New Digital Services from the BIPM

Dr Martin Milton
The BIPM - Bureau international des poids et mesures

The Metre Convention was signed in Paris by 17 nations on 20 May 1875 "to assure the international unification and perfection of the metric system"
The BIPM

... is the intergovernmental organization established by the Metre Convention in 1875, through which Member States act together on matters related to measurement science and measurement standards.
Members and Associates (May 2023)

- 64 Member States* and
- 36 Associates of the CGPM
  (States and Economies)

* The official term is "States Parties to the Metre Convention"; the term "Member States" is its synonym and used for easy reference.
**Members and Associates (May 2023)**

- **64 Member States** and
- **36 Associates of the CGPM**
  
  *(States and Economies)*

*The official term is "States Parties to the Metre Convention"; the term "Member States" is its synonym and used for easy reference.*

---

**251 Institutes participating in the CIPM MRA**

- 97 National Metrology Institutes + 3 Ministries
  - 64 Member States
  - 36 Associates
- 4 International organizations
  - (ESA, IAEA, JRC, WMO)
- plus 150 Designated Institutes
- 64 Member States* and
- 36 Associates of the CGPM
  (States and Economies)

* The official term is "States Parties to the Metre Convention"; the term "Member States" is its synonym and used for easy reference.

251 Institutes participating in the CIPM MRA
- 97 National Metrology Institutes + 3 Ministries
  - 64 Member States
  - 36 Associates
- 4 International organizations
  (ESA, IAEA, JRC, WMO)
- plus 150 Designated Institutes
The BIPM – main technical roles.

**Travelling standards**
Maintains travelling standards to compare fixed national references *e.g.*, Josephson Junctions for the volt, Quantum Hall devices for the ohm, etc.

**Coordinated Universal Time**
Realizes and disseminates Coordinated Universal Time (UTC) based on weighted averages of ~500 clocks from over 80 national laboratories world-wide.

**kilogram**
Ensures metrological traceability of mass measurements based on the new definition of the kilogram in terms of a physical constant.

**Coordinate comparisons**
Organizes comparisons for physical and chemical quantities world-wide.

**Unique world reference facilities**
Maintains unique world reference facilities *e.g.*, SIR (ionizing radiation and isotopes), ozone spectrophotometers.
The BIPM works to foster cooperation with international organizations and promotes the world-wide comparability of measurements.
The Joint Statement

"On the digital transformation in the international scientific and quality infrastructure"

Digital Transformation
Joint Statement of Intent On the digital transformation in the international scientific and quality infrastructure

Joint Statement of Intent
On the digital transformation in the international scientific and quality infrastructure

We the undersigned undertake to support in a way appropriate to each organisation the development, implementation, and promotion of the SI Digital Framework as part of a wider digital transformation of the international scientific and quality infrastructure.

The Joint Statement
"On the digital transformation in the international scientific and quality infrastructure"
A brief history of the SI

The 26th CGPM agreed to change the definitions of:
- kilogram
- ampere
- kelvin
- mole

1960
The name adopted by the 11th CGPM in 1960 for the system with 6 base units.
- kilogram
- second
- metre
- ampere
- kelvin
- candela

