CCTF

CCFT Technical Exchange on Options for Redefinition of the SI Second

“Fulfillment for the Redefinition of the SI Second: Criteria and Challenges”

Based on the work of the
Task Force for the redefinition of the second, SG 2 “Criteria”

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CONSULTATIVE COMMITTEE
FOR TIME AND FREQUENCY

CCTF Task Force on the redefinition of second (CCTF-TFU)

After reorganization in 2023:

→ **Subgroup 2 „Criteria“**

10 members from 9 countries

3 chairs: D. Calonico (INRIM), T. Ido (NICT), S. Weyers (PTB)

line of action:

8 Mandatory Criteria (“must be achieved before changing the definition“)

6 Ancillary Conditions (“are not required to be fully achieved to change the definition, but reasonable account of progress“)

For details see:

“Roadmap towards the redefinition of the second”, N Dimarcq *et al* 2024 *Metrologia* **61** 012001

Criteria and Conditions for a redefinition

Sub-sub-group 1: "OFS status"	
Criterion I.1 - Accuracy budgets of optical frequency standards Criterion I.2 - Validation of Optical Frequency Standard accuracy budgets – Frequency ratios Condition III.3 - Continuous improvement of the realization and of time scales after redefinition Condition III.4 - Availability of commercial optical frequency standards	**T. Ido (NICT, cochair)** S. Bize (LNE-SYRTE) L. Donley (NIST)
Sub-sub-group 2: "OFS operation"	
Criterion I.3 - Continuity with the definition based on Cs Criterion I.4 - Regular contributions of optical frequency standards to TAI (as secondary representations of the second) Condition I.5 – High reliability of OFS Criterion II.2 – Knowledge of the local geopotential with an adequate uncertainty level Criterion III.2 - Access to the realization of the new definition	**S. Weyers (PTB, cochair)** M. Gertsvolf (NRC) H. Margolis (NPL)
Sub-sub-group 3: "TF links and dissemination"	
Condition I.6 - Regular contributions of optical frequency standards to UTC(k) Criterion II.1 – Availability of sustainable techniques for Optical Frequency Standards comparisons Condition II.3 – High reliability of ultra high stability TF links Criterion III.1 - Definition allowing future more accurate realizations Condition III.5 - Improved quality of the dissemination towards users	**D. Calonico (INRIM, chair)** P. Defraigne (ORB) C. Rieck (RISE) P.E. Pottie (LNE-SYRTE)

