Strategy (2022-2032)

Consultative Committee for Photometry and Radiometry (CCPR)

Last updated

25 May. 22

Contents

1. EXECUTIVE SUMMARY

Originally established in 1933 by the International Committee of Weights and Measures (CIPM) as the CCP and later in 1971 renamed as the CCPR, this Consultive Committee (CC) brings together world's experts in photometry and radiometry. Between 1997 and 2005, the CCPR established three Working Groups (WGs) to deal with specifics topics as outlined in their names: Strategic Planning (SP), Key Comparisons (KC), and Calibration and Measurement Capabilities (CMCs). In each of the three WGs, there are several Task Groups (TGs) and Discussion Forums (DFs) that are not permanent but address specific metrological needs or pressing issues. A list of the current task groups within each of these working groups is available in the Annex of this document and on the BIPM website.

CCPR WG-SP prepared this document with the intended audience including CCPR members and observers, NMI Directors, CGPM Delegates, the BIPM Director, and the CIPM. Additionally, it is made available on the BIPM website to stakeholders including industry, academia, standards-development organizations, and regulatory bodies.

This document presents the strategy to be followed by the CCPR in the period of 2022-2032 to deliver its mission of advancing the global and extra-terrestrial comparability of photometric and radiometric measurement standards and capabilities. As part of the 2021-2022 strategic planning process, the CCPR members conducted a comprehensive survey to identify key sectors that are expected to influence and drive the development of National Metrology Institutes' (NMI) and Designated Institutes' (DI) photometry and radiometry research and measurement services. This strategy document identifies the scientific, economic and social challenges which can be tackled through metrology at the CCPR level for the following sectors: lighting, optical properties of materials/appearance, energy sector/photovoltaics, environment/climate and quantum photonics.

The CCPR strategic goals for the 2022-2032 period are:

- to contribute to the resolution of global challenges in photometry and radiometry;
- to promote the uptake of metrologically-traceable photometric and optical radiometric measurements;
- to progress the state of the art of photometry and optical radiometry measurement science;
- to improve efficiency and efficacy of the global system of comparisons for photometry and optical radiometry;
- to continue evolving the set of Calibration and Measurement Capabilities (CMCs) to meet stakeholders needs;
- to maintain organizational vitality, regularly review and, if necessary, update the CCPR structure so it can perform its mission.

2. SCIENTIFIC, ECONOMIC AND SOCIAL CHALLENGES

Key scientific challenges in the field of photometry and radiometry are to improve and/or extend SI-traceability in response to the development of new photometric and radiometric devices and advanced emerging standards and technologies.

There has been an increasing demand in all metrology areas for availability of SI-traceable measurement and quality system data to promote global and extra-terrestrial accessibility, availability and exchange of information. This necessitates the implementation of a digital SI-framework for photometry and radiometry, including the dissemination of SI-traceable digital photometric and radiometric reference data, its incorporation in digitally-based observations systems e.g., imagery and for the data in calibration certificates.

In response to the evolution of the SI future of the candela, a longer-term strategic objective is to implement a scientifically rigorous photometric system based on cone-fundamentals to provide a new link between photometric and radiometric quantities. This could have a significant impact on measurement devices, manufacturers, regulations and standardization that are based on the present definition of the candela (2018) with a defining constant K_{cd}.

Listed below are key issues and challenges on a global scale that require measurement solutions from the field of photometry and radiometry. Scientific challenges are primarily focused on improving measurements with greater precision and lower measurement uncertainty, but also with respect to the robustness, speed and ubiquity of measurements and application proximity. The mastery of these scientific challenges is the key to overcoming economic and social challenges including standardization, product comparability, common trust and fair trade.

2.1 Lighting:

For several years, incandescent lamps have been replaced by LED and OLED lighting. Since the incandescent lamps used until now as reference standards are being phased out, NMIs must establish new artefact standards and photometric scales based on LEDs. While LED-lighting has the advantage of having significantly lower electrical power consumption, the spectral and electrical characteristics of LEDs require a complete overhaul of the measurement standards. Additionally, metrology institutes and testing laboratories must deal with temporal light modulation of LEDs and the use of camera-based systems for measuring complete light scenes.

Another aspect to tackle is the unwanted light emission, also known as light pollution or obtrusive light, as e.g., light intrusion (spill light), sky glow (direct upward light), back light and glare. To date there has been no standardized instrumentation or method for the traceable measurement of obtrusive light. The metrological challenges are to correctly measure these light emissions and thus to support standardization. However, lighting is not only used for visual tasks; it also has an influence on well-being and the human internal clock. The concrete relationship between optical stimulation and non-visual effects is still the subject of extensive research. To support this work and make research comparable, international metrics are necessary. The CIE has recently published such a metric (CIE S 026) and it is now the task of the metrology community to provide appropriate measuring instruments and methods and to guarantee that the measurements are traceable to the SI.

2.2 Optical properties of materials/Appearance:

Nowadays, visual appearance measurements go beyond colorimetry as visual effects like iridescence, sparkle, gloss, translucency are now commonly present in manufactured products. The control of appearance effects is crucial in many industries including the automotive, cosmetics, food, and packaging industries because the acceptance of the product is linked to the feeling of desirability and quality and thus to commerce. Such visual effects are a basic tool for the quality control of manufacturing, including additive manufacturing with 3D printers that aim to reproduce, in addition to the shape, the full visual attributes of objects. Progress in nano-texturation of surfaces brings the development of a new generation of functional surfaces that are spectrally and directionally selective in the way that they reflect and/or transmit light over the UV-VIS-IR spectral range to improve the energy efficiency of buildings and photovoltaic panels. In parallel, the increasing need of accurate appearance models in virtual worlds (digital twins, virtual prototyping, global trade, video gaming and special effects in movies) requires new measurements for validating these models.

