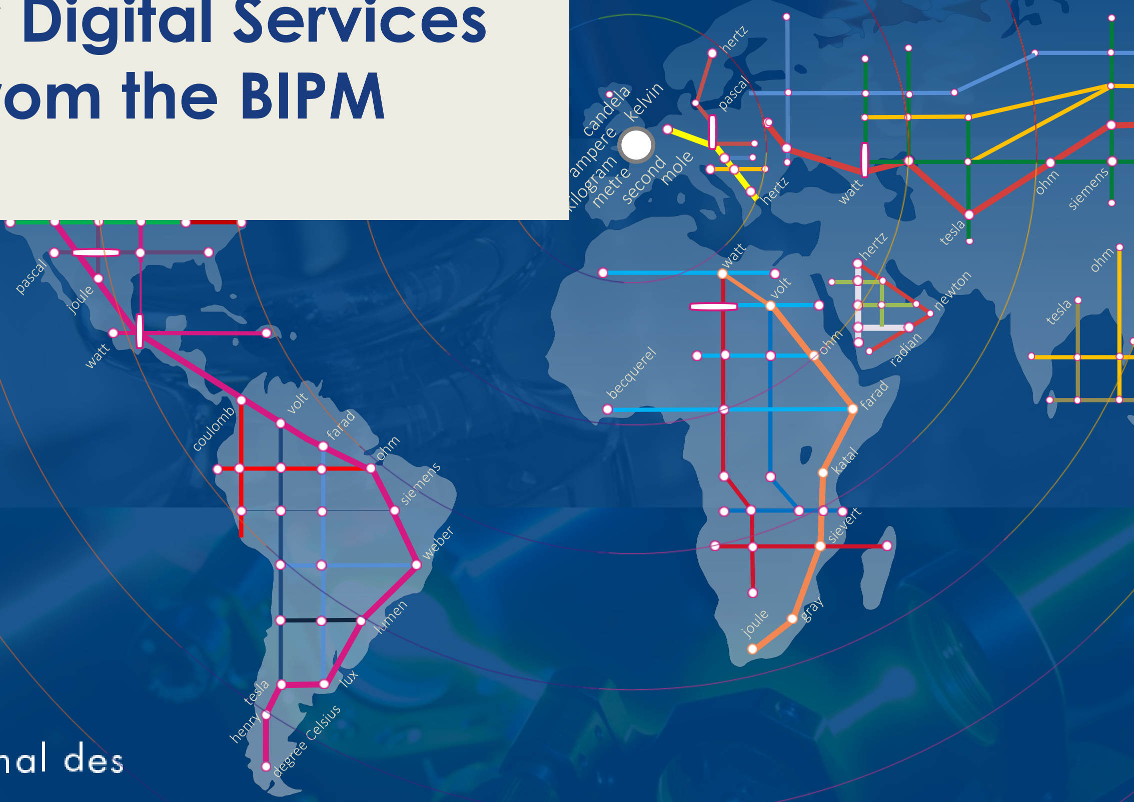
New Digital Services from the BIPM

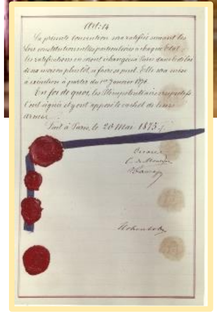


Bureau
International des
Poids et
Mesures

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"



CGPM – Conférence générale des poids et mesures

Official representatives of Member States

CIPM – Comité international des poids et mesures

14 then 18 members all from different nationalities and elected by the CGPM.

Headquarters (Scientific and technical secretariat, Sèvres, France)

1875

17 Member States

14 CIPM Members

Director + 2 Assistants

2022

64 Member States

18 CIPM Members

Director + 70 staff

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

THE VISION AND MISSION OF THE BIPM

The BIPM is an intergovernmental organization established by the Metre Convention, through which Member States act together on matters related to measurement science and measurement standards.

Its vision is to be universally recognized as the world focus for the international system of measurement.

Its mission is to work with the NMIs of its Member States, the RMOs and strategic partners world-wide and to use its international and impartial status to promote and advance the global comparability of measurements.

