic particle distribution and accumulation in the environment and food with potential long-range public health, economic and social impacts.

In order to monitor mitigation measures and emission control, efficient metrological traceability methods and technologies for SMPs/NPs are needed to support the EU's Green Deal, including the EU's Plastic Strategy and the Zero Pollution Action Plan for air, water and soil. Without the availability of traceable and quality assured analytical methods and reference materials, the goals of several EU directives on waste water treatment, sewage sludge, environment quality, marine framework and drinking water (UWWTD, SSD, EQSD, MFSD, and DWD) to reduce SMP/NP emissions to the environment cannot be achieved. By delivering cutting-edge outputs, including innovative measuring technologies combined with traceable QA/QC tools and environmentally relevant polymer reference materials, PlasticTrace will contribute directly to the EU Plastic Strategy objective to reduce the impact of SMPs/NPs to the environment.

Moreover, the development of novel analytical methodologies for the identification and quantification of SMPs/NPs in food matrices will facilitate the generation of critical exposure, ingestion and uptake data, thereby laying the basis for dietary exposure assessment. PlasticTrace has the ambition to provide the analytical tools necessary to facilitate a solid evidence-base for any regulatory action at national, EU and international level aimed at increasing the sustainability of the plastic industry and addressing the challenges posed by plastics throughout their entire life-cycle. The standardisation of methods will help to facilitate the assessment of the relevance, origin and fate of SMPs/NPs at European and international level and thus contribute to the creation of efficient strategies to reduce plastic inputs into the environment and food chain. This will also be in support of EFSA evaluation for risk assessment and toxicity of plastic materials along the food chain. In the long term, we expect PlasticTrace will directly contribute to new regulations for nanoplastics.

21XXX08 MetroSoilMoist

Metrology for multi-scale monitoring of soil moisture

Overview

Water and soil are vital resources seriously affected by climate change and degradation. Water at the land surface, primarily in the form of soil moisture, is a key resource influencing agriculture, forestry, groundwater recharge, weather, climate, and greenhouse gases emission at the landscape. Several soil moisture observation systems exist on multiple scales, but they need to be harmonized. The overall objective of this project is to develop novel metrological tools and establish a metrological foundation for soil moisture measurements on multiple lateral scales, ranging from decimetre to kilometre, ensuring the traceability and harmonization of the various soil moisture measurement methods.

Need

Soil moisture is one of the Essential Climate Variables (ECVs) as defined by the Global Climate Observing System (GCOS) of the World Meteorological Organisation (WMO). Soil moisture influences the land-atmosphere interactions at both weather and climate timescales. Long-term carbon storage and release in soil is strongly influenced by soil moisture ─ only a healthy and adequately moist soil can act as carbon sink in the strategies for greenhouse gases (GHG) reduction and adaptation to climate change impacts. Soils are a cross-cutting theme within the European Green Deal (EGD), communicated by the European Commission (EC) in 'EC COM/2019/640 final', as the sectors of water management, agriculture, forestry, and biodiversity are inherently strongly interdependent. Soil quality and soil moisture play a key role in the future EGD policies, namely in the future Common Agricultural Policies unified under the Farm to Fork Strategy ('EC COM/2020/381 final'), policies for environmental protection (Biodiversity Strategy for 2030, 'EC COM/2020/380 final') and the climate change action (The European Climate Law, 'EC COM/2020/80 final').

There is an urgent need to establish the chain of traceability, the metrological assessment of uncertainties and the harmonization of soil moisture measurements within the hydrological cycle as a whole, on multiple scales ranging from point-scale sensors to satellite remote sensing techniques. The need for the metrology community support in the soil moisture data harmonization was communicated by the European Metrology Network for Climate and Ocean Observation (EMN COO, 'Stakeholder Needs Review Report 2020').

Overall, there is an acute and overlapping need for real-time, continuous, high-quality, high-resolution and metrologically traceable and harmonized data on soil moisture, to provide data to optimize water management strategies that have an impact on agriculture, weather forecasting (relevant to the prevention of extreme events such as floods, droughts and wildfires), and climate change monitoring, modelling and mitigation.