Traceable indexes and scales that correlate with the visual sensation, moving from traditional colorimetry to spectrophotometric quantities that are spatially, spectrally, angularly and temporally resolved have to be developed and transfer standard artefacts have to be proposed to disseminate these new scales. Quantities such as the bidirectional reflectance distribution function (BRDF), bidirectional transmittance distribution function (BTDF), bidirectional scattering-surface reflectance distribution function (BSSRDF), and spatially-varying bidirectional reflectance distribution function (SvBRDF) covering the UV to IR spectrum need to be reconsidered to account for these additional variabilities and for the development of a new generation of spectrophotometric instruments that will be able to characterized these attributes.

2.3 Energy/Photovoltaics (PVs):

A central component of society's transition away from fuels that emit greenhouse gases in response to the climate change challenge, is the rapid growth of solar photovoltaics and the potential of these to become the dominant energy source. Solar energy is a major source of sustainable energy that not only limits climate change, but also reduces the exploitation of natural resources and limits the health problems of air pollution.

Measurement systems for the traceable calibration of solar cells under standard test conditions have been established at NMIs around the world. The principal metrological challenges for photovoltaics include developing energy rating standards, measuring equipment and methodologies to enable precise measurements of the parameters required for the energy rating, as well as the development of a quality and energy rating metric for PV power output sensitivity to enable more realistic results than the standard test conditions would allow. Solving these challenges requires PV systems to be completely characterized for all possible conditions. Solar module metrology should include the characterization of bifacial modules and innovative photovoltaic concepts such as floating photovoltaics and agrophotovoltaics. Additionally, digital twin models for solar parks are essential for the further growth of PV energy production and the efficient and reliable operation of PV systems because they enable accurate solar park planning and prompt detection of possible yield losses. Such digital twins must be underpinned by sound metrology of both laboratory and onsite characterizations.

2.4 Environment and climate observation:

The Earth's climate is changing primarily due to anthropogenic drivers. As humanity responds to the challenge through both mitigation and adaptation efforts, it is essential that there is a reliable set of environmental information monitoring the Earth system to inform decision makers. Because of the complexity of the Earth system, environmental monitoring makes use of a variety of indicators to monitor and infer change or the impact of change and to test the performance of the climate models used for predictions. These indicators are the so-called Global Climate Observing System (GCOS) Essential Climate Variables (ECVs), and over half the 54 involve some form of optical radiometric measurement, measuring the shortwave radiation emitted by the Sun, and how that is absorbed and reflected from the Earth's atmosphere or surface, or the longwave radiation emitted by the Earth. To provide global coverage, many of these observations are made by Earth observing satellites, supplemented by in situ observations to provide validation or complementary observations.

The Quality Assurance Framework for Earth Observation (QA4EO), endorsed by the Committee on Earth Observation Satellites (CEOS) and the World Meteorological Organization (WMO), establishes the principle that all Earth observations (whether in situ or remote) should be traceable to a community established reference (preferably SI) and should be accompanied with a quality metric (preferably a robust uncertainty budget). These principles encourage the active participation of the NMI community in the development of observational instruments, pre- and post-deployment calibration and comparison strategies of observational instruments and their data and in establishing validated uncertainty analysis for both long term "fundamental data records" of observational data and for the derived climate data records that come from those. It should be noted that most of the requirements specifically relate to digitally recorded and transmitted information and that the uncertainty requirements of this sector are arguably the most demanding application of radiometry in terms of requirements. The challenging uncertainty requirements are driven by the need to detect small changes that require decades to grow sufficiently to be detected from a background of natural variability.

2.5 Quantum photonics:

Quantum photonics, as part of quantum technology, makes a substantial contribution to innovation and advanced technology. Several international, regional, and national quantum programmes are currently under way. However, these initiatives do not yet comprehensively address the metrological challenges related to quantum photonics, such as traceability, standardization, and optimisation of optical quantum-enhanced measurements. A robust and reliable metrology infrastructure is required to exploit the benefits of optical quantum metrology, specifically of quantum communication, quantum radiometry, quantum imaging, and quantum microscopy. Furthermore, quantum-enhanced measurements are not yet exploited by NMIs for metrological applications, although they have the potential to reduce measurement uncertainty and noise.

2.6 General Challenges:

In the near future, extensions of comparisons into different spectral regions will become necessary. For example, semiconductor industries require SI-traceable measurement of extreme UV radiation. The field of high energy radiation requires radiometric standards down to the X-ray spectral range.

Mid-and far-infrared radiometry has become more important to support and increase the accuracy of Earth and climate observations. To allow the extension of the measured ranges, various activities to validate the methods and the equivalence of each laboratory should follow.

It may also become necessary to consider alternate reference instruments and methods, or a range of comparison artefacts to ensure that the full dynamic range of a quantity can be evaluated particularly as the needs of the few photon community start to become significant. As the properties of light in this extreme range are completely different from classical properties, the SI-traceable measurement at the few photon level requires further research and development activities.

