World-Wide Radiation Metrology: The BIPM, the CIPM MRA, and ICRU

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Common units are integral to any concept of equivalent measurements but for comparison purposes the choice is somewhat arbitrary and therefore not the focus here.

A brief history of the SI:

1799 – two platinum standards of the metre and kilogram deposited in the Archives de la République in Paris

1875 – Convention du Mètre signed

1889 – 1st CGPM sanctioned a three-dimensional mechanical unit system (mass-length-time)

1954 – 10th CGPM added the ampere, the kelvin and the candela as base units

1960 – SI gets its name!

1971 – mole completes present total of seven units
Convention of the Meter/Convention du Mètre

- Signed in Paris in 1875 (representatives of 17 nations)
- Established permanent organizational structure for members on all matters relating to units of measurement
- Created the BIPM – Bureau International des Poids et Mesures
  - Intergovernmental organization (now 55 Member States)
  - Under authority of General Conference on Weights and Measures (CGPM)
  - Under supervision of the International Committee for Weights and Measures (CIPM)
  - Acts in matters of world metrology (demands for increasing accuracy, range and diversity)
    - Facilitates needs to demonstrate equivalence between national measurement standards
- Remains the basis of international agreement on units of measurement
What is the CIPM MRA?

- **Mutual Recognition Arrangement**
- Paris 14 October 1999
- 40 entities originally, now 92 (plus 146 designated)
- Mutual recognition of
  - National measurement standards
  - Calibration and measurement certificates
- Structure
  - RMOs (Regional Metrology Organizations)
  - Member States
  - Associates of the CGPM
  - Designated Institutions
What are RMOs?

- Makes things a little more practical
- Fosters collaboration

Regional Metrology Organizations

APMP Members

Full Member ECO’s – 23
(MM Convention – 17)
(CIPM MLA – 29 Labs)
Designated Institutes 14
Associate Members – 5
Total 42 members
<table>
<thead>
<tr>
<th>Country</th>
<th>Institute</th>
<th>Date Signed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>INTI (CNEA designate)</td>
<td>14 Oct 1999</td>
</tr>
<tr>
<td>Bolivia*</td>
<td>IBMETRO</td>
<td>16 May 2008</td>
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<tr>
<td>Brazil</td>
<td>INMETRO (LNMRI/IRD designate)</td>
<td>14 Oct 1999</td>
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<tr>
<td>Canada</td>
<td>NRC-INMS</td>
<td>14 Oct 1999</td>
</tr>
<tr>
<td>Caribbean Community*</td>
<td>Designates in 11 countries (StKNBS)</td>
<td>12 Oct 2005</td>
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<tr>
<td>Chile</td>
<td>INN (CCEN designate)</td>
<td>18 Oct 2000</td>
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<tr>
<td>Costa Rica*, **</td>
<td>LACOMET</td>
<td>6 Oct 2004</td>
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<tr>
<td>Cuba (COOMET)*</td>
<td>NC (CENTIS and CPHR designate)</td>
<td>18 June 2001</td>
</tr>
<tr>
<td>Jamaica*</td>
<td>BSJ</td>
<td>21 July 2004</td>
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<tr>
<td>Mexico</td>
<td>CENAM (ININ designate)</td>
<td>14 Oct 1999</td>
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<tr>
<td>Panama*, **</td>
<td>CENAMEP AIP</td>
<td>16 Sept 2003</td>
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<tr>
<td>USA</td>
<td>NIST</td>
<td>14 Oct 1999</td>
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<tr>
<td>Uruguay</td>
<td>LATU (MIEM-LSMRI designate)</td>
<td>14 Oct 1999</td>
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<tr>
<td>International Organizations</td>
<td>IAEA; IRMM</td>
<td>14 Oct 1999</td>
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*Associate of the CGPM    **Anticipating designating
<table>
<thead>
<tr>
<th>Country</th>
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<th>Field</th>
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<tbody>
<tr>
<td>Argentina</td>
<td>CNEA</td>
<td>Dosimetry, Radioactivity</td>
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<tr>
<td>Brazil</td>
<td>LNMRI/IRD</td>
<td>Dosimetry, Radioactivity, Neutron measurements</td>
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<tr>
<td>Canada</td>
<td>NRC-INMS</td>
<td>Dosimetry, Radioactivity, Neutron measurements</td>
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<tr>
<td>Chile</td>
<td>CCHEN</td>
<td>Dosimetry, Radioactivity (under development)</td>
</tr>
<tr>
<td>Mexico</td>
<td>ININ</td>
<td>Dosimetry, Radioactivity, Neutron measurements</td>
</tr>
<tr>
<td>St. Kitts and Nevis</td>
<td>StKNBS</td>
<td>Dosimetry (under development)</td>
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<tr>
<td>Uruguay</td>
<td>MIEM-LSMRI</td>
<td>Dosimetry</td>
</tr>
<tr>
<td>USA</td>
<td>NIST</td>
<td>Dosimetry, Radioactivity, Neutron measurements</td>
</tr>
</tbody>
</table>
What does the CIPM MRA do?