Objectives

The overall objective of this research topic is to develop novel and sound metrological tools and establish a metrological foundation for soil moisture measurements on multiple scales, ranging from decimetre to kilometre, and thus ensuring the traceability and harmonization of the multiple soil moisture measurement methods. The specific objectives are:

1. To develop metrologically traceable methods for multi-scale soil moisture measurements, covering lateral scales ranging from decimetre to kilometre and to depths of about 1 metre, to assess the soil moisture with traceable relative uncertainty of 20 % or better.
2. To improve the metrological traceability of existing cosmic-ray neutron sensing (CRNS) devices currently available in the market. This includes the development and validation of the neutron transport models used to interpret CRNS detector signals specific to the soil moisture measurand.
3. To develop a multi-scale metrological system for soil moisture monitoring. This includes the development of a cross-disciplinary harmonisation system on the medium sub-kilometre-scale and the establishment of (i) metrological traceability of soil moisture measurements using point-scale sensors and satellite measurement techniques and (ii) fit for purpose modelling. In addition, to develop techniques to support the harmonisation of soil moisture assessment.
4. To investigate the constraints and accuracy of soil moisture measurement methodologies using intercomparison campaigns on local and remote sensing. In addition, to develop procedures to overcome (i) temporal and spatial differences regarding the sensing domains of soil moisture measurement methods and (ii) the influence of other state variables such as air humidity and soil temperature affecting the measurements.
5. To cooperate with user communities to define design criteria for emerging and future hydrological and meteorological/climatological soil moisture networks using the combination of point-, intermediate- and large-scale methods. To cooperate with the EMN COO and relevant international organisations (e.g., WMO)) to facilitate the dissemination of the project outputs.

Progress beyond the state of the art and results

Several soil moisture observation systems have been developed, ranging from invasive point-scale soil moisture sensors to large-scale remote sensing products. In addition, more recently, a non-invasive intermediate scale soil moisture method, cosmic-ray neutron sensing (CRNS) has found widespread use. Despite several initiatives, no harmonization approaches under metrology standards have been developed so far. This project will address this gap by developing the metrological tools needed for traceable and validated soil moisture measurements. For the first time, metrological tools for all three domains/scales will be considered in a holistic approach, to harmonize soil moisture monitoring across scales. The details for the progress beyond the state of the art are summarized here:

Metrologically traceable methods for multi-scale soil moisture measurements: New traceable methods for the measurement of soil moisture in outdoor conditions on lateral scales in the range of 10^{-2} m to 10^{3} m with relative combined uncertainty of 20 % will be developed. To achieve this, new standards and methods for the traceability of the point-scale soil moisture measurements under laboratory conditions will be developed. The measurement supply chain will be extended to outdoor conditions by transfer standards and an improved on-field sampling method.

New traceability scheme and validation practices for CRNS method: The expertise and facilities of metrological institutes will be applied to develop a traceability scheme of CRNS methodology for the first time. The neutron response functions of the CRNS devices will be validated using calculations and neutron reference fields. This will allow for an effective validation of the current and upcoming designs of CRNS devices. The combination of metrology of neutron radiation, temperature, and humidity will allow, for the first time, a traceable benchmarking of CRNS devices under outdoor conditions, leading to new validation practices. There will be improved understanding of the CRNS footprint, of systematic effects, and of the uncertainty of the soil moisture retrieval.

New on-field comparison campaigns on local and remote sensing: New data on soil moisture will be systematically collected at established experimental field sites, operated by partners and selected according to their relevance for the calibration and validation practices of soil moisture retrieval by CRNS and remote sensing. These data will be a clear improvement over previous historical data sets as they will base on newly characterized devices of point-scale and CRNS methods, and the measurements will be designed for the purpose of harmonization. The data will be used to investigate the limitations and accuracy of the individual methods. New approaches and methods will be developed to overcome the temporal and spatial differences regarding the sensing domains of the individual methods.

Cross-disciplinary harmonization system for soil moisture monitoring: Based on the newly collected data sets, and on the historical time series, novel procedures for harmonizing soil moisture assessments on different temporal scales and on lateral scales ranging from point scale to kilometre scale will be developed. New recommendations for the calibration and validation practices of the soil moisture retrieval by remote sensing, as well as new methodologies for data fusion, will be given.