3. Vision and mission

The CCPR vision is a world in which all photometric and radiometric measurements are made at the required level of accuracy to meet the needs of society.

The CCPR mission is to advance global compatibility of photometric and radiometric measurements through promoting traceability to the SI photometric unit, the candela, and associated derived units and related radiometric quantities, enabling member states and associates to make measurements with confidence.

4. Strategy

PROMOTING GLOBAL COMPARABILITY

To support the MRA through organizing an efficient and robust global system of comparisons for photometric and radiometric measurements; maintaining the quality of the necessary number of comparisons on key measurands organized by the CCPR and coordinating with Regional Metrology Organizations (RMOs) to organize subsequent regional key comparisons on the same measurands, as well as global supplementary comparisons for additional quantities.

To continue evolving CMCs in order to meet stakeholders' emerging needs; incorporating the use of broad-claim CMCs where applicable to cover a broader range of services; considering options to present CMCs in a way that is more understandable to the metrology community; and encouraging greater engagement with the CMC database.

IMPROVING STAKEHOLDER INVOLVEMENT INCLUDING MEMBERS AND OBSERVERS

To engage with stakeholders through members acting as liaisons with key organizations, to participate in and organise workshops and DFs facilitating cooperative agreements, and to receive stakeholder advice on priorities for future CCPR activities.

PROGRESSING METROLOGY SCIENCE

To progress the state of the art of photometric and radiometric measurement science, by investigating new and evolving technologies and developing measurement methods and standard artefacts.

CONTRIBUTING TO THE GLOBAL CHALLENGES

To contribute to the resolution of global challenges by developing and establishing new photometric and radiometric measurements targeted to the challenges identified in section 2 of this document.

5. Activities to support the strategy

The fulfilment of the CCPR strategies goals will be achieved through the CCPR plenary and WG meetings, workshops to survey emerging new fields and emerging metrological needs, establishing TGs or DFs for specific pressing issues, comparisons and pilot studies, training workshops and webinars for capacity and knowledge transfer between NMIs and to and from its stakeholders.

The following activities are necessary to support the CCPR's strategy to deal with the major challenges in SI-Traceability:

- To establish new research projects and collaborations between CCPR members to improve and/or extend SI-traceability for emerging photometric and radiometric standards and technologies
- To establish a CCPR DF under WG-SP on "SI-future of the candela" to develop a strategy for implementing a new photometry system based on cone-fundamental and how to minimize impacts to existing measurement devices, manufacturers and normative standards and regulations
- To establish a CCPR DF under WG-SP on "SI framework for digitization in photometry and radiometry" to address challenges in the field of photometry and radiometry caused by digital revolution in the global measurement system
- To establish a CCPR task group under WG-CMC on "digital calibration certificates" to address metrological needs for digitization of calibration certificates for photometry and radiometry CMCs. This includes digitization of all photometric and radiometric measurements, characterization, and reference data
- To establish CCPR TGs, DFs, and new research projects and collaborations between CCPR members to improve and/or extend their response to the major challenges in application areas as given below and to coordinate common activities between applications

5.1 Progressing metrology science

5.1.1 Lighting

The CCPR will facilitate its members in the following activities necessary to deal with the major challenges in lighting:

- To enable the phase-out of incandescent lighting and thus serve international goals on energy saving and reduced greenhouse gas emissions
- To ensure confidence in the performance of lighting products and to provide more comprehensive product specifications by implementing innovative instrumentation for characterization and testing
- To establish photometric scales that meet the needs of LED lighting
- To measure temporal light modulation and to establish calibration services of temporal light modulation measurement devices and/or reference sources for industry.

- To enable ongoing research on health, performance, and safety effects of temporal light modulation and to establish the research field on human perception of temporal light modulation
- To develop metrology for the improvement of urban lighting and thus reduce unnecessary light emission also known as light pollution and obtrusive light
- To develop metrology for end users such as building owners and governmental organizations in their efforts to save energy and cost by using efficient lighting
- To investigate the relationship between optical stimulation and non-visual effects, to establish comparable, international metrics and to guarantee SI-traceability of the measurements

5.1.2 Optical properties of materials/Appearance

The CCPR will facilitate its members in the following activities to deal with the major challenges in optical properties of materials and appearance:

- To propose, develop and provide traceable methods to characterize image-based radiance measurement devices
- To promote the accurate use of spectrophotometric quantities like BRDF, BTDF, BSSRDF, SvBRDF in order to support a clear and uniform use of these quantities across the different scientific communities
- To consolidate the traceability of the angularly-resolved spectrophotometric quantities from the micrometre to metre scale, over the UV to NIR range
- To support the development of a better comprehension of human visual mechanisms that are at the basis of visual perception
- To support the development of visual scales for all visual attributes such as chromaticity, gloss, translucency, glittering, brightness, etc... through psychophysical experiments
- To improve physically-based models on light propagation in real materials and models of light reflection at real interfaces
- To explore how progress on artificial intelligence and machine learning can open new routes to link spectrophotometric quantities to human visual sensation

5.1.3 Energy/Photovoltaics (PVs)

The CCPR will facilitate its members in the following activities to deal with the major challenges in energy and photovoltaics:

- To improve PV energy rating standards, measurement equipment and methodologies to enable precise measurements of the parameters required for the energy rating and to develop a quality and energy rating metric for PV power output sensitivity
- To develop methods for measuring the performance of PV-based energy-harvesting installations, e. g. solar parks
- To deliver input to international standards with special emphasis on realistic operating conditions
- To achieve a faster and more accurate characterization of PV cells and modules to enable manufacturers to better optimize their products for real applications and locations

5.1.4 Environment and climate observation

The CCPR will facilitate its members in the following activities to deal with the major challenges in environment and climate observation:

- To develop methods for the in-laboratory (often clean-room) calibration and characterization pre-deployment of instruments used in in-situ and satellite observations for the UV, Visible, SWIR and thermal infrared spectral regions. These instruments often have wider fields of view compared to other applications and are often array devices with a spectral and spatial dimension (image-based radiance)
- To develop methods, transfer standards, and in-situ calibration approaches to enable traceability to sensors used in non-laboratory field conditions
- To develop improved on-board calibration standards and methods for satellite radiometric instruments, including supporting the SI-traceable satellites (SITSats; e.g., TRUTHS and CLARREO)
- To establish fiducial reference measurement quality ground test sites for post-launch calibration and validation of radiometric satellites
- To support community efforts for comparisons of field instruments and satellite data
- To support community efforts to bring uncertainty analysis and traceability to historical sensors, current and future sensors and to create formal and informal standards for metrological methods.
- To support the analysis and propagation of uncertainties from observation through processing algorithms to bio-geophysical products where optical radiometric insight is required.

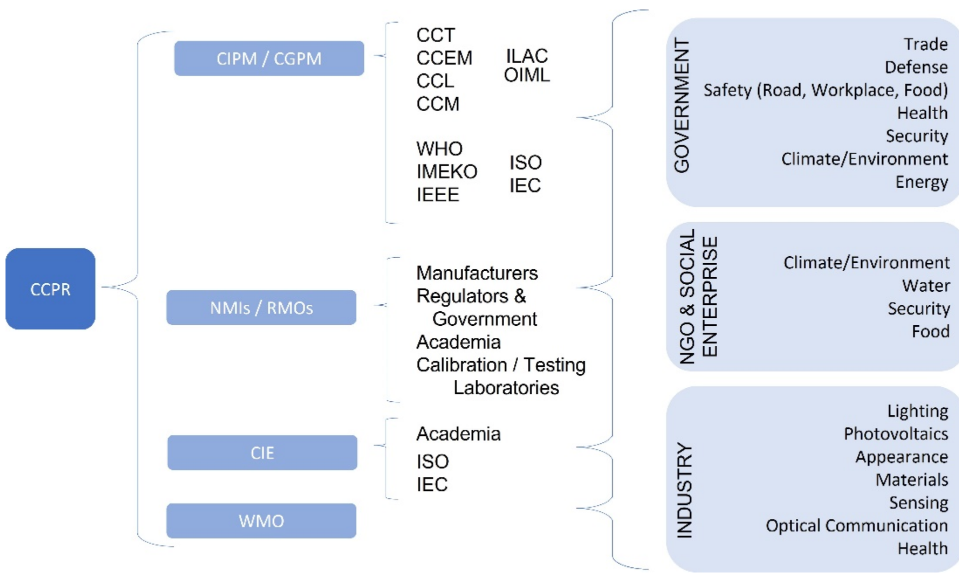
5.1.5 Quantum photonics

The CCPR will facilitate its members in the following activities to deal with the major challenges in quantum photonics:

- To comprehensively address the metrological challenges related to quantum photonics, such as traceability, standardization and optimization of optical quantum-enhanced measurements. For this, a robust metrology infrastructure is required that enables the traceable characterization of single- and entangled-photon sources for various applications
- To investigate optical quantum-enhanced measurement methods to overcome noise limits and to minimize the invasiveness of measurements with respect to assessing the quantum advantage
- To metrologically support the fabrication of single- and entangled photon sources for optimizing their specification (e. g. highest purity and indistinguishability)
- To develop new standard sources based on single-photon emitters for the realization of optical radiant flux scales in the low-photon-flux region and to develop quantum standards based on the counting of photons
- To ensure the necessary metrological support for quantum photonics to have a significant impact in the still-emerging field of quantum technologies
- To implement the current mise-en-pratique for the candela, i.e., to investigate and to realize a photon-number-based realization of the candela
- To develop new measurement methods for characterizing components, as well as complete systems, for quantum key distribution and to guarantee data safety, e. g. by supporting secure quantum communication and data storage
- To support the development of applications of quantum photonics sensor technologies and to exploit quantum sensors for e. g. for medical imaging

5.2 IMPROVING STAKEHOLDER INVOLVEMENT

The stakeholders of CCPR are shown in the graphic below. Direct stakeholders are NMIs, RMOs, international organizations with CCPR liaison status (CIE and WMO), and the CIPM/CGPM. Secondary stakeholders are other CCs that CCPR has established liaisons (notably CCT and CCEM on radiation thermometry and THz metrology, respectively), international organisations that are linked to CCPR through CIPM/CGPM agreements (WHO, IMEKO, IEEE), standardization organizations (ISO, IEC). A third level of stakeholders include regulators, instrument manufacturers, calibration and testing laboratories, and the research community. CCPR members traditionally serve a wide range of industries including lighting, space, semiconductor, optical communication, automotive, colour industries which span manufacturers of coloured goods (textiles, paints, plastics) to industries reproducing colour (printing, photography), defence agencies, and in health and safety. More recent industrial areas include appearance, displays, imaging and rendering, photonics, solid-state lighting, bio-medical, quantum-based information and quantum photonics, tera-hertz, environment and climate, space, and photovoltaics.



