NRIM-BIPM.EM-K13.a and b Key Comparisons of Electrical Resistance Standards using 1 Ω and 10 kΩ Resistors as Travelling Standards: INRIM results

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5HSRVLWRU\ ,VWLWX]LRQDOH

15,0 %,30 (0 . D DQG E .H\ &RPSDULVRQV RI (OHFWULFDO 5HVL
DQG N¾ 5HVLVWRUV DV 7UDYHOOLQJ 6WDQGDUGV ,15,0 UHVX

2ULJLQDO
15,0 %,30 (0 . D DQG E .H\ &RPSDULVRQV RI (OHFWULFDO 5HVLVWDQFH 6W
5HVLVWRUV DV 7UDYHOOLQJ 6WDQGDUGV ,15,0 UHVXOWV &DSUD 3,(5 3$
/DQ]LOORWWL 0DUFR 521&$*/,21( 7(7 /XFD SS

$YDLODELOLW\
7KLV YHUVLRQ LV DYDLODEOH DW VLQFH 7 =

3XEOLVKHU

3XEOLVKHG
'2,

7HUPV RI XVH

7KLV DUWLFOH LV PDGH DYDLODEOH XQGHU WHUPV DQG FRQGLWLRQV DV V
GHVFULSWLRQ LQ WKH UHSRVLWRU\

3XEOLVKHU FRS\ULJKW

$UWLFOH EHJLQV RQ QH[W SDJH

23 February 2024

Table 1. Travelling resistors to be calibrated in the comparison.

| *Standard* | *Manufacturer* | *Mod.* | *no.* |
|---|---|---|---|
| STD 1 Ω | CSIRO | *NML* | 64200 |
| STD 1 Ω | CSIRO | *NML* | 64203 |
| STD 10 k Ω | TEGAM | SR104 - B10K09 | K205039730104 |
| STD 10 k Ω | TEGAM | SR104 - B10K12 | K201089830104 |

The standards were carefully packed, but when the container arrived at INRIM one of the sides had been deformed during the travel (Fig. 1 a, and b). The condition of the container was promptly reported to the BIPM.



*Fig. 1a, b – Unboxing and check*

## 3. Climatic conditioning of the standards – oil and air baths

The 1 Ω resistors were placed in a Guildline 9732 VT no. 58.805 oil bath with a set point temperature of 23,000°C (Fig. 2). The oil temperature is measured with a calibrated Leeds & Northrup 25 Ω s/ 177 3055 thermometer. The depth of the resistors in the oil, measured between the surface and the top of the standards was 32 mm as indicated in Fig. 3.