- It simplifies the process by which one country recognizes the standards of another.
- Removes barriers to trade - previously calibration certificates issued by one country (e.g. where the device was manufactured) were not valid in another.
- This resulted in endless negotiation of bilateral agreements.
- Note it’s an arrangement, not an agreement, although it does have legal standing.
In Ionizing Radiation BIPM does the following:

- Establish and run comparisons,
- Maintain and develop the SIR (for radioactivity)
- Publish monographs on nuclear data and special issues of Metrologia
- Contribute to conferences, meetings
- Publish in scientific journals
- Transfer knowledge to NMI-staff (workshops and conferences at BIPM)
Consultative committees are the primary forum for discussing progress on primary standards and determining future directions (for NMIs and BIPM)

- Established in 1958 as CCEMRI (CCRI in 1997)
- 3 distinct sections – dosimetry, radioactivity, neutrons
- Activities
  - Definitions of quantities and units
  - Standards for x-ray, γ-ray, charged particle and neutron dosimetry
  - Radioactivity measurement and SIR
  - Advice to CIPM regarding IR standards and BIPM activities
  - Input to CCRI Strategy
MRA is mediated by the CMC gauge boson

- In 2008, BIPM, ILAC and RMOs agreed to a clarified, common, annotated definition:

  “A CMC is a calibration and measurement capability available to customers under normal conditions (a) as published in the BIPM key comparison database (KCDB) of the CIPM MRA; or (b) as described in the laboratory’s scope of accreditation granted by a signatory to the ILAC arrangement”
• A CMC is the formal ‘proof’ that a National Measurement Laboratory can carry out a particular measurement

• Comprises two components:

  1. Participation in a recognized comparison of a measurement standard with one or more other national standards

  2. Demonstration of an internationally recognized quality system for the dissemination of the standard
There are various ways to compare and demonstrate equivalency.
Components required:

1. An agreed comparison methodology to be used by each institution involved
   
   This is usually approved by the BIPM CC

2. Something to reliably transfer measurements from one location to another
   
   Will depend on methodology – ‘star’, ‘linear’, ‘single facility’

3. A consistent approach to estimating uncertainties
   
   The ISO GUM (JCGM 100) is the starting point

4. A stable comparison reference value (KCRV) to determine variations between participants
   
   Essential as comparisons often take several years to complete

Agreement with KCRV within stated (agreed) uncertainties = equivalency
Let's look at some real comparisons within ionizing radiation.
Currently, 43 comparisons in x and gamma rays, and electrons measurements (dosimetry) are listed in the Key Comparison Database (KCDB; Appendix B) [1]

Comparisons include:
- SIM, EURAMET, COOMET, APMP, CCRI(I), BIPM

Steps of a comparison are:
- Planned, in progress, measurements complete, Draft B, approved/published, equivalence
## Dosimetry Comparisons

