BUREAU INTERNATIONAL DES POIDS ET MESURES

Comité Consultatif pour les Rayonnements Ionisants

Section I (X- and γ-rays, charged particles)

Minutes of the 27th Meeting of CCRI(I), 1 – 2 June 2023

Hybrid meeting at the IAEA Headquarters (Vienna, Austria), with online participation

Chair	Dr Malcolm McEwen (NRC)
Co-chair	Dr Massimo Pinto (ENEA)
CCRI President	Dr JT Janssen (NPL)
CCRI Executive Secretary	Dr Vincent Gressier (BIPM)

List of attendees

Claus Andersen (DTU, Denmark)
Ulrike Ankerhold (PTB, Germany)
Jean-Marc Bordy (LNE-LNHB, France) – online
Duncan Butler (ARPANSA, Australia) – online
Mauro Carrara (IAEA, Austria)
Olivera Ciraj-Bjelac (IAEA, Austria)
Frank Delaunay (LNE-LNHB, France)
Jacco de Pooter (VSL, The Netherlands)
Néstor Cornejo Díaz (CIEMAT, Spain)
Victória Finta (BFKH, Hungary)
Reham Hamdy (NIS, Egypt)
Brendan Healy (ARPANSA, Australia)
Sibusiso Jozela (NMISA, South Africa)
Masahiro Kato (NMIJ, Japan) – online
In Jung Kim (KRISS, South Korea)
Yun Ho Kim (KRISS, South Korea)
Elisabeth Lindbo Hansen (NRPA, Norway) – online
Ron Minniti (NIST, USA) – online
Michael Mitch (NIST, USA) – online
Samia Mohamed (FANR, United Arab Emirates)
Zakithi Msimang (IAEA, Austria)
Chris Oliver (ARPANSA, Australia) – online
Fernando Ortega (CCHEN, Chile)
Peter Peier (METAS, Switzerland)
Linda Persson (SSM, Sweden)
Paulo Rosado (LNMRI, Brazil)
Thorsten Sander (NPL, United Kingdom)
Stanislav Sandtner (SMU, Slovakia)
Sunil Singh (BARC, India) – online
Vladimír Sochor (CMI, Czech Republic) – online
Andreas Steurer (BEV, Austria)
Magdalena Szymko (GUM, Poland)
Russell Thomas (NPL, United Kingdom)
Paula Toroi (STUK, Finland)
Ronald Tosh (NIST, USA)
Anna Villevalde (VNIIM, Russia)
Kun Wang (NIM, China)

Brian E Zimmerman (NIST, USA)

Observer
Wes Culberson (Univ. Wisconsin ADCL, USA)
Steven Kry (IROC-Houston and MDACC ADCL, USA)

BIPM Staff
Dr David Burns
Dr Cecilia Kessler
Mr Philippe Roger – online
Dr Olav Werhahn – online

1. Welcome by the chairs of CCRI(I)

Dr Malcolm McEwen (NRC; Chair – CCRI Section I) and Dr Massimo Pinto (ENEA; Co-chair – CCRI Section I) welcomed delegates to the meeting. Most of the delegates attended the meeting in person but a significant fraction (9 out a total of 47, ~ 20 %) joined online.

2. Welcome by the President of the CCRI to the participants

Dr JT Janssen (NPL) was recently elected as CCRI President. He is the Chief Scientist and International Director at the NPL, where he used to work in the Quantum Electrical Metrology group. As he was not able to attend the CCRI(I) meeting in person, due to other pre-arranged work commitments, his presentation was pre-recorded. He welcomed delegates to the meeting and thanked his predecessor Dr Martyn Sené, who recently retired, for his work on the CIPM and CCRI. He also thanked Dr Zakithi Msimang (IAEA) and Dr Mauro Carrara (IAEA) for hosting the CCRI(I) meeting at the IAEA.

3. Confirmation of the Agenda and appointment of the Rapporteur

The agenda as presented was approved without changes. There were no additions. Dr Thorsten Sander (NPL) agreed to act as Rapporteur for the meeting with assistance from Mr Russell Thomas (NPL). Dr McEwen expressed the thanks of all attendees for the NPL representatives taking on this activity.

4. Progress reports

4.1 CCRI reports (President, CCRI)

Dr JT Janssen (NPL) presented the CCRI vision and mission, emphasizing the importance of ionizing radiation metrology in the areas of diagnostic imaging, radiotherapy, industrial irradiations, radiation protection and security, nuclear power (new builds and decommissioning), environment and climate. He gave a summary of the main resolutions from the 27th CGPM meeting in November 2022 (mainly related to the development of the SI system). He also mentioned that the new CIPM strategy, including the CCRI strategy, would be implemented at the CIPM meeting on 20 May 2025, the 150th birthday of the Metre Convention. The presentation also discussed the CIPM strategy 2030+, the Metrology Grand Challenges, and the future priorities for metrology, i.e., a digitally-enabled global measurement system building on the redefinition of the SI, systems metrology and enabling decision making. Regarding the new CCRI strategy document, this will be built on the 2018 – 2028 strategy.

4.2 Section I reports

Dr Malcolm McEwen (NRC) announced that the Section I reports would be presented at appropriate times throughout the meeting.

4.3 BIPM reports of the Ionizing Radiation Department

Dr Vincent Gressier (BIPM) presented on recent developments at the BIPM Ionizing Radiation Department. The IR Department consists of a team of seven physicists/technicians: Dosimetry (3), Radioactivity (4), and one director. The BIPM maintains three international reference systems for radionuclides, based on high precision detector systems, providing the means to compare primary standards. There are also nine reference systems for dosimetry, with associated primary standards for key comparisons and calibrations. At the BIPM, three x-ray facilities and one high-activity Co-60 source are in operation. Off-site facilities are also accessed by the BIPM: the high-energy photon linac at the DOSEO facility near the LNE-LNHB laboratory; a Cs-137 irradiator at the IAEA Siebersdorf laboratory, and HDR Ir-192 brachytherapy sources as used by various NMIs (for BIPM.RI(I)-K8). The BIPM IR Department provides services for the radionuclide area (key comparisons for 26 CIPM MRA members with IR metrology) and for the dosimetry area (key comparisons and calibrations for 35 CIPM MRA members with IR metrology). Dr Vincent Gressier announced that Dr David Burns (BIPM) is planning to retire in 2024 and that a permanent full-time position for an experienced metrologist (~ 10 years experience) in the BIPM Ionizing Radiation department would be advertised shortly (date for applications: end of June to end of August 2023; start date: January 2024).

Three highlights from 2021 – 2023 were reported for radionuclide metrology: 1) an improved production of comparison reports for the international reference system for γ-ray emitters, 2) an increase in the number of short-lived radionuclide comparisons for nuclear medicine and 3) the implementation of a system for high energy pure β-emitter comparison services. Ionizing radiation metrology highlights from 2021 – 2023 were related to 'International liaison' (revision of IAEA TRS-398, membership of ICRU, vice-presidency of the ICRM and participation to ISO-SC2 meetings) and 'Capacity building and knowledge transfer activities' (including the organization of 15 webinars in the recently introduced CCRI webinar series and 30 international meetings).

Dr David Burns presented on the commissioning of BIPM's new medium-energy x-ray facility. The existing facility has been in operation since the early 1970's. The new x-ray tube stand and measurement bench were already described at the previous CCRI(I) meeting (see report CCRI(I)/2021-13). The x-ray tube support incorporates an automated shutter and filter wheel. There are also mechanical and optical features which allow fine adjustment of the different components. Ionization chamber positioning is possible within 10 μm, so positional uncertainties of 1 part in 10^4 will be achievable. As part of the commissioning of the new facility, beam alignment checks for the large and small focal spot configurations were performed. Radial beam profiles were also measured and the heel effect was observed. The exact position and shape of the focal spot of the x-ray tube is not known. To optimize the circular shape of the primary beam, seven conical collimators with different borehole diameters at the entrance and exit planes were manufactured at the BIPM. For a 6.92 mm diameter entrance and 8.90 mm diameter exit, the circular x-ray beam at the reference plane of the ionization chamber had a horizontal size of 99.8 mm and a vertical size of 99.3 mm. A new free-air chamber (FAC) was also built and commissioned. Mr Philippe Roger (BIPM) constructed the FAC stand, and Dr Cecilia Kessler (BIPM) performed finite-element simulations for the evaluation of some of the correction factors. The collectors of the new FAC M-02 were assembled with different gap widths, starting with 2 mm air gaps. The FAC was finally assembled with 0.5 mm gaps, which resulted in a 0.08% change in the chamber response. After a repeat assembly with 0.5 mm gaps, the response had changed by 0.11%. The results were fed into the uncertainty budget. To validate the new FAC M-02, it was compared against the existing FAC M-01, where the mean ratio between the two standards was found to be 1.0009. The BIPM medium-energy x-ray qualities (100, 135, 180 and 250 kV) have been characterized on the new facility in terms of air attenuation and HVL. The next steps will be to improve the radiation shielding of the facility and to improve the accuracy of the chamber temperature measurements. A third assembly of the FAC M-02 is also planned. Finally, a definitive comparison of FAC M-02 against FAC M-01 is planned in the old medium-energy x-ray beams and a definitive air kerma determination in the new beams.