The challenge for CCPR is to be responsive to our stakeholders and ensure access for traceability to the SI for existing needs while preparing for the future.

Many of the existing fields identified above require broadening the range or increasing the accuracy of our services. Developing and maintaining good relationships with our stakeholders allows us to anticipate these needs and respond. Our links with existing needs come mainly through the calibration and testing laboratories that CCPR members provide services to. Other stakeholders, in particular standardization bodies, such as the CIE and the WMO, also provide strong links to an even wider range of downstream users of SI traceability in photometry and radiometry.

In addition, new services will be required – either for new quantities or in the application of our current capabilities to new fields. Again, our stakeholders can help the CCPR identify these. Research priorities have been outlined by RMOs which set out areas of focus and make funding available for issues raised regionally, and by organisations such as the CIE which identify global trends and priorities in fields that overlap with the interests of CCPR members (http://cie.co.at/research-strategy). Continued engagement with all these stakeholders will allow the CCPR in turn to clarify its priorities and identify areas where its coordination capacity can greatly aid progress. The growth of optical methods across metrology disciplines (e.g., photonic sensors for temperature, humidity, force, distance; refractive index methods for pressure; optical communications for time and frequency; radiation pressure for mass and force) means that relationships with a broader range of Consultative Committees should be developed.

Many of the application areas considered above are highly multidisciplinary and there is a recognition that photometry and radiometry specialists must work in close collaboration with experts from other technical domains and those closer to the applications. Demands for cooperation with other international organisations will be stronger in the near future. This will include the need to work closely with the Earth Observation community through links with the Space Agencies and their international organizations. In the display and lighting industries, improved reliability of science and technology related to human vision and cognition are needed to support better product design and process control. For example, the newest displays for virtual reality will require metrology beyond the current measurement standards of photometry. In the medical/health sector, the development of quantitative diagnostic and therapeutic bio-photonics instrumentation requires metrology experts in optical radiation measurements collaborating in multidisciplinary work with experts in biotechnology and health and life sciences. The CCPR needs to link the experts of science with the experts of industry through joint activities with the relevant global organisations.

The following activities are necessary to support the CCPR's strategy to improve stakeholder relationships:

- Explore opportunities to build relationships with technical organisations and communities with common goals, prioritising those communities associated with the application areas discussed above
- Build links to other Consultative Committees where optical methods of metrology are being developed

5.3 PROMOTING GLOBAL COMPARABILITY

CCPR maintains and organizes, in cooperation with RMOs, a set of key comparisons in the field of photometry and radiometry to support the CIPM MRA. These key comparisons are essential to underpin the core capabilities of the member institutes in the context of the CIPM MRA. The CCPR intentionally focuses on a smaller set of key comparisons to improve the efficiency and efficacy of the global system of comparisons.

In particular, the CCPR coordinates international Key Comparisons, which benchmark claimed competencies of the NMIs and DIs for standards that are needed to underpin photometry, optical properties of detectors and sources, optical properties of materials and fibre optics. The following photometric, radiometric and spectrophotometric quantities have been identified as key measurands for this purpose: spectral irradiance, spectral responsivity, luminous intensity, luminous flux, spectral diffuse transmittance and spectral regular reflectance. The CCPR supports RMOs to coordinate subsequent key comparisons for NMIs or DIs in their regions to link to these CCPR key comparison reference values.

For quantities which are not directly supported by the current key comparisons, CCPR monitors supplementary comparisons conducted by RMOs. These have included comparisons of absolute radiometers, of spectral radiance, of spectral radiant flux, of colorimetric quantities and of optical fibre quantities such as attenuation, power meters, etc. CCPR also executes pilot studies to extend or improve the current system of international comparisons to meet future needs of the global comparability in the field of photometry and radiometry.

5.3.1 CCPR Key Comparisons

There are currently ten key comparisons for six key measurands held within the CCPR, considered to be adequate for underpinning the core photometry and radiometry measurement capabilities and associated CMCs (CCPR-K1 to K6, which may be divided in several parts, labelled a, b, etc., to cover the full measurement spectral range). These are, in general, conducted at a high level and cover the areas of radiometry and photometry of sources and detectors and spectrophotometry of materials. Each of the ten comparisons was performed once between 1991 and 2014. A second round of all ten comparisons is currently underway, with several comparisons finished, in process or planned to start soon. An overview of these ten key comparisons is provided in the Annex.

The results of these comparisons support a total of 1532 CMCs (up to 2020) in the fields of photometry, properties of sources and detectors, properties of materials and fibre-optics.

Rules for participation in the 2nd round of CCPR KCs were defined in 2009 and are described in detailed in the CCPR-G4 on "Guidelines for preparing CCPR Key Comparisons. In summary, the criteria for acceptance of participants are:

- They are limited to CCPR members with an independent scale realization at the time of the call for participants, who are willing to serve as link laboratories to their RMO and CMC coverage of the quantity over the whole wavelength range; in the case of a new KC, this final condition is not required.
- The number of participants is limited to 12 for each KC with a possible grouping and membership of: Group 1 (EURAMET+COOMET) with 6 participants; Group 2 (APMP+AFRIMETS) with 4 participants; and Group 3 (SIM) with 2 participants.
- The inclusion of other NMIs is carried out through linked RMO comparisons. If the total number of participants who fulfil the preceding entry conditions is 12 or less, all applicants are accepted.