1967
The second was redefined – the atomic second

1972
The mole was introduced – to provide a unit for chemistry

1979
The candela – redefined as monochromatic radiation

1983
The meter was redefined – the first fundamental constant

1990
Conventions for the volt and the ohm adopted

2018
The International Temperature Scale (ITS90) was adopted
The International System of Units (SI)

Prefixes

Table 5. SI prefixes

<table>
<thead>
<tr>
<th>Factor</th>
<th>Name</th>
<th>Symbol</th>
<th>Factor</th>
<th>Name</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>10⁻¹²</td>
<td>deca</td>
<td>da</td>
<td>10⁻⁸</td>
<td>deci</td>
<td>d</td>
</tr>
<tr>
<td>10⁻¹⁰</td>
<td>hecto</td>
<td>h</td>
<td>10⁻⁶</td>
<td>centi</td>
<td>c</td>
</tr>
<tr>
<td>10⁻⁸</td>
<td>kilo</td>
<td>k</td>
<td>10⁻⁴</td>
<td>milli</td>
<td>m</td>
</tr>
<tr>
<td>10⁻⁶</td>
<td>mega</td>
<td>M</td>
<td>10⁻²</td>
<td>micro</td>
<td>μ</td>
</tr>
<tr>
<td>10⁻⁴</td>
<td>giga</td>
<td>G</td>
<td>10⁻¹</td>
<td>nano</td>
<td>n</td>
</tr>
<tr>
<td>10⁻¹</td>
<td>tera</td>
<td>T</td>
<td>10⁻³</td>
<td>pico</td>
<td>p</td>
</tr>
<tr>
<td>10⁻³</td>
<td>peta</td>
<td>P</td>
<td>10⁻²</td>
<td>femto</td>
<td>f</td>
</tr>
<tr>
<td>10⁻²</td>
<td>exa</td>
<td>E</td>
<td>10⁻¹</td>
<td>atto</td>
<td>a</td>
</tr>
<tr>
<td>10⁻¹</td>
<td>zetta</td>
<td>Z</td>
<td>10⁰</td>
<td>zepto</td>
<td>z</td>
</tr>
<tr>
<td>10⁰</td>
<td>yotta</td>
<td>Y</td>
<td></td>
<td>yotto</td>
<td>y</td>
</tr>
</tbody>
</table>

Base units

Table 1. SI base units

<table>
<thead>
<tr>
<th>Base quantity</th>
<th>SI base unit</th>
<th>Name</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>metre</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>mass</td>
<td>kilogram</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>time, duration</td>
<td>second</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>electric current</td>
<td>ampere</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>thermodynamic temperature</td>
<td>kelvin</td>
<td>K</td>
<td></td>
</tr>
<tr>
<td>amount of substance</td>
<td>mole</td>
<td>mol</td>
<td></td>
</tr>
<tr>
<td>luminous intensity</td>
<td>candela</td>
<td>cd</td>
<td></td>
</tr>
</tbody>
</table>