TECHNICAL COOPERATION

COORDINATION

LIAISON

Decision CIPM/105-13

Bureau International des Poids et Mesures

www.bipm.org

CENTRE for <u>COLLABORATION</u>
Scientific and technical collaboration between Member States

<u>ADVOCACY</u>
Representing the world-wide measurement community

BIPM

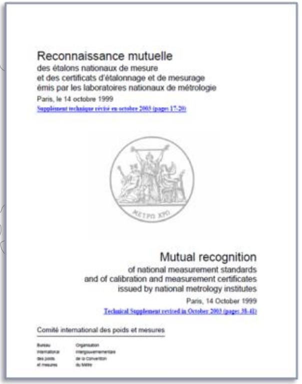
<u>COORDINATION</u>
of the world-wide measurement system

Laboratory activities

Calibrations	Comparisons

JCGM	CIPM MRA	UTC

CBKT	JCTLM



Reconnaissance mutuelle
des étalons nationaux de mesure
et des certificats d'étalonnage et de mesurage
émis par les laboratoires nationaux de métrologie
Paris, le 14 octobre 1999
Supplément technique révisé en octobre 2003 (pages 17-20)

Mutual recognition
of national measurement standards
and of calibration and measurement certificates
issued by national metrology institutes
Paris, 14 October 1999
Technical Supplement revised in October 2003 (pages 38-41)

Comité international des poids et mesures

Bureau international des poids et mesures
Organisation intergouvernementale de la Convention du Mètre

Established in 1875

"TO ASSURE THE INTERNATIONAL UNIFICATION AND PERFECTION OF THE METRIC SYSTEM"

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)*

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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

Members and Associates *(May 2023)*


Reconnaissance mutuelle
des étalons nationaux de mesure
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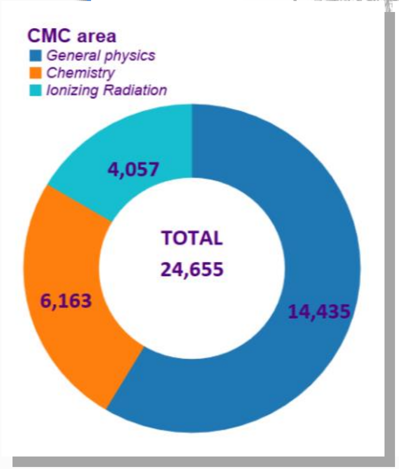

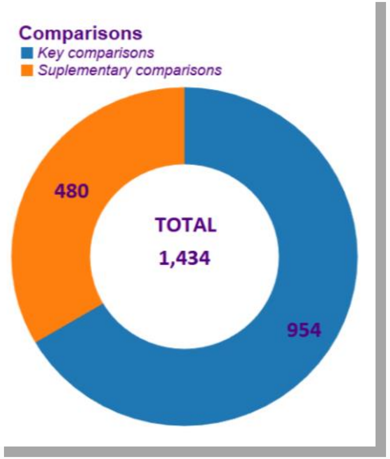

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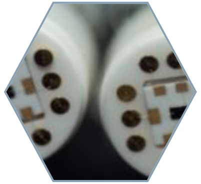
The BIPM – main technical roles.

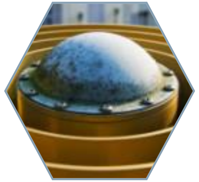
Travelling standards

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.

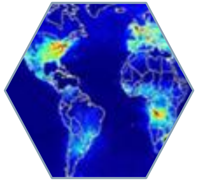


kilogram

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

Liaison and Coordination

The BIPM works to foster cooperation with international organizations and promotes the world-wide comparability of measurements.

Comités communs

JCGM

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.

A brief history of the SI

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

the **International Temperature Scale (ITS90)** was adopted

2018

The 26th CGPM agreed to change the definitions of :

- kilogram
- ampere
- kelvin
- mole

The **International System** of Units (SI)

Prefixes

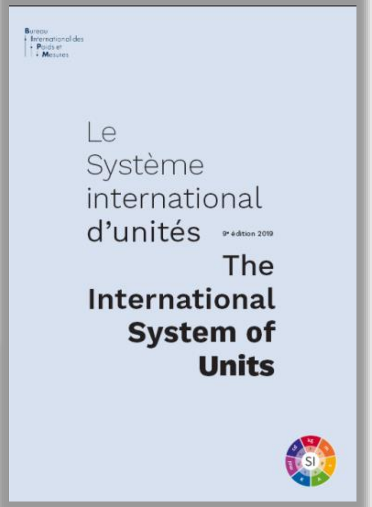
Table 5. SI prefixes

Factor	Name	Symbol	Factor	Name	Symbol
10^1	deca	da	10^{-1}	deci	d
10^2	hecto	h	10^{-2}	centi	c
10^3	kilo	k	10^{-3}	milli	m
10^6	mega	M	10^{-6}	micro	µ
10^9	giga	G	10^{-9}	nano	n
10^{12}	tera	T	10^{-12}	pico	p
10^{15}	peta	P	10^{-15}	femto	f
10^{18}	exa	E	10^{-18}	atto	a
10^{21}	zetta	Z	10^{-21}	zepto	z
10^{24}	yotta	Y	10^{-24}	yocto	y

Base units

Table 1. SI base units

Base quantity		SI base unit	
Name	Symbol	Name	Symbol
length	l, x, r, etc.	metre	m
mass	m	kilogram	kg
time, duration	t	second	s
electric current	I, i	ampere	A
thermodynamic temperature	T	kelvin	K
amount of substance	n	mole	mol
luminous intensity	I_v	candela	cd



The 9th edition of the SI Brochure is available from the BIPM website.

