

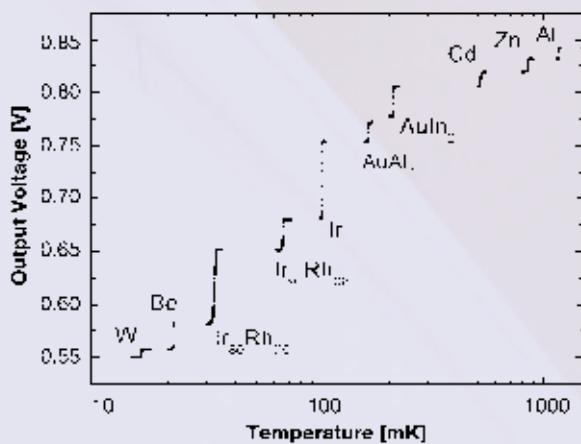
# Evaluation of SRD1000 Superconductive Reference Devices

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## Starting Point

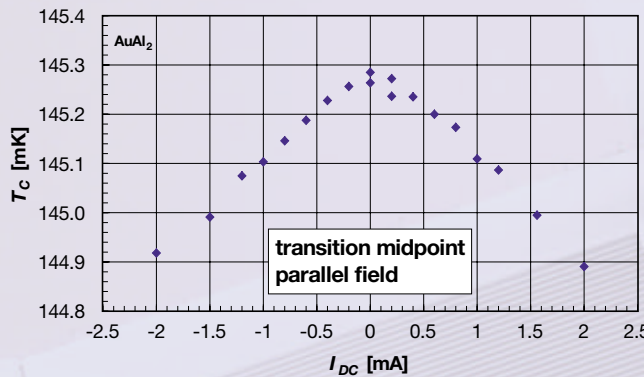
- New Superconductive Reference Device SRD1000
- 10 reference materials from 15 mK to 1200 mK
- For in situ calibration of interpolating thermometers
- Dissemination of the Provisional Low-Temperature Scale, PLTS-2000
- Prototypes
  - Built and tested by HDL and KOL
  - Calibrated at NMI-VSL
  - Evaluated at NPL, CNRS-CRTBT & AL, BNM-INM, PTB
- Results
  - Magnetic field effect
  - Transition temperatures  $T_C$  and widths  $W_C$
  - Temperature uncertainties



## Magnetic Field Tests

- $T_C$  suppression: -0.1 mK/ $\mu$ T
- Shields included: Cryoperm and Niobium, cylindrical
- Applied magnetic fields:
  - ac measuring field: 0.3  $\mu$ T (perpendicular to cylinder)
  - superimposed dc field perpendicular to cylinder
  - dc field in compensation coil parallel to device axis
- Trapped fields:
  - parallel to cylinder axis
  - perpendicular to device axis

|               |                            | CNRS-CRTBT    | PTB             | NPL                       |
|---------------|----------------------------|---------------|-----------------|---------------------------|
| Perpendicular | $B^{\text{meas}}$          | 0.3 $\mu$ T   | 0.3 $\mu$ T     | 0.3 $\mu$ T               |
|               | $\delta T_C^{\text{meas}}$ | 0.018 mK      | 0.013 mK        | 0.022 mK                  |
|               | $B^{\text{res}}$           | < 0.1 $\mu$ T | < 0.1 $\mu$ T   | 0.2 $\mu$ T - 0.3 $\mu$ T |
|               | $\delta T_C^{\text{res}}$  | < 0.006 mK    | $\leq$ 0.005 mK | 0.020 mK                  |
| Parallel      | $B^{\text{res}}$           | < 0.1 $\mu$ T | 0.4 $\mu$ T     | 0.2 $\mu$ T - 0.5 $\mu$ T |
|               | $\delta T_C^{\text{res}}$  | < 0.006 mK    | $\leq$ 0.005 mK | < 0.010 mK                |



## Evaluation Procedure and Measurements

- Warming - cooling (-2nd warming)
- Repeated to check for hysteresis
- Small temperature steps ( $\leq$  0.1 mK) and stabilisation plateaux (8 min - 30 min)
- Analog output of mutual inductance system monitored
- Normalised to fully normal (100%) and superconducting states (0%)
- Transition temperature  $T_C$ : midpoint (50%)
- Transition width  $W_C$ :  $T_{90\%} - T_{10\%}$

## Thermometry and Uncertainty

- PLTS-2000: <sup>3</sup>He melting pressure (PTB and CRTBT cell designs)
- ITS-90: RhFe resistance thermometers
- CRTBT: also CMN and NBS-768
- Uncertainties: scale realisation & midpoint identification

Uncertainty ( $k = 2$ ) of  $T_C$  determination. In parenthesis: uncertainty in realisation of PLTS-2000. NMI-VSL: preliminary tests only.

