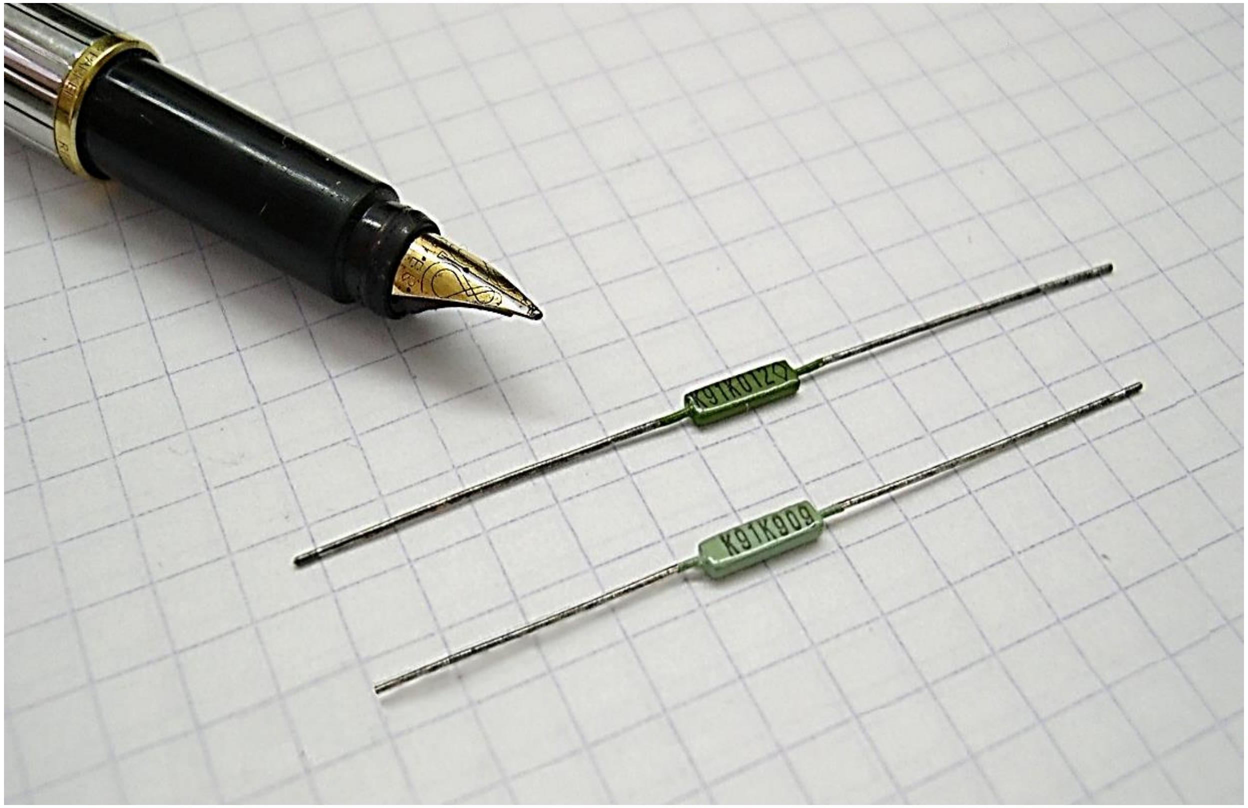
A comparison of Two Kinds of TVO Cryogenic Temperature Sensors

Yu.P. Filippov, V.M. Miklyaev

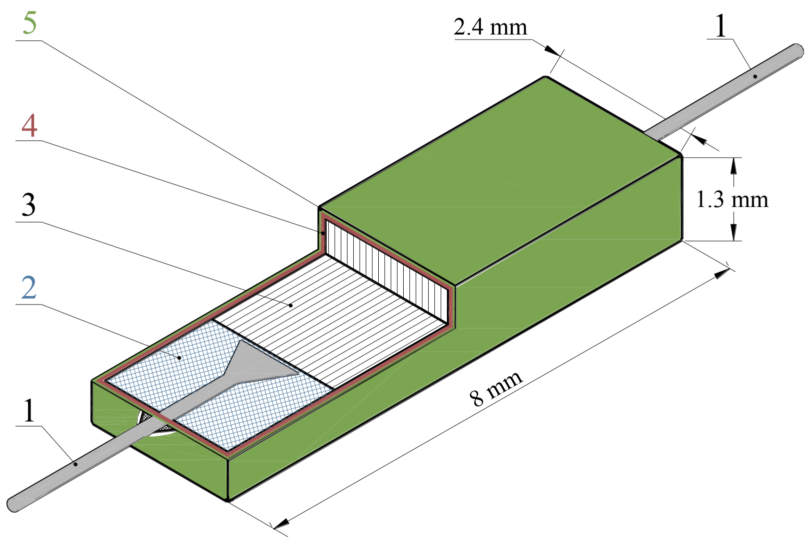
Joint Institute for Nuclear Research, Joliot-Curie, 6, Dubna, Russia, Cryophysics Group

Two kinds of cryogenic temperature TVO sensors



Temperature sensors based on TVO resistors:
TVO of dark green color – produced in the year 1991 (near the pen),
TVO of light green color – produced in the year 2009.

