Report of the operation of NICT-Sr1 in 2019

The frequency standard NICT-Sr1 is an ^{87}Sr optical lattice clock operated at NICT. Utilizing the method of intermittent evaluation [1], NICT-Sr1 contributed to TAI calibration as published in the *Circular T* for the following intervals*:*

MJD 58479 to 58509 (30 days) for Jan. 2019, *Circular T* 373
MJD 58514 to 58534 (20 days) for Feb. 2019, *Circular T* 374
MJD 58644 to 58679 (35 days) for June/July 2019, *Circular T* 379.

The last one in June/July contains three measurements on MJD 58646, MJD 58658 to 58666 and MJD 58675, with an 87% coverage of the central 9 day period.

Measurements of the scale interval use an optical frequency comb to down-convert the optical frequency of 429 THz stabilized to NICT-Sr1 to a signal in the microwave domain. This then serves as a reference to evaluate the frequency of a hydrogen maser (HM). In typical intermittent evaluation, the HM frequency is measured for three hours approximately once per week, and the mean frequency of the HM with respect to the frequency of NICT-Sr1 is determined from several such data blocks distributed over the target period. The uncertainty due to non-operation time of NICT-Sr1 [1-3] is then included in ul/Lab. Additionally, an average over multiple HMs mitigates the effect of sporadic phase excursions of a specific HM [3]. Intermittent evaluation makes it easier to extend the evaluation interval longer, reducing the uncertainty ul/Tai of the satellite link to TAI. The uncertainty ul/Tai often limits the overall uncertainty particularly at short evaluation intervals. Table 1 shows uncertainty contributions for such evaluations.

In the evaluation of ul/Lab, representing the uncertainty of the link between NICT-Sr1 and the local HM, we separately consider and reported Type A and Type B uncertainties, which add in quadrature to give ul/Lab as included in the current *Circular T*.

Period of evaluation (MJD)	Evaluation mode	uA	uB	(uA/Lab)	(uB/Lab)	ul/Lab	ul/Tai	u	uSrep
58479 – 58509 (30 days)	Intermittent	0.37	0.77	(3.08)	(0.80)	3.18	2.3	4.0	4
58514 – 58534 (20 days)	Intermittent	0.20	0.73	(2.09)	(0.80)	2.24	2.8	3.7	4
58644 – 58679 (35 days)	Intermittent	0.08	0.71	(2.08)	(0.14)	2.08	1.7	2.8	4

Table 1: Reported uncertainty contributions applying the method of intermittent evaluation. The last interval includes an extended center measurement period of near continuous operation. Values are given in units of 10^{-16}.

The typical systematic corrections and their uncertainties for NICT-Sr1 as previously published [1, 3, 4] are summarized as follows:

Effect	Correction (10^{-17})	Uncertainty (10^{-17})
Blackbody radiation	513.1	3.4
Lattice scalar / tensor	0	5.3
Lattice hyperpolarizability	–0.2	0.1
Lattice E2/M1	0	0.5
Probe light	0.1	0.1
Dc Stark	0.1	0.2
Quadratic Zeeman	51.2	0.3
Density	0.4	0.9
Background gas collisions	0	1.8
Line pulling	0	0.1
Servo error	1.8	1.5
Total	566.6	6.8
Gravitational redshift	–834.1	2.2
Total (with gravitational effect)	–267.5	7.1

Table 2. Systematic corrections and their uncertainties for NICT-Sr1 between MJD 58644 and 58679.

References

[1] H. Hachisu and T. Ido, “Intermittent optical frequency measurements to reduce the dead time uncertainty of frequency link,” Jpn. J. Appl. Phys. **54**, 112401 (2015).

[2] C. Grebing, A. A-Masoudi, S. Dörcher, S Häfner, V. Gerginov, S. Weyers, B. Lipphardt, F. Riehle, U. Sterr, and C. Lisdat, “Realization of a timescale with an accurate optical lattice clock,” Optica **3**, 563 (2016).

[3] H. Hachisu, G. Petit, F. Nakagawa, Y. Hanado and T. Ido, “SI-traceable measurement of an optical frequency at low 10^{-16} level without a local primary standard,” Opt. Express **25**, 8511 (2017).

[4] H. Hachisu, F. Nakagawa, Y. Hanado and T. Ido, “Months-long real-time generation of a time scale based on an optical clock,” Sci. Reports **8**, 4243 (2018).