Derived units

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

	SI coherent derived unit (a)			
Derived quantity	Name	Symbol	Expressed in terms of other SI units	Expressed in terms of SI base units
plane angle	radian (b)	rad	1 (b)	m/m
solid angle	steradian (b)	sr (c)	1 (b)	m^2/m^2
frequency	hertz (d)	Hz		s^{-1}
force	newton	N		$m\ kg\ s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1}\ kg\ s^{-2}$
energy, work, amount of heat	joule	J	N m	$m^2\ kg\ s^{-2}$
power, radiant flux	watt	W	J/s	$m^2\ kg\ s^{-3}$
electric charge, amount of electricity	coulomb	C		s A
electric potential difference, electromotive force	volt	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
capacitance	farad	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
electric resistance	ohm	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
magnetic flux	weber	Wb	V s	$m^2\ kg\ s^{-2}\ A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
inductance	henry	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
Celsius temperature	degree Celsius (e)	°C		K
luminous flux	lumen	lm	cd sr (c)	cd
illuminance	lux	lx	lm/m^2	m^{-2} cd
activity referred to a radionuclide (f)	becquerel (d)	Bq		s^{-1}
absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$m^2\ s^{-2}$
dose equivalent, ambient dose equivalent, directional dose equivalent, personal dose equivalent	sievert (g)	Sv	J/kg	$m^2\ s^{-2}$
catalytic activity	katal	kat		s^{-1} mol

27th meeting of the

General Conference of Weights and Measures (CGPM) in November 2022

https://www.bipm.org/en/committees/cg/cgpm

Resolution 2

"On the global digital transformation and International System of Units"

Encourages

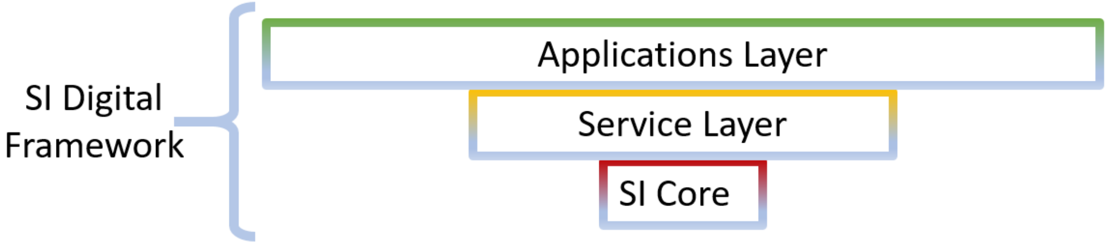
the CIPM to undertake the development and promotion of an SI Digital Framework, that will include the following features:

- 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.

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.



"Transforming the International System of Units for a Digital World"
Approved Oct 2020 - CIPM/109-17

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

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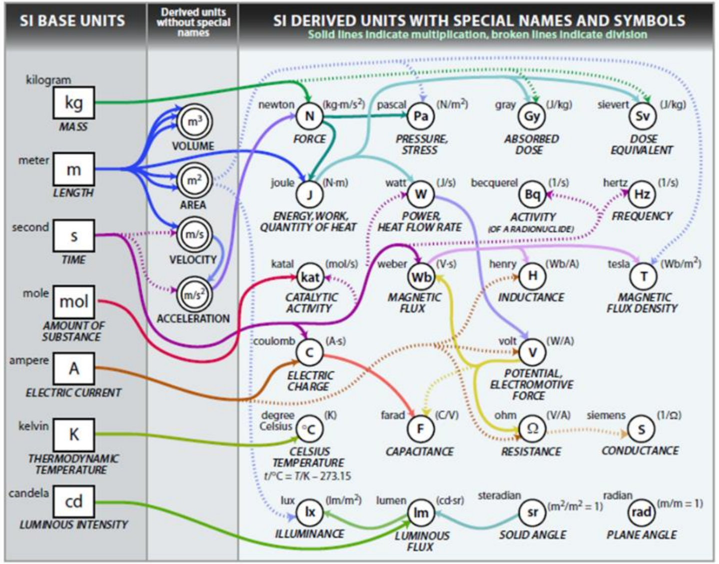