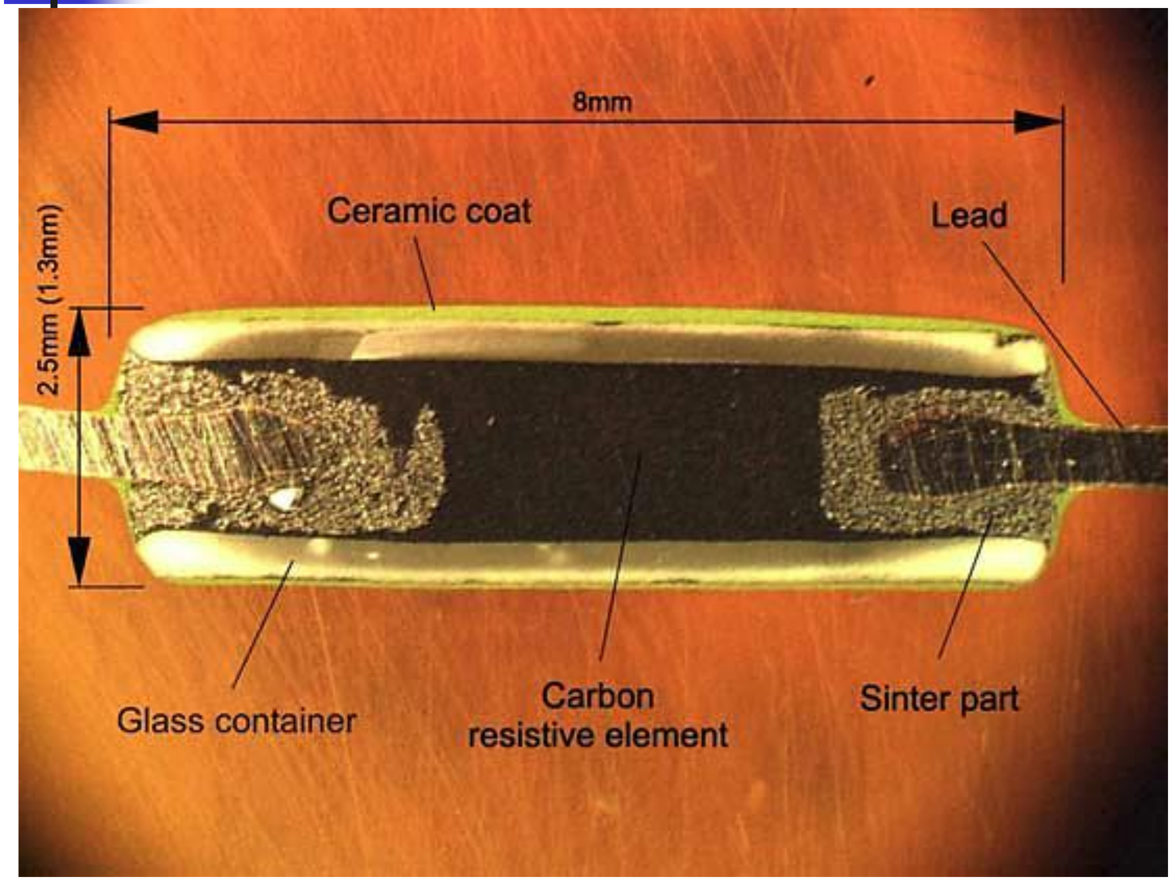
Compared T-sensors with negative temperature coefficients

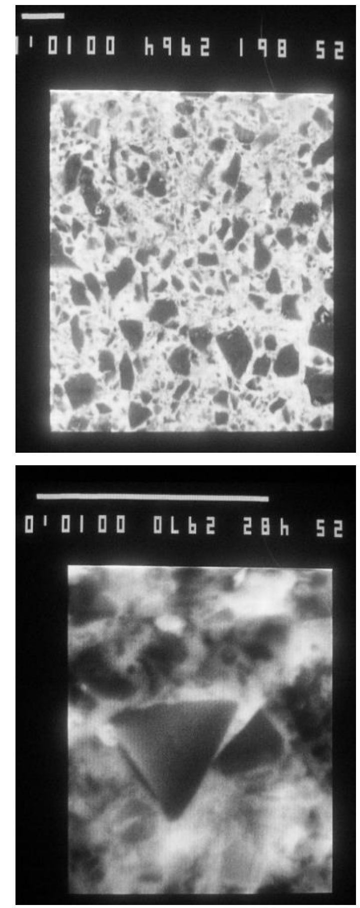


T-sensor based on the TVO resistor:
1 – electric leads, 2 – contact node,
3 – carbon-aluminum oxide mixture,
4 – glass case, 5 – outer hermetically sealed ceramic coating

Cernox Cx-1030-SD of Lake Shore [www.lakeshore.com]
Tested up to 0.2 MGy (electron beam of 5 MeV) – [Trenikhina, J., Barnett, T. et al, Adv. Cryog. Eng. (2008) v. 53B, p. 973]

Design of the composite TVO sensor





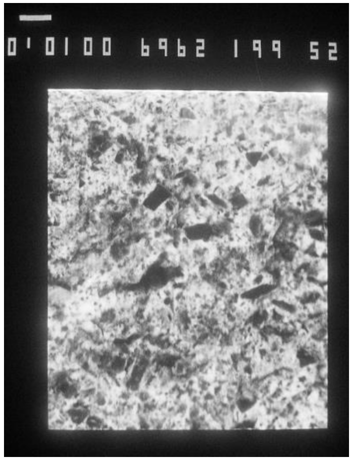
[M.Suesser, Cryogenics, 2004, v. 44, p.255-258]

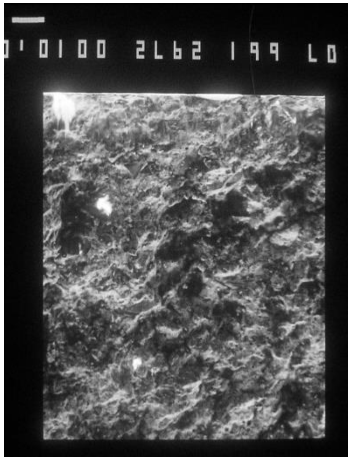
Micro-structure of the sensitive part: white marks are of 1 μm

Composition and structure of TVO resistors

Sensitive part of the composite TVO sensor consists of ~20 nm size carbon grains (~4 %) embedded in an Aluminum-oxide matrix/filler (~90 %), the rest is boron-lead binder ((~6 %) .
This is a semiconductor with a hopping type of conductivity.

Our T-sensors are selected not only after results on thermal cycling of TVO resistors between the 373 K and 77.3 K temperatures but also taking into account the calibration and fitting characteristics, and post-calibration measurements.

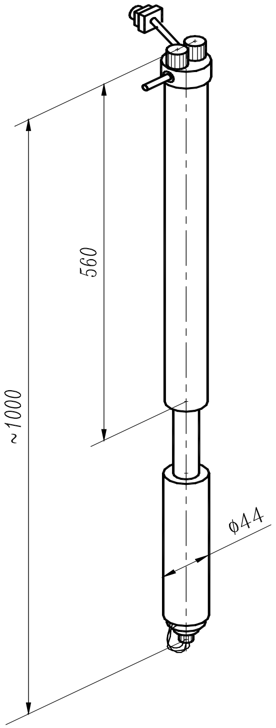


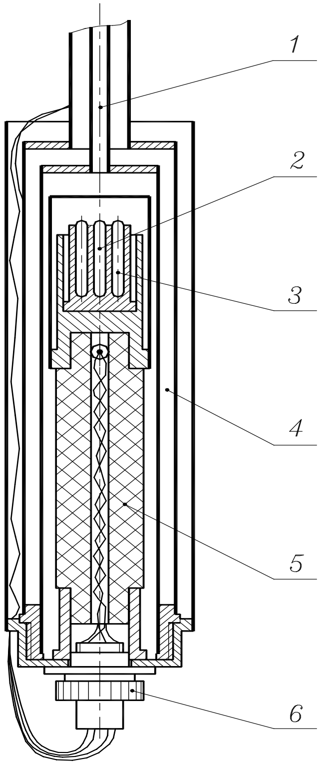


Surface of the sensitive part after grinding: white marks are of 1 μm

Metrological support:
ΔT<3 mK for the range from 1.5 to 300 K

The 17-channel system to calibrate cryogenic resistive temperature sensors [R – from 1 to 20 kΩ]
(it meets the ITS-90 requirements)





