Work by BIPM/CCL/CCTF on digitalisation of the SI metre

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Digitalisation/API programming

CONSULTATIVE COMMITTEE FOR LENGTH

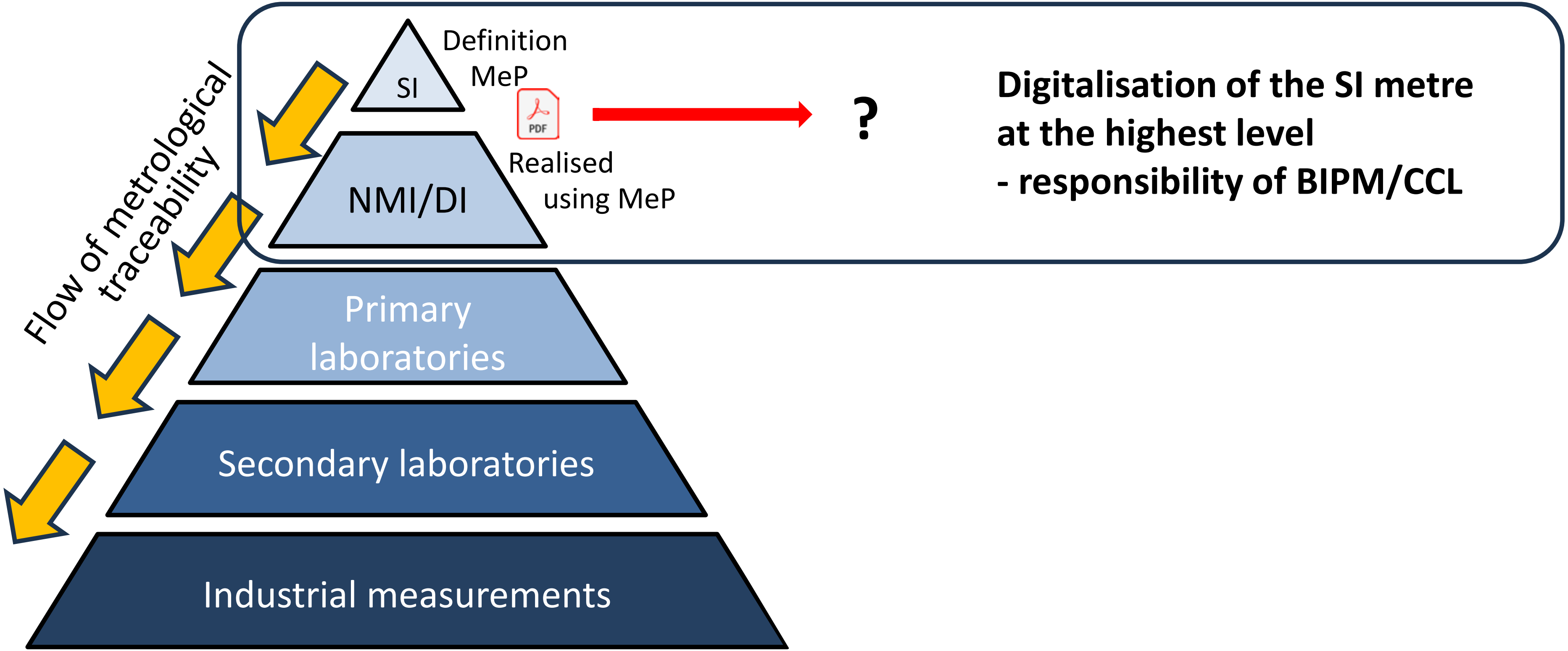
CONSULTATIVE COMMITTEE FOR TIME AND FREQUENCY

19 Oct 2023

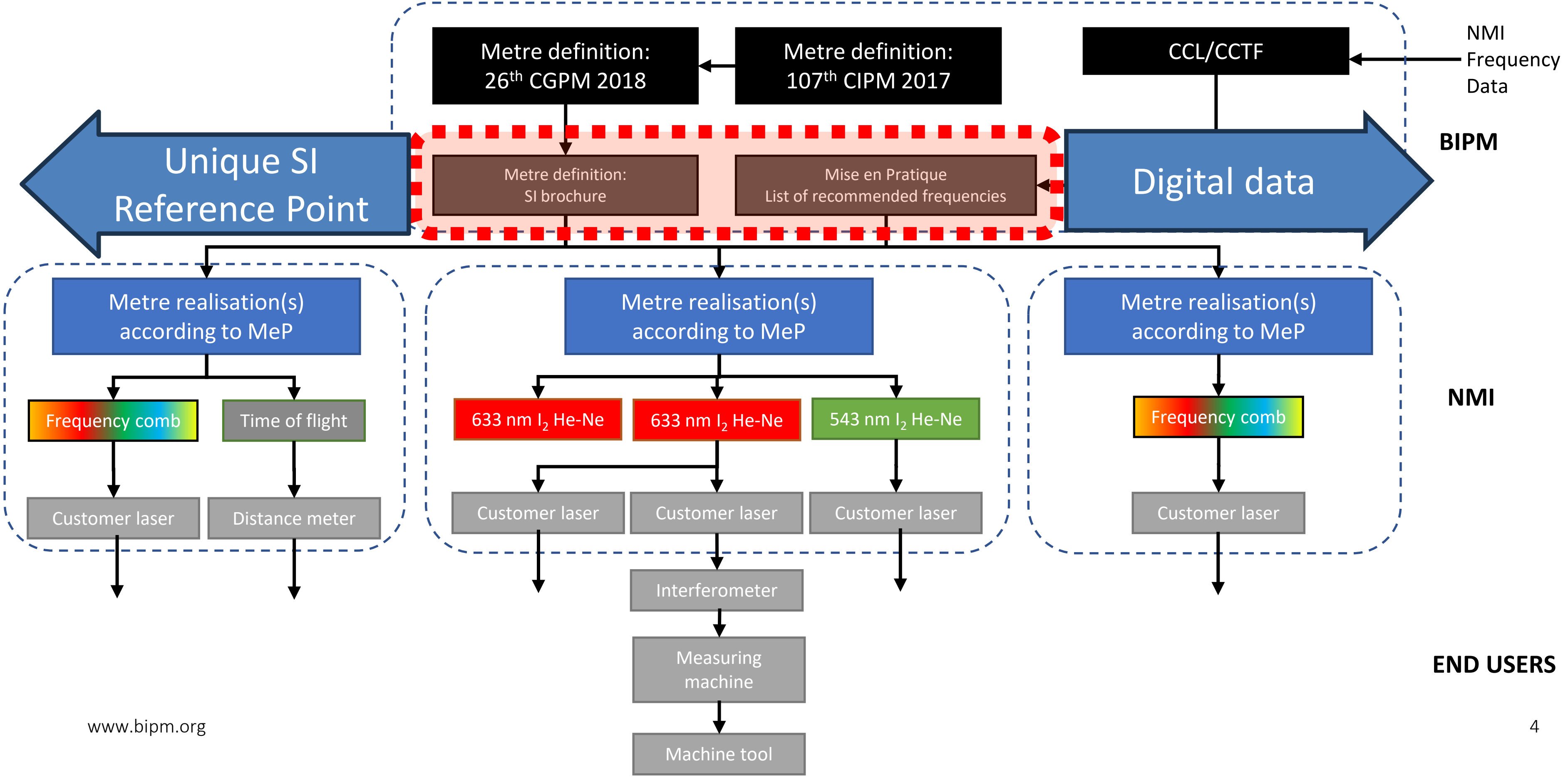
Overview

- Inspiration
- Digitalisation work required
  - Unique SI Reference Point
  - Conversion of PDF MeP to digital MeP
  - XML schema for download
  - API access
  - NMI hardware/software
- Digital control of laser
  - XML MeP data download
  - Meta data use in certificates
- Ontology of services for CMC Interoperability

