Consultative Committee for Photometry and Radiometry (CCPR)

President: Dr Maria Luisa Rastello Executive Secretary: Dr Joële Viallon

1. Executive summary

Established as the Consultative Committee for Photometry in 1933, and further extended to include Radiometry in 1971, the CCPR now covers metrological aspects of light, which range from well-known measurements to very advanced research fields. The activities of its 23 members reflect this duality. One working group is devoted to monitoring the efficient running of the ten key comparisons identified almost twenty years ago, but a number of Discussion Forums allow surveillance of challenges and needs in all sectors that benefit from advanced knowledge of light, such as quantum cryptography for security applications or accurate radiometers on board satellites for Earth observation systems.

Since the 25th CGPM meeting (2014), CCPR members have contributed to the revision of the SI Brochure, to be proposed to the 26th CGPM meeting (2018). In addition to the rewording of the definition of the candela they took part in the general efforts by the metrology community to improve the processes developed to demonstrate global compatibility of measurements (CIPM MRA review); they finalized guidance documents on conducting international comparisons and shared views on statistical treatments and software to improve the calculation of degrees of equivalence; and they started comparisons in challenging domains, such as standards at the single-photon level.

2. Scope of the CC

The responsibilities of the CCPR are:

- 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

In order to carry out its responsibilities, the CCPR has three established Working Groups (WGs): one to discuss its strategy, including matters related to quantities and units (CCPR-WG-SP); one to monitor how Key Comparisons are conducted (CCPR-WG-KC); and one to coordinate the submission and review of Calibration and Measurement Capabilities (CCPR-WG-CMC).

3. Strategy

The strategy developed by CCPR members to cover the responsibilities listed above are detailed in the Strategy document, which was recently updated to cover the period 2017 to 2027. A brief summary is provided below.

3.1 Establishment of global compatibility

The CCPR defined its strategy to develop and maintain the CIPM MRA soon after its implantation, and in general, similar policies are still being applied.

In particular, the CCPR coordinates international key comparisons performed to benchmark claimed competencies of the National Metrology Institutes (NMIs) and Designated Institutes (DIs) for standards that are needed to underpin photometry, optical properties of detectors and sources, optical properties of materials and fibre optics. **Six key measurands** have been identified (spectral irradiance, spectral responsivity, luminous intensity, luminous flux, spectral diffuse transmittance and spectral regular reflectance), leading to **ten key comparisons** to cover different spectral ranges. A first cycle of comparisons was completed in 2014, and cycle 2 started to repeat each comparison with an average period of 10 years.

Key comparisons organized by the CCPR are limited to about 12 member institutes. The CCPR allows Regional Metrology Organizations (RMOs) to coordinate subsequent key comparisons for NMIs or DIs in their regions to demonstrate compatibility with a greater number of laboratories.

RMOs are also invited to coordinate regional comparisons of measurement standards for additional quantities related to photometry and radiometry. These have included absolute radiometers, spectral radiance, spectral radiant flux, colorimetric quantities and optical fibre quantities such as attenuation of power meters.

3.2 Exchange of information and outreach

Member institutes are regularly invited to present their most advanced developments, to identify needs in new areas and perform pilot comparisons when required. At each CCPR meeting, they provide written reports on their activities in photometry and radiometry, which were made publicly available in 2016 (CCPR 2016 documents). Since 2016, meetings of the CCPR have been reorganized to include three discussions on challenges that build on presentations given by selected delegates. In 2016 this included Few Photon Metrology, LED sources, and Earth Observation and Climate.

Discussion Forums are also created when a new topic is raised. They typically include CCPR members but can be extended to individuals from universities or companies if required. The aim is to identify challenges, needs for cooperation and eventually, new comparisons. Presently, there are four Discussion Forums on: Fibre Optics, Few Photon Metrology, THz Metrology and Use of White LED Sources for Photometry. They work electronically or organize satellite meetings in parallel with relevant conferences.

4. Activities and achievements since the last meeting of the CGPM

4.1 Advising the CIPM and promoting traceability to the Candela

During the last four years, CCPR members have participated in the consultation process carried out by the Consultative Committee for Units on the new SI brochure. They implemented the

decisions already taken before 2014 regarding the rewording of the definition of the candela for the 26th CGPM meeting (2018) and developed the new *Mise en pratique* published in *Metrologia* in 2015.

Meanwhile, the CCPR worked with CIE representatives to update the *Principles Governing Photometry*, which includes information on all photometric quantities and units, as well as the International Commission on Illumination (CIE) standard spectral luminous efficiency functions for photopic and scotopic vision (daylight and dark night conditions). Since the first version of this document in 1983, studies undertaken by CIE members resulted in functions being defined for mesopic vision (twilight), and the wish to include them. The new version was also made consistent with the new SI brochure, and it was agreed to publish it as a *Metrologia* guide in May 2019, together with the SI Brochure.

4.2 Ensuring global compatibility of measurements

In accordance with its policy, international comparisons on key quantities currently undertaken at the CCPR level are repeats of the set of ten "cycle 1" comparisons. One was completed and published in 2017, and three are in progress. Meanwhile, RMOs performed five comparisons to demonstrate the compatibility of more laboratories around the world. A good example is the comparison CCPR-K4, which was completed with 17 participants at the CC level in 2000 and was followed by regional comparisons in recent years to allow 19 more participants. The second cycle of this comparison is in progress at the CCPR level.