Derived units

Table 3. Coherent derived units in the SI with special names and symbols

<table>
<thead>
<tr>
<th>Derived quantity</th>
<th>SI coherent derived unit (SI)</th>
<th>Expressed in terms of other SI units</th>
<th>Expressed in terms of base units</th>
</tr>
</thead>
<tbody>
<tr>
<td>plane angle</td>
<td>radian</td>
<td>rad</td>
<td>m⁻¹</td>
</tr>
<tr>
<td>solid angle</td>
<td>steradian</td>
<td>sr</td>
<td>m⁻¹</td>
</tr>
<tr>
<td>frequency</td>
<td>hertz</td>
<td>Hz</td>
<td>s⁻¹</td>
</tr>
<tr>
<td>force</td>
<td>newton</td>
<td>N</td>
<td>kg m s⁻²</td>
</tr>
<tr>
<td>pressure, stress</td>
<td>pascal</td>
<td>Pa</td>
<td>N m⁻²</td>
</tr>
<tr>
<td>energy, work</td>
<td>joule</td>
<td>J</td>
<td>N m</td>
</tr>
<tr>
<td>amount of heat</td>
<td>watt</td>
<td>W</td>
<td>kg m² s⁻³</td>
</tr>
<tr>
<td>power, radiant flux</td>
<td>electric charge</td>
<td>watt</td>
<td>W s⁻¹</td>
</tr>
<tr>
<td>electric potential difference, electromotive force</td>
<td>volt</td>
<td>V s⁻¹</td>
<td></td>
</tr>
<tr>
<td>capacitance</td>
<td>farad</td>
<td>F</td>
<td>C m⁻²</td>
</tr>
<tr>
<td>electric resistance</td>
<td>ohm</td>
<td>Ω</td>
<td>V m⁻²</td>
</tr>
<tr>
<td>electric conductance</td>
<td>siemens</td>
<td>S</td>
<td>A m⁻¹</td>
</tr>
<tr>
<td>magnetic flux</td>
<td>weber</td>
<td>Wb</td>
<td>V m⁻¹</td>
</tr>
<tr>
<td>magnetic flux density</td>
<td>tesla</td>
<td>T</td>
<td>Wb m⁻²</td>
</tr>
<tr>
<td>inductance</td>
<td>henry</td>
<td>H</td>
<td>Wb m⁻¹</td>
</tr>
<tr>
<td>Celsius temperature</td>
<td>degree Celsius</td>
<td>°C</td>
<td>K</td>
</tr>
<tr>
<td>luminous flux</td>
<td>lumens</td>
<td>lm</td>
<td>cd m⁻²</td>
</tr>
<tr>
<td>illuminance</td>
<td>lux</td>
<td>lx</td>
<td>lm m⁻²</td>
</tr>
<tr>
<td>activity referred to a radionuclide</td>
<td>bequerel</td>
<td>Bq</td>
<td>s⁻¹</td>
</tr>
<tr>
<td>absorbed dose, specific energy (implied)</td>
<td>joule</td>
<td>J kg⁻¹</td>
<td></td>
</tr>
<tr>
<td>dose equivalent</td>
<td>sievert</td>
<td>Sv</td>
<td>J kg⁻¹</td>
</tr>
<tr>
<td>ambient dose equivalent</td>
<td>rad</td>
<td>rad</td>
<td>m² s⁻¹</td>
</tr>
<tr>
<td>directional dose equivalent</td>
<td>rad</td>
<td>rad</td>
<td>m² s⁻¹</td>
</tr>
<tr>
<td>personal dose equivalent</td>
<td>rad</td>
<td>rad</td>
<td>m² s⁻¹</td>
</tr>
<tr>
<td>catalytic activity</td>
<td>kat</td>
<td>kat</td>
<td>s⁻¹ mol</td>
</tr>
</tbody>
</table>
Resolution 2
“On the global digital transformation and International System of Units”

Encourages

the CIPM to undertake the development and promotion of an SI Digital Framework, that will include the following features:

• a globally accepted digital representation of the SI, compatible with, and useable within, digital data exchange standards and protocols, whilst maintaining compatibility with existing non-digital solutions,

• facilitating use of digital certificates in the existing robust infrastructure for the world-wide recognition and acceptance of calibration and measurement capabilities,

• the adoption of the FAIR principles (Findable, Accessible, Interoperable, and Reusable) for digital metrological data and metadata, ensuring that other communities recognize the critical importance of metrological traceability for measurement data, the latter being an established requisite for building trust.

https://www.bipm.org/en/committees/cg/cgpm
the SI Digital Framework

Being developed by the CIPM with three layers:

1. **SI core representation**, defined by CIPM: Metadata models and exchange format implementations for basic data elements comprising values, units and uncertainty of a quantity based on the BIPM SI Brochure.

2. **Services**, implemented by the NMIs, BIPM and related organizations: Open data formats and software tools and services that build upon the SI core representation. Such services enable data to be ready for analysis, improve data quality and reliability, facilitate life-cycle analysis, communicate that data is fit for purpose, and improve data transparency.

3. **Applications**, developed and deployed in the broader metrology community and in research disciplines that rely upon the SI: Tools and services can be utilized in domain-specific applications, including sophisticated analysis and AI/ML methods, and, through layering on the SI core representation, assure reliability and traceability.
The CIPM Vision for
“Transforming the International System of Units for a Digital World”

**Vision for SI Digital Framework**
- the network of tools, services, and applications that instantiate the Digital SI
- assures that measurements are FAIR, machine-readable, machine-actionable, and support digital metrological traceability.