Inspiration



Length traceability chain at the highest level, through the primary realisations of the metre

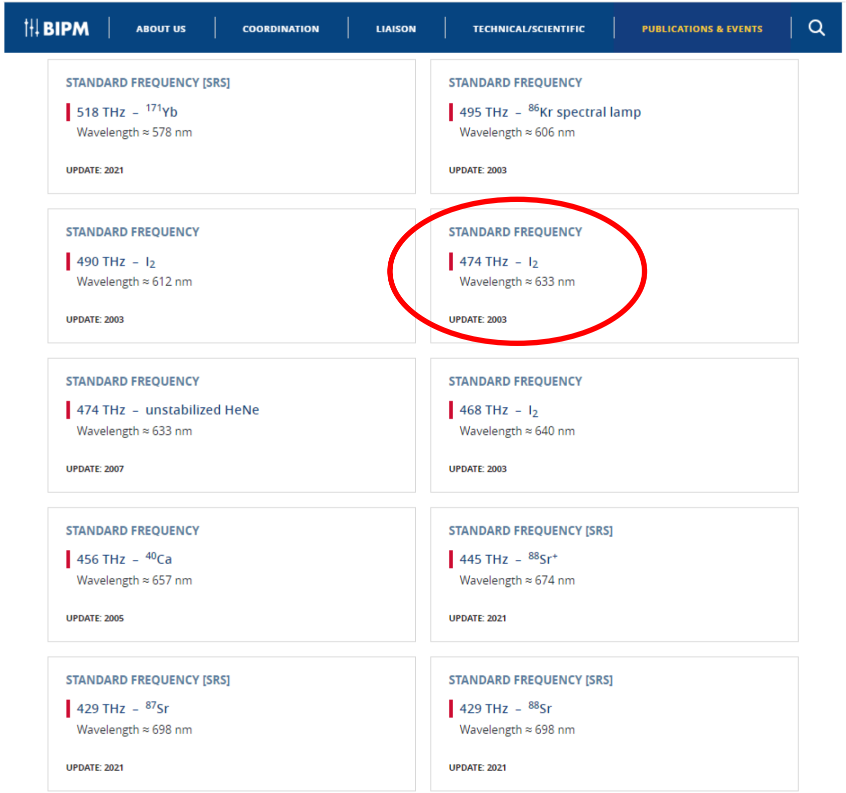


Situation on metre realisation data

- The information about the SI metre definition and realisation are both available electronically as PDF documents. They are intended for human interaction/interpretation. The ***Mise en Pratique*** and the ***List of Recommended values of Standard Frequencies*** are only available in PDF – they require **human** download, reading, selection and extraction of key data.
- The ***List of Recommended values of Standard Frequencies*** contains lots of meta data critical to both the approval/authority process and for the implementation. This is understood by the scientists in the field, and probably encoded into the operating procedures of their lasers.
- What happens if things change?
    - Does any **change** to the text in the ***List of Frequencies*** automatically trigger review/update of laser calibrations?
    - Are the **local assumed conditions** still valid?
    - Is the **latest** data used?
    - Are the latest values implemented in **my software**?
    - Who **approved** the latest update? (CCL? CIPM?)
    - Can I **guarantee** perfect **transcription** of the data into my operational system?

→ Make the critical metre realisation data available digitally

What does the data look like?



BIPM | ABOUT US | COORDINATION | LIAISON | TECHNICAL/SCIENTIFIC | PUBLICATIONS & EVENTS

STANDARD FREQUENCY [SRS]
518 THz – ^{171}Yb
Wavelength ≈ 578 nm
UPDATE: 2021

STANDARD FREQUENCY
495 THz – ^{86}Kr spectral lamp
Wavelength ≈ 606 nm
UPDATE: 2003

STANDARD FREQUENCY
490 THz – I_2
Wavelength ≈ 612 nm
UPDATE: 2003

STANDARD FREQUENCY
474 THz – I_2
Wavelength ≈ 633 nm
UPDATE: 2003

STANDARD FREQUENCY
474 THz – unstabilized HeNe
Wavelength ≈ 633 nm
UPDATE: 2007

STANDARD FREQUENCY
468 THz – I_2
Wavelength ≈ 640 nm
UPDATE: 2003

STANDARD FREQUENCY
456 THz – ^{40}Ca
Wavelength ≈ 657 nm
UPDATE: 2005

STANDARD FREQUENCY [SRS]
445 THz – $^{88}Sr^{+}$
Wavelength ≈ 674 nm
UPDATE: 2021

STANDARD FREQUENCY [SRS]
429 THz – ^{87}Sr
Wavelength ≈ 698 nm
UPDATE: 2021

STANDARD FREQUENCY [SRS]
429 THz – ^{88}Sr
Wavelength ≈ 698 nm
UPDATE: 2021

https://www.bipm.org/en/publications/mises-en-pratique/standard-frequencies

474 THz, 633 nm He-Ne laser (I_2 stabilised)

MEP 2003

IODINE ($\lambda \approx 633$ nm)

Absorbing molecule $^{127}I_2$, a_{16} or f component, R(127) 11-5 transition (1)

Atom/molecule, transition specification, selected component

1. CIPM recommended values

The values $f = 473\ 612\ 353\ 604$ kHz
$\lambda = 632\ 991\ 212.58$ fm

with a relative standard uncertainty of 2.1×10^{-11} apply to the radiation of a He-Ne laser with an internal iodine cell, stabilized using the third harmonic detection technique, subject to the conditions:

Values for frequency, (vacuum) wavelength and uncertainty, basic stabilisation technique

- cell-wall temperature (25 ± 5) °C (2);
- cold-finger temperature (15.0 ± 0.2) °C;
- frequency modulation width, peak-to-peak, (6.0 ± 0.3) MHz;
- one-way intracavity beam power (i.e. the output power divided by the transmittance of the output mirror) (10 ± 5) mW for an absolute value of the power shift coefficient ≤ 1.0 kHz/mW.

