Consultative Committee for Photometry and Radiometry (CCPR)

President: Dr Takashi Usuda                               Executive Secretary: Dr Michael Stock

1. Executive summary
The CCPR covers metrological aspects of optical light in terms of its brightness (photometry) and colour (colorimetry) as perceived by the human eye. The CCPR also deals with radiometry; the measurement of absolute radiation power and related quantities in the visible spectral range and the adjacent ranges of the infrared and the UV. Radiometry and photometry also include the measurement of optical properties of materials such as reflectance, transmittance and appearance.

The realization of the International System of Units (SI) photometric base unit, the candela, is the foundation of lighting evaluation. Activities in this field are closely connected to improvement of energy efficiency (solid-state lighting, photovoltaic cells), environment and climate studies (Earth observation), and quality of life (to aid human vision). Precise radiometric measurements are expanding into biotechnologies (fluorescent detection) and cyber security ( photon counting for quantum cryptography).

2. Scope of the CCPR
The Consultative Committee for Photometry (CCP) was established in 1933 and became the Consultative Committee for Photometry and Radiometry (CCPR) in 1971. The CCPR is responsible for providing advice to the International Committee for Weights and Measures (CIPM) on matters concerned with photometry and radiometry. It is presently responsible for:

- the practical realization of the SI photometric base unit, the candela, and measurement standards for related photometric and radiometric quantities (luminous flux, luminous intensity, illuminance, spectral radiant flux, spectral radiance, spectral irradiance);
- the development of absolute radiometry (absolute spectral responsivity scales);
- the development of measurement scales for the optical properties of materials, including the provision of SI traceability for colorimetry of materials (spectral reflectance and spectral transmittance scales);
- the identification and support of measurement needs in fibre optics; and
- the organization of key comparisons to establish world-wide comparability of measurement standards.

3. Strategy
The CCPR established the Working Group on Strategic Planning (WG-SP) in 2005 to advise the CIPM on future directions in photometry and radiometry, relevant to the SI. Another objective for this working group was the optimization of the operational structure and consideration of the technical priorities of the CCPR in the context of the needs of the global community, such as the need for new definitions/standards and coordinated research. In 2007, the terms of reference of the WG-SP were expanded to include monitoring developments with respect to the future of the SI system and as a consequence a Task Group on the SI was established.
Since its inception, the CCPR WG-SP has carried out the following activities. Its first output was an opinion paper on the evolving needs in the field of photometry and radiometry for the 2007 BIPM Report ‘Evolving Needs for Metrology in Trade, Industry and Society’. During 2012 and 2013, the working group developed the CCPR strategic plan, which is relevant to member National Metrology Institutes (NMIs), Designated Institutes (DIs) and their stakeholders. The strategic plan needs to be updated regularly. To ensure this update cycle, and to provide a forum for scientific discussions of new application-related themes, the WG-SP introduced Discussion Forums as a new category of CCPR Task Group. The less formal structure will allow the discussion of measurement issues and other emerging topics of interest that would benefit from broader participation of experts, from outside the CCPR. These Discussion Forum task groups are intended to be short-lived and to recommend specific tasks to the CCPR, such as the establishment of new CCPR technical working groups, the identification of needs for cooperative NMI research or new pilot or key comparisons to provide SI traceability and to underpin associated Calibration and Measurement Capabilities (CMCs).

From the outset the CCPR has collaborated with other international organizations. In particular, it maintains regular liaison activities with the International Commission on Illumination (CIE), which has observer status in the CCPR. The CIE is responsible for standardizing the human response functions for photopic, scotopic and mesopic vision. An agreement was signed in 2007 between the CIE and the CIPM, which recognizes the complementary roles of both bodies. The CIPM is responsible for the definition of the photometric units, whereas the CIE is responsible for the standardization of the action spectra of the human eye. The World Meteorological Organization (WMO) also has observer status in the CCPR. In this case the area of common interest is climate-change related studies, since many essential climate variables require ground- or satellite-based radiometric measurements.

Interdisciplinary topics, e.g., quantum optics, earth observation, solar/stellar radiometry, etc. are exchanged with NMIs and other academic institutes at NEWRAD conferences, which are held once every three years. Internal collaborations with other CCs are also becoming popular with reference to recent terahertz (THz) measurement needs with the Consultative Committee for Electricity and Magnetism (CCEM) and radiation thermometry with the Consultative Committee for Thermometry (CCT).
4. Activities and achievements since the last meeting of the CGPM

In 2012, a workshop on the *mise en pratique* (*mep*) for the candela was held, with participation from the CIE. It resulted in a recommendation to the CCPR to create a joint CCPR/CIE Task Group to develop a joint CIPM/CIE publication on “Principles Governing Photometry”. It will include information on all photometric quantities and units and the CIE standard spectral luminous efficiency functions for photopic, scotopic and mesopic vision. This document will replace the existing BIPM Monographie: *Principles Governing Photometry* (1983) and it is expected that it will also serve as an update of the CIE technical report, *CIE 18.2-1983: The Basis of Physical Photometry*, which is almost identical. The best way to prepare a *mep* was also discussed. The new document will include recent CIE action spectra for human vision in intermediate (mesopic) lighting conditions.

