Electrical Metrology Projects

Objectives

The electricity laboratories of the BIPM provide the following services to the NMIs of Member States:

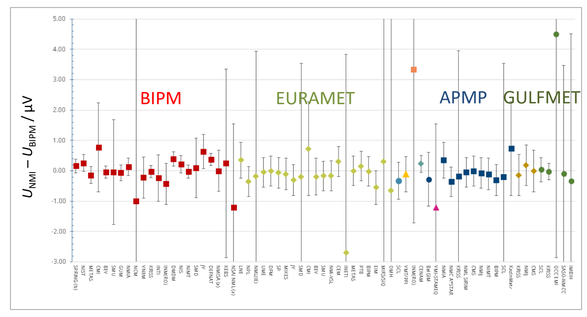
- **Organization of comparisons of primary standards to support the CIPM MRA**
- **Calibrations of secondary standards to support NMIs without quantum standards**

In addition, the electricity laboratories are involved in development activities focused on an improved realization of the units.

Organization of comparisons to support the CIPM MRA

In the field of electricity, the BIPM carries out five ongoing bilateral key comparisons on a continuous basis. They allow NMIs to demonstrate their measurement capabilities and to evaluate their equivalence:

- **dc voltage:** - Josephson quantum voltage standards, on-site
  - Zener voltage standards, 1.018 V and 10 V
- **resistance:** - quantum Hall resistance standards, on-site
  - resistance standards, 1 Ω and 10 kΩ
- **capacitance:** - capacitance standards, 10 pF and 100 pF



BIPM.EM-K11: Comparison of calibrations of Zener voltage standards at 10 V, linked to several RMO comparisons

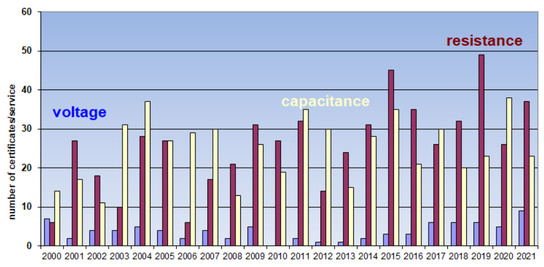
Occasionally the BIPM organizes CCEM comparisons (CCEM-K4, capacitance)

and participates in RMO comparisons (GULFMET.EM.BIPM-K11 , APMP.EM.BIPM-K11.3, voltage)

Calibrations, supporting NMIs without quantum standards

The electricity laboratories provide the following calibration services to Member States:

- **voltage: 1.018 V and 10 V**
- **resistance: 1 Ω, 100 Ω and 10 kΩ**
- **capacitance: 1 pF, 10 pF and 100 pF**



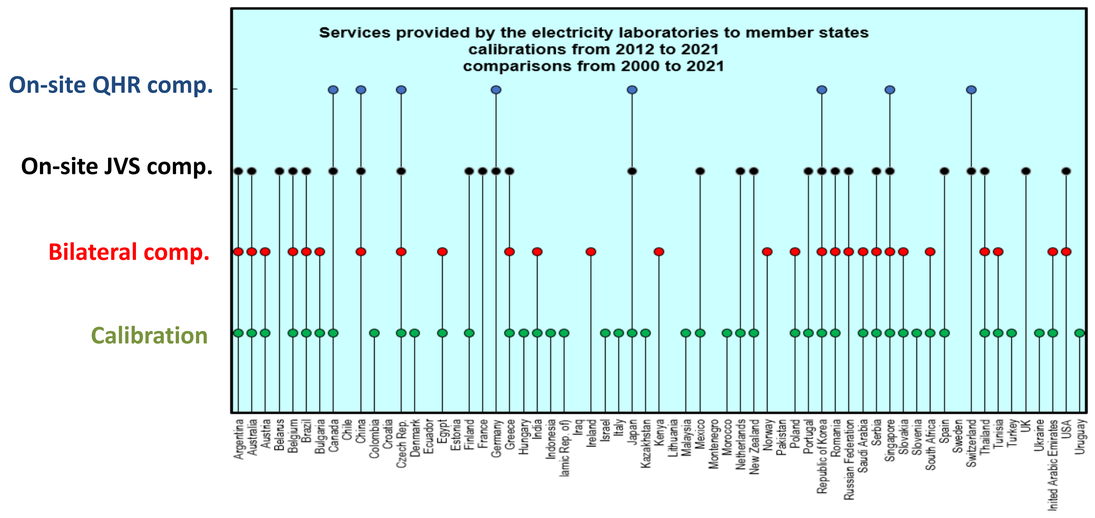
On average, the department provides about 70 calibration certificates per year.