Requirements to achieve specified uncertainty level:

Cell wall temperature
Cold finger temperature
Frequency modulation
Intra-cavity power

These conditions are by themselves insufficient to ensure that the stated standard uncertainty will be achieved. It is also necessary for the optical and electronic control systems to be operating with the appropriate technical performance. The iodine cell may also be operated under relaxed conditions, leading to the larger uncertainty specified in section 2 below.

2. Source data

Adopted value:	$f = 473\ 612\ 353\ 604\ (10)$ kHz	$u_c/y = 2.1 \times 10^{-11}$
	for which:	
	$\lambda = 632\ 991\ 212.579\ (13)$ fm	$u_c/y = 2.1 \times 10^{-11}$

Requirements were tightened in recent years – did everyone notice?

474 THz, 633 nm He-Ne laser (I_2 stabilised) ...continued

Table 1

$\lambda \approx 633$ nm $^{127}I_2$ R(127) 11-5

Other components, same transition

a_n	x	$[f(a_n)-f(a_{16})]$ /MHz	]/MHz	u_c/MHz
a_2	t	−721.8		
a_3	s	−697.8		
a_4	r	−459.62		
a_5	q	−431.58		
a_6	p	−429.18		
a_7	o	−402.09		
a_8	n	−301.706		
a_9	m	−292.693		
a_{10}	l	−276.886		
a_{11}	k	−268.842		

Frequency referenced to

Ref. [18–29]

Table 2

$\lambda \approx 633$ nm $^{127}I_2$ P(33) 6-3

Components of a different transition

b_n	x	$[f(b_n)-f(b_{21})]$/MHz	u_c/MHz	b_n	x	$[f(b_n)-f(b_{21})]$ /MHz	u_c /MHz
b_1	u	−922.571	0.008	b_{12}	j	−347.354	0.007
b_2	t	−895.064	0.008	b_{13}	i	−310.30	0.01
b_3	s	−869.67	0.(				
b_4	r	−660.50	0.(				
b_5	q	−610.697	0.(				
b_6	p	−593.996	0.(				
b_7	o	−547.40	0.(				
b_8	n	−487.074	0.(				
b_9	m	−461.30	0.(				
b_{10}	l	−453.21	0.(				
b_{11}	k	−439.01	0.(				

Frequency referenced to a_{16} (f), R(127) 11-5, ^{1}
$f(b_{21}$, P(33) 6-3) − f(

Ref. [25, 30–34]

Table 3

$\lambda \approx 633$ nm $^{129}I_2$ P(54) 8-4

Components of a third transition

a_n	x	$[f(a_n)-f(a_{28})]$ /MHz	u_c/MHz	a_n	x	$[f(a_n)-f(a_{28})]$/MHz	u_c /MHz
a_2	z′	−449	2	a_{16}	i′	−197.73	0.08
a_3	y′	−443	2	a_{17}	h′	−193.23	0.08
a_4	x′	−434	2	a_{18}	g′	−182.74	0.03
a_5	w′	−429	2	a_{19}	f′	−162.61	0.05
a_6	v′	−360.9	1	a_{20}	e′	−155.72	0.05
a_7	u′	−345.1	1	a_{21}	d′	−138.66	0.05
a_8	t′	−340.8	1	a_{22}	c′	−130.46	0.05
a_9	s′	−325.4	1	a_{23}	a′	−98.22	0.03
a_{10}	r′	−307.0	1	a_{24}	n_2	−55.6 see m_8 table 7	0.5
a_{11}	q′	−298.2	1	a_{25}	n_1	−55.6 see m_8 table 7	0.5
a_{12}	p′	−293.1	1	a_{26}	m_2	−43.08	0.03
a_{13}	o′	−289.7	1	a_{27}	m_1	−41.24	0.05
a_{14}	n′	−282.7	1	a_{28}	k	0	—
a_{15}	j′	−206.1	0.2				

Frequency referenced to a_{16} (f), R(127) 11-5, $^{127}I_2$: f = 473 612 353 604 kHz [17]
$f(a_{28}$, P(54) 8-4) − $f(a_{16}$, R(127) 11-5 {$^{127}I_2$}) = −42.99 (4) MHz [35–36]

Ref. [35–43]

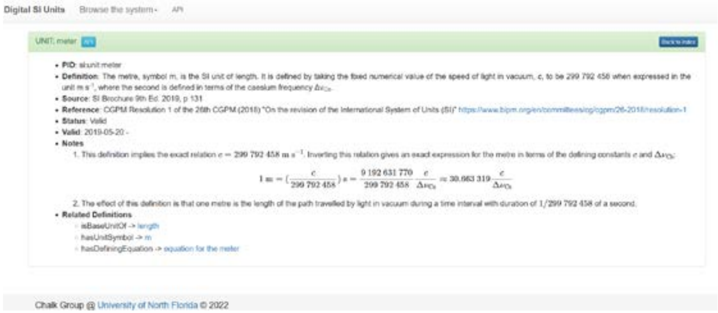
Lots of information, paper format

Hand-typed into software !

Digitalisation tasks

Task 1: The “Unique SI Reference Point” – a digital implementation of the **SI Brochure**

BIPM



Digital SI Units Browse the system ▾ API

UNIT: meter API

- **PID**: siunit:meter
- **Definition**: The metre, symbol m, is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum, c, to be 299 792 458 when expressed in the unit $m\ s^{-1}$, where the second is defined in terms of the caesium frequency $\Delta\nu_{Cs}$.
- **Source**: SI Brochure 9th Ed. 2019, p 131
- **Reference**: CGPM Resolution 1 of the 26th CGPM (2018) "On the revision of the International System of Units (SI)" https://www.bipm.org/en/committees/cg/cgpm/26-2018/resolution-1
- **Status**: Valid
- **Valid**: 2019-05-20 -
- **Notes**
  1. This definition implies the exact relation $c = 299\ 792\ 458\ m\ s^{-1}$. Inverting this relation gives an exact expression for the metre in terms of the defining constants c and $\Delta\nu_{Cs}$:

  $$1\ m = \left(\frac{c}{299\ 792\ 458}\right) s = \frac{9\ 192\ 631\ 770}{299\ 792\ 458}\frac{c}{\Delta\nu_{Cs}} \approx 30.663\ 319 \frac{c}{\Delta\nu_{Cs}}$$

  2. The effect of this definition is that one metre is the length of the path travelled by light in vacuum during a time interval with duration of 1/299 792 458 of a second.
- **Related Definitions**
  - isBaseUnitOf -> length
  - hasUnitSymbol -> m
  - hasDefiningEquation -> equation for the meter

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Task 2: CCL-CCTF **database** of recommended **frequencies with API access**

BIPM

Related transitions from MeP_I2_612nm

component	transition	operation	aref	transition_ref	diff	diff_unit	unc	unc_unit
a1	R(47) 9-2	minus	a7	R(47) 9-2	-357.16	3	0.02	3
a2	R(47) 9-2	minus	a7	R(47) 9-2	-333.97	3	0.01	3
a3	R(47) 9-2	minus	a7	R(47) 9-2	-312.46	3	0.02	3
a4	R(47) 9-2	minus	a7	R(47) 9-2	-86.168	3	0.007	3
a5	R(47) 9-2	minus	a7	R(47) 9-2	-47.274	3	0.004	3
a6	R(47) 9-2	minus	a7	R(47) 9-2	-36.773	3	0.003	3
a8	R(47) 9-2	minus	a7	R(47) 9-2	81.452	3	0.003	3
a9	R(47) 9-2	minus	a7	R(47) 9-2	99.103	3	0.003	3