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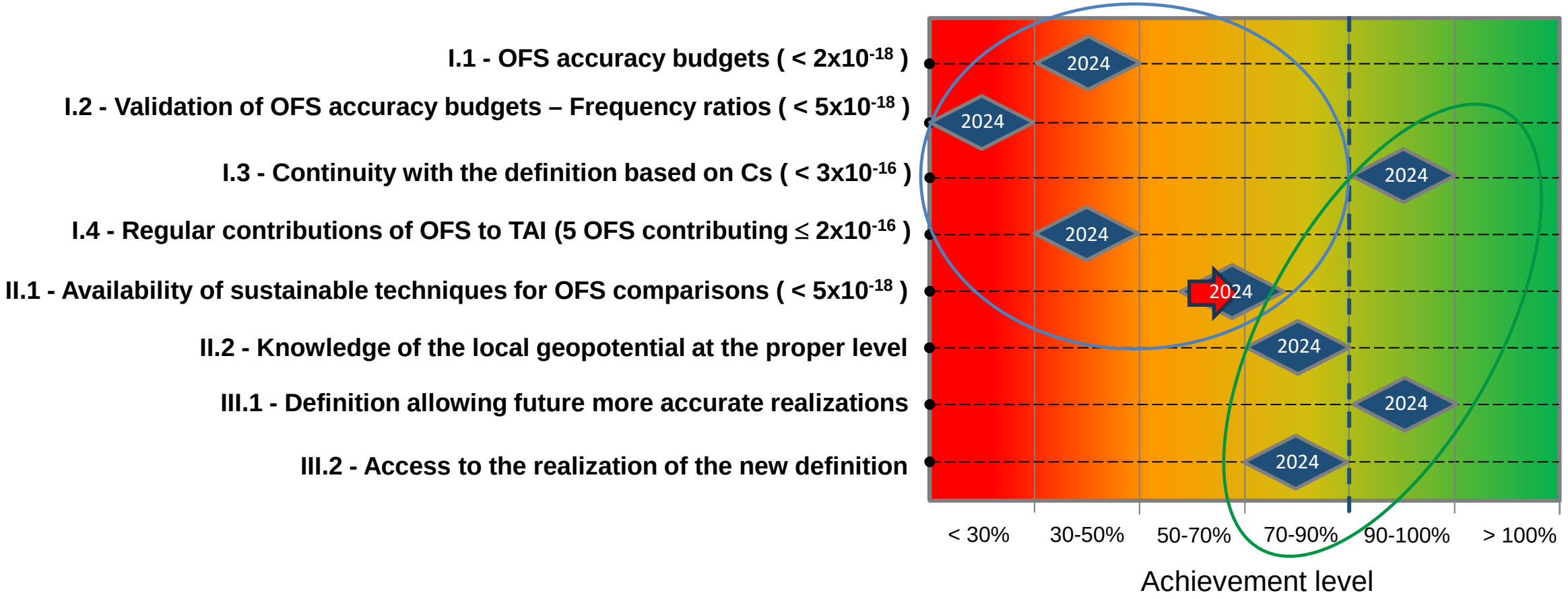
Redefinition of the Second: Criteria and their Fulfillment

8 Mandatory criteria:



Status: November 2024 - Little progress (➡) in fulfilling the criteria for redefinition since 2022

see also N Dimarcq et al 2024 Metrologia 61 012001

Criterion I.1 - OFS accuracy budgets (Nov. 2024)

Criterion	Achieved	Criticalities	Proposed mitigation actions
I.1.a ≥ 3 OFS same reference transition in different institutes $u_B \lesssim 2 \times 10^{-18}$	I.1.a **2** OFS same reference transition in different institutes $u_B \leq 2 \times 10^{-18}$ [Al^+: NIST, HUST]	I.1a Limited OFS number same reference transition in different institutes $u_B \leq 2 \times 10^{-18}$	**Additional OFS evaluations** towards an accuracy ≤ 2×10^{-18} are encouraged; in particular for reference transitions where at least 3 groups are already active (e.g. ^{87}Sr, Sr^+, Yb, Yb^+ (E3), Al^+).
I.1.b ≥ 3 OFS different reference transitions in the same or different institutes $u_B \lesssim 2 \times 10^{-18}$	I.1.b 3 different ref. trans. (Sr, Yb, Al+) with $u_B \leq 2 \times 10^{-18}$ [Sr: JILA, Yb: NIST, Al^+: NIST, HUST] Transition Yb^+(E3) is close: 2 OFS with $u_B < 3 \times 10^{-18}$ [NPL, PTB]		

Achievement Level: 30 – 50%

Criterion I.2 - Validation of OFS accuracy budgets (Nov. 2024)

Criterion	Achieved	Criticalities	Proposed mitigation actions
I.2.a ≥ 3 unit ratio measurements (same reference transition) between **different** institutes in agreement at $\lesssim 5 \times 10^{-18}$ (applicable to at least one transition of I.1)	I.2.a 3 unit ratio measurements of OFS in the **same** institute agree to $\leq 5 \times 10^{-18}$. [NIST, PTB, RIKEN]	I.2a not even 1 of the required 3 unit ratio measurements between OFS in **different** institutes in agreement at $\lesssim 5 \times 10^{-18}$	**More comparisons** are essential (e.g. fibre links, transportable clocks). This is particularly desirable for reference transitions where at least 3 groups are already active (e.g. ^{87}Sr, Sr^+, Yb, Yb^+ (E3), Al^+).
I.2.b ≥ 5 non-unit ratio measurements (different reference transitions) each ratio measured at least twice by different institutes **in agreement at $\lesssim 5 \times 10^{-18}$**	I.2.b 3 non-unit ratio measurements of OFS with **ratio uncertainties $\leq 10^{-17}$** [NIST/JILA]	I.2b not even 1 of the required 5 non unit ratio measurements between OFS at the **uncertainty level $\lesssim 5 \times 10^{-18}$**	