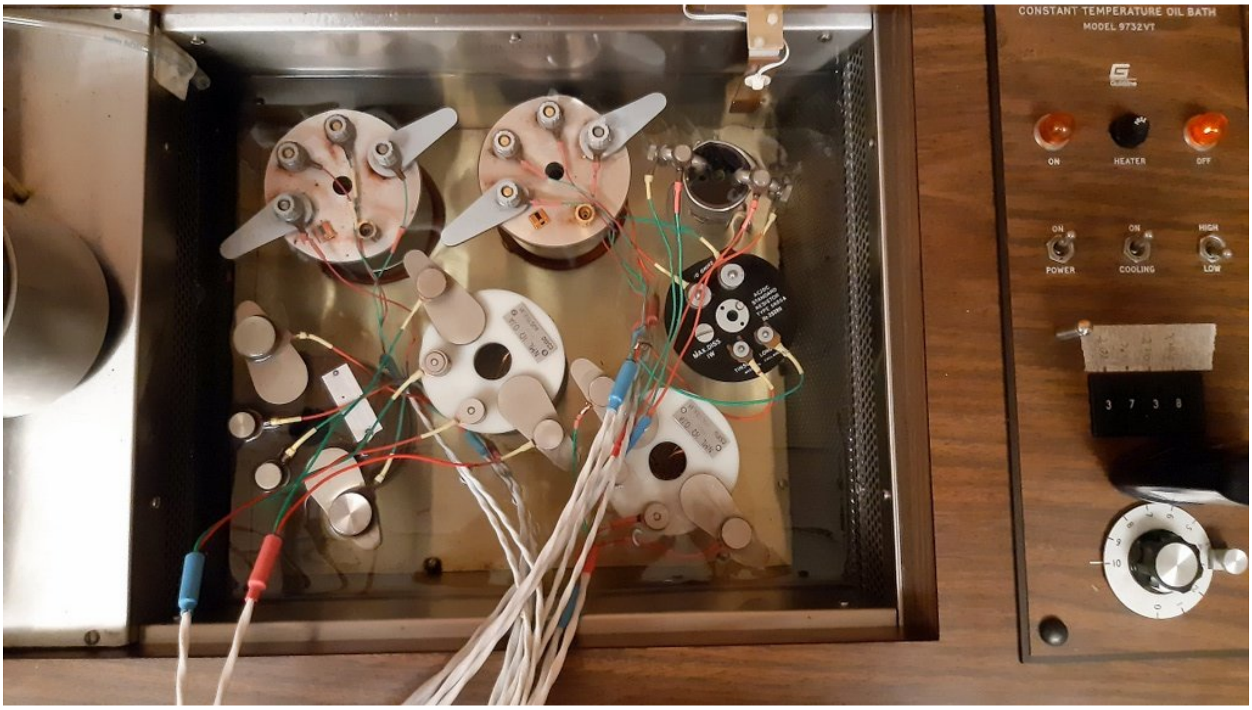


*Fig. 2 - Guildline 9732 VT oil bath. The short-term stability of the bath is approximately 0.001°C*

The 10 kΩ resistors were housed inside a Kambic air bath mod. TK-105 US no. 15115002 set at the temperature of 23°C. The air temperature near the two resistors was measured with a calibrated 100 Ω no. 4446 FLUKE thermometer.