Task 3: Agreed **XML schema** for data download

CCL-CCTF + NPL

NPL–proposed XML schema
Based on Digital-SI XML schema
from SmartCOM project

Proposed MeP standard frequencies XML schema

The XML schema defines five elements:

`stdfreq`	- standard frequencies – values of reference frequency, administrative information *e.g.* validity
`funcc`	- fixed uncertainty contributions – *e.g.* iodine purity
`rule`	- implementation rules – constraint information, *e.g.* cold-well temperature (min, max, nominal, sensitivity)
`transition`	- optical transitions – target atom/molecule/ion, name, offset from nominal frequency
`component`	- optical components – names & offsets from the transition reference

Using XML makes the data clear, robust, machine readable, searchable, parsable, standardised

Draft Schema and example data files

A. J. Lancaster and A. J. Lewis, “NPL MeP standard frequencies XML schema,” 07 April 2022. https://doi.org/10.5281/zenodo.6412020.

Publication and XML schemas

A digital framework for realising the SI—a proposal for the metre

A J Lewis *et al.* 2022 *Metrologia* **59** (4) 044004

https://doi.org/10.1088/1681-7575/ac7fce

NPL MeP standard frequencies XML schema

A J Lancaster *et al.* (2022)

https://doi.org/10.5281/zenodo.6412020

SmartCom Digital-SI (D-SI) XML exchange format for metrological data version 1.3.1

D Hutzschenreuter *et al.* (2020)

https://doi.org/10.5281/zenodo.3826517

IOP Publishing | Bureau International des Poids et Mesures Metrologia
Metrologia 59 (2022) 044004 (9pp) https://doi.org/10.1088/1681-7575/ac7fce

A digital framework for realising the SI—a proposal for the metre

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Abstract

A current focus of the international metrology community is the digitalisation of documents, certificates and services in response to initiatives underway throughout industry and to the requirement to follow the principles of data being Findable, Accessible, Interoperable, and Reusable. We propose the key elements of a digital framework for the SI metre, at the point of realisation, showing how it may be implemented in practice. We give examples of direct benefits of this approach, which may be extended to other SI units.

Keywords: SI, metre, digitalisation, FAIR, XML, traceability, metadata

(Some figures may appear in colour only in the online journal)

1. Introduction: digitalisation in manufacturing and metrology

The process of digitalisation is revolutionising how products are designed, produced, used, and maintained throughout their lifecycle [1], transforming factory operations and processes and their supply chains. The drivers for digitalisation are varied, being largely focussed on improving: efficiency, productivity, accuracy, or responsiveness; and through these improvements, deriving a reduction in cost. Digitalised manufacturing also has a key part to play in design for recyclability and product end of life management [2].

Metrology lies at the heart of manufacturing, and the international system of units, the SI, lies at the heart of metrology. There are two main drivers for the digitalisation of metrology. Firstly, the need for metrology to assume the same digital status as other technologies underpinning the Industry 4.0 [3] and Factory of the Future [4] paradigms; and secondly the requirements for metrology data produced though calibration to fulfil as many Findable, Accessible, Interoperable, and Reusable (FAIR) data principles as possible, especially where a publicly-funded National Metrology Institute (NMI) is the provider [5] and they are re-using high-level information on SI unit definitions and realisations.

The digitalisation of metrology is being encouraged by the International Committee for Weights and Measures (CIPM) which has tabled a Draft Resolution for the General Conference on Weights and Measures (CGPM) which will meet for its 27th meeting in November 2022. The draft resolution, 'On the global digital transformation and the International System of Units' states:

> *'The General Conference on Weights and Measures… (anticipates)… creation of a fully digital representation of the SI, including robust, unambiguous, and machine-actionable representations of measurement units, values and uncertainties; … 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 … 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, …'*

The majority of members of the CIPM Consultative Committee for Length (CCL) plan to offer digital calibration certificates and digitalisation work is already underway at the

* Author to whom any correspondence should be addressed.

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CCL-CCTF database of recommended frequencies

Welcome on CCL-CCTF database consultation

[Last update 26/01/2023 : see changes log]
>> This page is only for data content checking <<
- On request to the BIPM Time Department, a dump of the database can be provided.
- Database scheme can be accessed here
- Example of call to get XML file result : **curl -k -u ccl-cctf --url 'https://webtai.bipm.org/ccl-cctf/xml_auto.html?target=127I2|552+THz&date=2022-11-15'**

CCL+CCTF mixed informations

XML files generator

114Cd 641 THz | View

```
<freq:stdfreq xmlns:freq="NPL_MeP_Schema" xmlns:xs="http://www.w3.org/2001/XMLSchema" xmlns:si="https://ptb.de/si">
  <freq:label>474 THz - 127I2</freq:label>
  <freq:freqlabel>474 THz</freq:freqlabel>
  <freq:target>127I2</freq:target>
  <freq:validfrom>2003-10-10</freq:validfrom>
  <freq:srs>false</freq:srs>
  <freq:transitionname>R(127) 11-5</freq:transitionname>
  <freq:compname>a16</freq:compname>
  <freq:altcompname>f</freq:altcompname>
  <freq:value>
    <si:real>
      <si:value>473612353604</si:value>
      <si:unit>\kilo\hertz</si:unit>
      <si:expandedUnc>
        <si:uncertainty>9</si:uncertainty>
        <si:coverageFactor>1</si:coverageFactor>
        <si:coverageProbability>0.68</si:coverageProbability>
        <si:distribution>normal</si:distribution>
      </si:expandedUnc>
    </si:real>
  </freq:value>
  <freq:numberofrules>6</freq:numberofrules>
  <freq:rule>
    <freq:description>cell wall temperature</freq:description>
```

Reference frequencies + source data: (by transition) [CCL&CCTF]

all | View

Global content view for final XML input data check

all | View

CCL informations

See Reference frequencies list " For the meter"

CCL Table 3 related transitions (by MeP -- specie+lambda)

MeP_C2H2_1.54µm | View

CCTF informations

See Reference frequencies list "For the second"

annual calculation source data (CCTF use)

all | View

Any comment to report ? Contact us

CCL-CCTF API prototype Web Service

Bureau International des Poids et Mesures

BIPM Time Department Data Base

Home | Timing centers | Lab. equipment | Clocks / PSFS | Calibrations | Interactive plots | Web services