Achievement Level: < 30%

Criterion I.4 - Regular contributions of OFS to TAI (Nov. 2024)

Criterion	Achieved	Criticalities	Proposed mitigation actions
I.4 ≥ 3 state-of-art calibrations of TAI (uncertainty $\lesssim 2 \times 10^{-16}$ without the recommended uncertainty of the secondary representation of the second u_{srep}) each month from a set of at least 5 OFS for at least 1 y check that there is no degradation of TAI if its calibrations were done by OFS considered as primary standards and Cs frequency standards considered as secondary standards	8 OFS from 7 institutes have performed 140 TAI calibrations to date. [INRIM, KRISS, NICT, NMIJ, NIST, NPL, SYRTE]	There have not been 3 OFS calibrations of TAI every month for 1 year at any uncertainty levels. There also has not been even 1 month with 3 OFS calibrations of TAI with uncertainty $\lesssim 2 \times 10^{-16}$. Also, the number of TAI calibrations by OFS have dropped off in 2024/2025.	Encourage labs developing OFS to perform **regular TAI calibrations**. Encourage labs performing TAI calibrations with OFSs to make efforts to perform **calibrations over ≥20 d with high uptimes** to achieve contributions with total uncertainties $\lesssim 2 \times 10^{-16}$. **Future decrease of satellite transfer uncertainties.** Availability of **Commercial systems** for higher reliability.

Achievement Level: 30 – 50%

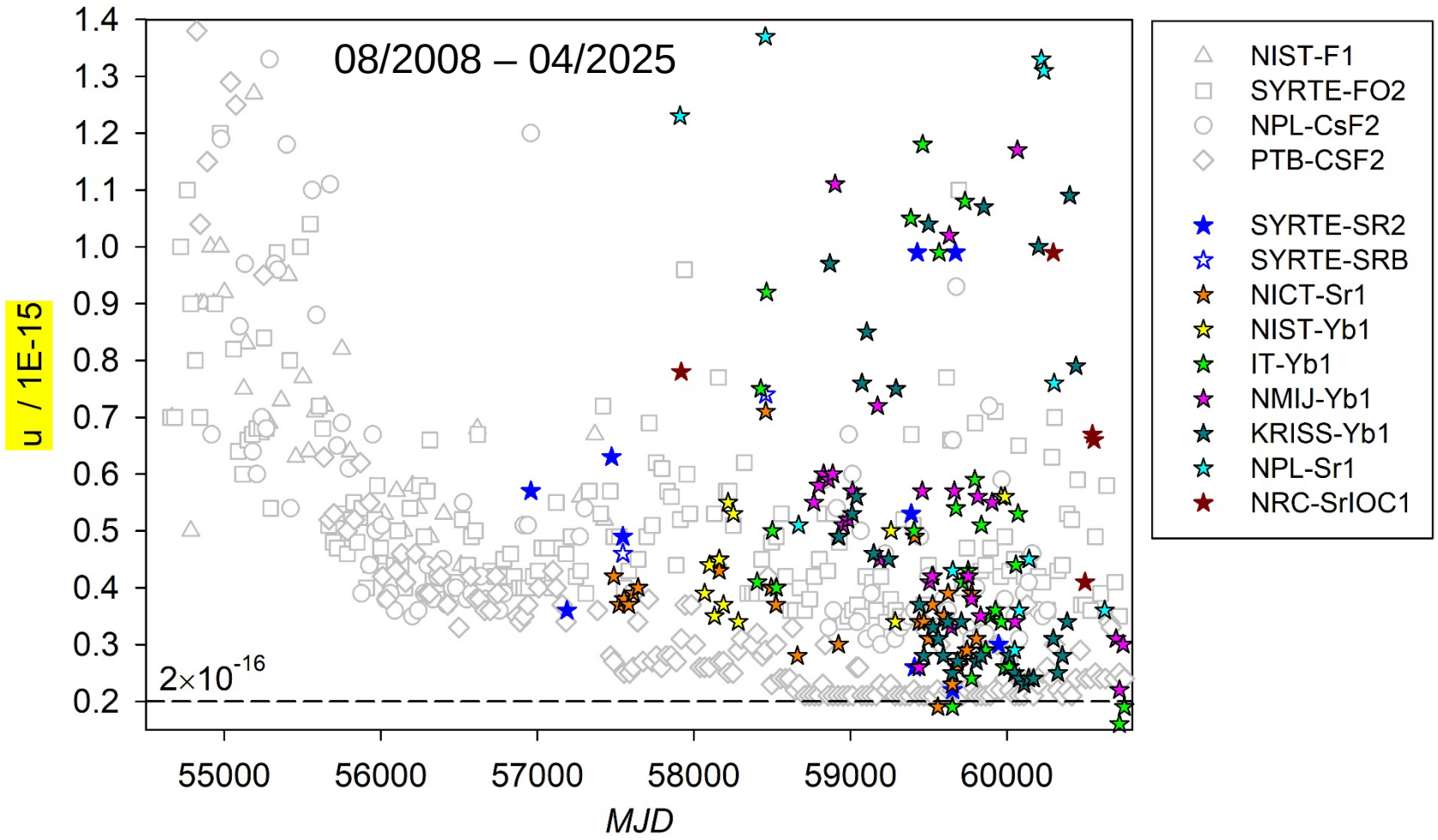
Criterion I.4 - Regular contributions of OFS to TAI (**Apr. 2025**)

