National Institute of Standards & Technology

Certificate

Standard Reference Material® 1750

Standard Platinum Resistance Thermometer
Certified Thermometer for the Range 13.8033 K to 429.7485 K
on the International Temperature Scale of 1990

Serial No.

This Standard Reference Material (SRM) is intended for use as a defining instrument of the International Temperature Scale of 1990 (ITS-90) [1] that was officially adopted by the Comité International des Poids et Mesures (CIPM) in September 1989. One unit of SRM 1750 [2] consists of a calibrated capsule-type Standard Platinum Resistance Thermometer (SPRT) and a 60 cm long borosilicate glass adapter probe. The SPRT, which is a four-wire device with an electrical resistance at the water triple point (TP) of $R(273.16\ \text{K}) = (25.5 \pm 0.1)\ \Omega$, has been calibrated at NIST over the combined ITS-90 sub-ranges of 13.8033 K to 273.16 K and 273.15 K to 429.7485 K. The resistance element is wound in an unconstrained fashion, insulated by a ceramic multi-bore tube, and fully annealed. The element is hermetically sealed with a high purity helium gas atmosphere into a cylindrical capsule of 5.7 mm outer diameter and an external sheath of INCONEL X-750®.

Certified Values and Uncertainties: Table 1 contains the calibration fixed-point uncertainties in the specified temperature range. Table 2 contains the values of the coefficients of the two deviation functions of the ITS-90 appropriate for this calibration. For the convenience of the user, coefficients are given for three different currents, 0 mA, 1.0 mA, and 2.0 mA, as derived from measurements at the two currents I_1 and I_2, given on page two of this certificate. Tables 3, 4, and 5 contain values for the resistance ratio, $W(T_{90}) = R(T_{90})/R(273.16\ \text{K})$, for temperatures T_{90} in one kelvin increments and were generated using the three sets of coefficients listed in Table 2. Tables 3 and 4 were generated using the 0 mA calibration and 1.0 mA calibration, respectively, for the entire range of the calibration. Table 5 was generated using the 2.0 mA calibration for the lower sub-range, 13.8 K to 273.16 K, only.

Expiration of Certification: The certification of this SRM is valid indefinitely to within the stated uncertainties over the temperature range specified in Table 1, provided that the SRM is used in accordance with the Notice and Warning to Users section of this certificate. The certification is nullified if the SRM is damaged, mechanically shocked, chemically contaminated, overheated, or modified. Such severe treatment by rough handling or by accident is generally accompanied by large and abrupt upward shifts in the SPRT resistance, $R(273.16\ \text{K})$, at the water TP. Abrupt changes in $R(273.16\ \text{K})$ of more than 100 μΩ may indicate this condition. Monitoring of $R(273.16\ \text{K})$ by following the procedures outlined under "Periodic Checks at Water TP" given below is recommended. In many cases, it may still be possible to recertify SRM 1750 even in the event that severe treatment has been verified. For recertification, contact W.L. Tew by telephone at 301-975-4811, fax at 301-548-0206, or e-mail at weston.tew@nist.gov.

Preparation and calibration of this SRM were performed by W.L. Tew and G.F. Strouse of the NIST Process Measurements Division.

The support aspects involved in the preparation, certification, and issuance of this SRM were coordinated through the NIST Standard Reference Materials Program by J.W.L. Thomas.

James R. Whetstone, Chief
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Gaithersburg, MD 20899
Certificate Issue Date: 26 June 2001

Nancy M. Trahey, Chief
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Maintenance of SRM Certification: NIST will monitor this SRM over the period of its certification. If substantive technical changes occur that affect the certification, NIST will notify the purchaser. Return of the attached registration card will facilitate notification.

Discussion of Calibration Fixed-Point Uncertainties: The NIST calibration uncertainty for this SRM for each of the ten fixed-point temperatures is shown in Table 1. For calculation of the calibration uncertainty at all other temperatures in the calibration range, refer to the discussion under Appendix A, "Total Calibration Uncertainty".

All measurements of the SPRT resistance have been made with an AC resistance bridge operating at a frequency of 30 Hz and with continuous measuring currents of I_1 and I_2 as given below. The calibration points at the argon (Ar) TP, mercury (Hg) TP, water (H_2O) TP, gallium (Ga) melting point (MP), and indium (In) freezing point (FP) were measured in fixed-point cells [3] with expanded uncertainties as given below for the particular cells used in conjunction with this type of SPRT [4]. The calibration points at the oxygen (O_2) TP, neon (Ne) TP, equilibrium-hydrogen (e-H_2) TP, and e-H_2 vapor pressure (VP) points were measured by comparison [5] to a reference SPRT, s/n 1004131, that has been calibrated according to the ITS-90 using recent realizations of these fixed points at NIST [6]. The comparison measurements were performed under isothermal conditions, in vacuum, and the expanded uncertainties given below [7] were combined from NIST uncertainties due to the comparison measurements and the fixed-point realizations.

Table 1. Calibration Fixed-Point Uncertainties

Fixed Point		Temperature		Currents		Uncertainty, (k = 2)
		T_{90} (K)	t_{90} (°C)	I_1(mA)	I_2 (mA)	(mK)
e-H_2	TP	13.8033	–259.3467	2.828	5.0	0.25
e-H_2	VP	17.036	–256.1143	2.828	5.0	0.19
e-H_2	VP	20.271	–252.8799	2.0	2.828	0.17
Ne	TP	24.5561	–248.5939	2.0	2.828	0.31
O_2	TP	54.3584	–218.7916	1.0	2.0	0.14
Ar	TP	83.8058	–189.3442	1.0	2.0	0.15
Hg	TP	234.3156	–38.8344	1.0	1.414	0.15
H_2O	TP	273.16	0.01	1.0	1.414	0.04
Ga	MP	302.9146	29.7646	1.0	1.414	0.04
In	FP	429.7485	156.5985	1.0	1.414	0.32

This thermometer is satisfactory as a defining instrument of the ITS-90 in accordance with the criteria that $W(302.9146 \text{ K}) \geq 1.11807$ or $W(234.3156 \text{ K}) \leq 0.844235$.