Outcomes and Impact

Outcomes for industrial and other user communities

The project will provide the metrological tools needed by experts performing and utilizing soil moisture measurements on multiple scales. The newly developed standards and improved sampling method of point-scale measurements will support the industrial community of sensors manufacturers. The CRNS method will be metrologically established, with validated devices' sensing footprint and area-averaged soil moisture measurand definition. This will support the existing, emerging, and future CRNS networks and, in general, the uptake of this method in sectors such as precision agriculture. Finally, the harmonization and improved comparability of the soil moisture methods will strongly support the remote sensing community dealing with soil moisture assessment on kilometre scales.

The adoption of this project's definition and requirements for the technical setup, measurement procedures and uncertainty evaluation, will substantially address the present lack of a common approach. This will improve data comparability across regions, time, and communities and allow for a more robust data exchange. This will provide the basis for a better understanding of climate evolution locally and globally, to better support water resources management and planning and climate change mitigation. The availability of traceable and comparable data from a range of both critical and representative global environments will be invaluable in supporting soil moisture and cross-validation of methods.

Outcomes for the metrology and scientific communities

SI-traceable metrology for water content in materials has been partly established over the last decade. At present, no countries have BIPM Calibration and Measurement Capabilities (CMCs) for moisture measurement, and SI-traceable measurements of soil moisture on primary level have, to our knowledge, not been reported. One important outcome of this project is to establish primary-level soil moisture measurement with developed uncertainty budgets. This allows for traceable calibration and validation of secondary measurement standards such as those based on traditional loss-on-drying and of transfer standards. It is anticipated that these methods are adapted by the metrology community.

For soil moisture measurement there are currently open issues of appropriate transfer standards and sampling methods. Within this project, these issues will be addressed, to properly transfer the metrological chain of traceability to outdoor conditions. Among others, by new transfer standards based on visible and near-infrared spectral reflectance measurements for on-site calibrations. This improved metrological basis will be used for improving the CRNS methodology. Harmonized soil moisture sensors and data processing schemes will have direct impact on networks in Europe (TERENO, COSMOS-UK) and worldwide (COSMOS, CosmOz, COSMOS-India). Harmonized multi-scale soil moisture data, with reliable uncertainties, will improve hydrological modelling, climate and weather forecasting by ensuring better comparability between data sets obtained with different methods.

This project will promote the widest possible uptake of its outputs, globally, through reporting and informing relevant worldwide Institutions, such as the WMO, the BIPM and International associations of Manufacturers (members of this proposal sit in and chair relevant WMO expert teams and BIPM CCs working groups). This will be achieved through direct interactions with stakeholders and institutes. This will facilitate project result dissemination directly to the relevant expert teams for inclusion in guidance material such as the WMO ‘Guide to Meteorological Instruments and Methods of Observation’ (WMO-No. 8), and the results will be reported to the GCOS where members of this proposal contribute as experts.

Outcomes for relevant standards

Currently, most of the guidance for soil moisture measurements in the field is contained in good practice guidelines (e.g., IAEA technical documents on field estimation of soil water content and on CRNS, CEOS good practice protocol for remote sensing, and methods of soil analysis by American Society of Agronomy), and there is a lack of relevant validation and standardization. Standardised procedures based on suitable calibration devices would have a strong impact on the market of soil moisture instruments. Indeed, their diffusion is now limited due to insufficient standardized calibration procedures and absence of both metrological comparison and harmonization among different sensor typologies and gravimetric/volumetric manual soil moisture measurements. The work proposed here will fill this gap both on providing standardized calibration procedures and intercomparison of instruments in laboratory and field.

Longer-term economic, social and environmental impacts

This project’s results will be of interest to instrument manufacturers to test and validate new measurement systems. The process works both ways: technological advances, new measuring principles, evolving measurement and calibration procedures, should be immediately recognised and integrated to improve soil moisture observations for climate reference stations and networks.

As for other observed quantities in meteorology, such as temperature, wind and precipitation, it is expected that non-contact systems will slowly replace instruments based on the direct interaction between sensor and measured quantity. Having calibration and documented traceability available will support the diffusion of such systems, with direct economic and technological benefit. Together with more reliable data, this will also contribute to better environmental analysis, e.g., nitrogen and carbon cycling which are dependent on soil water content in agroecosystems, and climate studies and mitigation of GHG emission.