The **SI Digital Framework** is coordinated by CIPM and consists broadly of three layers:

**SI core representation and core data services**
defined by CIPM and implemented by the BIPM: Metadata models and digital references for measurement data elements, including values, units, types of quantities, uncertainty, and metrological traceability.

**Data services**
provided by the NMIs and related organizations: Open data formats, software tools, and services that build upon the SI core representation and core data services. Such services enable data to be ready for analysis, improve data quality and reliability, facilitate life-cycle analysis, communicate that data is fit for purpose, and improve data transparency.

**Applications**
developed and deployed in the broader metrology community and in research disciplines that rely upon the SI: Tools and services can be utilized in domain-specific applications, including sophisticated analysis and AI/ML methods, and, through layering on the SI core representation, assure reliability and metrological traceability.

*Decision CIPM/112-12 (2023)*
The **SI Digital Framework** provides a fully digital representation of the SI

- Provide the globally accepted anchor of trust for metrology in the digital era
- Facilitate the use of digital certificates and the adoption of the FAIR principles
The **SI Digital Framework** provides a fully digital representation of the SI

- Provide the globally accepted anchor of trust for metrology in the digital era
- Facilitate the use of digital certificates and the adoption of the FAIR principles

The **SI Digital Framework** provides a fully digital representation of the SI

- Provide the globally accepted anchor of trust for metrology in the digital era
- Facilitate the use of digital certificates and the adoption of the FAIR principles

The **SI Digital Framework** provides a fully digital representation of the SI

- Provide the globally accepted anchor of trust for metrology in the digital era
- Facilitate the use of digital certificates and the adoption of the FAIR principles
The **SI Digital Framework** provides a fully digital representation of the SI

- Provide the globally accepted anchor of trust for metrology in the digital era
- Facilitate the use of digital certificates and the adoption of the FAIR principles
The **SI Digital Framework** provides a fully digital representation of the SI

What are **digital references**?

- A persistent identifier (PI or PID) is a long-lasting reference to a document, file, web page, or other object.
- You can plug it into a web browser and be taken to the identified source.

---

### Barcodes

**eg DOIs**

10.1088/1681-7575/aca67a

---

### QR codes

**eg ORCID iDs**

[https://orcid.org/0009-0004-0902-417X](https://orcid.org/0009-0004-0902-417X)

[https://orcid.org/0000-0002-2317-3436](https://orcid.org/0000-0002-2317-3436)
The SI Digital Framework provides a fully digital representation of the SI

• To provide the globally accepted anchor of trust for metrology in the digital era
• Facilitate the use of digital certificates and the adoption of the FAIR principles

Digital access to BIPM databases
• Key Comparison Database
• UTC database

BIPM digital service
• SI Reference Point
The SI Digital Framework provides a fully digital representation of the SI

- To provide the globally accepted anchor of trust for metrology in the digital era
- Facilitate the use of digital certificates and the adoption of the FAIR principles

Digital access to BIPM databases
- Key Comparison Database
- UTC database

BIPM digital service
- SI Reference Point

BIPM digital references
Available for beta testing
- Units
- Prefixes
- Defining constants
- Quantities - used in the SI Brochure
- Decisions
- CMCs
- Measurement service categories
  - for Physics (exc RI)
The SI Digital Framework provides a fully digital representation of the SI

- To provide the globally accepted anchor of trust for metrology in the digital era
- Facilitate the use of digital certificates and the adoption of the FAIR principles

**Digital access to BIPM databases**
- Key Comparison Database
- UTC database

**BIPM digital service**
- SI Reference Point

**Digital references**

**(v1.0) Available for beta testing**
- Units
- Prefixes
- Defining constants
- Quantities - *used in the SI Brochure*
- Decisions
- CMCs
- Measurement service categories
  - for Physics (exc RI)

**(v2.0) Under development**
- Measurement service categories
  - for RI and chemistry
- NMIs/DIs
- Quantities – *used in the KCDB*
- Fundamental constants
- .....