- In April 2025: 161 TAI calibrations from 9 OFS from 8 institutes
  (since 10/2014) on average only 0.5 OFS calibrations per month (in the last 12 month) [Cs fountains: 7.5]

- Overall OFS calibration uncertainty
  u(uA, uB, u/Lab, ul/TAI)
  is almost always larger than the
  best Cs fountain calibrations.
  (even without considering u_{srep})

u/Lab ↔ uptime

ul/TAI ↔ evaluation duration



Criterion II.1 - Availability of sustainable techniques for OFS comparisons

Criterion	Achieved	Criticalities	Proposed mitigation actions
II.1 Availability and sustainability of transportable clocks or TF links with uncertainties $< 5 \times 10^{-18}$ for frequency comparisons between at least NMIs operating OFS of I.1 on a national/intracontinental basis (baseline up to about 1000 km)	Fiber T/F links: Uncertainties $< 5 \times 10^{-18}$ have been demonstrated, e.g. in Europe, and Japan. Comparisons in Europe involved up to 11 OFSs, in 2022 and 2023. Transportable clocks: Existing transportable OFS in Germany, Japan, and China have been operated at accuracy levels around 5×10^{-18}. In 2023, campaign with transportable clocks in Europe (transportable clocks from Japan and Germany went to UK and Germany).	Sustainability of TF links or transportable clocks with uncertainties $< 5 \times 10^{-18}$ for frequency comparisons is not yet achieved. **Achievement Level: <70%**	Encourage plans for sustainable T/F fibre links and more and better transportable clocks.