The devices studied here are suited to operate in unmanned meteorological stations, e.g., stations located far from urban settlements. These remote stations are needed to monitor the whole territory of hydrological basins and large agricultural areas, for improved coverage and completeness. More reliable early warnings would therefore be possible to promptly inform weather services, local agro-meteorology consortia and users, about the risk of drought and required irrigation plans. The accuracy of such information is vital to issuing effective and timely warnings. The main economic impact would therefore be in the form of more trustable and more prompt irrigation plans, with direct benefits on agriculture and farming: reduction of water waste for irrigation, reduction of nutrient loss in leaching, reduction of GHG emissions from soil, and associated costs, with increased water availability.

Having assessed traceability and considering the robustness of the systems here studied, a reduction in maintenance costs for hydro-meteorological agencies and agro-meteorology consortia and users is foreseen. This has the potential to increase the demand for such systems, possibly lowering their commercial costs.

21XXX09 MetEnvPol

Metrology for the harmonisation of measurements of environmental pollutants in Europe

Overview

To comply with the zero-pollution ambition promoted by the European Green Deal, highly sensitive and state-of-the-art detection techniques for ultra-low amounts of pollutants and determination of their isotope ratios are required. Mass spectrometry is a key method for non-radioactive polluting elements determination and of increasing importance for long-lived radionuclides. This project will bridge the gap between both methods and will establish new tools for tracing pollutants. Measurement uncertainties and detection limits will be significantly reduced using newly developed reference materials and SI-traceable measurement procedures with an immediate impact for tracking pollution sources by commonly available mass spectrometers.

Need

This project supports the strategies described by the upcoming European Metrology Network (EMN) on Pollution Monitoring (POLMO) and the established EMN on Radiation Protection (supporting the BSS). With reference to the described strategy by the EMN POLMO, there is a strong need to improve data quality for the monitoring and reporting of pollution in air, water, and soil. In addition, comparability and robustness of measurements are often compromised by a lack of suitable traceability chains and appropriate quality control.

To detect radioactive isotopes and stable polluting elements in the environment, fast, sensitive and inexpensive analytical procedures are needed. Mass spectrometry techniques have a great potential to address this requirement. Despite the increasing application of single collector ICP-MS, the potential cannot be fully realised unless techniques can be validated with traceable multi-element reference materials. However, multi-element certified reference materials are usually not available and even single-element certified reference materials are limited to very few elements. Nevertheless, these reference materials are urgently needed to calibrate mass spectrometric measurements, due to mass bias effects occurring during the measurements in mass spectrometers [1,2,3].

The orientation document issued by EURAMET´s Ionising Radiation Technical Committee and the EMN on Radiation Protection clearly describes a metrological need for a project in the area of ‘traceability of radionuclide concentration measurements in the environment’. This topic refers to the classification of the Green Deal ‘A zero-pollution ambition for a toxic-free environment’. There is a need to increase the use of modern mass spectrometric techniques for measurements of both radioactive and non-radioactive pollutants in monitoring labs and beyond. However, this will require increased access to certified reference materials that are traceable to the SI.

Objectives

The overall goal is to extend and harmonise mass spectrometry measurement methods. The specific objectives are:

1. To establish and compare the selectivity and detection limits of different types of mass spectrometers (e.g. AMS, HR-ICP-MS, ICP-MS/MS, ICP-QMS, MC-ICP-MS, SIMS, SNMS, TIMS) for the radioactive pollutants U, Np, Pu, Am using single and mixed activity standard solutions. This includes assessing relative instrument performance with respect to current measurement challenges and establishing detection limits in relation to regulatory waste criteria levels or environmental regulations.
2. To develop measurement methods for isotope ratios, traceable to the SI by using multi-collector ICP-MS and apply these methods on more commonly available techniques (ICP-MS/MS, ICP-QMS) by providing suitable operating procedures focussing on stable polluting elements (e.g. Li,

B, Cr, Cd, Ni, Sb, Pb, U). To produce recommendations for sample processing, treatment, uncertainty budgets, and the quantification of the mass bias.

3. To develop two radioactive reference material with the sample matrix containing radioactive pollutants (e.g. U, Np, Pu, Am) for use in an inter-laboratory comparison employing techniques used in objective one, which will demonstrate the variations in parameters including detection limits, sample preparation requirements, sample introduction methods, total procedural time, and uncertainty budgets.
4. To implement and validate the methods for isotope ratio measurements established in objective 2 by the development of one aqueous certified reference material that is certified for the same stable polluting elements with lowest possible uncertainties using multi-collector instruments, in order to facilitate the calibration of single collector ICP-MS, instrument validation, as well as quality control.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (e.g. accredited laboratories), standards developing organisations and international organisations (JRC, CIPM CCs [CCQM-IRWG, CCQM-IAWG, CCRI], IAEA, ICRM) and end users (e.g. environmental monitoring agencies).