The SI Digital Framework provides a fully digital representation of the SI

- To provide the globally accepted anchor of trust for metrology in the digital era
- Facilitate the use of digital certificates and the adoption of the FAIR principles

Digital access to BIPM databases
- Key Comparison Database
- UTC database

BIPM digital service
- SI Reference Point

External digital references
- ROR
- ORCID
- InChI

Under development
- Unit interoperability service

digital references

**(v1.0) Available for beta testing**
- Units
- Prefixes
- Defining constants
- Quantities - *used in the SI Brochure*
- Decisions
- CMCs
- Measurement service categories
  - for Physics (exc RI)

**(v2.0) Under development**
- Measurement service categories
  - for RI and chemistry
- NMI/DIs
- Quantities – *used in the KCDB*
- Fundamental constants
- ....
The SI Reference Point

Machine-interpretable reference for the International System of Units
Motivation

• provide trusted knowledge bases to describe metrological information
• prepare existing documents for L3+

Reference:
addition of formal logic to the web
- express data and rules
- reason about content
- describe and express complex properties
- remain decidable

integration with existing standards
- build on accepted tools
- use (hidden) annotations in XML
- describe meaning and relations with RDF
- identify concepts globally using a URI

available collections of information
- capture domain specific knowledge
- ontologies define concepts and relations
- interrelate concepts between ontologies
The principal pillars

- SI units
- SI prefixes
- Defining constants
- Selected quantities
- Decisions concerning the SI

Information encoded in knowledge graphs (serialized as TTL / JSON-LD)
Usable by both humans and machines.
Unit Equation: \( N = \text{kg} \text{ m} / \text{s}^2 \)

Turtle Syntax:

```turtle
units:newton a si:SISpecialNamedUnit;
    si:hasDefiningResolution cgpm:CGPM9-Res7;
    si:hasSymbol "N"^^xsd:string;
    si:hasUnitTypeAsString "Named SI derived unit"^^en,
        "Unité SI dérivée ayant un nom spécial"^^fr;
    si:inBaseSIUnits [ a si:UnitProduct;
        si:hasLeftUnitTerm units:kilogram;
        si:hasRightUnitTerm [ a si:UnitProduct;
            si:hasLeftUnitTerm units:metre;
            si:hasRightUnitTerm [ a si:UnitPower;
                si:hasNumericExponent "-2"^^xsd:short;
                si:hasUnitBase units:second ] ] ];
    si:isUnitOfQtyKind quantities:FORC;
    si:prefixRestriction false;
    skos:prefLabel "newton"^^en,
        "newton"^^fr.
```

Diagram: See diagram showing the relationships between units and their properties.
"The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom (1967)."
Links and thanks

• https://si-digital-framework.org/ : the root URI and web endpoint
• https://github.com/TheBIPM/SI_Digital_Framework : public github repository where files and documentation are available, and issues can be raised.
• Current version : 1.0beta, comments and feedback welcome.

Thanks to
Janet Miles (BIPM), A. Ben Abdallah (web dev), S. Chalk (UNF), G. Dudle (METAS, now OST), M. Gruber (PTB), J.-L. Hippolyte (NPL), F. Meynadier (BIPM)
Quick Start: CMC Identifiers

Published on the KCDB Help page.

QUICK START: CMC IDENTIFIERS

USE CASES
1. In its Recommendation JCGM 111:2012, the Joint Committee for Measurement CMC recommends the use of NMI and IHO of CMC identifiers, for example in quality management documentation and in calibration certificates (digital or otherwise).
2. The CPM has established a new digital service that allows a permanent link to be provided to the corresponding CMC.

YOUR CMC IDENTIFIER
The identifier is automatically attributed as soon as a CMC is declared on the KCDB platform, and is displayed in the KCDB along with the CMC when the CMC is published.