From NIST -http://physics.nist.gov/cuu/Units/SIdiagram.html

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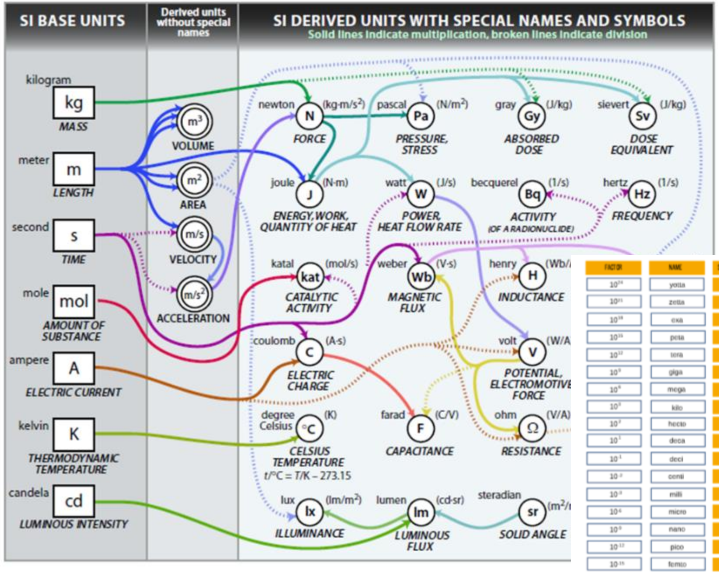

FACTOR	NAME	SYMBOL	MULTIPLYING FACTOR
10^{24}	yotta	Y	1 000 000 000 000 000 000 000 000
10^{21}	zetta	Z	1 000 000 000 000 000 000 000
10^{18}	exa	E	1 000 000 000 000 000 000
10^{15}	peta	P	1 000 000 000 000 000
10^{12}	tera	T	1 000 000 000 000
10^{9}	giga	G	1 000 000 000
10^{6}	mega	M	1 000 000
10^{3}	kilo	k	1 000
10^{2}	hecto	h	100
10^{1}	deca	da	10
10^{-1}	deci	d	0.1
10^{-2}	centi	c	0.01
10^{-3}	milli	m	0.001
10^{-6}	micro	µ	0.000 001
10^{-9}	nano	n	0.000 000 001
10^{-12}	pico	p	0.000 000 000 001
10^{-15}	femto	f	0.000 000 000 000 001
10^{-18}	atto	a	0.000 000 000 000 000 001
10^{-21}	zepto	z	0.000 000 000 000 000 000 001
10^{-24}	yocto	y	0.000 000 000 000 000 000 000 001

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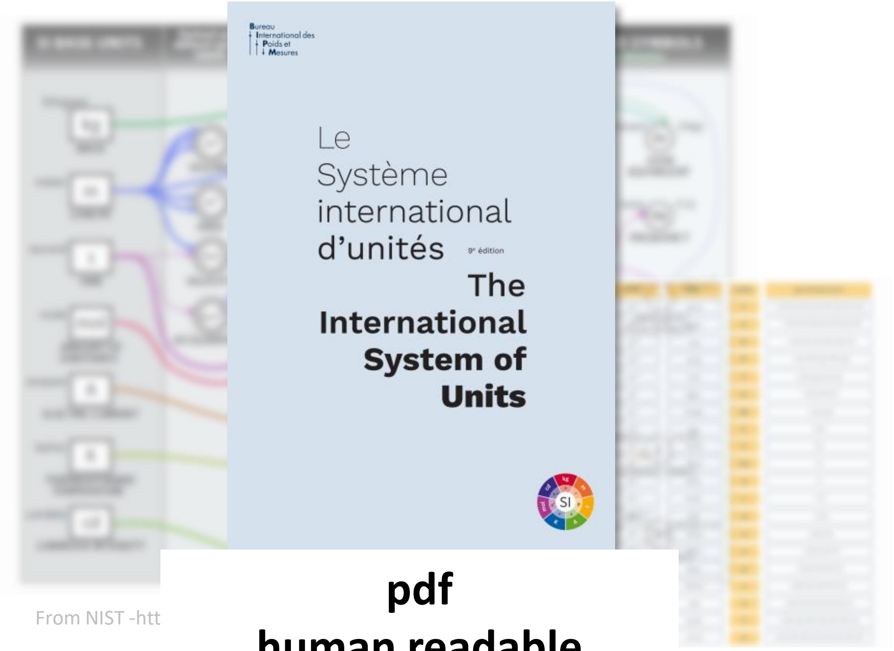

