TC for Metrology in Length:
Highlights and Challenges

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PTB, Germany

13th General Assembly

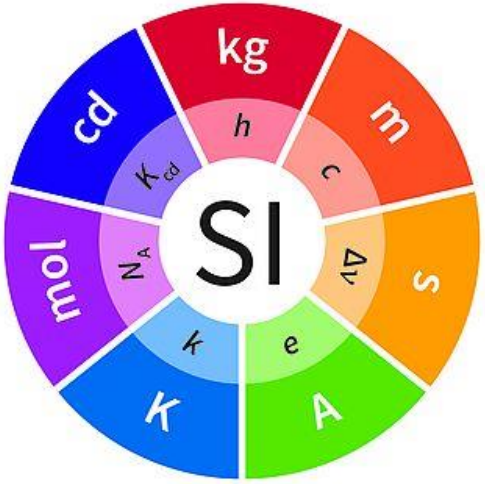
Boras, Sweden
21-24 May 2019

G13.08.05

Length

OUTLINE

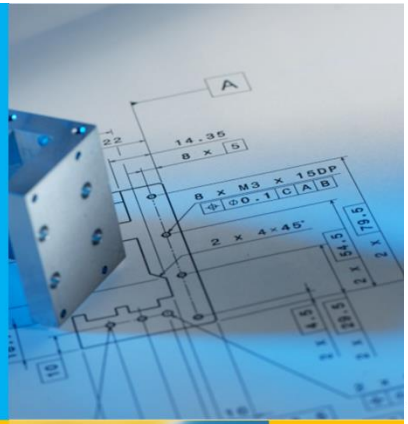
- TC-L areas of impact
- EMRP project results from Calls 2015 (to be finished in 2019)
- Revision of the SI and new *MeP* for the metre
- Nanoscale 2019 conference and future TC-L meetings



Length

Length metrology - Areas of Impact

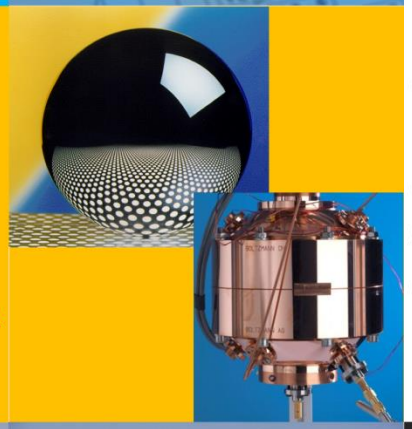
Traceability in dimensional measurements underpins all manufacturing, engineering and assembly industry worldwide, ensuring compatibility & interchangeability of parts.



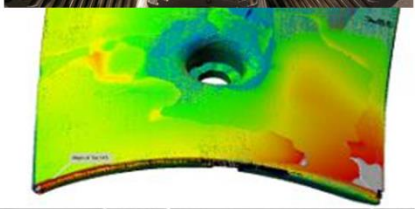
CCL Strategy Document
with input from **EURAMET TC-L members of WG-S**

Topics are dealt with in **four TC-L Roadmaps**

Precision engineering and dimensional metrology are key to 3 SI re-definitions based on fundamental constants: form & dimension of Avogadro spheres and Boltzmann resonators, Planck balance interferometry

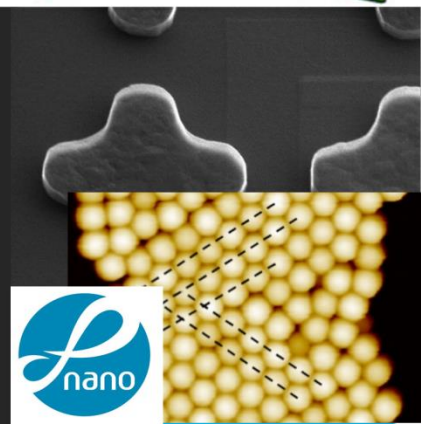


For new science (particle accelerators), energy generation (wind, civil nuclear), better accuracy & *in situ* calibration are speeding up manufacturing and enabling better efficiency, longer lifetimes. Solving gearbox problems is key to wind energy.