5.3.2 CCPR Pilot Studies

Advances in technologies can lead to a requirement for new or significantly modified international comparisons. Modifications may be needed due to a change in the availability of comparison artefacts (e.g., the phase out of tungsten-based lamps), and new comparisons may be needed to extend the working range of an existing comparison, or to introduce a new quantity. When a new comparison requirement is raised, CCPR initiates a pilot study to understand the need for the comparison and to verify the practicability of the comparison. The pilot study is assigned to a task group (TG) in the appropriate working group. In 2022, the following pilot studies are active in CCPR:

- Pilot study for spectral regular transmittance in the UV to investigate the extension of the wavelength range of the existing KC CCPR-K6 (TG1 of WG-KC)

- Pilot study for the use of alternative standards for photometric comparisons to investigate LED-based standard lamps for the existing KCs (TG4 of WG-KC)
- Pilot study to investigate a comparison of spectral responsivity in the THz spectral range (TG8 of WG-SP)
- Pilot study to investigate a comparison on detection efficiency of single-photon detectors (TG11 of WG-SP)
- Pilot study to investigate a comparison on optical fibre power responsivity using fibre-coupled cryogenic radiometer (TG13 of WG-SP)

Future needs for Pilot studies are being investigated during the 2022 CCPR survey and at yearly CCPR working group meetings.

5.3.3 RMO Comparisons

These comparisons are used to include the full NMI and DI community in key comparisons; for this the RMO comparison follows the CCPR key comparison. RMO supplementary comparisons cover a wider range of quantities. The RMOs coordinate their comparison plans with both CCPR and other RMOs. This coordination limits the overall number of comparisons, and hence community workload, and also enables supplementary comparisons to involve global participants. Where several RMOs wish to perform similar supplementary comparisons, these can be coordinated as linked comparisons, with additional benefits. This procedure was used very effectively for the RMO comparisons of LED measurement quantities, piloted by APMP that had participants from all interested RMOs. Currently, several spectrophotometric quantities, such as BRDF, transmittance haze and grey scale diffuse reflectance are the subject of cross-RMO comparisons.

5.4 CAPACITY BUILDING AND KNOWLEDGE TRANSFER

The activities of the CCPR working groups are geared towards the progress of measurement science. This is accomplished by the execution of comparison, pilot studies and formation of task groups to investigate new methods or measurements areas, and workshops, surveys, webinars, and guidance documents focusing on new measurements challenges and knowledge transfer.

Activities that will be undertaken within the period of 2022-2032 are:

1. Workshops to explore emerging PR applications and traceable metrological needs
2. Surveys to determine best suitable standards for emerging technologies
3. Pilot studies on the new selected standards
4. Workshops on capacity transfer on new methodologies to all members and observers of the CC
5. Establish new CMCs as needed by the CC members
6. Workshops and webinars providing knowledge transfer opportunities between Metrology Institutes and to and from stakeholder communities, based on a mid and longer-term plan for stakeholder engagement identified by the committee

During the first quarter of 2022, the CCPR WG-SP TG10 prepared a comprehensive survey to gain better understanding of the metrological needs and priorities of the CCPR members and observers. The results of survey will guide future activities of the CC and lead to advances in measurement science. Once the results of the survey have been analysed, a detailed plan of these activities with a timetable will be added to this document.

Furthermore, CCPR will facilitate knowledge transfer for NMIs as needed in the area of radiometry and photometry with the goal of enabling fully participation in the CIPM MRA by:

1. Expanding the use of teleconferencing technologies to support face-to-face meetings, which will increase accessibility to the wider community.
2. Coordinating capacity-building and knowledge-transfer activities with the RMOs.
3. Expanding training and mentoring support for NMIs piloting comparisons.

5.4.1. Guidance documents on comparisons

The CCPR has produced several guidelines to advise its members on the preparation and the coordination of comparisons, and on treating and reporting their results (date of publication in parentheses):

- CCPR-G1 Guidelines for membership of WG-KC (2009)
- CCPR-G2 Guidelines for CCPR KC Report Preparation Rev 4* (2019)
- CCPR-G3 Guidelines for acceptance of CCPR Key Comparisons participants (2009)
- CCPR-G4 Guidelines for preparing CCPR KCs (2013)
- CCPR-G5 Guidelines for CCPR and RMO bilateral KCs (2014)
- CCPR-G6 Guidelines for RMO KCs in PR (2014)
- CCPR-G7 Guidelines for RMO PR Supplementary Comparisons (2018)
- CCPR-G8 Guidelines for the evaluation of CMC claims in light of comparison results (2019)
- CCPR-G9 Rules for review of CMC claims and requirements for supporting evidence (2021)

The CCPR Working Groups have also produced guidance documents to assist in carrying out their respective Terms of Reference, such as WG-CMC's responsibilities to define service categories and supporting evidence for CMCs in PR.