In addition, supplementary comparisons were carried out within the RMOs to underpin measurements related to the use of optical fibres, such as fibre optic power responsivity, which was compared in the APMP comparison APMP.PR-S2.

Finally, following discussions that started before 2014 in a dedicated CCPR Task Group, the first key comparison undertaken in the far-infrared spectral region was carried out between three NMIs and was published in a peer-reviewed journal (*IEEE Transactions on Terahertz Science and Technology*, **6**(5), 2016). It represents a milestone which will greatly benefit commercial development of instrumentation and sensors for remote sensing, THz imaging, high-speed telecommunications, and time-domain spectroscopy.

4.3 Improvements in the CIPM MRA

Following Resolution 5 of the 25th CGPM meeting (2014), a review of the CIPM MRA was undertaken by a CIPM working group with the involvement of all consultative committees. CCPR members took part in this process, with a number of discussions during their usual meetings as well as in devoted workshops. They shared their best practices with other CCs and improved their own processes for conducting international comparisons, claiming measurement capabilities and reviewing those claims.

International comparisons

Between 2009 and 2014, CCPR members developed a number of guidance documents to harmonize how comparisons are carried out, both at the CC level and within RMOs. A document to cover supplementary comparisons in RMOs has been under develpment since 2014 and will be published. In parallel, there has been a focus on software and statistical tools to help implement the principles developed in the guidelines.

Calibration and Measurement Capabilities (CMCs)

It was decided during the 23rd CCPR meeting (2016) to extend the chairmanship of the working group devoted to CMCs from 2 to 4 years in order to leave more time for the chair to monitor and complete the tasks undertaken by this group. As a consequence, two important guidance documents for CMC review were updated in 2017 and 2018 and have been made publicly available (Services in PR and Supporting evidences for CMCs in PR). Rules were clarified, and the CMC review process should be more efficient in the future.

4.4 Workshops

Since the 25th CGPM meeting (2014), two workshops have been organized to discuss the best mathematical treatment of comparison results (in 2015 and 2017). They resulted in the decision to write another guidance document, and the appropriate software to perform the required calculation was selected and shared among CCPR participants as a tool for laboratories in charge of coordinating comparisons. The aim is to harmonize the treatment of comparisons but also to reduce the workload of pilot laboratories.

In addition, a workshop on Metrology Needs in Fibre Optics took place in conjunction with the 23rd CCPR meeting (2016). During this workshop, it was decided to carry out a Pilot Comparison on optical fibre power responsivity using a fibre-coupled cryogenic radiometer, in order to respond to the needs of communication via fibres.

A number of members of the CCPR were very active during the session on single-photon measurements and radiometry with entangled sources at the Quantum Revolution in Metrology workshop organized at the BIPM in September 2017. This reflects the significant interest in better standards at the single-photon level, with promising applications in quantum cryptography and photo-bio-photonics.

4.5 Challenges and difficulties

The few-photon community is starting to become significant. As the properties of light in this extreme range are completely different from classical properties, SI-traceable measurement at the few-photon level requires further research and development.

In terms of units and definitions, there remains an ongoing discussion within the CCPR as to the choice of base unit, with suggestions that the lumen may be a better choice than the candela. While it would have little impact on the nature and type of comparisons performed to support the CIPM MRA, the CCPR community would be impacted by the change in definitions and relationships of the traceability chain.

5. Outlook in the short and long term

In the short term, the existing portfolio of key comparisons is considered to be adequate to underpin the needs of the CCPR community, but within the next two decades, extensions 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 range. Mid- and far-infrared radiometry has become more important in order to increase the accuracy of Earth and climate observations. THz-radiation has found commercial applications in remote sensing. To allow the extension of the measurand range, various activities to validate the methods and the equivalence of each laboratory should follow.

Many of the fields considered in the strategy document 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 closer to those applications. Demands for cooperation with other international organizations 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 such as the Committee on Earth Observation Satellites (CEOS) and the Group on Earth Observations (GEO). In the display and lighting industries, improved reliability of the 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 biophotonics instrumentation requires metrology experts in optical radiation measurements to collaborate in multidisciplinary work with experts in biotechnology, health and life sciences. The CCPR needs to link scientific experts with industrial experts through joint activities with the relevant global organizations such as the International Commission on Illumination (CIE) and the Society for Information Display (SID) to promote the development of measurement standards that can meet urgent practical demands.

Annex: CC Data

CCPR set up in 1933
President: M.L. Rastello — Executive secretary: J. Viallon
Membership: 23 members, 2 liaison and 3 observers
List of CCPR members and observers: https://www.bipm.org/en/committees/cc/ccpr/members-cc.html

Meetings since the 24th CGPM meeting: 22−23 September 2016
Full reports of the CCPR meetings: https://www.bipm.org/en/committees/cc/ccpr/publications-cc.html

3 Working Groups: http://www.bipm.org/en/committees/cc/ccauv/working_groups.html
Key Comparisons (CCPR−WG−KC)
CMC (CCCPR−WG−CMC)
Strategic Planning (CCPR−WG−SP)

CCPR Comparison activity	Completed	In progress	Planned [period]
CCPR key comparisons (and supplementary comparisons)	10 KC, plus 3 SC, 3 before MRA, 1 repeat, 4 bilateral	1 KC	5 KC (all repeats), 1 bilateral [until 2022]
BIPM comparisons	3	0	0
CC pilot studies	3	2	3
CMCs	1345 CMCs in 85 service categories registered in the KCDB		