A workshop on SI units for Photometry and Radiometry was organized in 2013; again with representation from the CIE. The workshop included a discussion on the proposal to replace the candela as the photometric SI base unit with the lumen. The CIE representative presented the outcome of discussions within the CIE which resulted in the recommendation that “in the absence of compelling reasons to change from the candela to the lumen as the SI base unit, it is highly recommended to maintain the status quo.” The participants at the workshop agreed with this recommendation.

The Discussion Forum task groups have advanced their aims through the use of surveys. Both TG6 and TG8 have conducted surveys of NMI capabilities and needs for traceability of fibre optic and THz measurements, respectively. An outcome of these surveys has been the prioritization of measurement needs and the establishment of a new Task Group, TG9, to develop the technical protocol for a pilot comparison of optical time domain reflectometry (OTDR) length and a preliminary investigation of a THz detector comparison by NMIs active in this field.

4.1. Main activities

- Review and comment on the CCU proposal for the wording of the candela definition
- Creation of a number of technical task groups
  - Few-photon metrology
  - Fibre optics
  - Comparison analysis
  - OTDR length comparison
  - SI
  - *Mise en pratique*
  - THz metrology, with a liaison person to the CCEM
- Information exchange with the CIE in fields of common interest:
  - Introduction of the mesopic observer by the CIE
  - Reworded definition of the candela
- Joint CIE-CCPR publication “Principles governing photometry”
- Publication of the *mise en pratique* for photometric units
- Publication of a series of internal CCPR guidelines, to streamline processes related to key comparisons (KCs)
- Organization of two workshops, with participation from the CIE
  - *Mise en pratique* for the candela (2012)
4.2. Challenges and difficulties

The current definition of the candela, the base unit for photometry, was adopted in 1979. It offered the user more flexibility in the choice of the method for realization of the unit, whereas the 1948 definition was specific to the use of a particular source - a platinum blackbody at its freezing point, which was difficult to operate. The new definition can be realized more easily by a direct method in which the standard lamp is directly calibrated in luminous intensity against a photometer, which itself is calibrated against an absolute radiometer.

Based on the possibilities offered by this definition and the wide availability of primary radiometric standards, and due to resource constraints, the BIPM closed its radiometric and photometric laboratories in 2003. However, this does not mean that photometric and radiometric metrology became mature. In fact, there has been a transformational change in light and lighting with the improved technology offered by light-emitting diodes (LEDs) whose application in general purpose lighting has been growing rapidly over the past decade, and which is replacing traditional incandescent and fluorescent light sources. This impacts the NMIs and the CCPR since the methodologies for measuring the optical quantities that are most relevant for these LEDs are different from those of traditional light sources and need to be more fully developed. Member NMIs are requested to adopt their national standards from traditional light sources to solid-state lamps.

Before its closure, the Photometry and Radiometry Section at the BIPM had been a viable and active contributor to the sectors served by the NMI members of the CCPR and had organized several key comparisons. These activities ceased when the CGPM decided to close the Photometry and Radiometry Section in 2003. However, expectations that the BIPM could serve again as a coordinating entity in this area are growing.

While the current traceability system for relatively large radiation levels is well established, photon-based quantum standards for low levels of optical radiation are in the process of being developed. It remains a challenge to bridge the gap between both regimes.

Vision is one of the most important means for humans to obtain information on their surroundings and for making key decisions. Thus, robust measurement systems for appearance, display and imaging are emerging industrial needs. The drivers are consumer perceptions of “quality”, “suitability” and “desirability” and the means to assess these at the design, production and test phases of product development and production cycles independent of the human observer.
5. **Outlook in the short and long term**

**Energy**

*Photovoltaics*

In the context of the CCPR, photovoltaics are the key technology for energy production. Driven by the desire to reduce dependency on fossil fuels, to reduce carbon emissions and improve sustainability, photovoltaics are the subject of world-wide research. In this context, improved accuracy for photovoltaic efficiency measurements under “real conditions” and at production-level spatial scales, as well as consistent international traceability for all types of photovoltaic cells, are requested from stakeholders.