The BIPM measuring equipment for use in the IAEA Cs-137 radiation field has been assembled and initial testing completed in the spring of 2023. This system will be entirely separate from anything used by the IAEA and fully under the control of BIPM staff. It is expected that commissioning will be complete before the end of 2023, allowing the relaunch of BIPM.RI(I)-K5 and associated calibration service.

A discussion period followed:

Dr Malcolm McEwen (NRC) asked if there were any plans to decommission the old medium-energy x-ray facility at the BIPM. Dr David Burns (BIPM) responded that this is not planned at this stage. The old and the new facility would be kept operational for the time being.

Dr Massimo Pinto (ENEA) asked whether the K3 key comparison reference value would be changed. Dr David Burns indicated that this would have to be decided by the CCRI.

Mr Russell Thomas (NPL) asked for the dimensions of BIPM's water tank for medium-energy absorbed dose to water determination. Dr David Burns (BIPM) responded that the 20 cm × 20 cm × 20 cm water tank has a 1.7 mm thick PMMA front window. Changes in the position of the window have been observed depending on the water level. The window size was kept as small as possible to minimize this effect. A 1 µm positional uncertainty can be achieved for the measured distance between the x-ray tube and the front face of the water tank.

Dr Duncan Butler (ARPANSA) reported that a type A uncertainty of around 0.5% was typical for FAC measurements at ARPANSA. He also reminded the delegates to pay attention to the positioning of temperature probes when measuring the air temperature of the collecting volume of ionization chambers (FACs, secondary standards and monitor chambers). Dr David Burns confirmed that it is always challenging to measure the ambient temperature close to the chamber volume without disturbing the air kerma measurement. Dr Paula Toroi (STUK) indicated that the IAEA uses dummy chambers with temperature probes inserted into the collecting volume to estimate the air temperature inside the actual chambers.

At the end of this session, Dr Malcolm McEwen mentioned that since Dr David Burns is planning to retire in 2024, this would be his final CCRI(I) meeting. Dr McEwen thanked Dr Burns for all his contributions to CCRI and Ionizing Radiation Metrology at the BIPM over the last 25+ years.

4.4 Acceptance of publications and reports from members, observers, liaisons

Reports from NMIs/DIs and liaisons were accepted without review, members were invited to read through the meeting material uploaded to the CCR(I) website. NMIs were asked to make the 2021 – 2023 laboratory reports public, if possible, to increase the visibility of CCRI(I).

5. CIPM MRA

5.1 JCRB Report (Olav Werhahn)

Dr Olav Werhahn (JCRB Executive Secretary, BIPM) gave a presentation on the Joint Committee of the RMOs of the BIPM. The 46th meeting of the JCRB was held at the BIPM on 15 – 16 March 2023. All RMOs were represented, with delegations and RMO reports to the JCRB. The review durations for the calibration and measurement capabilities (CMCs), i.e., the time it takes to get CMCs published in the KCDB has been reduced to a median of less than 70 days. It was pointed out that the CIPM MRA-G-1 revision on statistical evaluations was not sufficiently supported by the Consultative Committees (CCs). Six documents were produced to cover the JCRB-governance of the Mutual Recognition Arrangements: three policy documents and three guideline documents. The greying out procedure for CMCs has been streamlined. At the 2023-meeting, the JCRB asked each of the RMOs to nominate one (or two) RMO coordinators for the Young Metrologists 2030+ vision. As part of the digital transformation programme, BIPM MicroProject placements are planned. At the end of his presentation, Dr Olav Werhahn gave an update on the CMC status. The total number of CMCs has remained almost constant due to similar numbers of deletions and new entries over recent

years. 25863 CMCs in total are currently published on the KCDB, with 3738 CMCs for the Ionizing Radiation area.

A discussion period followed:

Dr Jacco de Pooter (VSL) asked if the publication time of CMCs included the review times. Dr Olav Werhahn confirmed that the CMC review time was defined as the time from the original submission to the final publication, including the time needed for the review.

Dr Anna Villevalde (VNIIM) remarked that the COOMET TC chair cannot get access to the CMCs anymore. Dr Olav Werhahn responded that the COOMET TC chair should e-mail the JCRB Executive Secretary to identify the issues.

Dr Zakithi Msimang (IAEA) remarked that other laboratories also had problems accessing the CMCs. Dr Olav Werhahn responded that representatives from the relevant laboratories should e-mail the JCRB Executive Secretary to identify the issues.

5.2 Comparisons

5.2.1 BIPM and CCRI(I) key comparisons status

Dr Cecilia Kessler (BIPM) presented on BIPM dosimetry comparisons and calibrations for CCRI Section I over the last two years.

A summary of all BIPM facilities and services used for both comparisons and calibrations was shown. The following facilities for the BIPM.RI(I) key comparisons (K) and related calibration services (C) are installed at the BIPM:

- low-energy / mammography x-ray beams (10 kV – 50 kV) for the K2 and C2 services (air kerma, *W/Al* qualities), for K7M / C7M (air kerma, *Mo/Mo* qualities) and for K7W / C7W (air kerma, *W/Mo* qualities),
- medium-energy x-ray beams (100 kV – 250 kV) for K3 / C3 (air kerma, *W/Al* and *W/Cu* qualities) and for K9 / C9 (absorbed dose to water), and
- Co-60 source for K1 / C1 (air kerma) and K4 / C4 (absorbed dose to water).

The remaining BIPM comparisons and calibrations are performed using off-site facilities, i.e., the high-energy photon linac at the DOSEO facility (6, 10 and 18 MV x-rays) for K6 / C6 (absorbed dose to water) and HDR Ir-192 brachytherapy sources at NMIs (or hospitals in their proximity) that participate in K8 key comparisons. There is no brachytherapy afterloader installed at the BIPM. Further to the decommissioning of BIPM's Cs-137 facility, the Cs-137 radiation protection service has been re-launched at the IAEA's Dosimetry Laboratory in Seibersdorf, Austria, in 2023. Mr Philippe Roger (BIPM) has set up the measurement capability at the IAEA. BIPM's equipment, procedures and personnel will be used for the K5 / C5 (air kerma) work.

For the 21-23 period, eleven comparisons were planned for low-energy/mammography x-ray beams. Four comparisons were performed in 2021 (BFKH, Hungary, BIPM.RI(I)-K2 (report ready for publication) and K7 (report in Draft A form), and GUM, Poland, K2 (published) and K7 (referred to KCWG(I))). Three comparisons were performed in 2022 (ARPANSA, Australia, K2 (published), and NIST, USA, K2 and K7 (for both cases awaiting NIST's final results)). Another four calibrations were planned for 2023. However, the K2 and K7 comparisons for VNIIM, Russia will have to be re-scheduled because it is currently not possible to transport the measurement instruments. The K2 and K7 comparisons for ENEA, Italy have been postponed due to a failure of the low-energy x-ray tube at ENEA that requires replacement.

One comparison was performed for medium-energy x-ray beams in 2021 (BFKH, Hungary, BIPM.RI(I)-K3 (report in Draft B form)).

Seven comparisons were performed in the Co-60 γ-ray beam, three in 2021 (BFKH, Hungary, BIPM.RI(I)-K1 and K4 (reports sent for publication), and NIM, China, K4 (report published)), and four in 2022 (NMIJ, Japan, K1 and K4 (reports published) and KRISS, Korea, K1 and K4

(reports published)). Two further comparisons (NIST, USA, K1 and K4) are scheduled for October/November 2023.