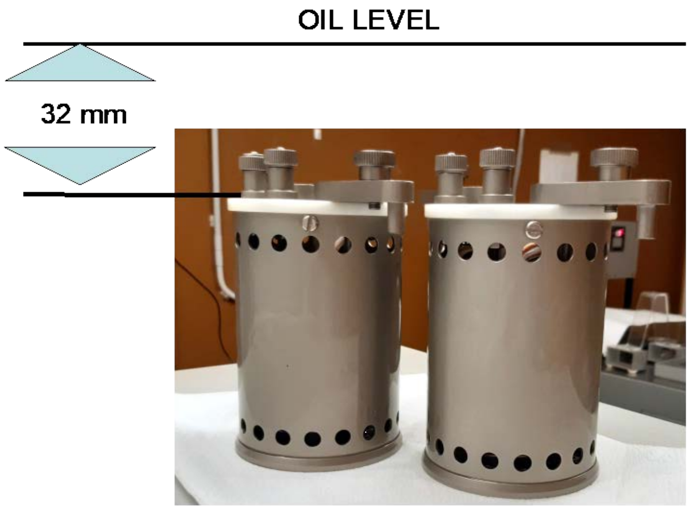


*Fig. 3 - Oil immersion depth of the 1 Ω standards.*

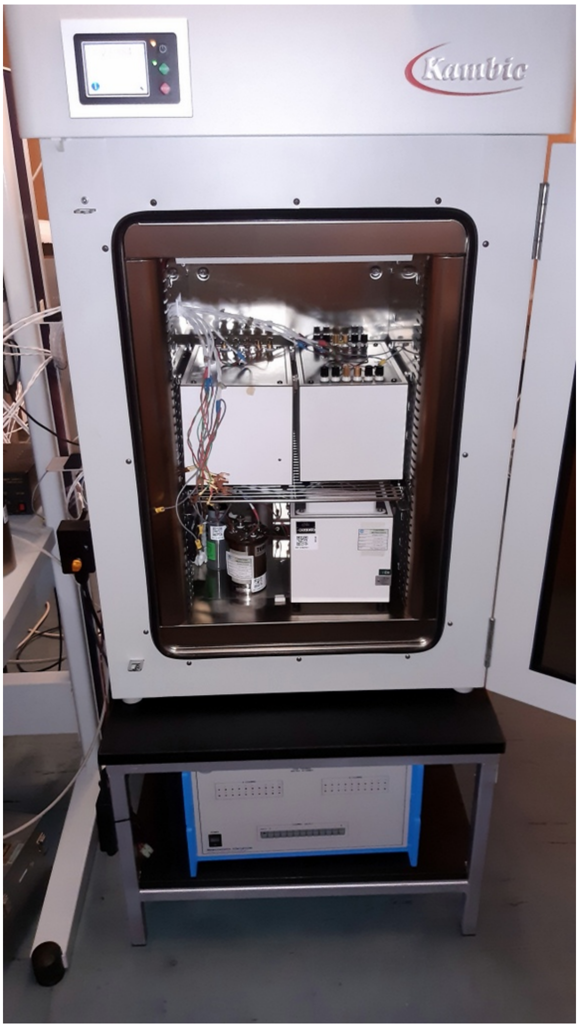


*Fig. 4 - 10 kΩ standards air-bath. The resistors were placed inside a Kambic air-bath mod. 105 with a set-point of 23.000°C and a short-term stability of approximately 0.005°C. The temperature was monitored with a PT100 platinum thermometer.*

All the resistors were connected to the measuring instrumentation by means of Teflon-insulated twisted AXON-type cables equipped with copper termination forks. The temperatures of the two baths were measured by always carrying out two series of resistance measurements in succession and at two different current values (1 mA and 1.41 mA) and making the correction due to self-heating. In correspondence with the resistance measurements of the traveling standards, the atmospheric pressure was also acquired using a Barocap-Technology instrument.

## 4. Main instrumentation – Measurements system

The measurement system used by INRIM for this international comparison is described in detail in the INRIM technical procedure [2]. Nevertheless, the same system is still based on the one described in [3] with only little difference as the use of a new high-performance automated CC bridge in place of the previous manually operated bridge.The group of INRIM working standards consists of the resistors in fig. 5. The arrows indicated in the diagram show the comparisons and the direction of the traceability in the measurements for the calibration of all the INRIM standards and for the periodic checks. The origin of traceability is the QHE that is used for the calibration of a material transfer resistor, used for the calibration of a 12960 Ω/10 Ω Hamon network. Subsequently, by means of ratios 1:10 directly with a Measurements International MI 6010Q (DCC) bridge, or in ratio 1:100 with Hamon and DCC networks, all the elements of the scale are calibrated. The first step of the precision measurements was carried out during week No. 46 with a calibration of the QHE-10 Ω transfer Hamon network with an associated uncertainty equal to U= $7\times10^{-7}$ at $2\sigma$ confidence level. The transfer of traceability from the 10 Ω Hamon network to the first element of the decade scale must take place within a short time, usually a few hours. The first group of resistors to receive traceability consists of the 10 Ω– 1 Ω – 100 Ω standards, which are calibrated and compared with each other both in a 1:10 ratio and with the 10 Ω Hamon network. Due to the impossibility of exchanging the compared resistors when they are in a ratio of 1:10, to reduce the bridge interchange error, the Hamon network is used by comparing the resistors following the diagram in Fig. 5, which allows reducing this type of systematic error. The second group of resistors consists of 100 Ω– 1kΩ – 10kΩ. Traceability is transferred to the 10 kΩ resistor via a 1kΩ step Hamon network, while the 1 kΩ resistor is calibrated against both 100 Ω and 10 kΩ, again in a 1:10 ratio. The precision measurements on the K13 traveling standards are carried out in a 1:1 ratio with 1 Ω and 10 kΩ standards of the INRIM working standard scale.

# Annex

In table 5 the measurement results provided by INRIM to the BIPM for the comparison are listed along with the corresponding dates, temperature and pressure values.

Table. 5 –INRIM measurement results in Excel format along with the corresponding dates, temperature and pressure values.