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Quantity</th>
<th>Energy</th>
<th>Year</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIPM.RI(I)-K1</td>
<td>Air kerma</td>
<td>Co-60</td>
<td>Ongoing</td>
<td></td>
</tr>
<tr>
<td>BIPM.RI(I)-K2</td>
<td>Air kerma</td>
<td>10-50 keV</td>
<td>Ongoing</td>
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<tr>
<td>BIPM.RI(I)-K3</td>
<td>Air kerma</td>
<td>50-250 keV</td>
<td>Ongoing</td>
<td></td>
</tr>
<tr>
<td>BIPM.RI(I)-K4</td>
<td>Absorbed dose to water</td>
<td>Co-60</td>
<td>Ongoing</td>
<td></td>
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<tr>
<td>BIPM.RI(I)-K5</td>
<td>Air kerma</td>
<td>Cs-137</td>
<td>Ongoing</td>
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<tr>
<td>BIPM.RI(I)-K6</td>
<td>Absorbed dose to water</td>
<td>4-25 MV (linac photons)</td>
<td>Ongoing</td>
<td>First round to be completed 2019</td>
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<tr>
<td>BIPM.RI(I)-K7</td>
<td>Air kerma</td>
<td>mammography</td>
<td>Ongoing</td>
<td></td>
</tr>
<tr>
<td>BIPM.RI(I)-K8</td>
<td>RAKR (air kerma strength)</td>
<td>Ir-192 HDR</td>
<td>Ongoing</td>
<td>HDR only for first round, LDR to follow as standards are developed</td>
</tr>
<tr>
<td>BIPM.RI(I)-K9</td>
<td>Absorbed dose to water</td>
<td>50-250 keV</td>
<td>Under development</td>
<td>First bilateral comparison carried in 2016</td>
</tr>
<tr>
<td>BIPM.RI(I)-K?</td>
<td>Absorbed dose to water</td>
<td>4-25 MeV (linac electrons)</td>
<td>Under development</td>
<td>Trial comparison carried out between NPL, NRC and METAS</td>
</tr>
</tbody>
</table>
Dosimetry Comparisons – BIPM.RI(I)-K4

Co-60 absorbed dose to water

Fundamental to nearly all linac-based dose delivery worldwide

Key and supplementary comparisons - Results

<table>
<thead>
<tr>
<th>BIPM.RI(I)-K4</th>
<th>Equivalent statements</th>
<th>Degrees of equivalence</th>
<th>Graph(s) of equivalence</th>
</tr>
</thead>
</table>

Results

Laboratory individual measurements

BIPM.RI(I)-K4, SIM.RI(I)-K4, and EUROMET.RI(I)-K4

MEASURAND: Absorbed dose to water

Degrees of equivalence, $D_i$ and expanded uncertainty $U_i$ ($k = 2$), expressed in mGy/Gy.

Red diamonds: participants in BIPM.RI(I)-K4
Black squares: BIPM.RI(I)-K4 participants’ results that are more than ten years old
Blue triangle: participant in SIM.RI(I)-K4
Green circles: participants in EUROMET.RI(I)-K4
BIPM primary standard for clinical accelerator dosimetry

No linac beams at BIPM, so a travelling comparison was developed based on a transportable graphite calorimeter.

First comparison was carried out at NRC in 2009.

Newly built VSL water calorimeter mounted on the NPL linac couch.
For dosimetry comparisons, CCRI(I) adopted the position that the BIPM result would be the KCRV (key comparison reference value).

This is not the same as being the ‘correct’ answer!

But it’s much simpler to interpret inter-laboratory differences than if some mean was used.

First round of labs with primary absorbed dose standards due to be completed in 2019.
Ir-192 HDR air kerma

This requires another BIPM travelling standard, but simpler than for linac beams – just need to take two ion chambers (thimble, well)
**Dosimetry Comparisons – BIPM-RI(I)-K8**

Good consistency seen with first four labs

<table>
<thead>
<tr>
<th>Country</th>
<th>Result/Average</th>
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<tr>
<td>NL</td>
<td>0.980</td>
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<tr>
<td>UK</td>
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<tr>
<td>GER</td>
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<tr>
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Summary

- Measurement traceability enables international trade
- World-wide metrology supports legal and regulatory aims
- “Mutual Recognition” and “Equivalency” allow comparability within stated uncertainties
- Comparisons provide basis of analysis and confidence to customers
- International approach brings robustness and validity to measurements
- BIPM and the CIPM MRA provide the framework