CCL-CCTF API prototype Web Service

Introduction

- Overview
  The Mises en Pratique for the metre and the second are currently published in the BIPM website as PDF files ("Recommended values of standard frequencies"). The CCL and CCTF communities expressed the needs to have access to these data in a machine-readable format. More about this matter can be found in A.J. Lewis and al.(2022), "A digital framework for realising the SI-a proposal for the metre" , *Metrologia 59 044004*.
  To answer to this need the BIPM Time Department started a digitalization project allowing an automatized process based on a a dedicated database and API.
  In the first release of this project the data currently available in PDF files will be provided in XML format.
- Scope
  This application programming interface (API) is providing to machines the access to the list of recommended values of standard frequencies for applications including the practical realization of the definition of the metre and secondary representations of the definition of the meter and the second.
- Technical aspects
  The following API using GET method, the access to the data is using HTTP/HTTPS protocol.
  This can be obtained using utilities to transfer data from a server (such as cURL, wget or any programming languages supporting HTTP protocol).
  A dedicated shared script to be run as client has been created for a very easy access to all the available XML files. The current version is to be considered as a prototype for extensive testing and feedbacks from users are welcome.
- Ouput format
  Data are provided in standard exchange format : XML
  (The XML schema has been defined by the National Physical Laboratory and posted on Zenodo : https://zenodo.org/record/6412020).

Technical documentation

Client download

To allow an quick and easy generation of the XML documents, a small bash script client has been developped.
This script allows to automatically download all available XMLs files with results corresponding to all reference frequencies for the meter and the second for the current date.
You can download this script: Documentation + Source code (TAR and ZIP).
It has been validated under Linux. For Windows use WSL, MSYS2, etc. to emulated the Linux environment.

URL parameters for query (syntax and arguments)

The API using GET method uses URL general syntax below :

```
https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|552+THz&date=2022-11-15
```

- "*target=*" and "*date=*" arguments are compulsory
- *date=* stands for the date "YYYY-MM-DD" for which the valid results will be returned
- *target* stands for the couple (*specie* | *frequency*), where specie is the chemical element and frequency is the short-name of the frequency as expressed in BIPM webpage which contains all 'Mises en Pratique' for the realization of the meter and the second.
  The list of all available (specie|frequency) couples can be accessed here : >> See list specie|frequency available <<

Examples of requests

It is required to use utilities supporting HTTP protocol to get the data, such as cURL , wget or other programming languages such as Python, Perl,etc.

Below you can find examples of commands:

Using wget

```
wget -O 127I2-552THz.xml "https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|552+THz&date=2022-11-15"
```

Using cURL

```
curl -k --url "https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|552+THz&date=2022-11-15" > 127I2-552THz.xml
```

Using Perl

```
#!/usr/bin/perl
use LWP::UserAgent;
my $ua = LWP::UserAgent->new;
my $response = $ua->get("https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|552+THz&date=2022-11-15") ;
if ($response->is_success) { print $response->decoded_content; }
```

Using Python

```
import requests
r = requests.get("https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|552+THz&date=2022-11-15")
print(r.text)
```

CCL-CCTF API prototype Web Service

Since 19 June 2023 V1 access open

The API using GET method uses URL general syntax below :

```
https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|552+THz&date=2022-11-15
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Using wget

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```

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if ($response->is_success) { print $response->decoded_content; }
```

Using Python

```python
import requests
r = requests.get("https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|552+THz&date=
print(r.text)
```

www.bipm.org

Example of API requests available:

Specie	Frequency	URL of query
114Cd	465 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=114Cd|465+THz&date=2023-10-01
114Cd	589 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=114Cd|589+THz&date=2023-10-01
114Cd	624 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=114Cd|624+THz&date=2023-10-01
114Cd	641 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=114Cd|641+THz&date=2023-10-01
115In+	1267 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=115In\%2B|1267+THz&date=2023-10-01
127I2	468 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|468+THz&date=2023-10-01
127I2	474 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|474+THz&date=2023-10-01
127I2	490 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|490+THz&date=2023-10-01
127I2	520 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|520+THz&date=2023-10-01
127I2	552 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|552+THz&date=2023-10-01
127I2	563 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|563+THz&date=2023-10-01
127I2	564 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|564+THz&date=2023-10-01
127I2	582 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=127I2|582+THz&date=2023-10-01
13C2H2	194 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=13C2H2|194+THz&date=2023-10-01
171Yb	518 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=171Yb|518+THz&date=2023-10-01
171Yb+	642 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=171Yb\%2B|642+THz&date=2023-10-01
171Yb+	688 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=171Yb\%2B|688+THz&date=2023-10-01
198Hg	518 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=198Hg|518+THz&date=2023-10-01
198Hg	519 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=198Hg|519+THz&date=2023-10-01
198Hg	549 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=198Hg|549+THz&date=2023-10-01
198Hg	688 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=198Hg|688+THz&date=2023-10-01
199Hg	1129 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=199Hg|1129+THz&date=2023-10-01
199Hg+	1065 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=199Hg\%2B|1065+THz&date=2023-10-01
27Al+	1121 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=27Al\%2B|1121+THz&date=2023-10-01
40Ca	456 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=40Ca|456+THz&date=2023-10-01
40Ca+	411 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=40Ca\%2B|411+THz&date=2023-10-01
85Rb	385 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=85Rb|385+THz&date=2023-10-01
86Kr	464 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=86Kr|464+THz&date=2023-10-01
86Kr	467 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=86Kr|467+THz&date=2023-10-01
86Kr	495 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=86Kr|495+THz&date=2023-10-01
86Kr	530 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=86Kr|530+THz&date=2023-10-01
86Kr	666 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=86Kr|666+THz&date=2023-10-01
87Rb	384 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=87Rb|384+THz&date=2023-10-01
87Rb	6.835 GHz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=87Rb|6.835+GHz&date=2023-10-01
87Sr	429 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=87Sr|429+THz&date=2023-10-01
88Sr	429 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=88Sr|429+THz&date=2023-10-01
88Sr+	445 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=88Sr\%2B|445+THz&date=2023-10-01
CH4	88.4 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=CH4|88.4+THz&date=2023-10-01
CH4_unresolve	88.4 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=CH4_unresolve|88.4+THz&date=2023-10-01
H	1233 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=H|1233+THz&date=2023-10-01
HeNe	474 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=HeNe|474+THz&date=2023-10-01
OsO4	29.1 THz	https://webtai.bipm.org/api/ccl-cctf/v1.0/xml_auto.html?target=OsO4|29.1+THz&date=2023-10-01