Zener voltage standard

Standard resistor

Standard capacitor

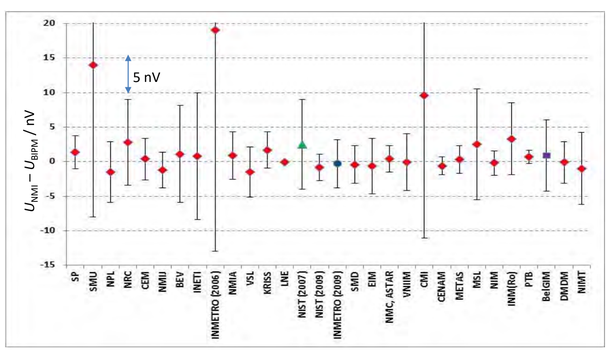
Users of the BIPM technical services in Electricity



86 % of the Member States have been served

On-site Josephson voltage standard comparisons (BIPM.EM-K10)

To verify international coherence of primary dc (direct current) voltage standards by comparing Josephson-effect-based standards of the NMIs with that of the BIPM.



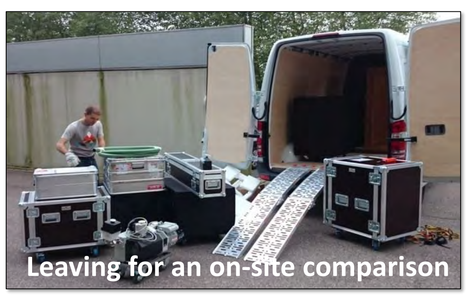
BIPM.EM-K10.b: comparison of Josephson voltage standards at 10 V

A future comparison of ac (alternating current) Josephson voltage standards is being prepared with active support from

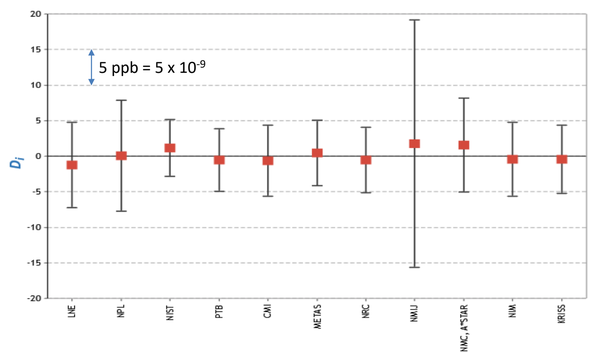
- **NIST** (USA): programmable Josephson voltage standard
- **KRISS** (Republic of Korea): guest scientist for 15 months
- **CENAM** (Mexico), **NMIJ** (Japan), **PTB** (Germany), **NPL** (UK): trial comparisons
- **VTT** (Finland), **NMIA** (Australia), **VNIIM** (Russia): instrumentation

On-site quantum Hall resistance standard comparisons (BIPM.EM-K12)

To verify international coherence of primary resistance standards by comparing quantum-Hall-effect-based standards of the NMIs with that of the BIPM.



Comparison of calibrations of a 100 Ohm resistor against the quantum Hall standard



$D_i \equiv$ Relative difference between the result of measurement of laboratory *i* and that of the BIPM in parts in 10^9

Calculable cross capacitor: Primary capacitance standard, to verify the theoretical basis of the "quantum ohm"

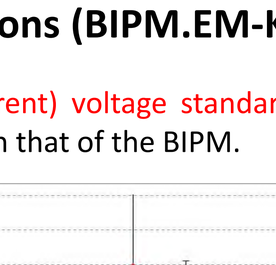
- Test of the relationship

$$R_K = h / e^2$$

basis for the realization of the ohm in the revised SI:

comparison of the SI "quantum" ohm with the ohm realized from the farad

- Primary capacitance standard



Quantum standard

Quantum Hall effect

(magn. field $B \approx 10$ tesla, $T < 1$ K)

$R_{hall} = R_K / i$ (i = 1,2,4…)

$R_K = h / e^2 \approx 25.8$ kΩ

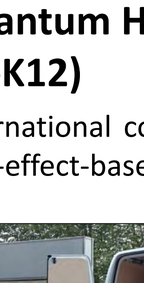
for i = 2 plateau: $R \approx 13$ kΩ

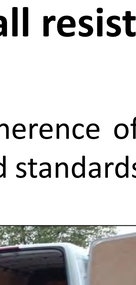
Classical standard

Calculable capacitor

$$\Delta C = \epsilon_0 \frac{ln2}{\pi} \Delta l$$

for $\Delta l \approx 0.2$ m: $\Delta C \approx 0.4$ pF





BIPM calculable capacitor

Investigation of graphene quantum Hall resistance standards

The objective is to take advantage of the most recent progress on graphene-based QHRs (quantization for low magnetic field and high temperature, typically B < 4 T and T = 4.2 K) to design and implement a new compact QHR system at the BIPM:

- being easily transportable and allowing reduced operation costs (for on-site comparisons),
- integrable in a cryogen-free system (for usual operation at BIPM - no liquid He consumption)

Graphene QHR samples based on NIST and PTB technology