One comparison was performed in the Cs-137 beam at the IAEA in 2023 (BEV, Austria, BIPM.RI(I)-K5 (data being analyzed)). Repeat measurements for BEV and another K5 comparison (CIEMAT, Spain) are scheduled for September 2023.

One MV x-ray comparison was performed at the DOSEO facility in 2021 (PTB, Germany, BIPM.RI(I)-K6 (report published)) and one in 2022 (ARPANSA, Australia, K6 (report published)). Another K6 comparison (NIST, USA) has been scheduled for October 2023.

One comparison in the HDR Ir-192 beam at NPL was performed in 2022 (NPL, UK, BIPM.RI(I)-K8 (report published)) and one in the HDR Ir-192 beam at PTB in 2023 (PTB, Germany, K8 (report in Draft A)). Another K8 comparison (NIM, China) is planned for 2024 (to be scheduled).

Three comparisons performed by KRISS, Korea, in 2017 (K2, K3 and K7) were published in 2022. The BIPM.RI(I)-K4 comparison was performed by VNIIFTRI, Russia, in 2019. The final results have not been received by the BIPM. VSL, The Netherlands, performed a K8 comparison in 2019. The draft A report was sent to the VSL in March 2022.

Based on the 15-year validity of CCRI(I) key comparisons, the following key comparisons will be due within the next three years: K2 (LNHB, France, by 2024; VNIIM, Russia, by 2026; ENEA, Italy, by 2026), K7 (PTB, Germany, by 2025), K1 (VNIIM, Russia, by 2024), K4 (ENEA, Italy, was due in 2022; VNIIFTRI, Russia, by 2024).

For the BIPM.RI(I)-K6 comparison, BIPM expects participation by NPL, UK, in 2024 (previous comparison in 2013) and VSL, The Netherlands, in 2025 (previous comparison in 2014).

The next BIPM.RI(I)-K5 comparisons need to be scheduled for GUM, Poland; ITN, Portugal; LNHB, France and VNIIM, Russia.

A total of 21 comparisons with 11 NMIs, and 59 calibrations for 11 NMIs and the IAEA were performed by the BIPM from 2021 – 2023.

A question period followed:

Dr Anna Villevalde (VNIIM) asked what the issues were with the K4 comparison for Russia. Dr Cecilia Kessler (BIPM) responded that the pre-BIPM results had been sent to the BIPM, but not the post-BIPM results. Dr Anna Villevalde will check with her colleagues at the VNIIFTRI, Russia.

Dr Massimo Pinto (ENEA) remarked that one of the X-ray tubes at ENEA failed after more than 30 years. Once the X-ray tube has been replaced, ENEA will contact BIPM regarding the K2 and K7 comparisons. A new Co-60 irradiator will be set up at ENEA by the end of 2024. ENEA will then contact BIPM to arrange a K4 comparison. Given the relatively small number of BIPM staff in the IR Department, Dr Massimo Pinto also asked whether an automation of the writing of key comparison reports should be considered in the future. Dr Cecilia Kessler responded that an automated production of comparison reports would probably not be feasible. Dr David Burns (BIPM) added that the comparison reports are currently not the main reason for delays in the reporting on key comparison results. The main issue is usually the time it takes to receive the final results and the uncertainty budgets from the participating NMIs. Dr Malcolm McEwen (NRC) emphasized that comparisons are multi-parameter situations, where different numbers of transfer instruments might be used, so any attempted automation of the production of comparison reports could be problematic.

5.2.2 Regional key and supplementary comparisons status

Mr Sibusiso Jozela (NMISA) reported for AFRIMETS that currently there are no ongoing comparisons.

Dr Duncan Butler (ARPANSA) reported for APMP that one key comparison on mammography is currently in progress. One bilateral comparison is planned. There are also plans for an electron absorbed dose to water comparison, which is not registered in the KCDB yet.

Dr Anna Villevalde (VNIIM) reported for COOMET that currently there are no ongoing comparisons. The draft B report for the COOMET.RI(I)-S3 comparison (air kerma for x-ray qualities) has been revised for the last two years. Two of the participating laboratories had not submitted their full uncertainty budgets. Correlations between laboratories were not considered. The information has been submitted in the meantime, so the comparison report should be completed shortly. Dr Jacco de Pooter (VSL) confirmed that the S3 report can be reviewed soon.

Dr Jacco de Pooter reported for EURAMET that a beta-ray comparison is close to the reporting phase. The DOSEtrace comparison is currently in the Draft B phase. Measurements for a Co-60 air kerma and absorbed dose comparison (led by STUK; VSL is the link) have almost been completed. There are also two ongoing bilateral comparisons, one for Cs-137 and one for Cr-51.

Ms Samia Mohamed (FANR) reported for GULFMET that two comparisons are underway, one for radiation protection (x-ray beam qualities and Cs-137) and one for diagnostic radiology.

Dr Malcolm McEwen (NRC) reported for SIM that measurements for a supplementary comparison (K1 for Co-60 air kerma and K4 for Co-60 absorbed dose) will be completed soon. For this comparison, SIM implemented a modified star-shaped comparison, effectively a sequential series of bilateral comparisons between the pilot and each participant, as a risk–management measure. Large comparisons are risky because of potential delays due to cross-border transport of equipment and possible equipment failure.

5.2.3 Key Comparisons Working Group (I) report

Dr Malcolm McEwen (NRC) reported that the Key Comparisons Working Group I (KCDB(I)) only meets on rare occasions, usually after any issues with key comparison measurements has been identified. Two new members were added during the last period but additional members are welcome.

The KCWG(I) has recently met to discuss measurement issues of one NMI that participated in two different key comparisons. A few proposed actions were passed on to the relevant NMI to resolve the issues. Dr Malcolm McEwen mentioned the low activity of the KCWG(I) is due to the well-established system of Key Comparisons overseen by the staff at the BIPM.

As at a decision taken at the previous CCRI(I) meeting (2021), the validity of BIPM key comparisons has been extended from 10 to 15 years, after which the entries on the KCDB will be removed. It is still expected that key comparisons will be repeated approximately every ten years, when BIPM will start sending reminders. 13 years after the previous comparison, BIPM sends a final notice. It was noted that, ultimately the individual laboratories are responsible to contact the BIPM to arrange key comparisons well ahead of any anticipated laboratory downtimes. Re-comparisons and re-calibrations should be based on a risk-based approach, i.e., after significant changes (key staff, introduction of new measurement instruments, *etc*).

A discussion period followed:

Dr Massimo Pinto (ENEA) asked what would happen if a comparison was arranged for year 14 and there were some technical issues. Dr Malcolm McEwen (NRC) responded that this would have to be decided on a case-to-case basis.

Dr Anna Villevalde (VNIIM) asked whether VNIIM's CMCs would have to be removed from the KCDB if the relevant key comparisons could not be performed soon. Dr Malcolm McEwen responded that due to the special circumstances this would have to be discussed with the KCWG(I).

Dr Malcolm McEwen remarked that for CMCs that must be removed from the KCDB, data from previous comparisons will remain in the database.

At the joint CCRI(I)/SSDL network meeting on 31 May 2023 it was discussed that the KCWG(I) should draft a 'How far does the light shine?' guidance document on how to link comparisons with CMCs. Dr Malcolm McEwen remarked that in some cases the beam qualities that have been chosen for comparisons might not be comparable to beam qualities used in the clinic, e.g., it is not clear which comparison should be performed for HDR Co-60 brachytherapy sources. The 'how far the light shines'-motto is a driver to reduce the total number of CMCs. Rather than using all standard CCRI qualities for comparisons, it might be possible to only use those beam qualities which are relevant for individual NMIs, for instance for the K2 and K3 x-ray key comparisons. Dr Ulrike Ankerhold (PTB) and Dr Malcolm McEwen pointed out that the CCRI beam qualities were chosen in the 1970s to cover the general range of beam qualities used for radiotherapy and that they would remain relevant. Dr Anna Villevalde remarked that many SSDLs have not set up all of the CCRI qualities, so it should be clarified how many qualities will be needed, e.g., for the K7 comparison. Dr David Burns (BIPM) reminded all delegates that the BIPM can usually set up a supplementary comparison if there is doubt that the normal comparison does not cover any specific aspects.