From NIST -htt

pdf
human readable

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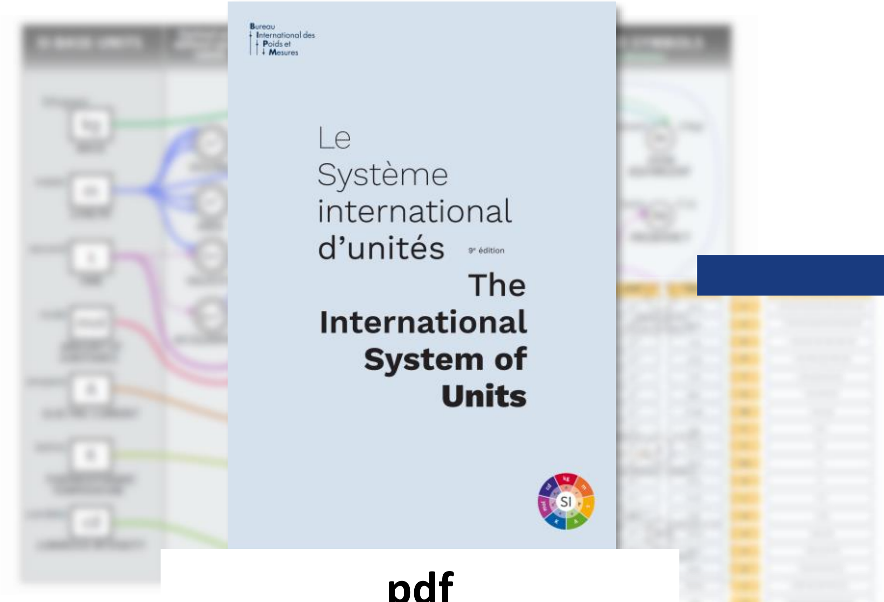

From NIST -htt

pdf
human readable

Digital Reference Point
SI
bipm.org/digital-transformation

FAIR
machine readable

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

9 771234 567003

eg DOIs

Citation S M Judge *et al* 2023 *Metrologia* **60** 012001

DOI 10.1088/1681-7575/aca67a

10.1088/1681-7575/aca67a

QR codes

eg ORCID iDs

Olav Werhahn https://orcid.org/0000-0002-2317-3436

Chingis Kuanbayev https://orcid.org/0009-0004-0902-417X

0009-0004-0902-417X

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

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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)*

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digital references

(v1.0) Available for beta testing

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- Decisions
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- Measurement service categories
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(v2.0) Under development

- Measurement service categories
    - *for RI and chemistry*
- NMIs/DIs
- Quantities – *used in the KCDB*
- Fundamental constants
- ….

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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*
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- Quantities – *used in the KCDB*
- Fundamental constants
- ….

The SI Reference Point

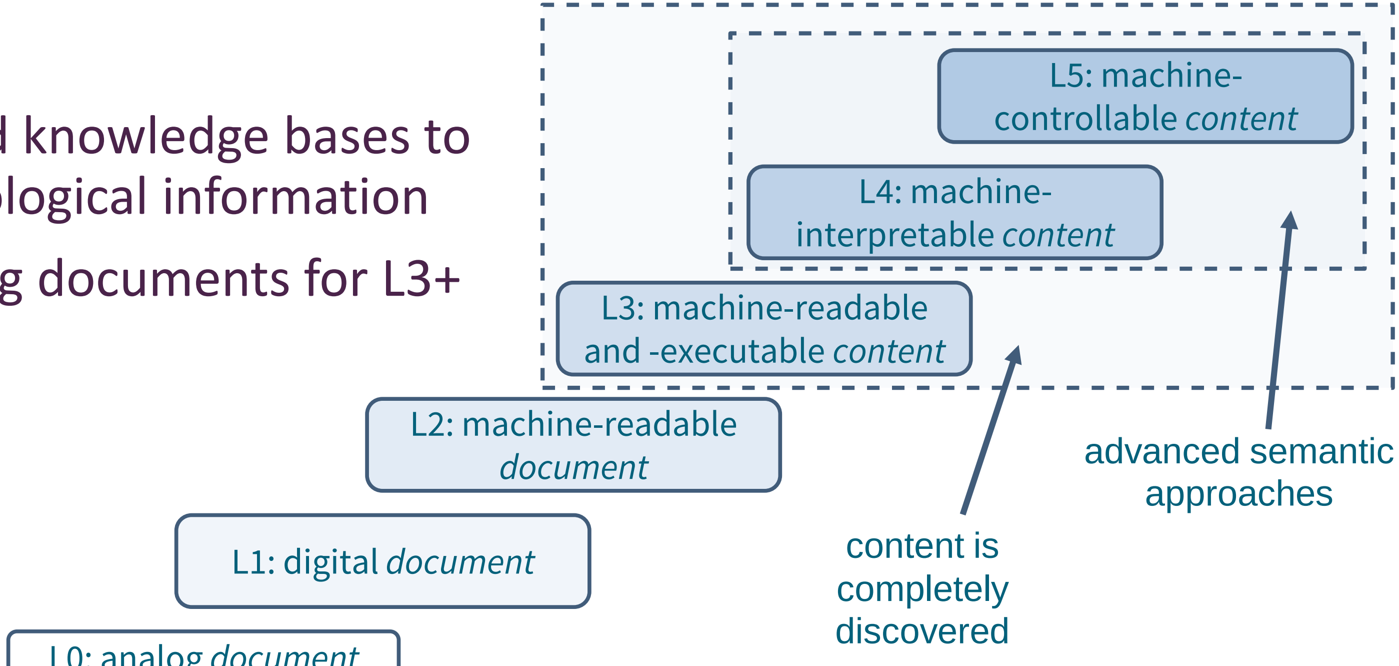
Machine-interpretable reference for the International System of Units