Example use of schema – 474 THz (633 nm)

```
curl -k -u ccl-cctf --url 'https://webtai.bipm.org/ccl-cctf/xml_auto.html?target=127I2|474+THz&date=2023-05-22'
```


```xml
<?xml version="1.0" encoding="UTF-8"?>

<freq:stdfreq
    xmlns:freq="NPL_MeP_Schema"
    xmlns:xs="http://www.w3.org/2001/XMLSchema"
    xmlns:si="https://ptb.de/si"
    >
    <freq:label>474 THz - I2</freq:label>
    <freq:freqlabel>474 THz</freq:freqlabel>
    <freq:target>127I2</freq:target>
    <freq:validfrom>2002-10-11</freq:validfrom>
    <freq:srs>false</freq:srs>

    <freq:transitionname>R(127) 11-5</freq:transitionname>
    <freq:compname>a16</freq:compname>
    <freq:altcompname>f</freq:altcompname>
    <freq:value>
        <si:real>
            <si:value>473612353604</si:value>
            <si:unit>\kilo\hertz</si:unit>
            <si:expandedUnc>
                <si:uncertainty>10</si:uncertainty>
                <si:coverageFactor>1</si:coverageFactor>
                <si:coverageProbability>0.68</si:coverageProbability>
                <si:distribution>normal</si:distribution>
            </si:expandedUnc>
        </si:real>
    </freq:value>

    <freq:numberofrules>5</freq:numberofrules>
    <freq:rule>
        <freq:description>Iodine cell: cell-wall temperature</freq:description>
        <freq:nominal>
            <si:real>
                <si:value>25</si:value>
                <si:unit>\degreecelsius</si:unit>
            </si:real>
```


MEP 2003

IODINE ($\lambda \approx 633$ nm)

Absorbing molecule $^{127}I_2$, a_{16} or f component, R(127) 11-5 transition (1)

1. CIPM recommended values

The values $f = 473\ 612\ 353\ 604$ kHz
$\lambda = 632\ 991\ 212.58$ fm
with a relative standard uncertainty of 2.1×10^{-11} apply to the radiation of a He-Ne laser with an internal iodine cell, stabilized using the third harmonic detection technique, subject to the conditions:

- cell-wall temperature (25 ± 5) °C (2);
- cold-finger temperature (15.0 ± 0.2) °C;
- frequency modulation width, peak-to-peak, (6.0 ± 0.3) MHz;
- one-way intracavity beam power (i.e. the output power divided by the transmittance of the output mirror) (10 ± 5) mW for an absolute value of the power shift coefficient ≤ 1.0 kHz/mW.

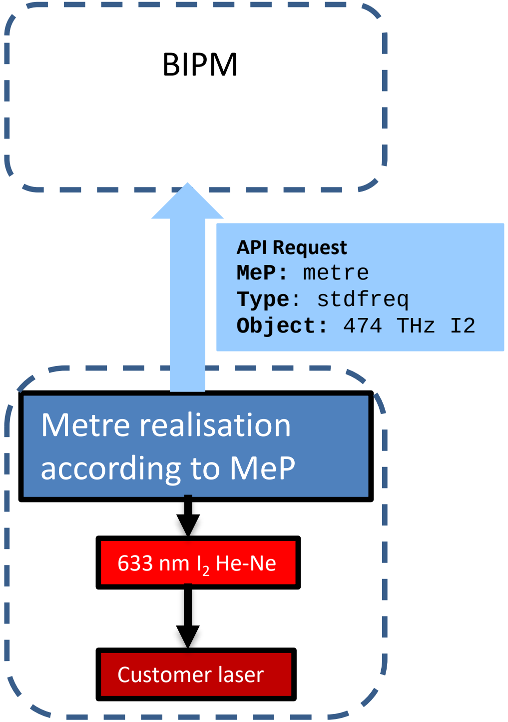
These conditions are by themselves insufficient to ensure that the stated standard uncertainty will be achieved. It is also necessary for the optical and electronic control systems to be operating with the appropriate technical performance. The iodine cell may also be operated under relaxed conditions, leading to the larger uncertainty specified in section 2 below.

2. Source data

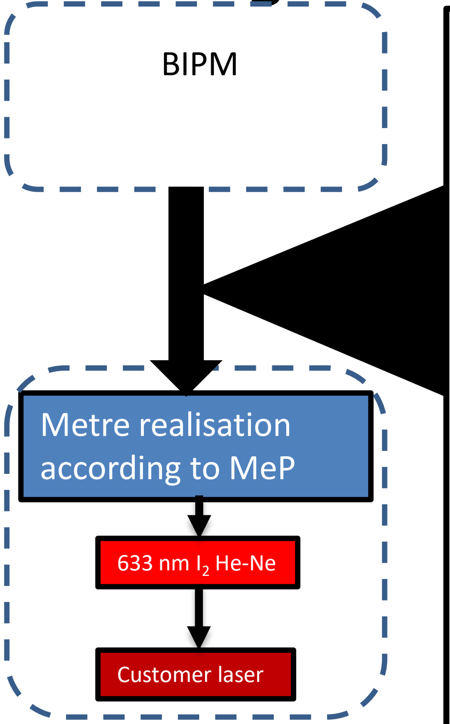
Adopted value:	$f = 473\ 612\ 353\ 604\ (10)$ kHz	$u_c/y = 2.1 \times 10^{-11}$
	for which:	
	$\lambda = 632\ 991\ 212.579\ (13)$ fm	$u_c/y = 2.1 \times 10^{-11}$


```xml
<si:value>473612353604</si:value>
            <si:unit>\kilo\hertz</si:unit>
            <si:expandedUnc>
                <si:uncertainty>10</si:uncertainty>
                <si:coverageFactor>1</si:coverageFactor>
                <si:coverageProbability>0.68</si:coverageProbability>
                <si:distribution>normal</si:distribution>
            </si:expandedUnc>
```