These include:

- Classification of Services in PR
- Supporting Evidence for CMCs in PR
- Code of procedure for CCPR Working Groups and Task Groups, CCPR-CODE
- CCPR-WG-SP Membership Criteria, 2012

6. Work programme of the BIPM laboratories

In the early 2000s, the BIPM closed its radiometric and photometric laboratories. The BIPM serves as a coordinating entity for the CCPR comparisons and, where appropriate, can become a representative voice of the NMI community through use of expertise loaned, seconded or acting on its behalf from an NMI with relevant expertise.

The BIPM continues to serve the needs of CCPR by providing Executive Secretary and organizational support for CCPR sessions, working group meetings, as well as Workshops and training.

7. Document revision schedule

Minor revisions are planned every two years and major revisions are expected every four years.

Document	Type of revision	Date of revision
Version 1	Draft by CCPR WG-SP TG10 sent for comments to CCPR v1.0	4/29/2022

Annex

A.1 General information

CC Name: Consultative Committee for Photometry and Radiometry (CCPR)

Date established: 1933 as Consultative Committee for Photometry, 1971 as CCPR

CC President: Maria Luisa Rastello, INRIM, since 1st January 2017

CC Executive Secretary: Joële Viallon, BIPM, since 1st January 2016

Number of CC Members: 23 members, 3 official observers and 2 liaisons

Periodicity between Meetings and date of last/next Meeting: 2-3 years in between meetings. The last meeting took place in September 2019.

A.2 Working Groups (WGs)

In between 1997 and 2005, the CCPR established three working groups to deal with some of its specific roles as described below:

WG	Date of creation	Terms of reference
Key Comparisons (WG-KC)	1997	• establish and maintain a list of key and other comparisons in the field of photometry and radiometry, which will adequately support CMC claims by NMIs in this field of measurement in the spirit of the global MRA between NMIs; • coordinate and schedule key comparisons, to review progress in comparisons and to recommend to the CCPR the inclusion of the results of key comparisons in Appendix B of the MRA database; • provide supplementary guidelines and/or interpretations to the guidelines on conducting key comparisons included in the MRA, specifically for the field of photometry and radiometry; • recommend general principles for the calculation of key comparison reference values in photometry and radiometry; • provide advice to the WG-CMC on the range of CMCs supported by particular key comparisons; • monitor and approve RMO key comparisons and provide advice on RMO supplementary comparison activities.
Calibration and Measurement Capabilities (WG-CMC)	2003	• coordinate and approve the definition of service categories requested by RMOs and to maintain lists of service categories, and – where necessary – rules for the preparation of CMC entries; • agree on detailed technical review criteria; • coordinate and, if necessary, conduct inter-regional reviews of CMCs submitted by RMOs for posting in Appendix C of the MRA; • provide guidance on the range of CMCs supported by particular key and supplementary comparisons; • suggest to the WG-KC areas where additional key and supplementary comparisons may be needed; • coordinate the review of existing CMCs in the context of new results of key and supplementary comparisons.
Strategic Planning (WG-SP)	2005	• establish and maintain a strategic planning document for the CCPR in line with the CIPM guidance document for CCs; • advise the CCPR on the optimal operational structure;

		• draft and maintain admission criteria for membership of the CCPR and its working groups; • monitor and respond to developments with respect to the future of the SI; • regularly review and update, as needed, the mise en pratique for the candela.

A.3 Task Groups (TGs)

Within the organisational structure of the three WGs, there are several TGs that are not considered permanent but respond to a specific task or pressing issue. The current list of task groups within each of these working groups can also be found at the BIPM website. Information is also provided at this site on the terms of reference of these TGs and their membership.

TG	Title
CCPR-WG-SP-TG-CIE-JTC-2 [CLOSED]	JOINT CCPR/CIE TASK GROUP ON "PRINCIPLES GOVERNING PHOTOMETRY"
CCPR-WG-SP-TG4 [CLOSED]	SI
CCPR-WG-SP-TG5 [CLOSED]	MISE EN PRATIQUE
CCPR-WG-SP-TG6	DISCUSSION FORUM ON FIBRE OPTICS
CCPR-WG-SP-TG7	DISCUSSION FORUM ON FEW-PHOTON METROLOGY
CCPR-WG-SP-TG8	DISCUSSION FORUM ON THZ METROLOGY
CCPR-WG-SP-TG9	OTDR LENGTH COMPARISON
CCPR-WG-SP-TG10	CCPR STRATEGY DOCUMENT
CCPR-WG-SP-TG11	SINGLE-PHOTON RADIOMETRY
CCPR-WG-SP-TG12	DISCUSSION FORUM ON THE USE OF WHITE LED SOURCES FOR PHOTOMETRY
CCPR-WG-SP-TG13	OPTICAL FIBER POWER RESPONSIVITY
CCPR-WG-SP-TG14	RADIOMETRY TO SUPPORT GRAVITATIONAL WAVE DETECTION
CCPR-WG-KC-TG1	PILOT COMPARISON FOR SPECTRAL REGULAR TRANSMITTANCE IN THE UV
CCPR-WG-KC-TG2	RMO LINKAGE
CCPR-WG-KC-TG3	COMPARISON ANALYSIS
CCPR-WG-KC-TG4	PILOT STUDY FOR THE USE OF ALTERNATIVE STANDARDS FOR PHOTOMETRIC COMPARISONS
CCPR-WG-CMC-TG1	USE OF COMPARISON RESULTS IN ASSESSMENT OF CMC CLAIMS
CCPR-WG-CMC-TG2	UPDATE EXCEL PR CMC SUPPORTING EVIDENCE FILE
CCPR-WG-CMC-TG3	CLARIFY AND HARMONIZE THE CMC REVIEW PROCESS
CCPR-WG-CMC-TG4	RECOMMENDING A CMC STRUCTURE FOR FIBRE OPTICS