|                                   | approx. $T_C$ [mK] | CNRS-CRTBT [mK] | PTB [mK]    | BNM-INM [mK] | NPL [mK]    | NMI-VSL [mK] |
|-----------------------------------|--------------------|-----------------|-------------|--------------|-------------|--------------|
| W                                 | 15                 | 0.04 (0.03)     | 0.06 (0.04) | -            | -           | 0.2          |
| Be                                | 20                 | 0.04 (0.03)     | 0.06 (0.04) | -            | -           | 0.2          |
| Ir <sub>80</sub> Rh <sub>20</sub> | 35                 | 0.04 (0.03)     | 0.24 (0.06) | -            | 0.20 (0.06) | 0.2          |
| Ir <sub>92</sub> Rh <sub>8</sub>  | 60                 | 0.06 (0.04)     | 0.20 (0.06) | 0.6 (0.2)    | 0.10 (0.08) | 0.2          |
| Ir                                | 100                | 0.06 (0.05)     | 0.14 (0.06) | 0.4 (0.1)    | 0.12 (0.10) | 0.2          |
| AuAl <sub>2</sub>                 | 160                | 0.08 (0.07)     | 0.14 (0.10) | 0.4 (0.1)    | 0.16 (0.12) | 0.5          |
| AuIn <sub>2</sub>                 | 210                | 0.16 (0.14)     | 0.20 (0.14) | 0.4 (0.1)    | 0.32 (0.24) | 0.9          |
| Cd                                | 520                | 0.18 (0.12)     | 2.90 (0.12) | 4.0 (0.1)    | 1.20 (0.20) | 0.6          |
| Zn                                | 850                | 0.10 (0.06)     | 1.08 (0.06) | 6.0 (0.2)    | 0.58 (0.10) | 0.8          |
| Al                                | 1200               | 4 (4)           | 0.48 (0.36) | 1.4 (0.2)    | 1.1 (1.0)   | 1.0          |

## Results

|                                   | SRD003<br>CNRS-CRTBT |            | SRD004<br>PTB |            | SRD005<br>BNM-INM |            | SRD006<br>NPL |            |
|-----------------------------------|----------------------|------------|---------------|------------|-------------------|------------|---------------|------------|
|                                   | $T_C$ [mK]           | $W_C$ [mK] | $T_C$ [mK]    | $W_C$ [mK] | $T_C$ [mK]        | $W_C$ [mK] | $T_C$ [mK]    | $W_C$ [mK] |
| W                                 | 15.25                | 0.07       | 15.2          | 0.17       | -                 | -          | -             | -          |
|                                   | (-)                  | (-)        | (-)           | (-)        | (16.03)           | (0.58)     | (-)           | (-)        |
| Be                                | 20.56                | 0.33       | 20.1          | 0.03       | -                 | -          | -             | -          |
|                                   | (21.12)              | (0.11)     | (21.98)       | (0.08)     | (20.98)           | (0.84)     | (20.98)       | (0.51)     |
| Ir <sub>80</sub> Rh <sub>20</sub> | 31.45                | 1.17       | 31.7          | 1.13       | -                 | -          | 34.21         | 0.68       |
|                                   | (32.09)              | (0.97)     | (32.32)       | (0.99)     | (31.85)           | (0.50)     | (32.22)       | (0.62)     |
| Ir <sub>92</sub> Rh <sub>8</sub>  | 65.05                | 0.65       | 65.7          | 0.94       | 65.3              | 0.7        | 65.57         | 0.57       |
|                                   | (65.52)              | (0.66)     | (66.10)       | (0.94)     | (65.70)           | (0.93)     | (65.93)       | (0.45)     |
| Ir                                | 94.13                | 1.07       | 99.2          | 0.57       | 98.9              | 0.3        | 98.91         | 0.52       |
|                                   | (94.38)              | (1.07)     | (99.34)       | (0.55)     | (99.53)           | (0.38)     | (99.39)       | (0.41)     |
| AuAl <sub>2</sub>                 | 137.23               | 0.56       | 160.6         | 0.44       | 160.8             | 0.7        | 144.95        | 0.48       |
|                                   | (n. a.)              | (n. a.)    | (160.89)      | (0.73)     | (160.93)          | (0.82)     | (n. a.)       | (n. a.)    |
| AuIn <sub>2</sub>                 | 207.72               | 1.0        | 207.9         | 0.65       | 207.9             | 0.5        | 208.4         | 3.20       |
|                                   | (207.94)             | (0.94)     | (207.80)      | (1.58)     | (206.24)          | (0.67)     | (n. a.)       | (n. a.)    |
| Cd                                | 520.18               | 12.5       | 520.5         | 14.5       | 522.6             | 12.1       | 530.4         | 12.6       |
|                                   | (515.9)              | (9.1)      | (516.9)       | (14.0)     | (525.3)           | (17.4)     | (517.7)       | (8.7)      |
| Zn                                | 851.71               | 9.08       | 851.7         | 5.42       | 853.3             | 15.6       | 850.9         | 7.8        |
|                                   | (844.6)              | (8.6)      | (843.7)       | (5.9)      | (n. a.)           | (13.7)     | (844.1)       | (9.9)      |
| Al                                | 1185                 | 3.4        | 1178.2        | 1.66       | 1185              | 3.1        | 1178.6        | 3.8        |
|                                   | (n. a.)              | (n. a.)    | (1166)        | (3.5)      | (n. a.)           | (n. a.)    | (n. a.)       | (n. a.)    |

Transition temperatures  $T_C$  and transition widths  $W_C$  of the SRD prototypes. In parenthesis: preliminary tests at NMI. "n. a.": not applicable either because sample replaced or insufficient data.

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