A feature of our calibration set-up is that it has the copper comparison block in the vacuum environment. The reference sensor is the rhodium-iron temperature sensor RIRT-1 of the ±1 mK accuracy for all the range from 1.5 to 300 K

Metrological support: the formal certificate

ВНИИФТРИ

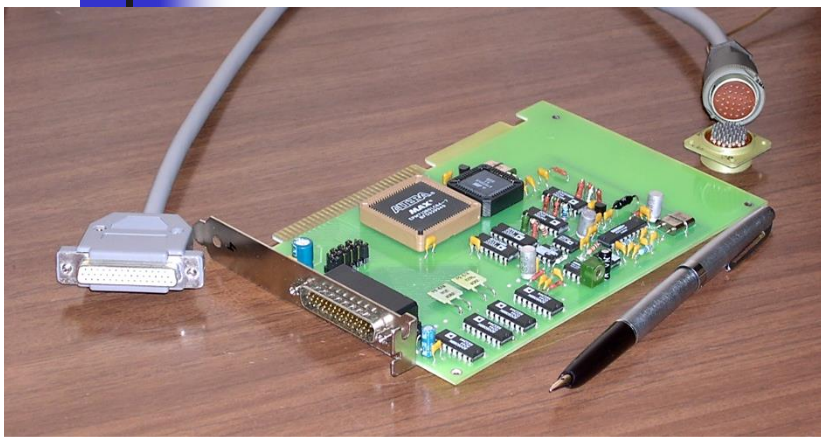
Свидетельство о поверке

Установка УГТ-10В

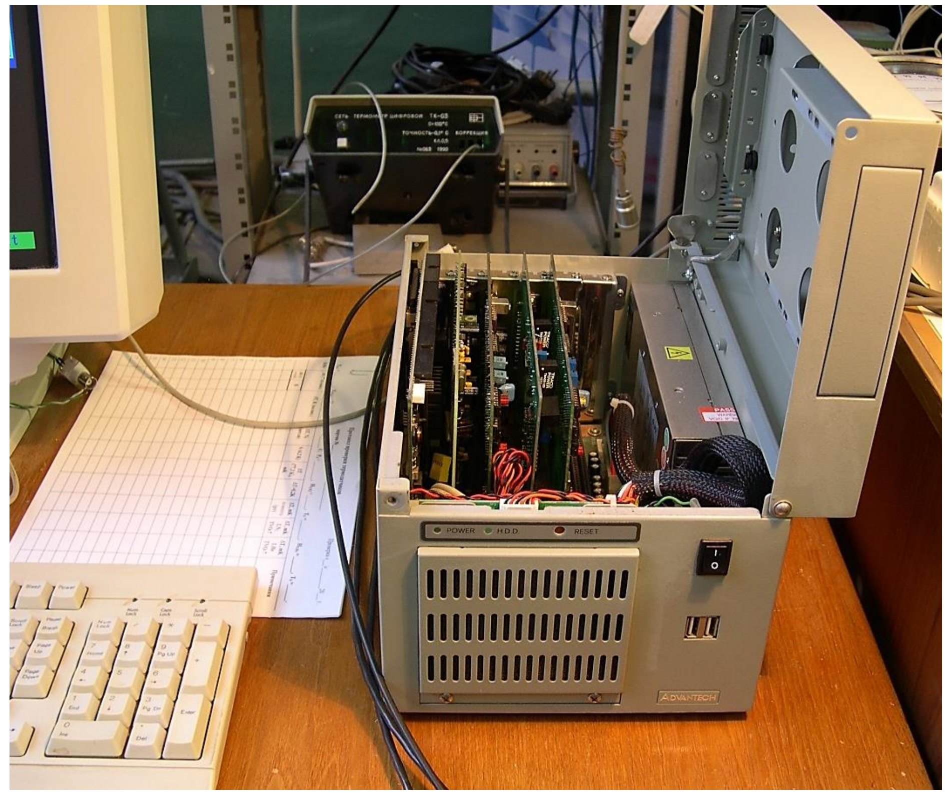
Диапазон 1,5 – 300 К,

доверительная погрешность не более 0,005 К

Our measuring devices, **ΔR/R<0.01 %**