In aerospace, improving accuracy in aircraft assembly is reducing weight, reducing fuel burn (lower environmental impact, better energy efficiency). Key needs are accuracy and traceability for parts up to 40 m size.

Surface form and texture are critical to many nano-scale devices, particularly for *in-vivo* applications for health. Traceability infrastructure for 3D surface texture and simple dimensions on nano particles



3DNano, 15SIB09, Call 2015

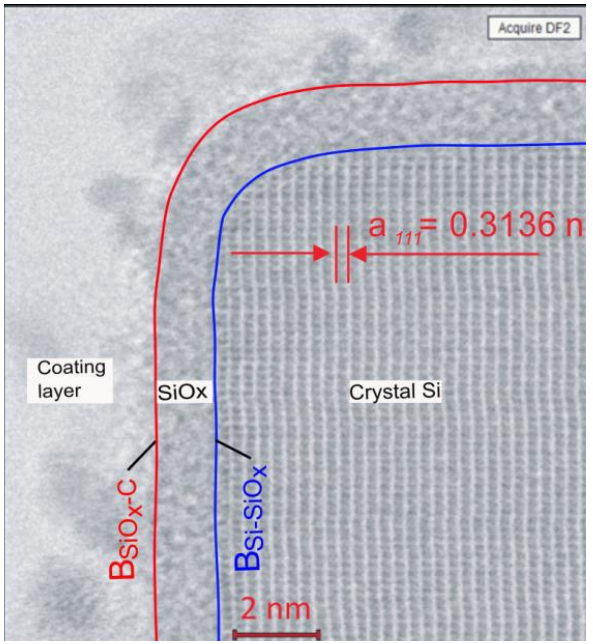
Traceable three-dimensional nanometrology

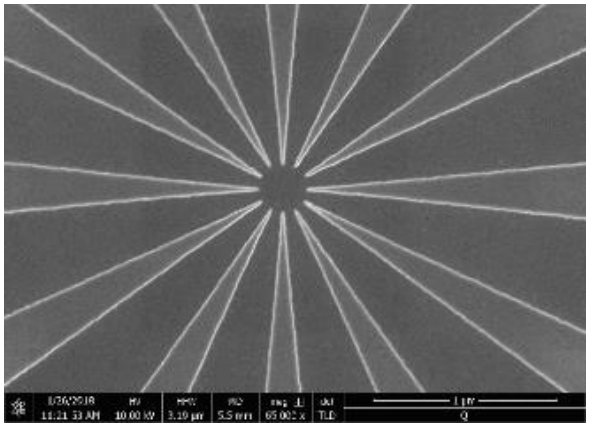
Main Challenge:

- Realisation of traceable calibration services for 3D nanometrology with uncertainty < 1 nm

Approach and main Results:

- Bottom up approach for traceability
  - Use of crystal silicon as an “internal ruler”
  - Heading to a new *mise en pratique* for the metre
- Top down approach for traceability
  - Improvement of MAFMs (Noise level, scanning speed and range)
- Reference material development
  - Siemens star, pillar structures
- Simulations on tip –sample interaction
- Hybrid metrology
  - Data fusion & Instrument fusion (Scatterometry & AFM)





Details

MetAMMI, 15HLT09, Call 2015

Metrology for additively manufactured medical implants

Main Challenge: fabrication, in additive manufacturing (AM), of medical devices (implants and chirurgical guides) that fulfil medical specifications:
=> dimension, geometry, surface accuracy, material quality.

Approach:

- Characterisation and validation of non-destructive methods enabling inspection of complex and rough AM parts (internal defects, geometrical accuracy): XCT, THz-CT
- Quantification of dimens. measurement errors in whole process AM chain of perso-nalised body part replication and standard production parts including image analysis.