Progress beyond the state of the art and results

Measured selectivity and detection limits of different types of mass spectrometers for selected radioactive pollutants using single and mixed activity standard solutions

Non-radiometric techniques show great potential for the measurement of radioactive pollutants. However, the traceability and validation of the methods are missing. The project will go beyond the state of the art by establishing the capabilities of different mass spectrometry designs including highly sophisticated and specialized designs (AMS, HR-ICP-MS, ICP-MS/MS, ICP-QMS, MC-ICP-MS, SIMS, SNMS, TIMS) using single and mixed activity standard solutions of actinides (^{237}Np, ^{234,235,236,238}U, ^{239,240}Pu, ^{241}Am), accessible by mass spectrometry, at activities relevant to regulatory limits. The focus will be on relative instrument performance with respect to current measurement challenges; establishing detection limits at levels below current environmental regulations, the reduction of isobaric interferences, and comparison to decay counting techniques. The range of radionuclides chosen are well suited for comparison based on the range of half-lives (<500 years to >4×10^{9} years), the presence of multiple spectral interferences that must be overcome to ensure accurate measurement, and precise isotopic ratio measurements (^{239}Pu/^{240}Pu, ^{236}U/^{238}U) for source identification.

SI-traceable measurement methods for isotope ratios of stable polluting elements

SI-traceable isotope ratios for Li, Pb, and U as pilot elements with relative measurement uncertainties, u_{rel}, of <0,01 % will be realised. The process is based on the *ab initio* calibration for SI-traceable isotope ratios without any *a priori* assumptions, introduced for Mg as a three-isotope system in 2016. This approach will be expanded to other multi-isotope systems and will set the basis for the certification of the first iRM (e.g. Li) with SI-traceable isotope ratios and u_{rel} ≤0,01 %. For many stable elements, enriched isotopes are not available, or the required uncertainty level does not justify the costs and efforts of applying a gravimetric isotope mixture approach to obtain SI-traceable isotope ratios. For quantitative elemental analysis, and for general isotope ratio applications, less expensive and laborious approaches based on inter-element normalisation will be developed.

Inter-laboratory comparison with a new reference material containing radioactive pollutants

Existing radioactive RM and CRM adapted to mass spectrometry measurements on environmental samples are limited and often lacking relevant parameters including isotopic ratios. The project will go beyond the state-of-the-art with the development of two RMs – liquid and solid – containing the radioactive pollutants U, Np, Pu, Am for use in an inter-laboratory comparison employing techniques used for the measurement of the activity standards solutions, which will demonstrate the variations in parameters including detection limits, sample preparation requirements, sample introduction methods, total procedural time, and uncertainty budgets, this way characterising the matrix related mass bias. The RMs to be produced also aim at being used in future QC measurements.

Aqueous certified reference material with stable polluting elements (and traces of radioactive pollutants) for the calibration of single-collector ICP-MS

One certified seawater reference material with clearly defined concentrations at natural levels should be developed for use in the validation of analytical procedures, supporting proficiency testing and quality control in future monitoring campaigns.

Outcomes and Impact

Outcomes for industrial and other user communities

This project will enable and harmonise measurement methods for the detection and characterisation of both radioactive isotopes and stable polluting elements in support of the EU Green Deal aim of progress towards a zero pollution toxic free environment. The measurement of the species in this project (Li, B, Cr, Ni, Cd, Sb, Pb, U, Np, Pu and Am) are of interest to those in the stakeholder group who are the users of such data, including monitoring organisations and the owners and operators of potentially polluting facilities or sites. The developers of the instrumentation used in this work need to react to, and predict, trends in the development of such measurements. As such, the outcomes of this project address their needs in several ways. Providing information to the ICP-MS (of whatever type) measurement community allows the selection of the most appropriate technology (which may be drawn from AMS, HR-ICP-MS, ICP-MS/MS, ICP-QMS, MC-ICP-MS and single collector ICP-MS) for the measurements that they are required to carry out. Thus, users seeking to invest in one of the available ICP-MS based modalities will be able to make informed decisions on the ICP-MS system to meet their particular data quality objectives, based on the extensive comparison of instrument capabilities undertaken in this project. The Europe-wide collaboration developed in the project will provide the foundation for future inter-laboratory comparison exercises for the determination of species of interest in a variety of environmental matrices where ICP-MS based techniques offer significant advantages over decay counting. The new RMs developed in this project will address the ongoing need to produce suitable and relevant (in terms of matrices and analytes) RMs that can validate state-of-the-art measurement capabilities.