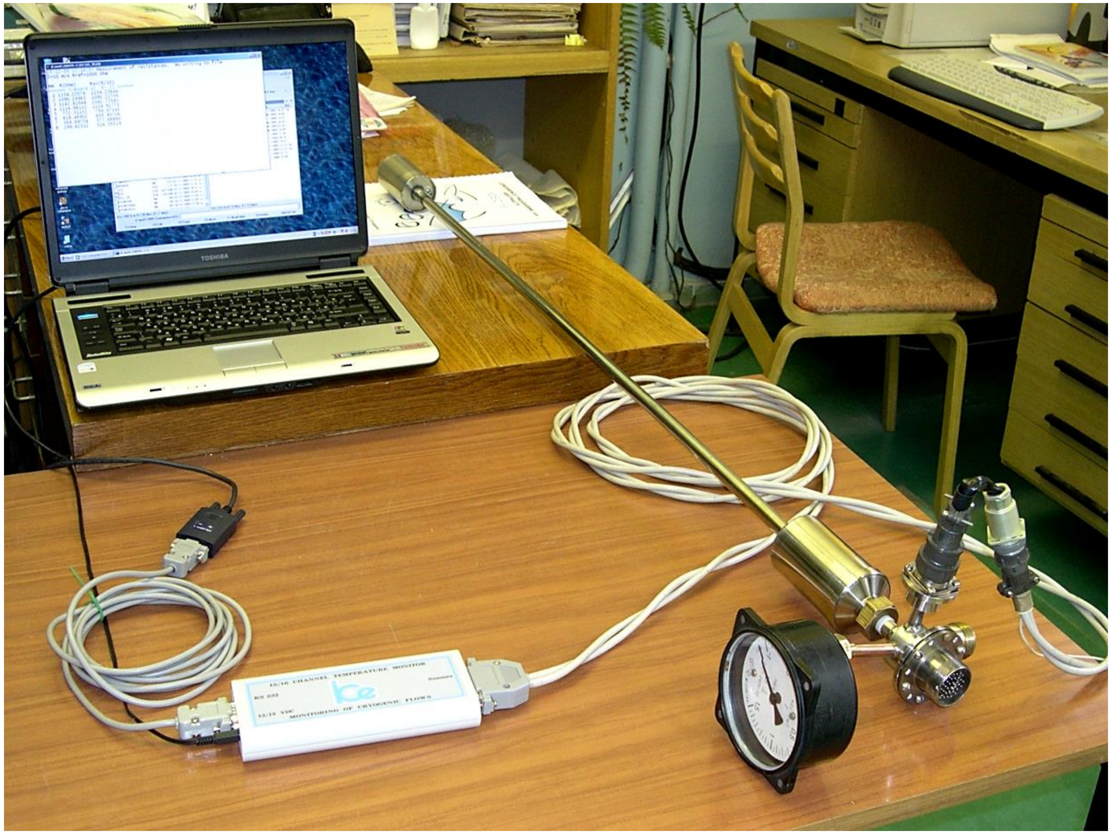


15-channel temperature monitors:
upper – ISA bus, lower – RS232 (remote)



The 6-slot industrial computer for boards to measure temperatures, pressures, level of cryogens, quality and mass flow rate of 2-phase cryogen flows (TCP/IP interaction with server)

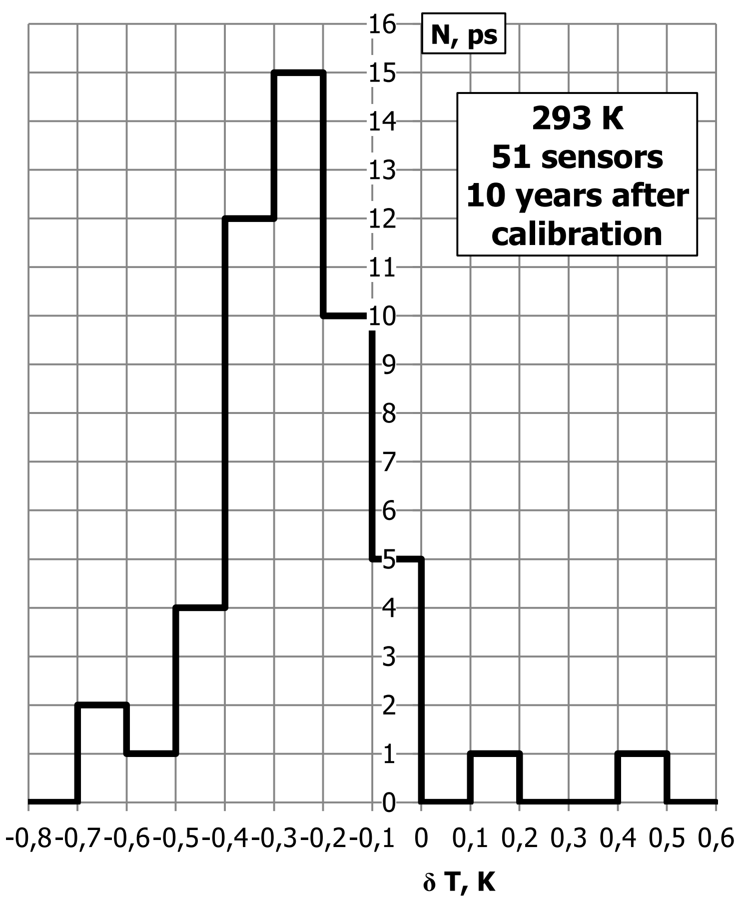
The used measurement equipment

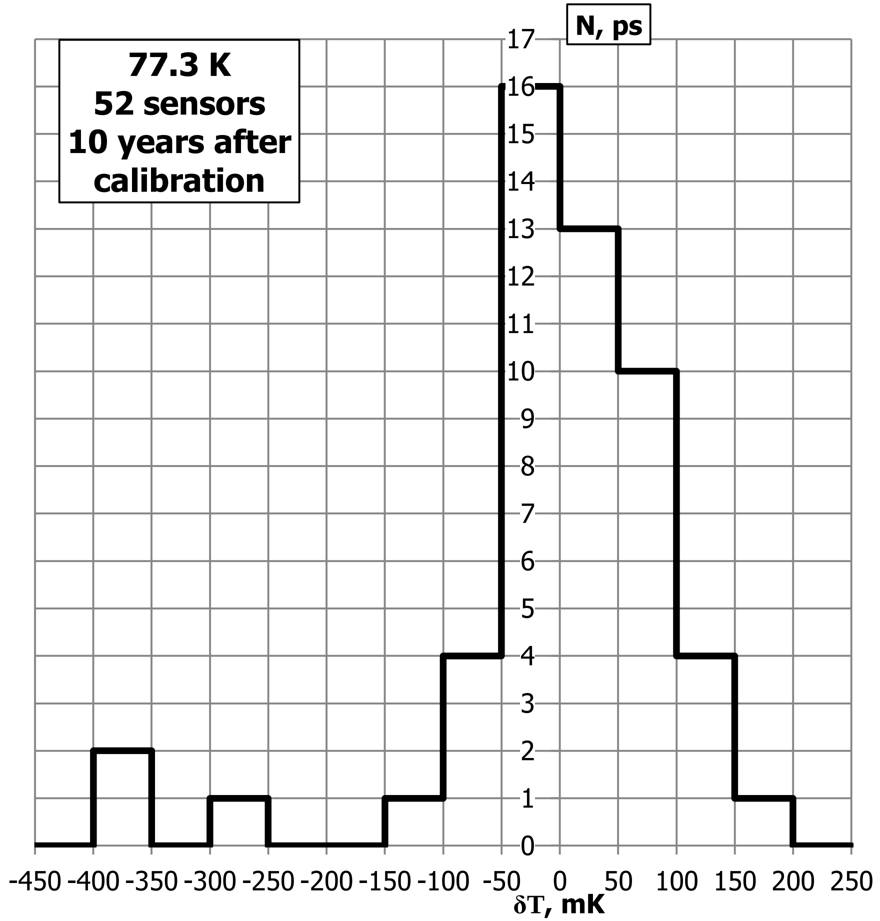


The RS232-temperature monitor connected with notebook and one of the tested devices