Main Results: Good practice guides, protocols and reports on various advanced and routine non-destructive methods to characterise AM medical devices (description of the methods, comparison of methods, choice of the appropriate methods), on image acquisition and analysis, on medical devices along the AM process chain (characterisation, identification of geometrical deviations, identification of errors).

Details

FreeFORM, 15SIB01, Call 2015

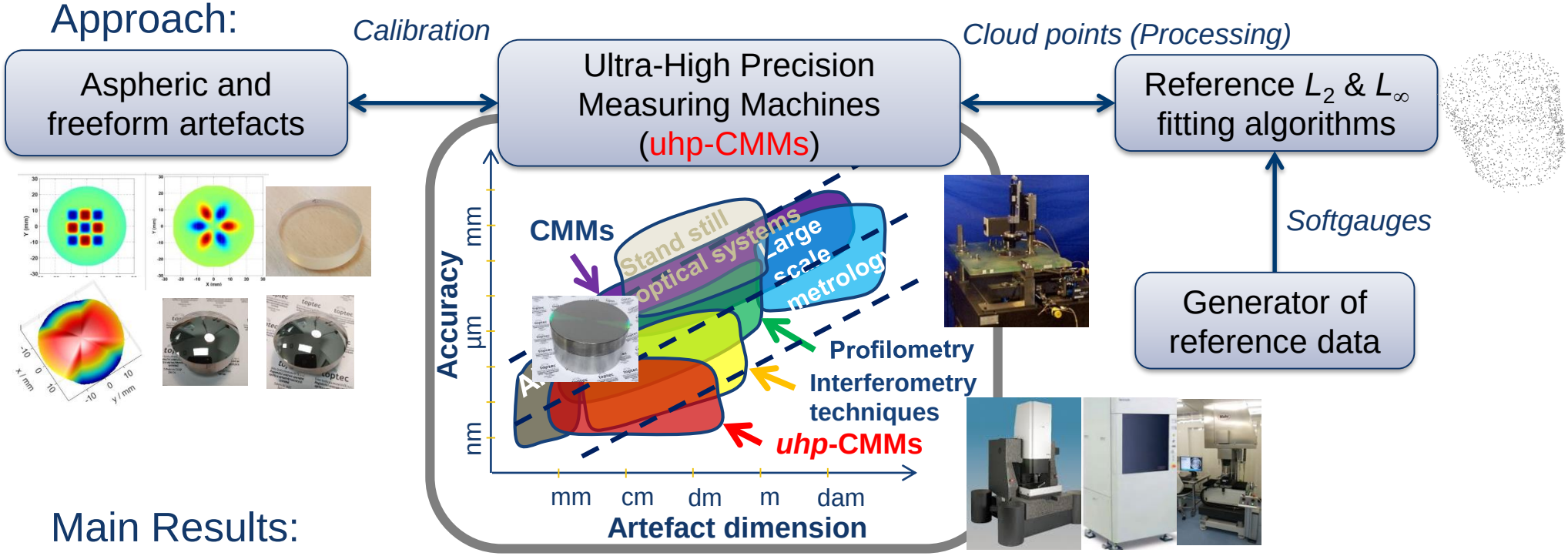
Reference algorithms and metrology on aspherical and freeform lenses

Main Challenge:

- Reference metrology (~30 nm) for aspherical and freeform optical surfaces including: software, material standards and improved measurement capabilities.

https://www.ptb.de/empir/freeform-home.html

Approach:



Main Results:

- Reference min-max and least square fitting algorithms available at LNE and CMI
- At least 10 reference softgauges available in open access through the website
- 7 thermo-invariant material standards available at PTB & LNE
- Improved measurement capabilities (TWI, UA3P-4000, F25, MFU, ISARA400, etc.)