INRIM
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2022

| | 07-nov | 08-nov | 09-nov | 10-nov | 11-nov | 12-nov | 13-nov | 14-nov |
|---|---|---|---|---|---|---|---|---|
| NML 64200 - 50mA | 0.999999222 | 0.999999231 | 0.999999235 | 0.999999249 | 0.999999248 | 0.999999246 | 0.999999251 | 0.999999176 |
| NML 64200 - 100 mA | 0.999999204 | 0.999999212 | 0.999999218 | 0.999999236 | 0.999999236 | 0.999999229 | 0.999999237 | 0.999999232 |
| NML 64203 - 50 mA | 1.000000466 | 1.000000477 | 1.000000484 | 1.000000505 | 1.000000509 | 1.000000505 | 1.000000511 | 1.000000511 |
| NML 64203 - 100 mA | 1.00000046 | 1.000000466 | 1.000000467 | 1.000000485 | 1.000000497 | 1.000000483 | 1.000000498 | 1.000000494 |
| T oil bath (°C) | 23.001 | 23.001 | 23.001 | 23.000 | 23.001 | 23.001 | 23.002 | 23.001 |
| P (hPa) | 991.4 | 988.0 | 990.0 | 992.0 | 1005.0 | 1003.5 | 996.5 | 993.7 |

| | 15-nov | 16-nov | 17-nov | 23-nov | 24-nov | 25-nov | 26-nov | 27-nov |
|---|---|---|---|---|---|---|---|---|
| NML 64200 - 50mA | 0.999999255 | 0.999999262 | 0.999999254 | 0.999999201 | 0.999999181 | 0.999999167 | 0.999999208 | 0.999999197 |
| NML 64200 - 100 mA | 0.999999235 | 0.999999245 | 0.999999237 | 0.999999206 | 0.999999177 | 0.999999182 | 0.999999187 | 0.999999176 |
| NML 64203 - 50 mA | 1.000000511 | 1.000000532 | 1.000000516 | 1.000000482 | 1.00000046 | 1.000000453 | 1.000000419 | 1.000000445 |
| NML 64203 - 100 mA | 1.000000496 | 1.000000503 | 1.000000494 | 1.000000459 | 1.000000438 | 1.000000442 | 1.000000432 | 1.000000422 |
| T oil bath (°C) | 23.002 | 23.001 | 23.001 | 23.001 | 22.999 | 22.998 | 22.999 | 22.999 |
| P (hPa) | 989.9 | 978.1 | 974.0 | 972.8 | 983.7 | 989.5 | 995.4 | 1000.0 |

| | 07-nov | 08-nov | 09-nov | 10-nov | 11-nov | 12-nov | 13-nov | 14-nov |
|---|---|---|---|---|---|---|---|---|
| B10K09 | 10000.00052 | 10000.00025 | 10000.00041 | 10000.00048 | 10000.00051 | 10000.00021 | 10000.00022 | 9999.99984 |
| B10K12 | 10000.01144 | 10000.01097 | 10000.01093 | 10000.01121 | 10000.01118 | 10000.01103 | 10000.01092 | 10000.01067 |
| T air bath (°C) | 22.959 | 22.960 | 22.980 | 22.980 | 22.981 | 22.980 | 22.981 | 22.980 |
| P (hPa) | 991.91 | 990.60 | 990.50 | 994.00 | 1005.81 | 1003.42 | 998.37 | 995.31 |

| | 15-nov | 16-nov | 17-nov | 23-nov | 24-nov | 25-nov | 26-nov | 27-nov |
|---|---|---|---|---|---|---|---|---|
| B10K09 | 10000.00019 | 10000.00017 | 10000.00011 | 9999.999979 | 10000.00014 | 10000.0003 | 10000.00013 | 10000.00005 |
| B10K12 | 10000.01095 | 10000.01081 | 10000.01068 | 10000.01102 | 10000.01097 | 10000.01097 | 10000.01091 | 10000.01084 |
| T air bath (°C) | 22.980 | 22.979 | 22.979 | 22.976 | 22.980 | 22.979 | 22.979 | 22.980 |
| P (hPa) | 989.52 | 977.52 | 974.93 | 975.06 | 985.56 | 991.23 | 997.57 | 1000.08 |