Criteria with high achievement levels (Nov. 2024)

I.3 - Continuity with the definition based on Cs (< 3×10^{-16})

3 independent absolute frequ. measurements of optical frequency transitions ($\Delta\nu/\nu < 3\times10^{-16}$): ^{87}Sr, ^{171}Yb

+ 1 OFS measurement $\Delta\nu/\nu < 3\times10^{-16}$ for $^{171}Yb^{+}$ (E3) → Achievement level 90-100%

II.2 - Knowledge of the local geopotential at the proper level

high-accuracy Relativistic Redshift determinations $\Delta\nu_{RR}/\nu < 10^{-17}$ at 7 institutes → Achievement level 70-90%

III.1 - Definition allowing future more accurate realizations

No identified fundamental effect limiting OFS accuracy at 10^{-18} level (potential to go beyond 10-18)

→ Achievement level 90-100%

III.2 - Access to the realization of the new definition

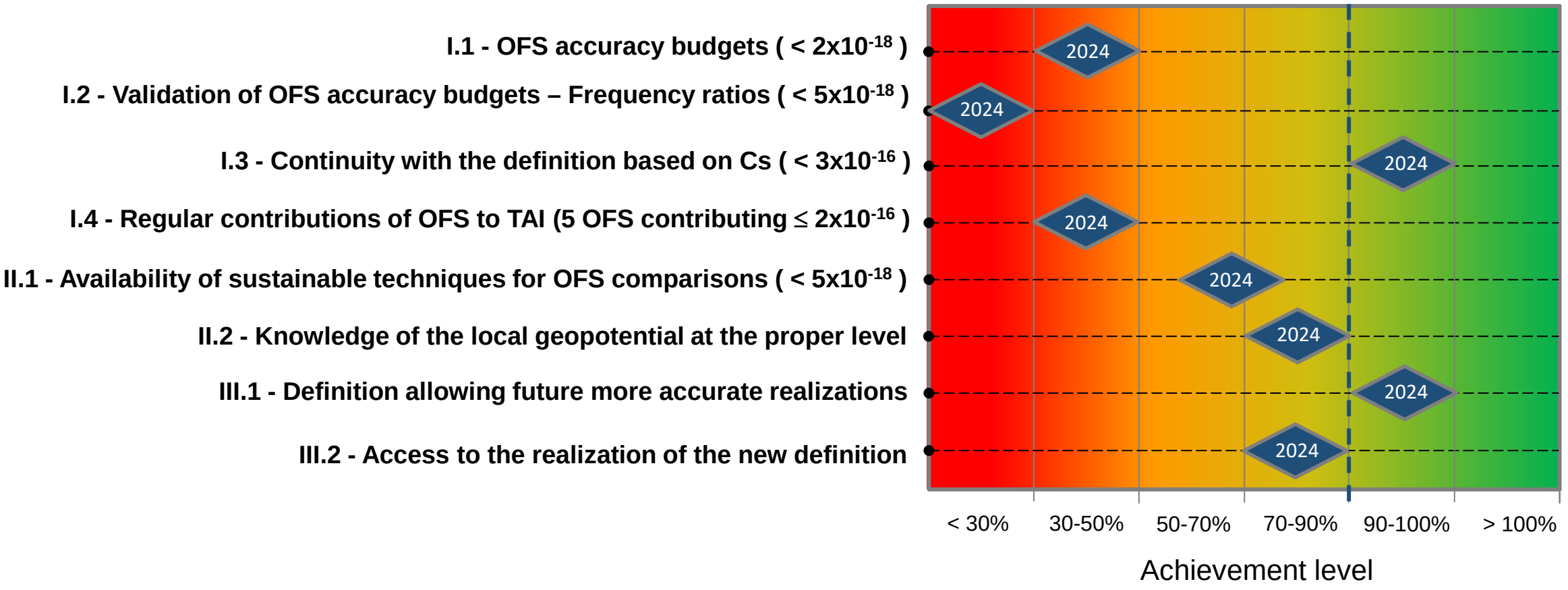
Realization / “mise en pratique” of the new definition must be easily understandable with a clear uncertainty evaluation process → corresponding documents have already been drafted

Primary/secondary representations of the SI second will continue to be accessible via metrology institutes or TAI

Cs frequency standards ensure a secondary realization of the new definition → Achievement level 70-90%

Criteria and their Fulfillment: Summary – November 2024

8 Mandatory criteria:



Update in August/September 2025

see also N Dimarcq et al 2024 Metrologia 61 012001