SI Revision: *Mise en pratique*

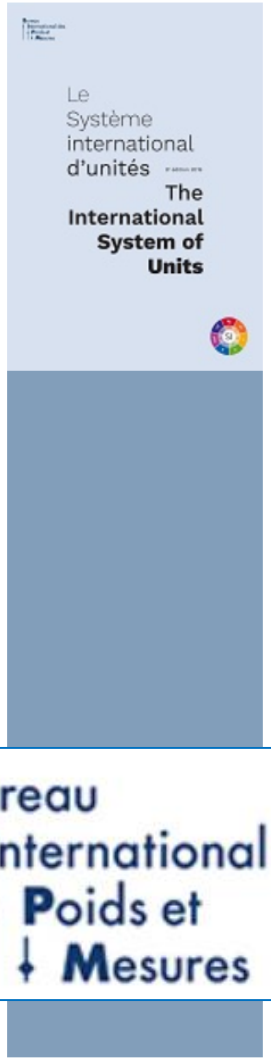
Practical realizations of the definitions of some important units

Appendix 2: *Mises en pratique* | SI Brochure (9th edition)

→ Appendix 2 of the SI Brochure

The *mises en pratique* are prepared by the relevant Consultative Committees and are then published in electronic form here on the BIPM website, where they may be revised more frequently than if they were printed in the SI Brochure.

- **second**
  - *Mise en pratique* for the definition of the second in the SI (20 May 2019)
  - Recommended values of standard frequencies (last updated 30 November 2018)
- **metre**
  - *Mise en pratique* for the definition of the metre in the SI (20 May 2019)
  - Guidance document CCL-GD-MeP-1
  - Guidance document CCL-GD-MeP-2
  - Guidance document CCL-GD-MeP-3
  - Recommended values of standard frequencies (last updated 30 November 2018)
- **kilogram**
  - *Mise en pratique* for the definition of the kilogram in the SI (20 May 2019)
  - Note on the impact of the redefinition of the kilogram on BIPM mass calibration uncertainties
- **ampere**
  - *Mise en pratique* for the definition of the ampere and other electric units in the SI (20 May 2019)
  - CCEM Guidelines for Implementation of the Revised SI
- **kelvin**
  - *Mise en pratique* for the definition of the kelvin in the SI (20 May 2019)
  - Temperatures scales and the kelvin
- **mole**
  - *Mise en pratique* for the definition of the mole in the SI (20 May 2019)
- **candela**
  - *Mise en pratique* for the definition of the candela in the SI (20 May 2019)
  - Principles governing photometry (2019)