BIPM

Motivation

Motivation

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



Reference:
https://www.din.de/resource/blob/801106/0251eb1280a9a97e53285d42d3bf1fea/whitepaper-idis-en-data.pdf

Building blocks of the semantic web

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

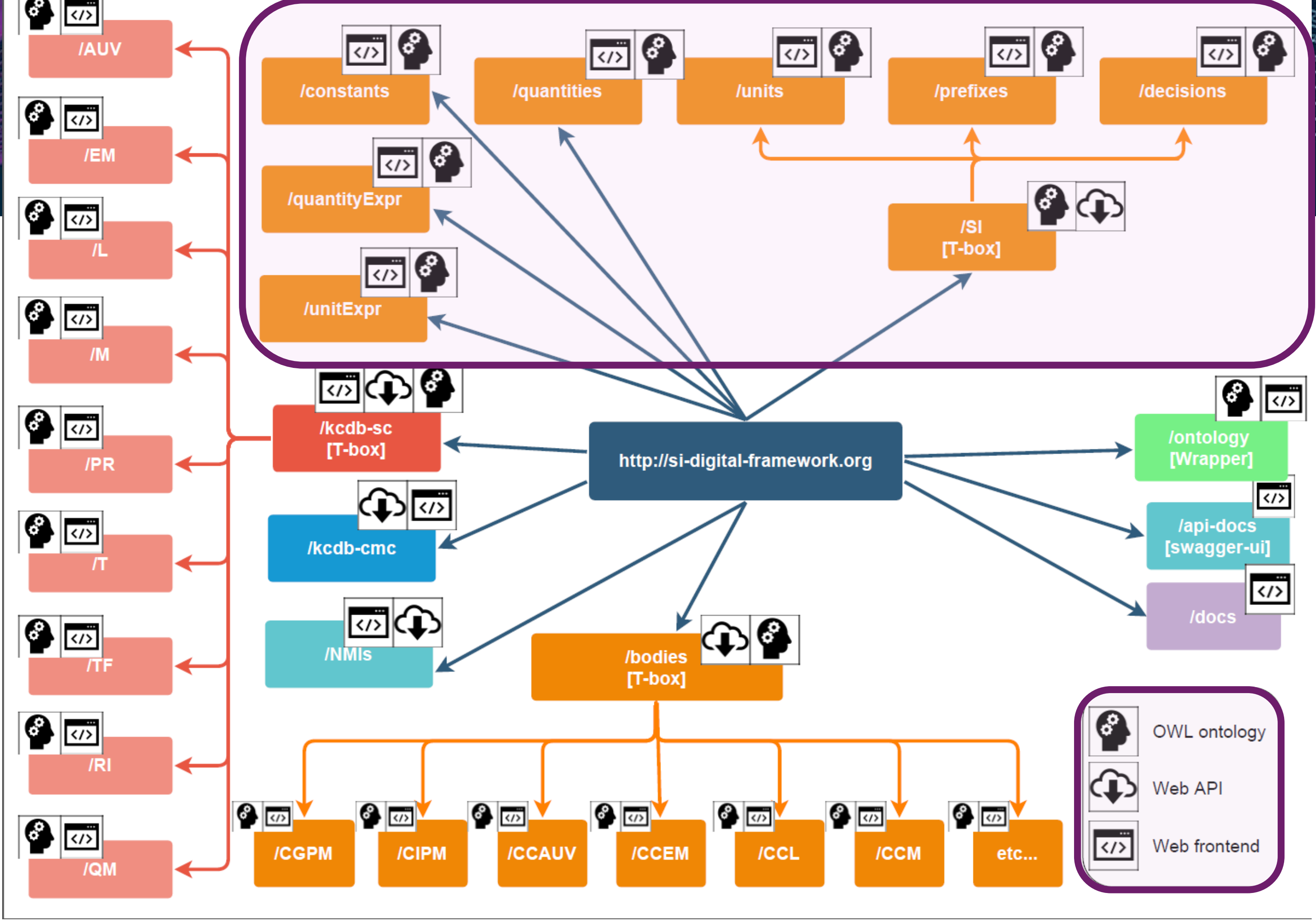
The principal pillars

The main 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.



/AUV
/EM
/L
/M
/PR
/T
/TF
/RI