5.2.4 Current and future comparison needs

Best practice for comparisons

Dr Cecilia Kessler (BIPM) presented on the practical aspects of taking part in BIPM dosimetry comparisons and calibrations. Information on the measurement conditions at the BIPM, the determination of absorbed dose to water and an analysis of the measurement uncertainties are given in Rapport BIPM-2018/06. To request a comparison / calibration, the BIPM should be contacted by e-mail (dosimetry@bipm.org) at least one year before the desired period. Detailed information on the process is also available on the BIPM website. The BIPM will then send a form to request the comparison / calibration, and a form for administration and customs (if applicable). Equipment being shipped to the BIPM must arrive no later than the week before the planned measurements. All delegates were reminded that customs clearance formalities can take a very long time. Three different types of key comparisons can be performed: 1) direct (using a primary standard), 2) indirect (using transfer chambers) and 3) direct and indirect, using both a primary standard and transfer chambers. Existing primary standards are usually compared by using the indirect method. Two or three transfer instruments are calibrated at the participating NMI before and after the BIPM measurements. The degrees of equivalence (DoE) are evaluated from the calibration coefficients. For new primary standards, both the direct and indirect methods may be used. In this case the DoE will be evaluated from the primary measurements of air kerma or absorbed dose to water. Dr Cecilia Kessler remarked that it would be preferable to run comparisons using transfer instruments because the NMIs would then also compare what is disseminated at the national level. After completing all the comparison measurements, the results are evaluated at the BIPM and a Draft A report is prepared. The NMI will then add any specific information (details of the NMI's primary standard, uncertainty budget, *etc.*) to the Draft A report and return it to the BIPM. The Draft A will then be converted to a Draft B report which will be sent to the CCRI(I) reviewers for comments and approval. Finally, the comparison report will be sent to the KCDB for publication. Dr Cecilia Kessler reminded all delegates that the BIPM should be informed of any changes to the national primary standards that have been adopted after key comparisons to enable the BIPM to keep the KCDB up to date.

A general discussion followed:

Dr Massimo Pinto (ENEA) asked whether all changes to correction factors implemented by an NMI between key comparisons should be immediately communicated to the BIPM. Dr Cecilia Kessler responded that any significant changes that would impact the reported value in the KCDB should be communicated once the new correction factors (and/or uncertainties) have been implemented at the relevant NMI. A recent example was the implementation of the ICRU 90 recommendations. Dr David Burns (BIPM) remarked that values in the KCDB cannot be changed without appropriate evidence supplied by the NMI. Dr Cecilia Kessler emphasized that a key comparison must be performed after changing a primary standard.

Dr David Burns also asked all NMIs to send plastic waterproofing sleeves (if required) together with the transfer chambers when taking part in comparisons because all sleeves have slightly different dimensions.

Dr Malcolm McEwen (NRC) asked if any proton comparisons are planned. Mr Russell Thomas (NPL) responded that NPL is planning going to launch a proton calibration service at the end of 2023. One major issue is that none of the PSDLs have their own proton beams, external facilities will have to be used for any comparison. Mr Russell Thomas asked whether anyone would be interested in a bilateral comparison. No firm commitment was made but NIM, GUM and NRC have started some work on primary standards for proton beams (VSL also expressed interest). NMIJ have some experience of making calorimeter measurements in both proton and carbon-ion beams and ARPANSA are actively planning for future proton calorimetry. Dr Claus Andersen (DTU) asked about the reference field for a future proton comparison, would it use the transmission part of the proton beam or another configuration. Mr Russell Thomas responded that there were different options, which would have to be discussed, e.g., reference beams, scanned beams, monoenergetic beams and more clinically relevant beams such as the standard test volumes (SOBPs) developed for the forthcoming UK IPEM proton code of practice.

Dr Malcolm McEwen remarked that NMI interest appears to oscillate between electron and proton beams, so a new key comparison - BIPM.RI(I)-K10 - might be a proton rather than an electron comparison.

Dr Massimo Pinto (ENEA) remarked that only PTB and LNHB have participated in the K9 comparison so far. ENEA is interested in taking part. Dr Jacco de Pooter (VSL) mentioned that any further involvement of VSL needs to be discussed. Dr In Jung Kim (KRISS) indicated that KRISS might join K9 in the future. Dr David Burns reported that up to now only 3 - 4 customers have used BIPM's absorbed dose to water calibration service for thimble chambers. Dr Malcom McEwen commented that this might be due to the fact that many national protocols are still based on air kerma, e.g., TG-61 in the USA and the IPEMB CoP in the UK. Medium energy x-ray absorbed dose standards have been developed at the PTB in Germany, but not in many other countries. The TRS-398 International Code of Practice still supports air kerma, and will do in its upcoming revision.

Dr Malcolm McEwen asked what anticipated need was there for future comparisons. Mr Kun Wang (NIM) responded that NIM have started looking into extending the existing kV x-ray range from 250 kV to 600 kV. This would require the use of a cavity ionization chamber rather than a free-air chamber. For the cavity standard, a similar procedure to the one currently used for Cs-137 and Co-60 could be applied. Dr Malcolm McEwen (NRC) asked if the extended kV range could be covered by K5. NIM should develop the standard, then publish the results and arrange a key comparison. Dr David Burns (BIPM) asked why this new standard was needed. Dr Malcolm McEwen (NRC) responded that the higher kV x-rays would either cover or be closer to the radiation beams from certain radionuclides (e.g. Co-60, Cs-137, Ir-192, Am-241) which might have to be replaced with x-rays for security reasons. Regarding NIM's planned development of a cavity standard for 250 kV – 600 kV x-rays, Dr Néstor Cornejo Díaz (CIEMAT) remarked that cavity theory does not hold if there are many low energy x-rays in the spectrum. Dr Thorsten Sander (NPL) indicated that Monte Carlo methods could be used to derive a fluence perturbation correction factor to account for deviations from ideal Bragg-Gray conditions.

Brachytherapy Standards WG status

Dr Malcolm McEwen (NRC) gave an update on the status of the Brachytherapy Standards Working Group (BSWG(I)), originally set up in 2005.The main output was the launch of the BIPM.RI(I)-K8 key comparison for the measurement of reference air kerma rate for HDR Ir-192 brachytherapy sources. The number of HDR afterloaders used worldwide is still growing, and HDR Co-60 sources are also used clinically. At the BSWG(I) kick-off meeting in 2005, the possibility of a new key comparison for LDR I-125 seeds was also discussed. However, a protocol for this comparison has never been drafted due to potential issues with the transport of I-125 seeds between laboratories in different countries and the relatively short half-life of I-

125. Dr McEwen also mentioned electronic brachytherapy (eBT) sources, for which no specific key comparison exists. He also remarked that it might be difficult to set up an eBT comparison due to the different types of eBT devices which are in use. Dr Massimo Pinto (ENEA) pointed out that some NMIs that participated in the recent EMPIR project 'PRISM-eBT' have modified their low energy x-ray sources to produce eBT-equivalent x-ray beams that could be used for future comparisons. Information on the EMPIR project can be found at the project website at http://www.ebt-empir.eu .

A discussion period followed:

Dr Ulrike Ankerhold (PTB) and Dr Anna Villevalde (VNIIM) mentioned that both laboratories provide absorbed dose to water calibrations for I-125 brachytherapy seeds. LDR I-125 seeds are still popular for brachytherapy.

Dr Mauro Carrara (IAEA) remarked that, according to the IAEA's DIRAC database, not many Zeiss Intrabeam and Xoft Axxent eBT x-ray sources are used worldwide, and that no consensus data are available for eBT sources. The database also shows that currently 1400 HDR Ir-192 afterloaders and 330 HDR Co-60 afterloaders are used worldwide. The number of HDR Co-60 afterloaders is expected to increase further over the next 5 years.

Dr Malcolm McEwen (NRC) concluded that the BSWG(I) might need to set up a key comparison for LDR I-125 brachytherapy sources and possibly for HDR Co-60 brachytherapy sources, but for eBT there would currently be no need for a key comparison. The BSWG(I) should be kept active to discuss any options for an LDR I-125 comparison. Any interest in this new key comparison could be evaluated via e-mail. In the meantime, any bilateral comparisons should be reported to the BIPM for inclusion in the KCDB.

Dr Massimo Pinto (ENEA) remarked that there might be a need for a spectrometry comparison in the future because this technique was heavily used for the characterization of very low, low and medium energy x-ray spectra.