Bureau International des Poids et Mesures

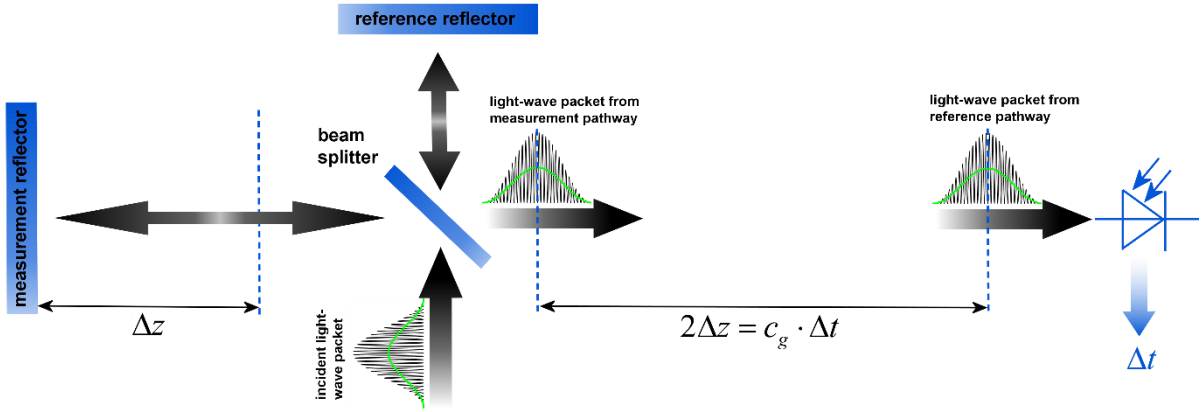
Revision of the SI: *MeP* for the metre

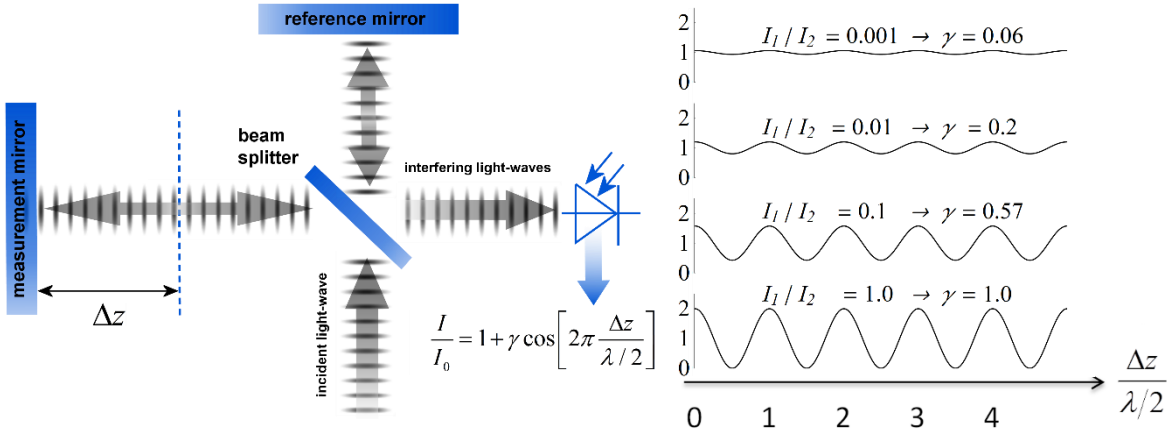
The metre, symbol m, is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum *c* to be 299 792 458 when expressed in the unit m s^{-1}, where the second is defined in terms of the caesium frequency $\Delta\nu_{Cs}$.

Mise en pratique:
Two ways for realisation of practical length meas.:

a) by direct measurement of light travelling time

b) by indirect measurement of light travelling time (optical interferometry)





Details

Revision of the SI: *MeP* for the metre

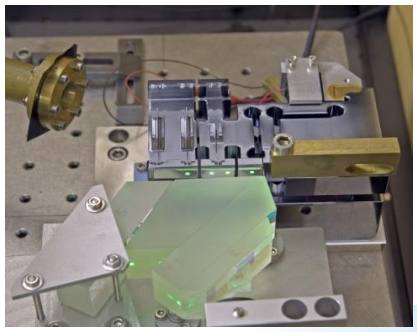
Secondary methods of realizing the metre for Dimensional Nanometrology:

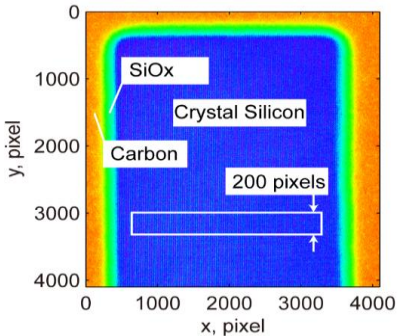
The Si {220} lattice spacing, d_{220} = 192.015 571 4 × 10^{-12} m, may be used as a secondary realisation of the definition of the metre, for dimensional nanometrology applications, using the following techniques, and with the associated caveats and uncertainty limits:

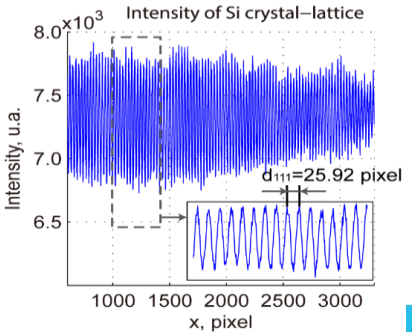
A) Measurement of a displacement by reference to the d_{220} lattice plane, using an **X-ray interferometer** can be made using either a monolithic interferometer or an interferometer comprising two parts. Both types of interferometer have uncertainties associated with them. Previous experience shows an uncertainty of 10 pm is realistic with a 10 µm displacement from a monolithic interferometer …