/QM
/constants
/quantities
/units
/prefixes
/decisions
/quantityExpr
/unitExpr
/SI
[T-box]
/kcdb-sc
[T-box]
/kcdb-cmc
/NMIs
http://si-digital-framework.org
/ontology
[Wrapper]
/api-docs
[swagger-ui]
/docs
/bodies
[T-box]
/CGPM
/CIPM
/CCAUV
/CCEM
/CCL
/CCM
etc...
OWL ontology
Web API
Web frontend

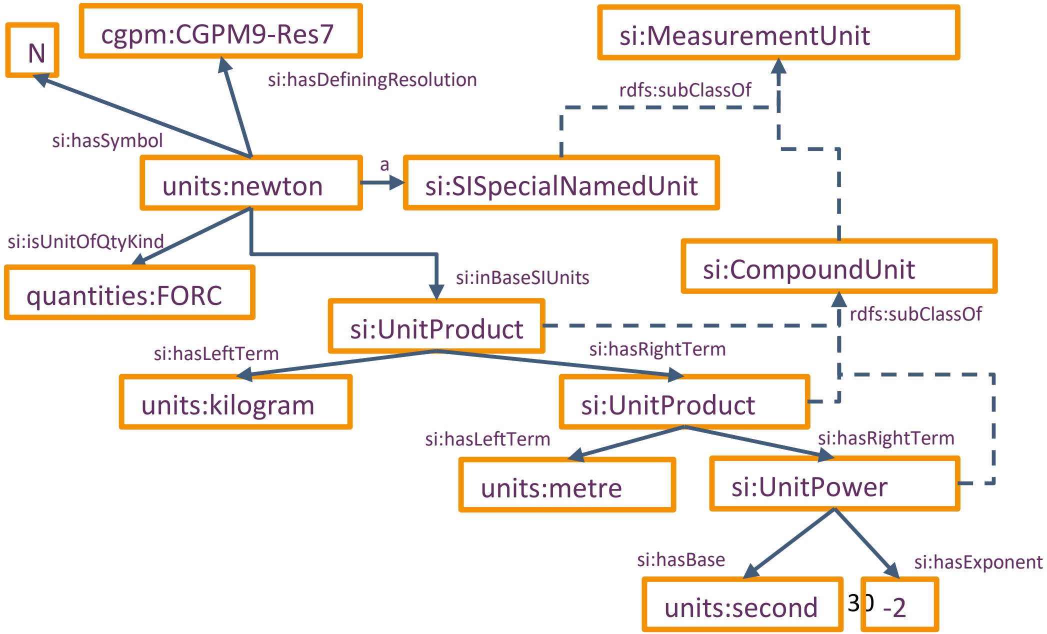
Contructing units from expressions

Unit Equation: $\mathrm{N} = \mathrm{kg\ m} / \mathrm{s}^2$

Turtle Syntax:

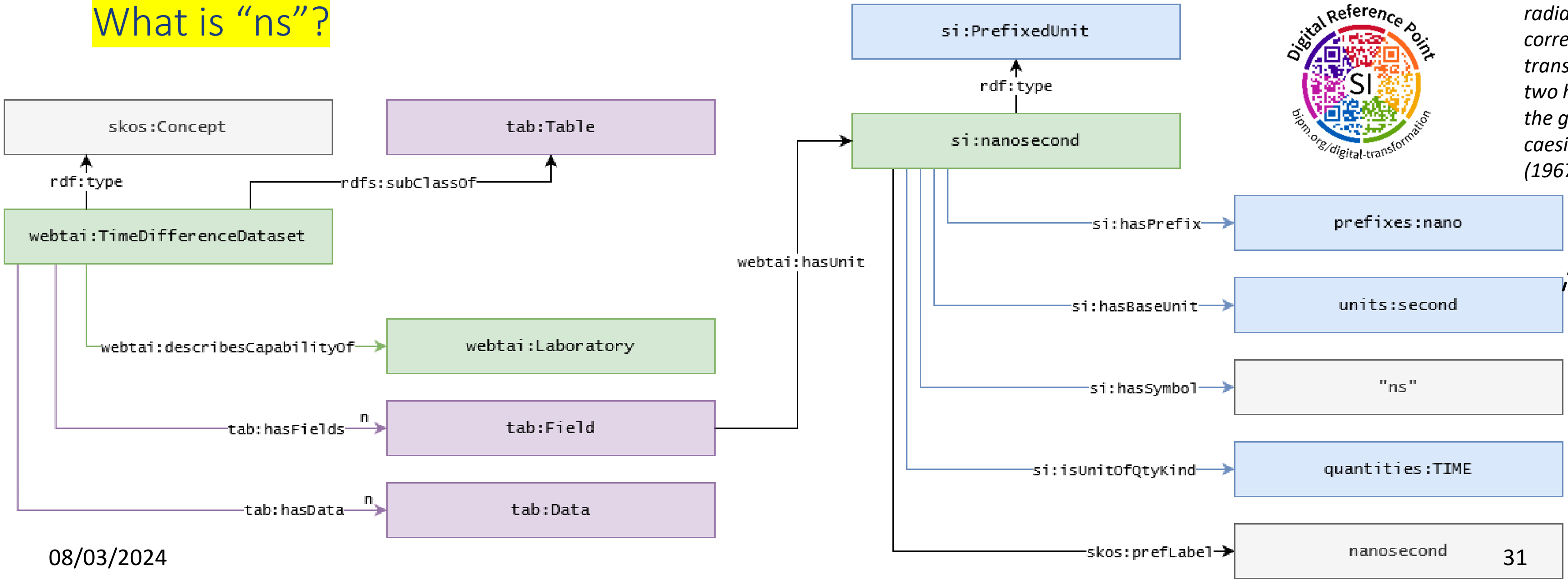
```
units:newton a si:SISpecialNamedUnit ;
  si:hasDefiningResolution cgpm:CGPM9-Res7 ;
  si:hasSymbol "N"^^xsd:string ;
  si:hasUnitTypeAsString "Named SI derived unit"@en,
    "Unité SI dérivée ayant un nom spécial"@fr ;
  si:inBaseSIUnits [ a si:UnitProduct ;
      si:hasLeftUnitTerm units:kilogram ;
      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 .
```

Implied Graph (excerpt):



How to link data to units?

What is “ns”?



“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 JCRB/46-1[i], the Joint Committee of Regional Metrology Organizations and the BIPM (JCRB) recommends the use by NMIs and DIs of **CMC identifiers**, for example in quality management documentation and in calibration certificates (digital or otherwise).
2. The BIPM 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 web 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 document CIPM MRA-G-13[ii]:

RMO-Area-A2-ID-V

where

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

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

EXAMPLE

This calibration service is underpinned by the CMC
AFRIMETS-EM-KE-00000MUX-1:

[i] https://www.bipm.org/committees/jc/jcrb/meeting-outcomes
[ii] CMCs - Calibration and Measurement Capabilities in the context of the CIPM MRA: Guidelines for their review, acceptance and maintenance (2022); CIPM MRA-G-13, https://www.bipm.org/documents/20126/43742162/CIPM-MRA-G-13.pdf

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

BIPM online 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

Available for beta testing

- Units
- Prefixes
- Defining constants
- Quantities - *used in the SI Brochure*
- Decisions
- CMCs
- Measurement service categories
  - *for Physics (exc RI)*

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

..

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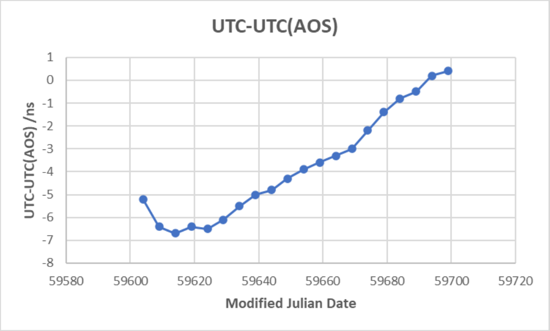

At the BIPM we are -

- supporting open data practices by providing digital reference points and machine-accessible data,
- providing the anchor of trust for metrology data.

Digital Reference Point
SI
bipm.org/digital-transformation

KCDB

JCTLM
Accurate results
for patient care

IMRR

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

"thank you"

Bureau International des Poids et Mesures