Dr Mauro Carrara (IAEA) stated that users of beta-emitting Ru-106 eye plaques would usually not carry out a second check. Users would refer to the manufacturers' source calibration certificates with expanded uncertainties up to 20% (k = 2). Mr Russell Thomas (NPL) mentioned that NPL offers an alanine calibration service for Ru-106 ophthalmic applicators with traceability to the Co-60 absorbed dose standard and by applying a quality correction factor from Co-60 to Ru-106. Dr Linda Persson (SSU) remarked that SSU is currently involved in setting up a new calibration service for Ru-106 in Sweden. An anecdote from Dr Massimo Pinto (ENEA), regarding a customer who indicated an intention to use a Co-60 calibration without the application of any quality correction factor for a Ru-106 dose realization, suggests a need for expanded service offerings as well as increased engagement with users.

5.3 Calibration and Measurement Capabilities

5.3.1 Review of impact of KCDB 2.0 – submission and review/approval process

Dr Paula Toroi (STUK) indicated that the e-learning platform on the BIPM website is very useful. Dr Toroi also remarked that at the SSDL level it would be difficult to reduce the number of CMCs because different standards are normally used for different services. Dr Massimo Pinto (ENEA) pointed out that it would be beneficial to have two different CMCs if different standards are implicated. If one of the standards would break, the other CMC would still be supported. Dr Vincent Gressier (BIPM) confirmed that the number of CMCs for neutrons has been drastically reduced over the last couple of years. Dr Ulrike Ankerhold (PTB) mentioned that the CCRI(I) CMCs are based on CCRI beam qualities. The validity of the relevant primary standard is demonstrated by the CMC. However, it is possible to disseminate beam qualities that are similar to the CCRI qualities, e.g., beam qualities from the IEC standard. Dr Penny Allisy-Roberts (BIPM) has written a procedure to show how to complete the table in the KCDB. Mr Sibusiso Jozela (NMISA) remarked that the final version of that document would be published in the next 2 months. Rules for Ionizing Radiation CMCs can also be found on the BIPM website.

5.3.2 Review of impact of revision of ISO17025

Dr Malcolm McEwen (NRC) reminded all attendees of the main changes in the ISO17025:2017 revision, including a revised scope, a stronger focus on digital processes and the promotion of a risk-based approach. ISO standards would have to be reviewed every 10 years, but this could be done any time after 5 years since the last review.

5.3.3 Comparison of perspectives on CMCs – NMIs/DIs, stakeholders

This topic was covered in section 5.3.1.

5.3.4 Digitalization – progress to date and future activities (M Pinto)

Dr Massimo Pinto (ENEA) presented on the use of digital technologies in ionizing radiation metrology. A CCRI working group has been set up to evaluate any possible impact of digitalization. CCRI(I) is represented by Dr Massimo Pinto and Dr Duncan Butler (ARPANSA). The purpose of the working group is to advise the CCRI on the SI Digital Framework. A kick-off meeting was held on 17 March 2023 and monthly meetings are planned. A SharePoint has been set up for sharing relevant files. Dr Massimo Pinto mentioned the introduction of the PDF/A-3 prototype for CCRI Section II comparison reports and that the working group had raised concern regarding security. Five levels of digitalization were defined. Level 1: produce PDF, not paper certificate; level 2: machine-readable document; level 3: machine-readable and -executable content; level 4: machine-interpretable content; level 5: machine-controllable content. The working party listed the following potential benefits of the introduction of digital methods: the possible automation of the production of BIPM reports; for dosimetry, a digital representation of physical constants and the model equations that would be needed for comparisons; direct access to fundamental data used in any standard/calibration, e.g., the transition energies listed in the Decay Data Evaluation Project (DDEP).

A discussion period followed:

Dr Paula Toroi (STUK) remarked that digital systems could use specific calibration points from calibration certificates and automatically interpolate to user beam qualities. Dr Malcolm McEwen (NRC) added that digitalization might be advantageous when trying to move the medical physics community to using consistent data (e.g., half-life values, decay schemes). The use of validated Monte Carlo data could be promoted (for example, the EGSnrc code now implements DDEP data). Dr Massimo Pinto (ENEA) indicated that anything that enters the measurement equations could be linked digitally. Dr Anna Villevalde (VNIIM) pointed out that VNIIM uses a digital method for verification. Apart from this, no digital systems are currently used. Ms Samia Mohamed (FANR) remarked that at FANR there are plans to issue barcodes to their users. This would enable the users to scan the barcode and get a direct link to the calibration laboratory. Mr Russell Thomas (NPL) mentioned that NPL has now moved over to issuing PDF versions of calibration certificates with electronic signatures.

6. Strategic planning 2023-2033

6.1 Review CCRI(I) strategic actions and working groups 2021-2023

Dosimetry for radiation therapy

Dr Ronald Tosh (NIST) reported that the development of the new dosimetry laboratories at NIST is still underway. All calibration services will be reinstated in 2024. The LDR brachytherapy WAFAC is currently being upgraded and will be back in use in 2024. The primary standard for electronic brachytherapy sources and the related calibration service will be up and running again at the end of 2023.

Dr Jacco de Pooter (VSL) remarked that VSL has recently been involved in two MR linac projects. Up to 2018, there was an EMPIR project on absorbed dose reference dosimetry for MR linacs which was mentioned in a recent review paper. The project showed that dosimetry for MR linacs can be performed with measurement uncertainties similar to those typical for conventional EBRT. The follow-up EMPIR project on small field dosimetry for MR linacs,

which was delayed due to the Covid pandemic, finished in March 2023. It was shown that TRS-483 uncertainties can be achieved. The dosimetry formalism for MR linacs is still based on TRS-483, with additional correction factors to account for the effect of the magnetic field. The BIPM.RI(I)-K6 key comparison is still sufficient to demonstrate CMCs for MR linacs. Dr Jacco de Pooter reported that both VSL and PTB have used their calorimeters in MR linac beams, mainly on the Elekta 1.5 T MR linac. Mr Russell Thomas (NPL) remarked that NPL has set up a reference dosimetry audit, which could be used to calibrate the radiotherapy delivery system of an MRI-linac and detectors via alanine with an uncertainty comparable to that applicable to dosimetry of conventional radiotherapy. Alanine is calibrated against NPL's primary standard of absorbed dose to water in a Co-60 beam, and its sensitivity is corrected for any beam quality and magnetic field effect. This service can be provided by NPL either as a site visit or as a postal dosimetry service. Dr Jacco de Pooter reminded all attendees that it is important to use water phantoms (not solid phantoms) for MR linac dosimetry to avoid any effects on the dose measurements.

Mr Russell Thomas (NPL) reported on NPL's recent involvement in the EMPIR project UHDpulse which finished in February 2023. Dr Peter Peier (METAS) remarked that UHD pulses used for FLASH are currently a hot topic. Ionisation chambers can be used for FLASH dosimetry provided they have been properly characterized. For a diamond detector which has recently been developed by PTW, it is not clear at this stage whether it can be used as a secondary instrument. METAS and PTB have carried out a comparison for FLASH electrons at the 1% level, based on Fricke dosimetry and water calorimetry, respectively. FLASH protons and VHEE (>250 MeV) were covered in the EMPIR project UHDpulse. Dr Jacco de Pooter (VSL) indicated that a proposal for a continuation of this project has been submitted to EURAMET's Metrology Partnership – Normative Call 2023. It is planned that the final version of the technical protocol will be submitted by September 2023.

Dr Malcolm McEwen (NRC) mentioned that for dosimetry in magnetic fields the effects on measurements with ionization chambers (e.g., curved trajectories, dead volumes) are now well-characterized for different types of ionization chambers. However, it was not clear whether ionization chambers were still appropriate for all applications. Dr Peter Peier responded that recently a few ionization chambers with very small collecting volumes were investigated and that they seemed to perform better than the established chamber types. Dr Ulrike Ankerhold (PTB) responded that the response of PTW diamond detectors varies considerably, even within the same batch.

Mr Russell Thomas (NPL) remarked that NPL took its proton calorimeter to the Cincinnati Children's Hospital in the USA to perform absolute absorbed dose measurements in their proton FLASH beam prior to the commencement of the FAST Forward Trial (clinical trial for FLASH protons).