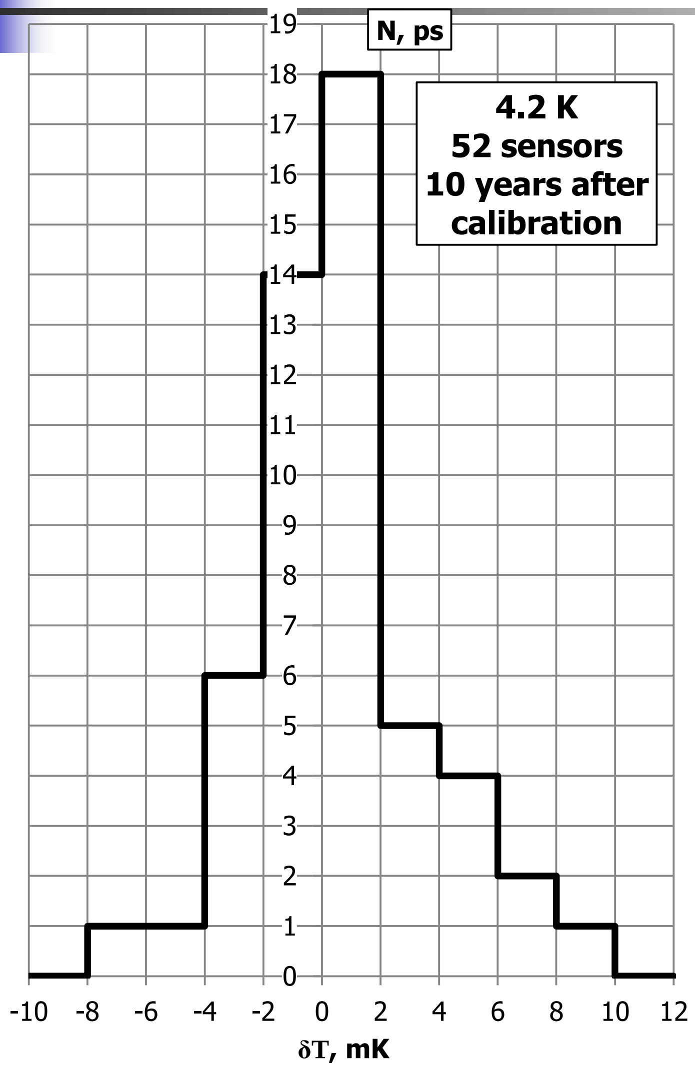
RESULTS for TVOdg[R(293 K)=910 Ohm]: at room temperature and in liquid nitrogen

Temperature shifts δT = $T_i - T_r$, K/mK; T_i and T_r – tested and reference T



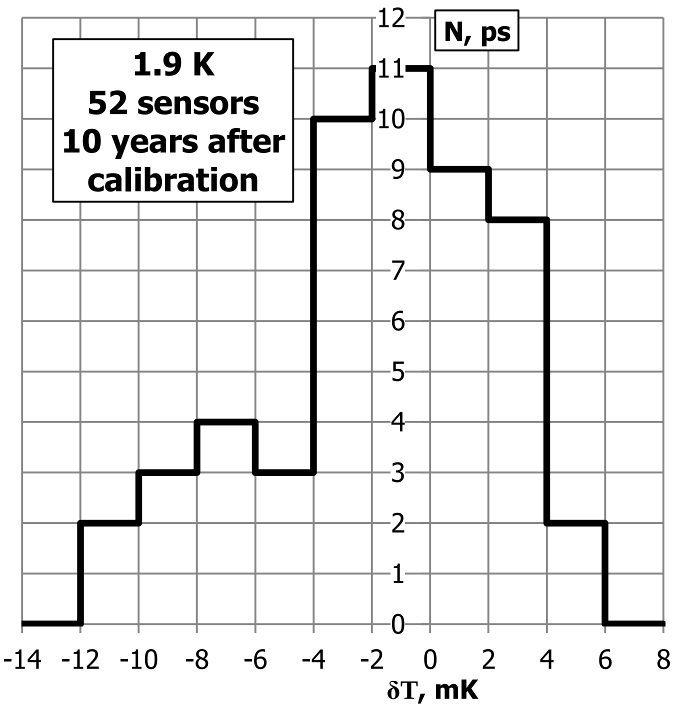


RESULTS for TVOdg[R(293 K)=910 Ohm]: in normal and superfluid liquid helium



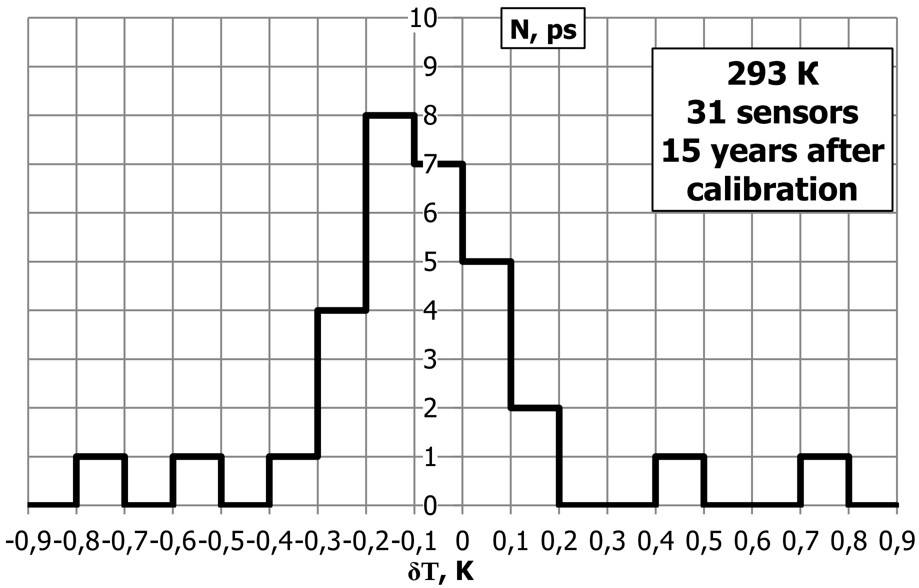
These sensors were used for XFEL-project, DESY