*Solid-state lighting (SSL)*

SSL is making major inroads into consumer applications with phased removal of energy-inefficient incandescent lamps. In the main, there are radiometric/photometric metrology challenges associated with the new light source technologies (LED, OLED) that are evolutionary in nature. However, in current practice, they are more about ensuring that an appropriate metric is associated to devices that are relevant to the customer and the intended application and ensuring that industry can standardize measuring conditions, etc. The longer-term move towards OLEDs and lighting panels will require further evolution and standardization of techniques. It will not be a driver for fundamentally new primary standards and key comparisons, but will require a careful consideration of the choice of artefacts for future comparisons. In this context, the standardization of specification of measurement conditions for new lighting types, and development of metrics to meet consumer needs are requested from stakeholders.

**Environment and climate**

Changes in the climate are due to subtle changes in the optical radiation balance (incoming to outgoing) of the Earth, leading to a resultant increase in global temperature. Although, in principle, the absolute change in temperature can be measured through a global network of “thermometers” this is not by itself a reliable metric due to sampling issues, local changes, as well as the sensing techniques themselves. The community thus makes use of a variety of indicators to monitor and infer change or the impact of change. These are the so-called Essential Climate Variables (ECVs); more than two thirds of the 50 ECVs involve some form of optical radiation measurement: emitted, direct, absorbed or reflected. This will require new measurement standards for environmental changes and the environmental performance of new technologies.

As climate change needs to be monitored globally, this drives the need for satellite-based observation of the Earth-Sun system. In order to reliably detect changes in the environment and to monitor the climate, a robust and stable satellite-based measurement infrastructure is required. This typically involves measurements at very low levels and over long timescales. The activities to be addressed most urgently through research include validated and traceable measurement techniques, sensors and measurement standards capable of detecting small changes over long periods, and the assessment and management of environmental noise. The metrological needs and key challenges in these sectors are:
• novel sensors and underpinning measurements for global surface and ocean
temperatures and stable long-term trends in the composition of the ocean and
atmosphere,
• provision of a distributed system capable of providing traceability to SI units for
measurement data from global ground and satellite-based networks,
• development of techniques which can make possible a set of SI-traceable radiometric
standards and instruments to make such measurements in space.

Health and Quality of life

The medical and health sectors continue to make increased use of optical radiation for both
diagnosis and treatment. Metrology for health underpins the more reliable and efficient
exploitation of diagnostic and therapeutic methods and the development of new techniques,
which is needed to improve health care, limit costs and foster the competitiveness of the
related industries and services.

Security

Security-related metrology includes development and characterization of THz sources and
detectors. The terahertz region is the last part of the non-ionizing EM spectrum to be
exploited technologically. An emerging THz industry is developing rapidly. Major drivers
for this rapid growth, besides security applications are, medical imaging, biological
screening, e.g. of toxins in the atmosphere, and biological and pharmaceutical spectrometry
of solids and liquids. At present, little metrological support can be provided for this activity,
although it has been requested by industry. The growth of this industrial need will require
the establishment of traceable radiometry in the THz range.

Another research option is underpinning quantum cryptography by entangled photon-
sources which are also of interest in radiometry, and by validation procedures for
information integrity, which also affects legal metrology. The extremely strong privacy
properties of quantum key distribution (QKD) can be used as security-enhancing
technologies to enforce protection of personal data. The target is to develop the
metrological expertise and capabilities to meet the needs of future developments in QKD
components such as sources, detectors, true physical quantum random number generators
and quantum repeaters.

Annex: CCPR Data

CCPR set up in 1933 (as CCP)
President: T. Usuda
Executive Secretary: M. Stock
Membership:
23 members and 4 observers
List of CCPR members and observers:
Meetings since the 24th CGPM meeting:
23-24 February 2012 / 17-18 September 2014
Full reports of the CCPR meetings:
3 Working Groups:
Key Comparisons (WG-KC)
CMCs (WG-CMC)
Strategic Planning (WG-SP)
http://www.bipm.org/en/committees/cc/ccpr/working_groups.html
<table>
<thead>
<tr>
<th>CCPR Comparison activity</th>
<th>Completed</th>
<th>In progress</th>
<th>Planned [period]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCPR key comparisons (and supplementary comparisons)</td>
<td>20 (including 3 approved for provisional equivalence, before 1999)</td>
<td>2</td>
<td>8 (until 2019)</td>
</tr>
<tr>
<td>BIPM comparisons</td>
<td>3 (activity now terminated at the BIPM)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CC pilot studies</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>CMCs</td>
<td>1271 CMCs in 85 service categories registered in the KCDB</td>
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