Dr Ulrike Ankerhold (PTB) commented that the EMPIR project UHDpulse focused on high energy electron FLASH. However, due to issues with electron beams, two centres in Germany (Heidelberg and Dresden) would now focus on proton FLASH. Dr Claus Andersen (DTU) confirmed that clinical trials for proton FLASH have also started in Denmark. Mr Russell Thomas added that NPL has recently built a new calorimeter for reference dosimetry with ultra-high pulse dose rates. FLASH beams are good for performing calorimetry because the short irradiation times do not lead to heat transfer issues. Dr In Jung Kim (KRISS) remarked that KRISS has performed FLASH dosimetry for an IBA proton source using alanine dosimetry based on Co-60. Graphite calorimetry is also planned at KRISS. Dr Malcolm McEwen mentioned that there are currently no activities on FLASH dosimetry in the SIM region. However, the AAPM has set up a new task group (TG359) on FLASH dosimetry.

Mr Russell Thomas stated that CCRI(I) should consider helping with pre-clinical dosimetry in kV x-ray small fields used in small animal irradiators. The main issue at the moment seems to be the reproducibility of measurements with differences up to 40%. Dr Malcolm McEwen (NRC) added that the small animal irradiators are usually operated by radiobiologists with no dosimetry experience. Dr Steven Kry (IROC-Houston) mentioned that AAPM is involved in this area, although currently there is no protocol and users rely on the manufacturer's data. It

was noted that working with small animal irradiators often requires collaboration between radiobiologists and dosimetrists.

Dr Claus Andersen (DTU) mentioned some work on blood irradiators. For the dosimetry measurements, DTU has used alanine dosimeters. Dr Malcolm McEwen highlighted that more work is still needed to characterize the energy response of alanine at low energies. Dr Thorsten Sander (NPL) mentioned that NPL measured the energy response of alanine to low energy x-rays at the Diamond Light Source synchrotron over the range 8 – 20 keV as part of the EMPIR project PRISM-eBT. Dr Brendan Healy (ARPANSA) remarked that ARPANSA has used a synchrotron facility to characterize the PTW PinPoint ionization chamber for FLASH work with a dose rate of 6000 Gy s^{-1}.

Report of the CCRI RTQI WG (Brian E. Zimmerman)

Dr Brian E. Zimmerman (NIST) presented on the CCRI Radionuclide Therapy and Quantitative Imaging Working Group (RTQI WG), of which he is the chair. The main objective of current radionuclide therapy treatment planning and validation is to derive a response relation between the radioactivity measurement at injection (realizing the units Bq or Bq/mL) and the absorbed dose delivered to the region of interest within the body. One significant main challenge is that the dose from the radionuclides is delivered at very short distances (a few microns). Dr Brian Zimmerman showed a list of radionuclides of interest for PET and SPECT imaging, and α- and β-emitters for therapy.

The RTQI WG was formed in late 2019 with the aim of enabling the CCRI to identify where radionuclide dosimetry can improve the effectiveness of radiopharmaceutical therapy (RTP). Up to now, four virtual meetings and three webinars have been held. The working group has also started interacting with professional societies and other partners to encourage collaboration between metrologists and RPT practitioners. Work on a Good Practice Guide on 'Traceability and Establishment of Secondary Standards Laboratories' is in progress. Work on a Good Practice Guide on 'Measurement Issues Associated with Targeted Alpha Therapy' will be starting mid-2024. A workshop on radionuclide metrology for α-emitter therapy is planned at the BIPM around the beginning of 2024.

A discussion period followed:

Dr Paula Toroi (STUK) asked if the aim is that the SSDLs deliver the calibration services for radiopharmaceutical therapy (RPT). Dr Brian Zimmerman responded that individual countries would have to decide who will be involved in the work.

Dr Claus Andersen (DTU) asked whether anyone has measured dose directly for RPT, or whether the usual procedure would be to convert from activity to dose. Dr Brian Zimmerman responded that this was exactly the issue, finding a way to validate that the MC simulations based on radioactivity measurements are correct. Dr Claus Andersen responded that we might need a definition of dose for RPT applications. Dr Brian Zimmerman pointed out that the quantity of interest needs to be defined – is it the number of DNA strand breaks or the energy delivered at the nanometre scale? Dr Néstor Cornejo Díaz (CIEMAT) highlighted that this would be difficult to decide because of the inhomogeneous target volumes. Dr Paula Toroi (STUK) emphasized that we should initially focus on good activity measurements and then start work on the conversion to dose. Dr Malcolm McEwen (NRC) mentioned that we might need more validation of Monte Carlo codes for radionuclide therapy applications. For validations over small distances, quantum effects might have to be taken into account for MC simulations.

Miscellaneous - radiation therapy

Dr Malcolm McEwen (NRC) asked if there were any other questions. Ms Samia Mohamed (FANR) stated that FANR intended to install a Co-60 source and asked for advice on any other facilities that would be needed in calibration laboratories. Dr Malcolm McEwen responded that

it would be good to have a Co-60 source for MV x-ray applications. Other facilities would depend on the medical physicists' requirements at the national level.

Dr Mauro Carrara (IAEA) pointed out that the new IAEA International Code of Practice for Brachytherapy is going to recommend the use of well-type ionization chambers for source dosimetry. Calibration laboratories would usually only have access to specific types of brachytherapy sources for the calibration of the users' well-type chambers. If the hospital uses a different source type (but same radionuclide), a source model correction factor should be applied to account for any difference in the well-chamber response due to different source geometries. This formalism in the new Brachytherapy CoP would be similar to the k_Q factor used for external beam radiotherapy (EBRT).

Dosimetry for diagnostic radiology

Dr Paula Toroi (STUK) presented on two normative European Partnership for Metrology (EPM, EURAMET) projects which started on 1 June 2023 and will be led by STUK.

The TraMeXI project (EPM 22NRM01) will be dealing with traceability in medical x-ray imaging dosimetry, where the four main challenges are: 1) the establishment of suitable RQ radiation qualities to cover IEC 61267 and IAEA TRS457; 2) dosimeter performance as specified in IEC 61674 and IAEA TRS457; 3) dosimetric instruments used for non-invasive measurement of x-ray tube voltage in diagnostic radiology; 4) lack of traceability in clinical x-ray measurements.

The GuideRadPROS project (EPM 22NRM07) will be dealing with the harmonization, update and implementation of standards related to radiation protection dosimeters for photon radiation. This project will also assess the impact of ICRU Report 95 on the measurement of operational quantities.

A discussion period followed:

Dr Olivera Ciraj-Bjelac (IAEA) remarked that for diagnostic radiology applications, there seems to be only one company left that manufactures ionization chambers. Semiconductor-based kV_p-meters are used instead. Manufacturers and suppliers use clinical x-ray beams (traceable to PTB) to calibrate kV_p-meters. The issue is that SSDLs cannot carry out kV_p-meter calibrations because they would normally use industrial x-ray sets. Dr Massimo Pinto (ENEA) stated that EURAMET and IAEA are involved in this area and asked whether any other RMOs were involved in this work. No additional activity was indicated.

Dr Malcolm McEwen (NRC) mentioned that quite often manufacturers develop new detectors and then pass on the problem of traceable calibration to the NMI community. Dr Paula Toroi (STUK) remarked that this would not only be an issue for diagnostic radiology but also other areas, e.g., electronic brachytherapy. Dr Jacco de Pooter (VSL) suggested that the characterization of new detectors and the development of traceable calibration methods should ideally be funded by the manufacturers. Dr Malcolm McEwen highlighted that international organizations (e.g., IAEA) might also have to be involved. Dr Paula Toroi remarked that STUK is happy to use the manufacturer's calibration certificate if the calibration is traceable. Dr Olivera Ciraj-Bjelac mentioned that suppliers of kV_p-meters usually provide test reports but no calibration certificates, so there would be no traceability. Dr Néstor Cornejo Díaz (CIEMAT) pointed out that manufacturers' calibration certificates for measurement instruments might not satisfy ISO17025 requirements. Dr Ulrike Ankerhold (PTB) remarked that, in Germany, dosimeters for diagnostic and radiation protection measurements must satisfy IEC requirements. Dr Anna Villevalde (VNIIM) confirmed that this is also the case in Russia. Dr Duncan Butler (ARPANSA) stated that in the APMP region there is plenty of interest in diagnostic radiology. ARPANSA has tested the suitability of solid-state detectors as transfer instruments for diagnostic radiology. The study showed that solid-state detectors were generally not suitable and that ionization chambers should be used instead.