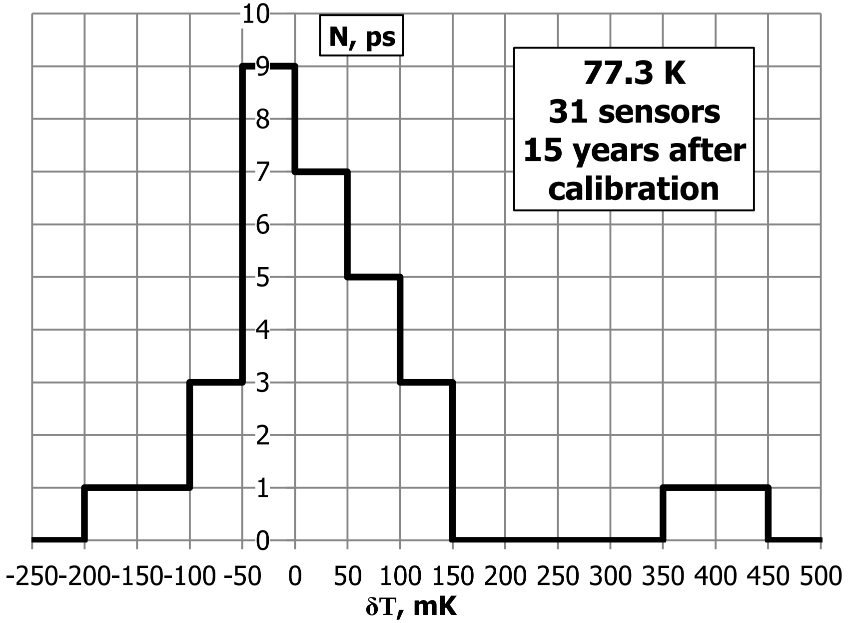
83 % of all the readings are within the ±6 mK-interval



RESULTS for TVO_{dg}[R(293 K)=1100 Ohm]: at room temperature and in liquid nitrogen

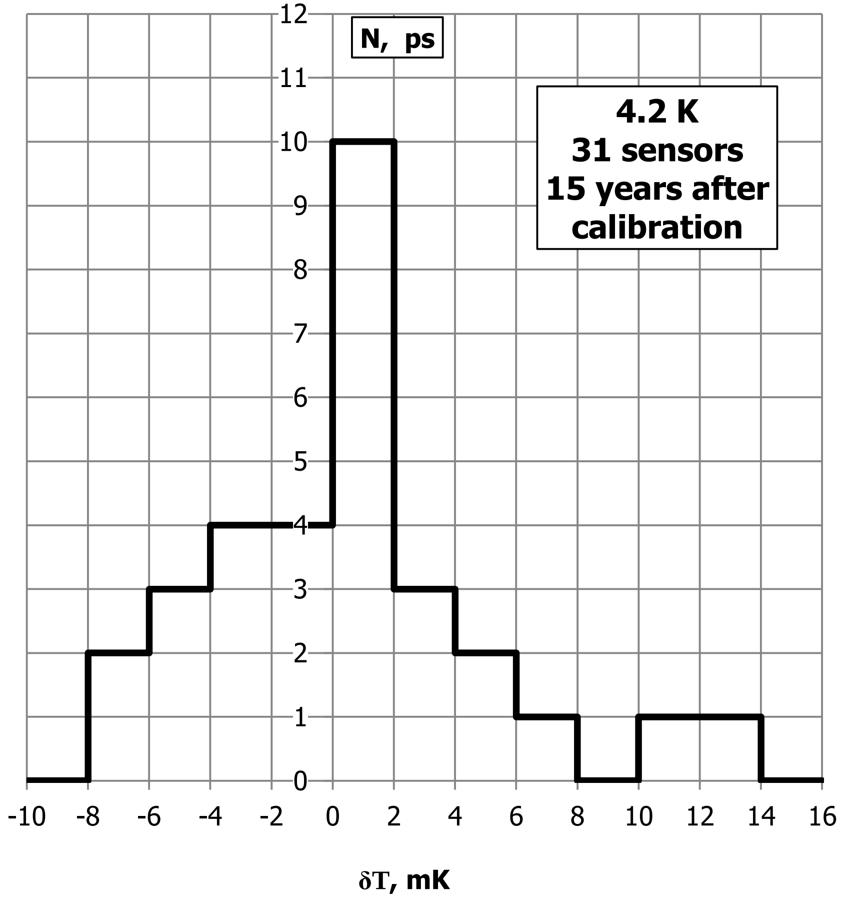
Temperature shifts δT = T_i – T_r, K/mK; T_i and T_r – tested and reference temperatures





RESULTS for TVO_{dg}[R(293 K)=1100 Ohm]: in liquid helium

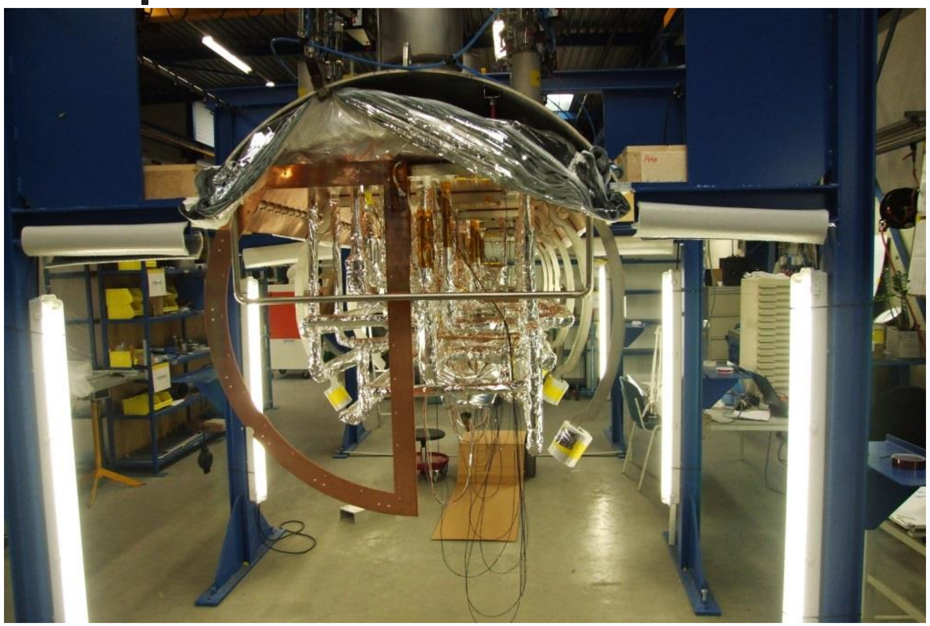
Temperature shifts δT = T_i – T_r, mK; T_i and T_r – tested and reference temperatures



These sensors were used for W7-X project, Greifswald, Germany

Temperature shifts for 3 **Cx-1030** sensors, tested 9 years after calibration, are as follows:
from 0.1 to 0.4 K at 293 K,
up to 85 mK at 77.3 K,
from 8 to 10 mK at 4.2 K.