Meta data download during a laser calibration



NMI laser system queries the BIPM server using a structured API call

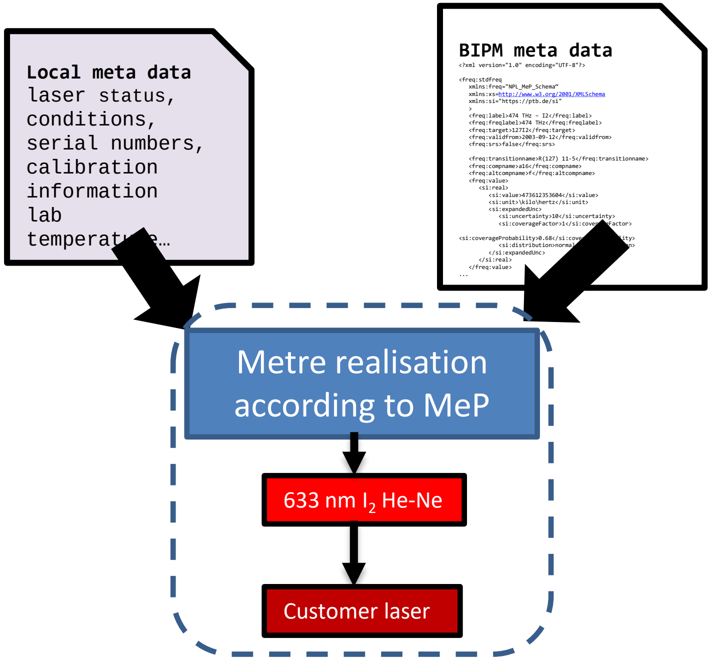


BIPM server responds with structured data based on agreed scheme

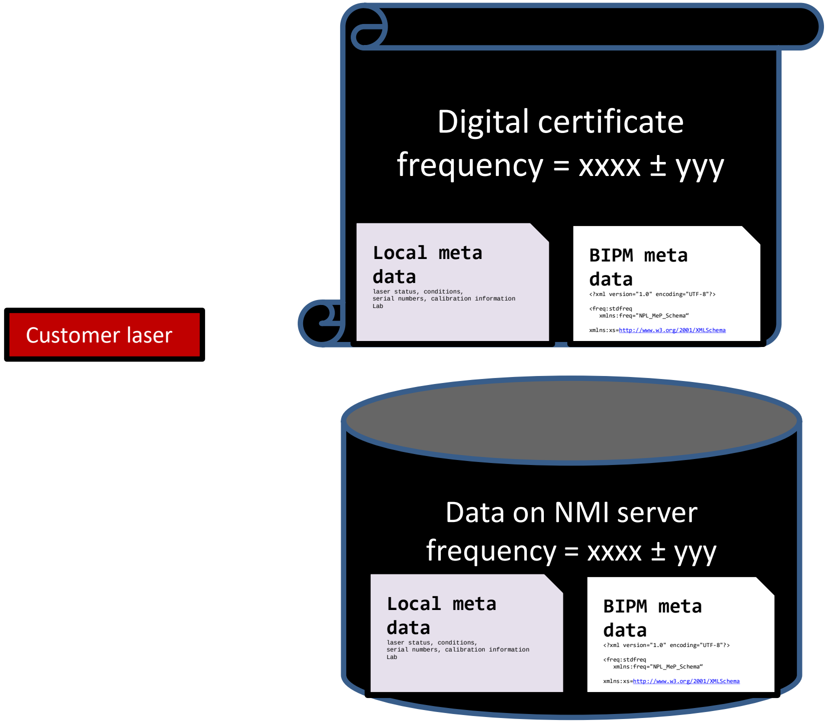

```
<?xml version="1.0" encoding="UTF-8"?>

<freq:stdfreq
   xmlns:freq="NPL_MeP_Schema“
   xmlns:xs=http://www.w3.org/2001/XMLSchema
   xmlns:si="https://ptb.de/si"
   >
   <freq:label>474 THz – I2</freq:label>
   <freq:freqlabel>474 THz</freq:freqlabel>
   <freq:target>127I2</freq:target>
   <freq:validfrom>2003-09-12</freq:validfrom>
   <freq:srs>false</freq:srs>

   <freq:transitionname>R(127) 11-5</freq:transitionname>
   <freq:compname>a16</freq:compname>
   <freq:altcompname>f</freq:altcompname>
   <freq:value>
      <si:real>
         <si:value>473612353604</si:value>
         <si:unit>\kilo\hertz</si:unit>
         <si:expandedUnc>
            <si:uncertainty>10</si:uncertainty>
            <si:coverageFactor>1</si:coverageFactor>

<si:coverageProbability>0.68</si:coverageProbability>
            <si:distribution>normal</si:distribution>
         </si:expandedUnc>
      </si:real>
   </freq:value>
...
```

Meta data exchange during a laser calibration

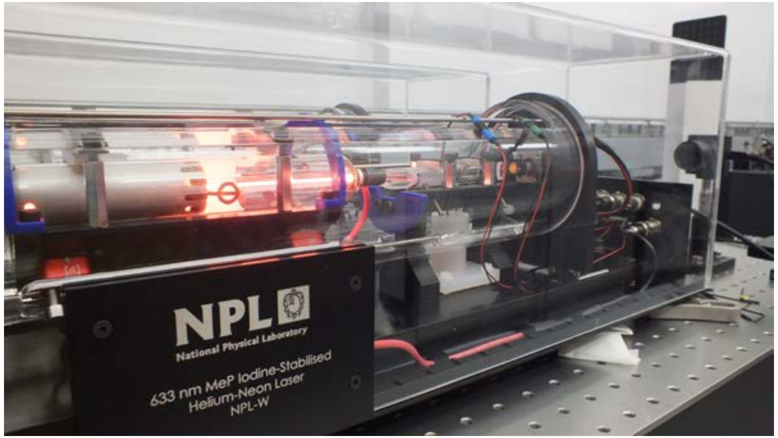
Laser calibration system performs the physical calibration, storing the XML meta data from the BIPM and additional meta data from the local system *e.g.* lab temperature, laser power



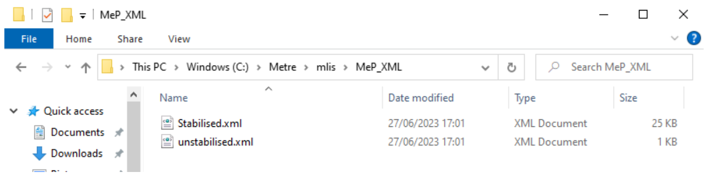
Laser is returned to customer, NMI makes the calibration data (including meta data) available from its server (or supplied on digital certificate)

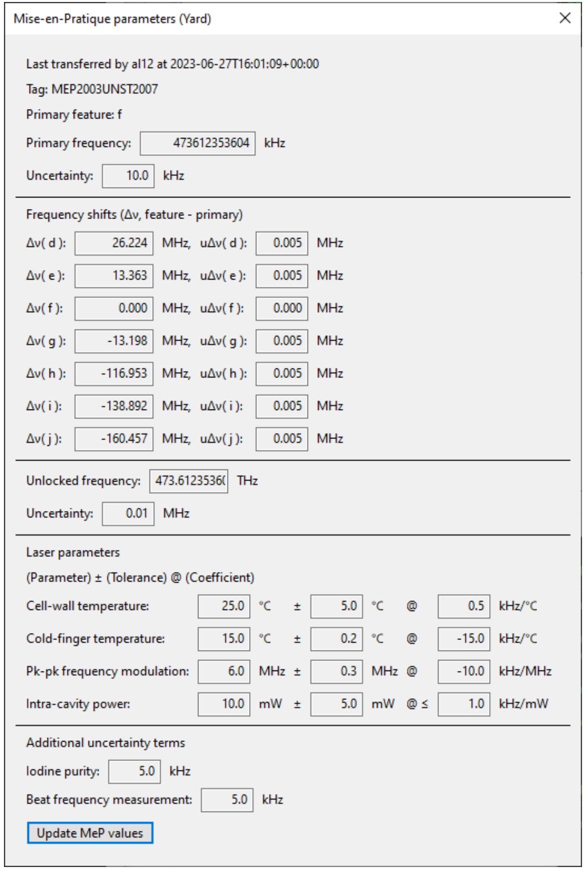


New NPL MeP laser – 'digital ready'



- Computer control of laser using embedded mini-computer (Raspberry Pi)
- Digital readout of operational parameters
- **API calls to obtain/query MeP data from the BIPM**
- Turnkey from switch-on to calibration certificate
- **27 June 2023** – live download of MeP data in XML format using API call to BIPM server