Mr Sibusiso Jozela (NMISA) asked if there was an opportunity for collaboration to ensure there was enough data for the two new EURAMET projects. Dr Paula Toroi (STUK) responded that ARPANSA already collaborates in the new normative projects and that STUK will organize stakeholder meetings to encourage even more collaboration. Dr Malcolm McEwen (NRC) clarified that EURAMET is not closed for external partners and collaborators. The available funding will be distributed to institutes within the European Union, but work can be done with other RMOs. Mr Sibusiso Jozela remarked that there are measurement capabilities for diagnostic radiology in South Africa, and that a collaboration with other RMOs and IAEA will be useful. Dr Paula Toroi stated that STUK has also invited hospitals as external collaborators.

Dosimetry for radiation protection

A general discussion was held on radiation protection issues:

Dr Linda Persson (SSM) asked about views on the future of microdosimetry and nanodosimetry. Dr Malcolm McEwen (NRC) responded that recently the focus has shifted towards microdosimetry.

Dr Jean-Marc Bordy (LNE-LNHB) remarked that personal dosimetry is an important area of work, e.g., for research facilities such as CERN.

Dr Massimo Pinto (ENEA) reminded all delegates that a European Metrology Network, i.e., institutes working together with stakeholders, has been established. PTB is currently leading an EMN on radiation protection. A workshop will be held in Porto (Portugal) in a few weeks. Dr Ulrike Ankerhold (PTB) highlighted that the EMNs show that the NMIs work together with stakeholders and that this would be an important objective for the European Commission.

Dr Stanislav Sandtner (SMU) mentioned that SMU has commissioned a new standard for β-radiation and asked if anyone was interested in a bilateral comparison. Masahiro Kato (NMIJ) responded that NMIJ might be interested. The recently-completeted EURAMET.RI(I)-S16 comparison could be used as the basis for a protocol.

Dr Malcolm McEwen (NRC) asked if there were any news from FANR regarding radiation protection. Ms Samia Mohamed (FANR) responded that FANR calibrates radiation protection dosimeters for nuclear power plants. There is an ongoing need for high dose rate sources to offer appropriate calibration services.

Dr Steven Kry (IROC_Houston) mentioned that dosimetry for clinical trials in the radiopharmaceutical area is challenging. Providing traceability for quantitative imaging for PET-CT would also be difficult. For electronic brachytherapy (eBT), there are metrological and clinical issues for finding appropriate dosimetry methods. The results of a recent clinical trial in the USA to find out if localized radiation would be beneficial for the treatment of early-stage breast cancer were inconclusive. Two different eBT platforms were used for the trial, which resulted in two different answers. The phase 3 trial was cancelled because there was no consensus on dosimetry. Better standards would be useful. Dr Malcolm McEwen (NRC) remarked that CCRI should check what groups would need to come together to ensure suitable comparisons.

Dosimetry for radiation processing

A general discussion was held on radiation processing issues:

Dr Malcolm McEwen (NRC) stated that dosimetry for radiation processing is only carried out by a small number of NMIs.

Dr Ronald Tosh (NIST) mentioned that a new high dose accelerator (producing 80 – 200 keV electron beams for surface sterilization) has been installed at NIST. Risø (Denmark) and NPL have already done some work on such electron beams in the past. Dr Claus Andersen (DTU)

remarked that DTU has measured the absorbed energy from low energy electrons in sterilization units. Any activities in this area were driven by ASTM-E61 and anyone interested in industrial irradiations would be welcome to join the group.

Dr Massimo Pinto (ENEA) stated that spectrometry could be implemented as an additional measurement method in the future, e.g., to investigate different unfolding methods. Anyone with an interest in spectroscopy could join a new ISO working group that has recently been set up. Dr Vladimír Sochor (CMI) indicated interested in joining the group.

The growing role of simulation methods

Dr Malcolm McEwen (NRC) proposed an *ad hoc* post-meeting working group that should be set up to discuss any simulation methods that might have to be developed in the future.

6.2 Input from RMOs: AFRIMETS, APMP, COOMET, EURAMET, GULFMET, SIM

GULFMET: Ms Samia Mohamed (FANR) reported that a supplementary comparison for neutrons was planned for 2024.

There were no other comments from the chairs of the other RMOs.

Dr Malcolm McEwen (NRC) reminded all delegates to read the 2021 – 2023 progress reports from the NMIs that have been submitted to CCRI(I) to find out what is going on elsewhere.

6.3 Input from institutional stakeholders

This was already covered in previous sections.

6.4 Interim report of the CCRI Sources TG

Dr Malcolm McEwen (NRC) reported on the types of radioactive sources that are currently used at dosimetry laboratories. Different radioactive sources are used at PSDLs and SSDLs to deliver crucial calibration services, from Sr-90 check sources for checking the stability of ionization chambers to high activity sources like Co-60, Cs-137, Ir-192 and Am-241 for therapy and protection-level calibrations. The current issue is that for security reasons the National Nuclear Security Administration (USA) is actively seeking to eliminate as many radioactive sources worldwide as possible. If this policy was implemented completely, this would have a huge effect on the work of dosimetry laboratories. Dr Malcolm McEwen then presented pros and cons of possible alternatives to radioactive sources.

kV x-ray sources would offer the highest level of precision. The long-term stability of x-ray sources is typically around 0.1% over several years. This level of stability would be sufficient to produce reference fields. However, the main problem would be the relatively low operating voltage of typically ≤300 kV with mean photon energies of <150 keV.

Electron linacs would potentially also be an alternative to radioactive sources. Many are in use, but the energy stability usually varies by up to ±0.3% over several years which would be worse compared to x-ray sources.

For some applications, there may be calculational alternatives. Industrial irradiation plants, for instance, could be simulated using Monte Carlo techniques.

The suitability of other electrically generated irradiation platforms as an alternative to radioactive sources is currently unknown. The use of lower risk radioactive sources is limited.

Dr Malcolm McEwen concluded that the preferred option would be if, in the future, calibration laboratories could still get access to all the radioactive sources which are currently in use.

A discussion period followed:

Dr Ulrike Ankerhold (PTB) remarked that the wish for ongoing access to radioactive sources for the work in dosimetry laboratories is understandable. However, the issue would be the ever-increasing cost of high activity sources, e.g., Co-60. It might be cheaper to buy a linac instead. Dr Mauro Carrara (IAEA) pointed out that Co-60 remains the best option for providing

calibrations for countries that cannot afford linacs. Not only the cost of a new linac should be considered, but also the ongoing annual maintenance cost of approximately 10% of the original prize of the linac. Dr Jean-Marc Bordy (LNE-LNHB) remarked that medical linacs have a typical life span of only 5 – 10 years. It should also be considered that linacs produce pulsed beams as opposed to continuous beams from radioactive sources, so ion recombination needs to be considered. Dr Vladimír Sochor (CMI) was concerned about a possible lack of Co-60 sources in the future. CMI might then have to use a 6 – 10 MV industrial linac in the existing laboratory. Mr Russell Thomas (NPL) pointed out that up to now NPL has not faced any problems obtaining Co-60 sources. Dr Malcolm McEwen (NRC) asked what type of source could be used for comparisons if we would not be able to obtain high activity Co-60 sources. Dr Jean-Marc Bordy responded that an industrial linac which can produce continuous electron beams might be an alternative. Dr David Burns (BIPM) remarked that BIPM would have to consider replacing Co-60 with an alternative source if the cost of Co-60 would be considerably higher than the cost of a linac (including maintenance costs). Dr David Burns added that he expects the security requirements for Co-60 to become more stringent in the future, so BIPM might have no other option than moving away from Co-60. In that case, X-ray sources may have to be used. Dr Jacco de Pooter (VSL) asked how any future developments will be monitored. Dr Malcolm McEwen responded that it was likely a working group would be required to take the recommendations from the current task group and look into implementation.

6.5 Beyond standards and CMCs – opportunities for knowledge distribution (training, standards development, *etc*)

This was already covered in previous sections. Dr David Burns (BIPM) remarked that due to new developments in computing over the last couple of years, it could be expected that soon there will be enough computing power to replace many dosimetric measurements with simulations.

6.5.1 CCRI Communications WG report (M Pinto)

Dr Massimo Pinto (ENEA) presented on recent developments in the CCRI communications working group (COM-WG). The COM-WG was created in February 2022 with the aim to support the CCRI Executive Secretary with communication activities. There are currently 12 members.