Practical application of TVO$_{dg}$ sensors: W7-X project, Greifswald, Germany & XFEL project, DESY–DeMaCo



Mounting of 210 pieces of temperature sensors TVO$_{dg}$ (4–300 K) and Pt1000 (40–300 K) in the sub-cooler and valve boxes : left – during mounting, right – assembled valve box, March-May 2012 (N. Scharwoude, The Netherlands)

Practical application of TVOdg sensors: XFEL-project, DESY, Hamburg

Assembled helium valve box at AMTF, DESY, December 2013

Assembled cryo-modules of XFEL, DESY, April 2015 (about 1000 of our T-sensors)

Comparison of main characteristics of two kinds of TVO sensors

T-shifts due to thermal cycling from 373 to 77.3 K during 25 times:
δR < −0.35 Ohm for **TVOdg**,
−0.5 Ohm < δR < −1 Ohm for **TVOlg** of the 1-st group (7 of 60 pieces),
−3 Ohm < δR < −8 Ohm for **TVOlg** of the 2-d group (9 of 60 pieces).

Table 1. Resistance R and sensitivity dR/dT versus temperature T

Kind of sensor	R (293 K) Ω	dR/dT (293 K) Ω/K	R (77.3 K) kΩ	dR/dT (77.3 K) Ω/K	R (4.2 K) kΩ	dR/dT (4.2 K) Ω/K
Light green	910±5%	−0.54±0.3	1.15±0.1	−2.6±0.3	1.9±0.25	−180±60
Dark green	910±5%	−0.63±0.3	1.2±0.1	−3.0±0.3	3.0±0.3	−430±150

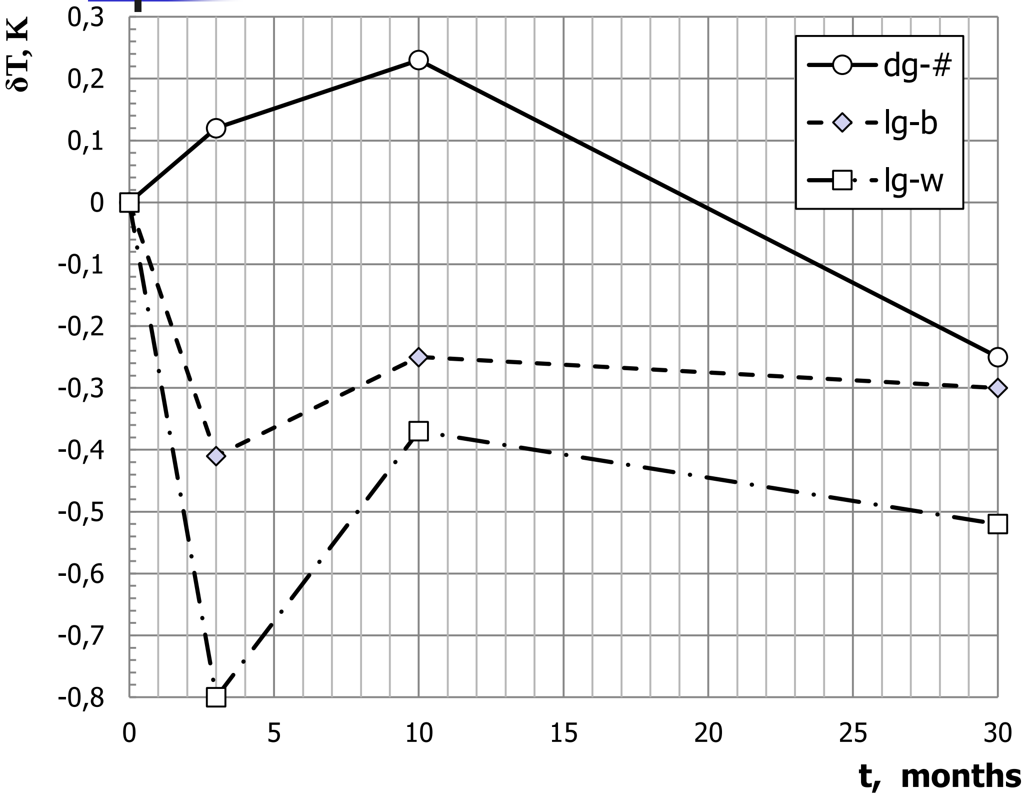
About polynomials to feet the calibration data

The accuracy of temperature sensor ΔT depends on:
- the uncertainty in the calibration points,
- the uncertainty caused by instability of the TVO resistor and
- the uncertainty due to deviations of a polynomial from the calibration points – δT_p.

To provide smallest uncertainties due to the used polynomial δT_p, it is preferable to apply such the polynomial as $\ln T = \Sigma A_i \ln(R/B)^i$, where A and B – coefficients, i – integer number up to 15; corresponding maximum values of $\delta T_p/T$ can be less than 0.05 % for all the T-range from 1.5 to 300 K

Another polynomial $T = \Sigma A_i\,(1000/R)^i$ is used by someone: it can lead to $\delta T_p/T$ deviations from 0.25 % to 0.5 % at T = 4.2 K even at i = 9 or more.

RESULTS for TVO_{lg}[R(293 K)=910 Ohm]: at room temperature for the 1-st group



TVO_{lg} sensors was used for XFEL project and can be used for NICA-project

One of these sensors showed the shift up to δT = 3.1 K after 30 months and it was rejected. So, only 6 sensors remained in this group or 10 % of 60 initial resistors.

Temperature shifts $\delta T = T_i - T_r$, K, versus the time t after calibration

As it was expected, the results for the 2-d group are much worse than for the 1-st one. The deviations are from 0.34 to –1.16 K for the best sensor and from –0.63 to 2.77 K for the worst one.

RESULTS for TVO_{lg}[R(293 K)=910 Ohm]: at 77.3 and 4.2 K for the 1-st group

As for the tests in liquid nitrogen and helium, the results look rather attractive at first glance:

At *77.3 K*, δT are in the range –33 mK < δT < 85 mK, and between –25 and –115 mK for #TVO_{dg}-sensor.

At *4.2 K*, δT are in the range –3 mK < δT < 8 mK, and between –5 and –7 mK for #TVO_{dg}-sensor.

However, a noticeable "LN_2 temperature hysteresis" ($\delta T_h = T_2 - T_1$) is revealed. It can be from –100 to –250 mK after 30 months for TVO_{lg} whereas it does not exceed –50 mK for #TVO_{dg}-sensor. These values for the used reference TVO- and Cx-1030 sensors are δT_h = –40 mK and δT_h = –20 mK, respectively.