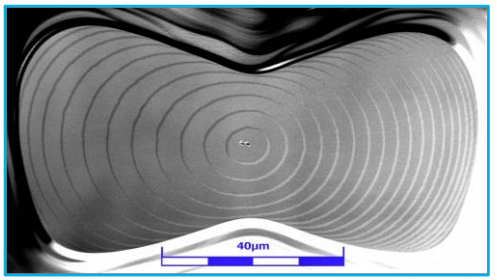
B) Calibration of **TEM** magnification by reference to a single crystal silicon artefact, where the **crystal lattice** is visible in the field of view of the TEM and the size or width of the single crystalline nanostructure can thus be determined by counting the number of lattice planes in the nanostructure. By this method U < 1 nm for the widths of line structures smaller than 200 nm could be achieved.

C) Measurement of **step height** standard artefacts manufactured from single crystal silicon, where the height range of multiple **monoatomic steps** currently is limited up to 10 nm and the uncertainties of the monoatomic step heights are 5 pm under UHV conditions and 15 pm under ambient conditions.









Details

TC-L meeting 2018

- Organised by LNE in Paris
- Oct. 15th to 16th, 2018
- Including 2 half days for workshops:
  - TC-L preparation: EMPIR calls 2019/2020
  - News from NMIs
- 34 participants

Next TC-L chairperson:
Emilio Prieto, CEM, ES

TC-L meetings 2019-2021

Thanks to TC-L for the support over last 4 years!

Thanks to EURAMET for your support!

Thank you for your attention!

Registration and payment
Registration is only possible online at
www.nanoscale.de

Early bird:	up to 15.08.19	200 €
Normal:	up to 15.09.19	270 €
Last minute:	up to 15.10.19	350 €

Students
We offer a reduced fee of 100 € (up to 15.09.19). Condition of student state has to be demonstrated at the registration desk.

Fees
The fee includes beverages, lunch, conference dinner and proceedings.

How to get to...?

Hotels
For hotels in Braunschweig, please visit http://www.nanoscale.de

Note
The special hotel rates are given for indicative purposes only and are subject to change. Participants are responsible for reserving their own accommodation and must settle their account directly with the hotel.

Scientific Committee
Jørgen Garnæs, DFM (DK); Petr Klapetek, CMI (CZ); Richard Koops (VSL); Antti Lassila, MIKES (FI); Felix Meli, METAS (CH); Gian B. Picotto, INRIM (IT); Ruedi Thalmann, METAS (CH); Sébastien Ducourtieux, LNE (FR); Andrew Yacoot, NPL (UK); Harald Bosse, PTB (DE); Hans-Ulrich Danzebrink, PTB (DE)

Organizing Committee
T. Dziomba, L. Koenders and K. Wolff, PTB, Braunschweig, Germany

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Time table
29.03.2019 Deadline for abstract submission
20.05.2019 Notification of acceptance
15.08.2019 Early bird registration
15.09.2019 Normal registration
15.10.2019 Last minute registration

NanoScale 2019

12th Seminar on Quantitative Microscopy (QM) &
8th Seminar on Nanoscale Calibration Standards and Methods

Dimensional and related measurements in the micro- and nanometre range

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT
BUNDESALLEE 100
BRAUNSCHWEIG, GERMANY

October 15th–16th, 2019

Organized by EURAMET

PTB HELMHOLTZ FONDS e.V.

µm nm

=> TC-L Meeting 2019:
14-15 Oct. 2019, PTB, DE

=> In conjunction with Nanoscale 2019 conference (15-16 Oct) and CCL WG-MRA & WG-N meetings (17-18 Oct)

=> TC-L Meeting 2020:
Oct. (?) 2020, DFM, DK

=> TC-L Meeting 2021:
Oct. (?) 2021, MBM, Podgorica, ME

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Length