The CMC identifier is composed as follows, according to the document CPM MRA-G-1.3:

RIOMO-A2-ID-V

where
- RMO: acronym of the Regional Metrology Organisation through which the CMC was submitted
- A2: ISO 3166-1 2-letter country code (or BPM code for an international organization participating in the CIPM MRA)
- ID: 8-character alphanumeric code
- V: 1-character alphanumeric version value (from 1 to 2).

PERMANENT LINK
To access a web address please use the following link including your CMC identifier:

https://si-digital-framework.org/kcdb-cmc/"CMC identifier"

(where "CMC identifier" is replaced by your CMC identifier).
To return machine-readable (JSON or XML) code (for example in a digital certificate), use:

https://si-digital-framework.org/kcdb-cmc/"CMC identifier"?type=json
https://si-digital-framework.org/kcdb-cmc/"CMC identifier"?type=xml

1 https://www.bipm.org/committees/jcml/meeting-outcomes
2 CMC - Calibration and Measurement Capabilities in the context of the CIPM MRA. Guidelines for their review, acceptance and maintenance (2012), CIPM MRA-G-1.3
The SI Digital Framework – next steps

- To provide the globally accepted anchor of trust for metrology in the digital era
- Facilitate the use of digital certificates and the adoption of the FAIR principles

<table>
<thead>
<tr>
<th>BIPM online databases</th>
<th>digital references</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Key Comparison Database</td>
<td>Available for beta testing</td>
</tr>
<tr>
<td>• UTC database</td>
<td>• Units</td>
</tr>
<tr>
<td></td>
<td>• Prefixes</td>
</tr>
<tr>
<td></td>
<td>• Defining constants</td>
</tr>
<tr>
<td></td>
<td>• Quantities - <em>used in the SI Brochure</em></td>
</tr>
<tr>
<td></td>
<td>• Decisions</td>
</tr>
<tr>
<td></td>
<td>• CMCs</td>
</tr>
<tr>
<td></td>
<td>• Measurement service categories</td>
</tr>
<tr>
<td></td>
<td>• for Physics (exc RI)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BIPM digital service</th>
<th>Under development</th>
</tr>
</thead>
<tbody>
<tr>
<td>• SI Reference Point</td>
<td>• Measurement service categories</td>
</tr>
<tr>
<td></td>
<td>• for RI and chemistry</td>
</tr>
<tr>
<td></td>
<td>• NMIs/DIs</td>
</tr>
<tr>
<td></td>
<td>• Quantities – <em>used in the KCDB</em></td>
</tr>
<tr>
<td></td>
<td>• Fundamental constants</td>
</tr>
<tr>
<td></td>
<td>• ....</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>External digital references</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• ROR</td>
<td>• Unit interoperability service</td>
</tr>
<tr>
<td>• ORCID</td>
<td></td>
</tr>
<tr>
<td>• InChI</td>
<td></td>
</tr>
</tbody>
</table>

Under development

- Measurement service categories
- for RI and chemistry
- NMIs/DIs
- Quantities – *used in the KCDB*
- Fundamental constants
- ....
The SI Digital Framework – actions by the Consultative Committees

The SI-digital framework provides the basis for new Digital Transformation actions in the CCs. Examples:

- **CCTF**: demonstration API to allow UTC labs to access Time Dept database directly
- **CCRI**: digital comparison report formats
- **CCL/CCTF**: database for wavelength and frequency standards for the Mise en Pratique of the meter and the second with API access
- **CCQM**: FAIR data workshop

..

..
At the BIPM we are -

• supporting open data practices by providing digital reference points and machine-accessible data,
• providing the anchor of trust for metrology data.
The development of the SI Digital Framework has been a collaborative effort.

Many thanks to:

• NMI Partners (PTB, NIST, NPL, METAS)
• QI partners collaborating on the SI Reference Point