TVO_{lg} sensors can be used for NICA-project

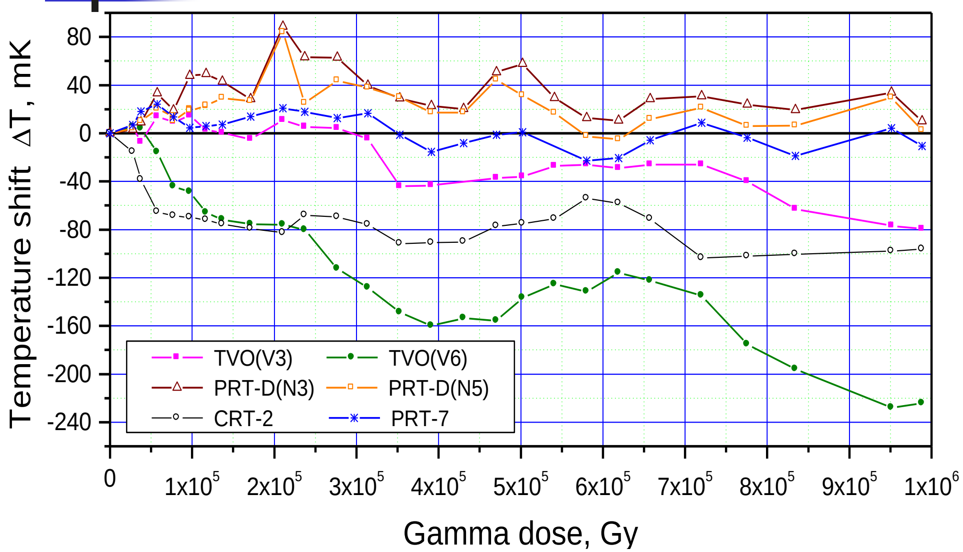
RESULTS for TVOlg[R(293 K)=910 Ohm]: at 77.3 and 4.2 K for the 2-d group

The deviations in LN_2 change from –250 mK after 3 months to almost zero after 30 months for the best sensor and from –504 mK after 3 months to –764 mK ($\delta T/T \approx 1$ %) after 10 months for the worst one.

In LHe maximum temperature deviations were revealed after 10 months: they are –8 mK for the best sensor and –25 mK ($\delta T/T \approx 0.6$ %) for the worst one.

As for the temperature hysteresis $\delta T_h = T_2 - T_1$, mentioned above, their maximum significant values were found after 3 months, and they are –0.67 K (≈0.9 %) and –1.41 K (1.8 %) for the best and worst sensors.

Additional investigation of TVO sensors on T-shifts due to gamma irradiation at 300 K



[Cs-137, 0.5 Gy/s, 77.3 K: ICEC-18 (2000); Rev. Sci. Instrum.]

New results were OK for TVO_{dg} sensors (6 pieces): $(\Delta T/T)_{max} \leq 0.3$ % at 4.2, 77.3 and 300 K during 6 months after gamma irradiation by Co-60 source.
As for behavior of TVO_{lg} sensors under irradiation, this is questionable! 10-year long-term stability – ?

Isotope	**Co-60**
Energy	**1.25 MeV**
Gamma rate	**1 Gy/s**
Room volume	**4×4×4.5 m**

Conclusion

- The tests demonstrated noticeably better results for older TVO resistors of dark green color $-TVO_{dg}$. The used technology to prepare non-calibrated sensors from TVO-resistors, to calibrate and to select them allow to choose three types of these sensors:

  high class of accuracy : $\Delta T = \pm 4$ mK at $T \leq 4$ K, $\Delta T/T \leq \pm 0.1$ % at $4 \text{ K} \leq T \leq 150$ K, $\Delta T = \pm 0.15$ K at $150 \text{ K} \leq T \leq 300$ K,

  the 1-st class of accuracy : $\Delta T = \pm 10$ mK at $T \leq 4$ K, $\Delta T/T \leq 0.25$ % at $4 \text{ K} \leq T \leq 120$ K, $\Delta T = \pm 0.3$ K at $120 \text{ K} \leq T \leq 300$ K, and

  the 2-d class of accuracy : $\Delta T = \pm 15$ mK at $T \leq 3$ K, $\Delta T/T \leq \pm 0.5$ % at $3 \text{ K} \leq T \leq 100$ K, $\Delta T = \pm 0.5$ K at $100 \text{ K} \leq T \leq 300$ K.

- Long-term stability for Cernoxs is better than for TVO_{dg} only at 77.3 K.
- Much younger TVO_{lg} sensors differ, first of all, in smaller sensitivities with respect to TVO_{dg} sensors for all the temperature range, especially at 4.2 K – by a factor of 2 approximately. ***The only class of accuracy*** is revealed for these sensors – of $\Delta T/T \leq 0.3$ % at $4.2 \text{ K} \leq T \leq 293$ K, which is mainly due to the value of so called LN_2-hysteresis ($\delta T_h = T_2 - T_1$). This maximum value can be of –250 mK that is more by a factor of 5 than for TVO_{dg} sensors ($\delta T_h < -50$ mK).
- A disadvantage of TVO_{lg} sensors is that only 10 % of initial amount of TVO_{lg}-resistors are able to be used as acceptable temperature sensors.

Conclusion

Cryogenics 100 (2019) 85–91

Contents lists available at ScienceDirect

Cryogenics

journal homepage: www.elsevier.com/locate/cryogenics

Research paper

A comparison of two kinds of TVO cryogenic temperature sensors

Y.P. Filippov*, V.M. Miklyaev

Joint Institute for Nuclear Research, Joliot-Curie, 6, Dubna 141980, Russia

A B S T R A C T

The characteristics of two kinds/types of well-known TVO sensors are compared. They differ, probably, with respect to the quality of initial components and the shade of their green ceramic coating. Detailed information about long-term stability of the first kind of sensors are presented 10 years after calibration for a fairly large group of 52 pieces at room temperature, in liquid nitrogen and liquid helium, at atmospheric pressure and at $T_s \approx 1.9$ K. Another group of 31pieces similar sensors was tested 15 years after calibration at room temperature, in liquid nitrogen and in liquid helium at atmospheric pressure. These sensors are based on TVO resistors produced previously, in the year 1991. Sixty pieces of the second kind of TVO resistors produced in 2009 were thermo-cycled between room temperature and 77.3 K, and two groups of 7 and 9 pieces were selected for test on their stability during 2.5 years at room temperature, in liquid nitrogen and in liquid helium at atmospheric pressure. A comparison shows noticeably better performances for the first kind of TVO resistors of dark green color. In particular, their sensitivity is roughly twice as high at liquid helium temperature. Information regarding the stability of well-known Cernox Cx-1030 sensors 9 years after calibration is also presented for comparison.

1. Introduction

A temperature sensor based on the composite TVO resistor is well

This is the sensor with predictable characteristics. As it is shown in [8], TVO sensors could be applied in the range from 1.5 to 5 K under the magnetic fields up to 9 T with maximum deviations of about ± 25 mK

Спасибо за внимание!

Дубна
30 мая 2019