Outcomes for the metrology and scientific communities

The scientific outcome of the proposed research will deliver validated and traceable analytical approaches for the analysis of the concentration of pollutants, as well as determining the source and monitoring any contamination of pollutants through isotope ratio measurements. This will close existing metrological gaps and will lead to a harmonisation of the different methods currently applied for the analysis of isotope ratios to support the investigation of natural environmental processes and anthropogenic impacts.

Combining the expertise in isotope ratio measurements of the CCQM and radioactivity measurement by the CCRI will provide new and innovative tools for advancing the application of mass spectrometry for contributing to improved half-life determinations.

Outcomes for relevant standards

This project will deliver an improved system of metrology and will establish infrastructure that directly supports the application of the following EU regulations or EU directives:

- Council Directive 2013/51/Euratom of 22 October 2013 laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption.
- Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation; Chapter VIII – Public Exposures.
- Treaty establishing the European Atomic Energy Community, Chapter III – Health Protection, Article 35: Each Member State shall set up the facilities necessary for the permanent control of the level of radioactivity in the atmosphere, water and soil and for controlling compliance with the basic standards. The Commission shall have right of access to such control facilities; it may examine their operation and efficiency.
- EU Regulation 995/2010: origin of legal timber by e.g. determining the Sr isotope composition.
- EU Regulation 2729/2000, 2220/2004, 2030/2006, 555/2008 and 1169/2011: provenance of food.
- Directive 2009/29/EC, decision No 406/2009/EC, directive 2009/31/EC: Climate research ($\delta^{11}B$), greenhouse gases (pathways of $\delta^{13}C$), carbon storage (possibly applicable for the geological assessment of Sr and Nd).

By implementing new traceability chains, different methods can be combined in the field of pollution monitoring, which will lower the detection limits. This results in a better protection of the environment, provides new tools for complex studies in climate observation, supports validated data collection of the European Research Centres and enhances the implementation of the ALARA goal expressed in the radiation protection regulation of the EC.

Longer-term economic, social and environmental impacts

The integration of other, highly specialised MS techniques such as AMS and SIMS into the project considerably widens the horizon for environmental monitoring or forensic studies and harmonises these detection methods with more commonly applied ICP-MS methods. The outcomes of the project will contribute to meeting the challenge of achieving highly sensitive and cost-effective pollution control. Using ICP-MS techniques in routine pollution monitoring allow the rapid determination of multiple elemental pollutants (both radioactive and stable) within a single sample. This ability, linked to the automated high sample throughput of ICP-MS systems, allows the capture of more and better sample information from single measurements. These factors combine to make the rapid and detailed mapping of pollutants within defined areas relatively straightforward, with the benefit that remediation (and/or decommissioning, where structures are involved) strategies can be closely targeted and operated with good resolution. This has the outcome that such activities can be carried out at less cost, with no loss of effectiveness and with considerably less disruption than techniques used hitherto.

The development of validated and traceable methods will improve societal confidence in the measurement and quantification of pollutants across many sectors, including manufacturing, industrial decommissioning, the long-term decommissioning and remediation of aged and disused nuclear sites and the legacy issues associated with the shutdown of ‘traditional’ heavy industry. Accurate waste classification engenders public confidence, and ensures inventories are correct for future infrastructure planning, such as the scale and design of pollutant remediation programmes.

The outputs from the project may be employed in a number of diverse fields including routine real time monitoring, emergency response, geological dating and climate change studies through isotopic ratio measurements, and as other activities, such as nuclear forensics, decommissioning non-nuclear industries (such as the oil industry in the north sea) and radiopharmaceutical facilities, where use is made of long-lived radioactive precursors. The collaboration between European laboratories established in this project is expected to continue beyond the end of the project.