INRIM
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| | 28-nov | 29-nov | 30-nov | 01-dic | 02-dic | 03-dic | 04-dic |
|---|---|---|---|---|---|---|---|
| NML 64200 - 50mA | 0.999999203 | 0.999999224 | 0.999999228 | 0.999999213 | 0.999999211 | 0.999999193 | 0.999999241 |
| NML 64200 - 100 mA | 0.999999184 | 0.99999921 | 0.999999206 | 0.999999205 | 0.9999992 | 0.999999207 | 0.999999216 |
| NML 64203 - 50 mA | 1.00000046 | 1.000000469 | 1.000000486 | 1.000000459 | 1.000000465 | 1.000000479 | 1.000000503 |
| NML 64203 - 100 mA | 1.000000432 | 1.000000454 | 1.000000456 | 1.000000446 | 1.000000452 | 1.000000463 | 1.000000464 |
| T oil bath (°C) | 22.998 | 22.995 | 22.996 | 22.996 | 22.997 | 22.996 | 22.998 |
| P (hPa) | 991.5 | 897.3 | 989.0 | 989.9 | 989.3 | 989.0 | 984.5 |

| | 05-dic | 07-dic | 08-dic | 09-dic | 10-dic | 11-dic | 12-dic |
|---|---|---|---|---|---|---|---|
| NML 64200 - 50mA | 0.999999243 | 0.999999224 | 0.999999172 | 0.999999215 | 0.999999224 | 0.999999227 | 0.999999206 |
| NML 64200 - 100 mA | 0.99999923 | 0.9999992 | 0.999999194 | 0.999999201 | 0.99999921 | 0.999999203 | 0.999999187 |
| NML 64203 - 50 mA | 1.000000497 | 1.00000047 | 1.000000456 | 1.00000048 | 1.000000479 | 1.000000471 | 1.000000444 |
| NML 64203 - 100 mA | 1.000000477 | 1.000000447 | 1.000000436 | 1.00000045 | 1.000000453 | 1.000000456 | 1.000000426 |
| T oil bath (°C) | 22.998 | 22.999 | 22.998 | 22.998 | 22.998 | 22.998 | 22.999 |
| P (hPa) | 988.3 | 986.5 | 982.0 | 976.3 | 970.5 | 970.2 | 978.0 |

| | 28-nov | 29-nov | 30-nov | 01-dic | 02-dic | 03-dic | 04-dic |
|---|---|---|---|---|---|---|---|
| B10K09 | 9999.999812 | 10000.00012 | 10000.00013 | 9999.999836 | 10000.00021 | 10000.00002 | 10000.00019 |
| B10K12 | 10000.01092 | 10000.0111 | 10000.01074 | 10000.01094 | 10000.01088 | 10000.01102 | 10000.01089 |
| T air bath (°C) | 22.979 | 22.980 | 22.979 | 22.979 | 22.979 | 22.979 | 22.980 |
| P (hPa) | 990.87 | 998.17 | 989.60 | 990.59 | 989.94 | 989.15 | 984.44 |

| | 05-dic | 07-dic | 08-dic | 09-dic | 10-dic | 11-dic | 12-dic |
|---|---|---|---|---|---|---|---|
| B10K09 | 9999.999904 | 9999.999989 | 10000.0001 | 9999.999754 | 9999.99974 | 10000.00007 | 10000.00027 |
| B10K12 | 10000.01071 | 10000.01076 | 10000.01106 | 10000.01094 | 10000.01084 | 10000.01107 | 10000.01114 |
| T air bath (°C) | 22.980 | 22.979 | 22.979 | 22.980 | 22.979 | 22.979 | 22.978 |
| P (hPa) | 989.34 | 987.00 | 982.00 | 975.50 | 970.50 | 972.00 | 980.00 |