Dr Massimo Pinto mentioned that the COM-WG set up the popular CCRI webinars during the COVID lockdowns. The webinars cover topics from all three CCRI sections and remain popular post-pandemic. 19 webinars have been run up to April 2023 and the COM-WG encourages more participation from women and young speakers. The webinar on the implementation of ICRU report 95 had the highest attendance, followed by the webinar on the ISO4037:2019 standard. Statistics on the webinars also show that stakeholders usually attend only once to learn about specific tasks (so far 1370 unique participants from a total of 2800 attendees). Participants from NMIs tend to show a greater repeat attendance. Further webinars are planned, e.g., one on FLASH and one on diagnostic radiology dosimetry. The COM-WG is also keen to cover other areas. Contributions from other RMOs are welcome and the format of the webinars is flexible. Typically, there are 1 to 5 speakers per webinar. Anyone who is interested in presenting at the webinars should contact either Dr Massimo Pinto (ENEA) or Dr Vincent Gressier (BIPM).

Dr Massimo Pinto remarked that the webinars are available at the BIPM's YouTube channel. However, the YouTube website has been blocked in some regions, so the COM-WG will consider alternative platforms.

6.6 Beyond the present – Short-term (2023-2025), medium-term (2025-2028)

Dr Vincent Gressier (BIPM) presented on the BIPM Ionizing Radiation department's 2024-2027 work plan in dosimetry. It is planned to upgrade the low-energy x-ray facility. The international reference system (SIR) for radionuclide metrology will be upgraded with a special low current device. The international transportable reference system (SIRTI) will also be

maintained as backup. Furthermore, it is planned to automate as many procedures as possible and to increase the number of secondees and collaboration with NMIs. New standards for high-energy photons and electrons will be developed. BIPM will continue to offer radionuclide services to NMIs, and dosimetry services to NMIs and the IAEA.

BIPM also proposes to set up new comparison and calibration services for high-energy electrons. Due to the rising incidence of cancer, the use of external beam radiotherapy and brachytherapy has been increasing over recent years. The use of proton therapy is also expected to increase, as well as FLASH radiotherapy using high-energy electron beams. Approximately 5% of radiotherapy treatments are currently carried out with electron beams. IAEA audits for electron beams have shown up to 30 % of doses out of tolerance, compared to less than 5 % for photon beams. ARPANSA has also reported that the spread in clinical doses is larger for MV electrons than for MV photons. NMIs and the BIPM are now responding to their stakeholders' demands for improved high-energy electron dosimetry by developing national standards. BIPM plans to build a new calorimeter standard for high-energy photons as part of the 2024-2027 work plan. It is also proposed to design this new calorimeter to extend comparison and calibration services to high-energy electrons at the off-site DOSEO facility.

Dr Vincent Gressier remarked that the planned work on the establishment of the new high-energy electron services would not be possible without secondments or NMI staff with expertise at the BIPM. Anyone with an interest in a 2-year secondment at the BIPM after 2024, to help with the establishment of the new high-energy electron services, should contact Dr Vincent Gressier.

A discussion period followed:

Mr Russell Thomas (NPL) remarked that he did a BIPM secondment a few years back to commission BIPMs new Co-60 facility and that the 2-month secondment was a good experience.

Dr Malcom McEwen reminded all attendees that the work on the new high-energy electron services would require a 2-year secondment and 20 weeks of DOSEO time for the VHEE work.

Dr Brendan Healy (ARPANSA) remarked that 4, 6 and 9 MeV electrons are used in Australia for superficial treatment. Apart from this, electron beams are not heavily used.

Mr Russell Thomas (NPL) added that the new BIPM standard would be valuable. NPL has already developed an electron standard. A few years ago, the use of electron beams declined in the UK. However, the use has increased again over recent years.

Dr Paula Toroi (STUK) remarked that she is happy with the BIPM services and asked if a new calibration service for diagnostic RQR qualities (50 – 150 kV x-rays, W-target) could be set up. Dr David Burns (BIPM) responded that this could be considered. However, he also emphasized that BIPM's work remains to be driven by the need for comparisons, not calibrations and that the current CCRI qualities were judged to be sufficient to demonstrate equivalence between NMIs. Dr Massimo Pinto (ENEA) suggested that IAEA could step in to provide calibrations. Dr Malcolm McEwen stated that worldwide not many NMIs perform diagnostic radiology calibrations.

Dr Duncan Butler (ARPANSA) also supported BIPM's plans to develop a high-energy electron standard. This would provide another route for the dosimetry of FLASH electron beams should there be issues with the availability of Co-60 sources in the future.

6.7 Long-term (2028 and beyond) – challenges, barriers, enablers

Dr Massimo Pinto (ENEA) presented on the long-term challenges (2028 and beyond) in ionizing radiation metrology. One of the tasks discussed at the CCRI(III) meeting in May 2023 was the possible need for high-energy proton and neutron facilities. Reference dosimetry for high-energy neutron metrology above 20 MeV is currently insufficient. Dedicated facilities will be needed to perform key comparisons. CCRI(III) has proposed to set up a task group on

‘Metrology for high-energy neutrons and protons’ to discuss any issues. A workshop could potentially be hosted by the BIPM. The aim of the workshop would be to discuss any future needs for traceable high-energy neutron metrology. The results of the workshop could be summarized in a document for further discussions. CCRI(III) are keen for CCRI(I) to support them.

A discussion period followed:

Mr Russell Thomas (NPL) suggested that CCRI(I) could take on the role of ‘observer’. Dr Massimo Pinto (ENEA) responded that the observer status might be an option.

Dr Jacco de Pooter (VSL) remarked that VSL will be preparing a strategic plan in 2024.

Ms Samia Mohamed (FANR) mentioned that detailed planning of the next five years is currently underway at FANR.

Dr Malcolm McEwen remarked that top-level long-term planning has started at the NRC. Different NMIs would follow their own procedures, but generally forward planning would enable other laboratories to see where any collaboration would be useful.

6.8 Synthesis and conclusions

Actions to be confirmed by CCRI(I)

1. At the joint CCRI(I)/SSDL network meeting on 31 May 2023 it was proposed that the KCWG(I) should draft a ‘How far does the light shine?’ guidance document on how to link comparisons with CMCs.

2. The BSWG(I) should be kept active to discuss any options for a brachytherapy LDR I-125 comparison and possibly an HDR Co-60 comparison.
3. *Ad hoc* post-meeting working group that should be set up to discuss any simulation methods that might have to be developed in the future.

4. A CCRI(I) WG may be required to take on the recommendations of the Radioactive Sources TG

5. COM-WG to find alternative methods to distribute CCRI files via the internet to enable worldwide access, e.g., CMC lists, archived BIPM webinars.

7. CCRI(I) membership changes

NIS (Egypt) is now a CCRI(I) member.

There were no presentations from any applicants.

8. Debrief on joint meeting with IAEA SSDL network and date of next meeting

This year, the biennial CCRI(I) meeting and the IAEA SSDL network meeting were held as a joint meeting at the IAEA in Vienna. CCRI(I) members could attend the SSDL network meeting on 29 – 30 May 2023, and also the joint CCRI(I)/SSDL meeting on 31 May 2023. The CCRI(I) meeting, which was held on 1 – 2 June 2023, was only attended by CCRI(I) members.

Dr Malcolm McEwen (NRC) thanked Dr Zakithi Msimang (IAEA) and Dr Mauro Carrara (IAEA) for organizing the meeting and asked attendees of the CCRI(I) meeting for feedback on the joint meeting. Mr Russell Thomas (NPL) responded that the SSDL part was very useful for attendees from NMIs to put their work into perspective. He also asked if some of the CCRI presentations could be made available for internal presentations to make new members of staff aware of CCRI’s objectives.

Dr Malcolm McEwen remarked that he had received comments that 5 days for all the meetings seemed to be a very long time. For online attendees, there will always be the issue with different time zones.

Dr Massimo Pinto (ENEA) asked if the joint CCRI(I)/SSDL meetings should be repeated in the future. Most attendees at the CCRI(I) meeting seemed to be happy with this proposal. The SSDL meetings are held every three years, whereas the CCRI(I) meetings are held every two years, so joint CCRI(I)/SSDL meetings could be held every six years, the next one in 2029.

9. Any other business, general discussion time

Dr Malcolm McEwen (NRC) thanked again Dr Zakithi Msimang (IAEA) and Dr Mauro Carrara (IAEA) for organizing the meeting at the IAEA. He also thanked all online participants for their contributions.

10. Adjourn