A.4 CCPR TERMS OF REFERENCE

The CCPR has the following responsibilities:

- To provide advice to CIPM on all matters concerned with photometry and radiometry;
- To establish global compatibility of related photometric and radiometric measurements through promoting traceability to the SI photometric unit, the candela, and associated derived units for photometric and radiometric quantities;
- To contribute to the establishment of a globally recognized system of national measurement standards for photometry and radiometry and development of absolute radiometry methods and facilities;
- To contribute to the implementation and maintenance of the CIPM MRA in the field of photometry and radiometry;
- To review and advise the CIPM on the uncertainties of the photometry and radiometry calibration and measurement capabilities as published on the BIPM website;
- To act as a forum for the exchange of information about the photometry and radiometry activities of the CCPR members and observers;
- To create opportunities for collaboration in the field of photometry and radiometry.

A.5 LIST OF KEY AND SUPPLEMENTARY COMPARISONS AND PILOT STUDIES

An overview of the ten key comparisons conducted at the CCPR level is provided in the table below, classified by Key Measurand first, then by division if appropriate (such as wavelength range), and by date, noting that the dates and status are subject to changes. The most up-to-date version is available on the BIPM website.

Key Measurand	Comparison	Description / Wavelength range	Pilot (Coordinating) Laboratory	Start date	Status
Spectral irradiance	CCPR-K1.a	Wavelength from 250 nm to 2500 nm	NPL	2002	Approved for equivalence
	CCPR-K1.a.2017	Wavelength from 250 nm to 2500 nm	VNIIOFI	2017	Report in progress, draft A
	CCPR-K1.b	Wavelength from 200 nm to 350 nm (16 values)	PTB	2004	Approved for equivalence
	CCPR-K1.b.2022		NIST	2022	Protocol in preparation
Spectral responsivity	CCPR-K2.a	Wavelength from 900 nm to 1600 nm	NIST	2001	Approved for equivalence
	CCPR-K2.a.2016		NPL	2017	Measurements completed
	CCPR-K2.b	Wavelength from 300 nm to 1000 nm	BIPM	2001	Approved for equivalence
	CCPR-K2.b.2017		KRISS	2017	Report in progress, pre-draft A
	CCPR-K2.c	Wavelength from 200 nm to 400 nm	PTB	2007	Approved for equivalence
	CCPR-K2.c.2022	Wavelength from 200 nm to 400 nm	PTB	2023	Planned
	CCPR-K2.d.2023	Wavelength from10 nm to 200 nm	PTB	2023	Call for participants
Luminous intensity & Responsivity	CCPR-K3.a	Luminous intensity	PTB	1998	Approved for equivalence
	CCPR-K3.b	Luminous responsivity	BIPM	1997	Approved for equivalence
	CCPR-K3.2014	(2nd round for K3.a and K3.b)	NRC	2014	Report in progress, draft B
Luminous flux	CCPR-K4		PTB	1998	Approved for equivalence
	CCPR-K4.2017		NMIJ AIST	2018	Measurements in progress
Spectral diffuse reflectance	CCPR-K5	Wavelength from 360 nm to 830 nm	NIST	2003	Approved for equivalence
	CCPR-K5.2019		MIKES-Aalto	2021	Protocol completed
Spectral regular transmittance	CCPR-K6	Wavelength from 380 nm to 1000 nm	LNE-LCM/Cnam	2001	Approved for equivalence
	CCPR-K6.2010		MSL	2014	Approved for equivalence

A.6 Past Workshops

In order to effectively carry out the key objectives of the CCPR Task Groups, several TG Chairs have organized Workshops in conjunction with the annual CCPR Working Group meetings or Conference Sessions at relevant specialized scientific conferences. The following is a listing of these activities over the past 8 years, the number of participants and the main outcome(s):

2015 – WG-KC TG3: Workshop on Comparison Analysis. Number of participants: 25. Outcomes: This information will be used by WG-KC to write a guidance document on which model should be the default for analysing KC data.

2016 –WG-SP TG6: Workshop on Metrology Needs in Fibre Optics. Number of participants: 40. Outcomes: creation of a new TG (TG13) to organize and carry out a pilot comparison on optical fibre power responsivity using a fibre-coupled cryogenic radiometer; establishment of liaison with IEC 86 Fibre Optics and change in Terms of Reference of TG6 to include: Monitor standards developments in IEC 86 Fibre Optics. More information is publicly available on the BIPM website at: http://www.bipm.org/wg/AllowedDocuments.jsp?wg=CCPR-WG-SP.

2017 – WG-KC TG2: Workshop on Models for Comparison Analysis. Number of participants: 33. Outcomes: The discussion of the four models proposed by TG2 at the Workshop will be continued and the TG2 Chair will share the software for doing these calculations with pilot labs interested in resolving the outstanding issues about the choice of model. This information will be used by WG-KC to write a guidance document on which model should be the default method used for analysing KC data.