Outcomes so far

- Digital certificate (or data on NMI server) can hold both parts of the traceability of the calibration: the physical data AND the authority and validity meta data
- No transcription errors, latest values automatically used
- Fully transparent, traceable (data & authority) to SI/CIPM/CGPM via NMI
- BIPM/CIPM/SI ‘cited’ as top level in the chain
- NMI adds own meta data (adding value)
- Customer can then integrate all or some of this meta data into their own process e.g. to demonstrate the traceability link to accreditors, or to place validity limits on their use of the laser
- **Metrological traceability mirrored by MetaData traceability**

Next stage – making CMCs Interoperable

CLASS

Consultative Committee for Length (CCL)
Working Group on the MRA (WG-MRA)

CCL Length Services Classification (DimVIM)

DimVIM : Multilingual CMC classification scheme

CCL Service Category	Instrument or Artifact	Measurand(s)
	English Language Approved Terms	
1 Radiations of the Mise en Pratique		
1.1 Laser Radiations		
1.1.1	frequency stabilized laser	vacuum wavelength; optical frequency
1.2 Lamp Radiations		
1.2.1	spectral lamp	vacuum wavelength
2 Linear Dimensions		
2.1 Length Instruments		
2.1.1	(laser, length) interferometer (system, optics, refractometer)	error of indicated displacement; wavelength compensation
2.1.2	EDM instrument	error of indicated distance
2.1.3	1-D measuring machine	error of indicated [size; displacement]
2.1.4	height measuring instrument	error of indicated [vertical size; displacement]
2.1.5	1-D displacement [transduscer, actuator] (LVDT, PZT,...)	error of indicated displacement
2.1.6	gauge block comparators	error of indicated displacement
2.1.7	dial-indicator tester	error of indicated displacement
2.2 End Standards		
2.2.1	gauge block	central length; variation in length; thermal expansivity; length difference of gauge block pairs
2.2.2	length bar (long gauge block)	central length; variation in length; thermal expansivity
2.2.3	[plane, thread] micrometer setting rod	length
2.2.4	step gauge	face spacing
2.2.5	gap gauge	face spacing
2.2.6	feeler (thickness) gauge	thickness

2 possible measurands, possibly different units,
what is a 'vacuum wavelength' or an 'optical frequency'?

2 × 3 instruments:
[{laser, length} × {system, optics, refractometer}]
two measurands, possible different (or no) units
What is a 'displacement' (water volume?)
What is a 'wavelength compensation'?

4 possible measurands, possibly different units
possibly involving non-length units (K^{-1})
What is 'central length'?
What is 'thermal expansivity'?

It’s even worse in the KCDB!

Results for: Length > Dimensional metrology > Linear dimensions > End standards > Gauge block

139 results

Gauge block: central length, L
Gauge block length
Gauge blocks: central length L
Steel gauge block: central length L
Gauge blocks (steel): central length L
Gauge blocks: central length L, steel
Gauge blocks (tungsten carbide): central length L
Gauge blocks: central length L, tungsten carbide
Gauge blocks: central length L, ceramic
Gauge blocks (ceramic): central length L
Gauge blocks (chromium carbide): central length L
Gauge Blocks
Length bar (long gauge block): central length L

13 terms for the same measurand

Gauge block: variation in length
Gauge block: central length, variation in length

Gauge block: length difference of gauge block pairs
Gauge blocks: length difference L

Gauge block: linear coefficient of thermal expansion
Gauge blocks: thermal expansivity
Gauge blocks: coefficient of thermal expansion

CMCs in the KCDB are NOT interoperable ……yet

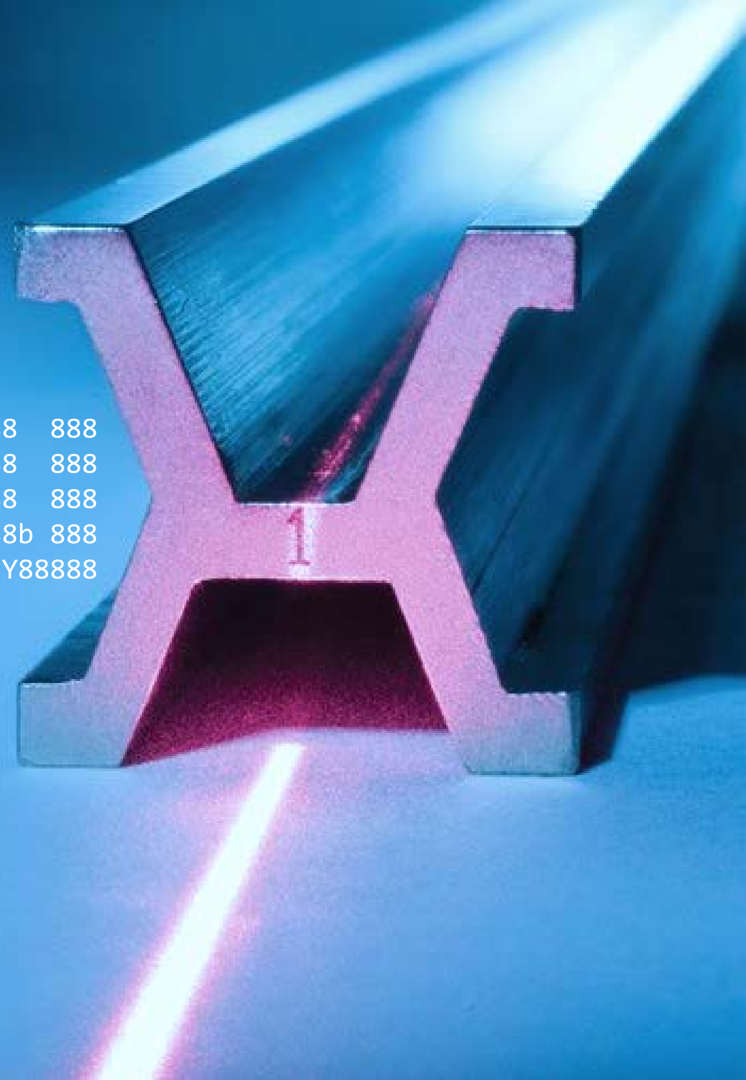
Acknowledgements

Special thanks to:

Andrew LANCASTER, NPL – XML schema, new NPL lasers

Aurélie HARMEGNIES, BIPM – digital *MeP* frequency database, web access, API

Gianna PANFILO, BIPM – CCL- CCTF liaison




```
88888888888 888                        888
    888     888                        888
    888     888                        888
    888     88888b.   8888b.  88888b.  888  888      888  888  .d88b.  888  888
    888     888 "88b     "88b 888 "88b 888 .88P      888  888 d88""88b 888  888
    888     888  888 .d888888 888  888 888888K       888  888 888  888 888  888
    888     888  888 888  888 888  888 888 "88b      Y88b 888 Y88..88P Y88b 888
    888     888  888 "Y888888 888  888 888  888       "Y88888  "Y88P"   "Y88888
                                                          888
                                                     Y8b d88P
                                                      "Y88P"
```