Source of Material: The platinum wire in this SRM was drawn from bars (Bars 240-203 and 240-206) having a reported purity as a mass fraction of 99.999+ % and was obtained from Sigmund Cohn Corporation, Mount Vernon, NY[1]. The SPRT element and capsule were prepared and fabricated by Rosemont Aerospace, Inc., Eagan, MN. The precision-bore borosilicate tubing was supplied by Richland Glass, Richland, NJ.

NOTICE AND WARNING TO USERS

Storage: For each unit of SRM 1750, the SPRT is made from a strain-free platinum element that is susceptible to mechanical shock. When not in use, the SPRT should be stored in the wooden case provided and this case should, in turn, be kept in a secure and protected location. Avoid long term exposure of the SPRT to high levels of mechanical vibration and to corrosive gases and fluids. The glass tube adapter should be kept clean and dry and stored in its original container when not in use.

Handling: Due to the relatively delicate nature of the platinum element, the handling of the SPRT should be limited to specially trained personnel. The degree of handling should also be kept to a minimum in order to reduce the risk of accidental mechanical shock. Avoid excessive bending or kinking of the platinum lead wires of the SPRT.

[1]Certain commercial equipment, instruments, or materials are identified in this certificate in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Follow the recommended procedures given in Appendix B, “Use of the Glass Adapter Probe”, for loading and unloading the SPRT into and out of the glass tube.

INSTRUCTIONS FOR USE

The SPRT capsule alone can be used over the entire range of its calibration (13.8 K to 430 K). The glass adapter probe allows the SPRT capsule to be used in the same way as a conventional long-stem SPRT within the temperature limits of 83.8 K to 430 K. The resistance of the SPRT can be measured with any high resolution four-wire resistance measurement system capable of sourcing excitation currents between 1 mA to 5 mA. To achieve the highest level of accuracy, the measurement system should be able to resolve voltages of 0.01 µV or less. The measurement current should be chosen to match or otherwise be extrapolated to one of the three currents listed in Table 2 for the deviation function coefficients. The 2.0 mA current is most appropriate for measurements below about 30 K, while 1.0 mA is normally adequate for all other temperatures. The 0 mA case is used when extrapolating to zero power dissipation to eliminate self-heating errors.

When using the SPRT capsule alone, it is customary to place it into a close fitting well in a copper block for comparison to other thermometers. The copper block may be held under vacuum, in a low pressure (≤ 100 kPa) inert gas or in an inert heat transfer fluid which is electrically insulating. The lead wires going between the SPRT and the ambient temperature regions should be thermally anchored near to or on the copper block itself to minimize heat flow into the SPRT through the leads. The SPRT is not designed to be directly immersed into water or any other electrically conductive fluid. Use of the SPRT in water baths is only possible when using the adapter probe.

The primary role of the adapter probe is to facilitate periodic checks of the SPRT resistance at the triple point of water R(273.16 K). Such checks are important to make in order to (a) properly calculate the resistance ratio $W(T) = R(T)/R$(273.16 K) that is used in the ITS-90 deviation equations and (b) verify the stability of the SPRT (see “Periodic Checks at water TP”, below). In this way, the user need not maintain a strict resistance scale calibration in 1990 ohms, as long as the same resistance scale or reference resistance standard is used in both of the measurements required to calculate the $W(T)$ value. These checks are also necessary to accommodate the inevitable trend of any SPRT to gradually increase in resistance over time from handling. **The user should first measure *R*(273.16 K) for the SRM 1750 SPRT with the user’s measurement system before using it in any measurements to determine any other temperatures.**

During use of the adapter probe in any fixed-point cell or bath for which the temperature is below ambient, the adapter should be pressurized with a slightly positive pressure (1 kPa to 3 kPa above ambient) of an inert gas, preferably helium. Maintaining this positive pressure is necessary to avoid condensation of atmospheric water vapor inside the probe. This can be accomplished by connecting a regulated gas supply to the small nipple at the top of the nylon tee fitting with a flexible hose of approximately 3 mm inner diameter. The connectors found in the nylon tee are not perfectly gas tight and some small gas leakage will occur in normal operation. Care must be taken not to over-pressurize the adapter tube, as this could result in personal injury, damage to the tube, SPRT, and/or contiguous equipment.

When used alone, the SPRT capsule can support external pressures from vacuum up to 6.8 MPa without gross mechanical failure. However, this certification is restricted in pressure range from vacuum to 0.3 MPa.

DO NOT attempt to bring any portion of the SRM adapter probe assembly to a temperature above 160 ºC, as this can cause the bonding film on the surface of the wiring harness to soften and stick to the inner surface of the borosilicate tube. In the event this does occur, follow the instructions given in Appendix B, “Use of the Glass Adapter Probe”, to safely remove the adhered section of wire. The upper temperature limit for the SPRT capsule is also 160 ºC. While the capsule may survive if exposed to temperatures higher than this limit, the accuracy of the NIST calibration will no longer be certified.

Periodic Checks at the Water TP: The stability of this SRM should be verified periodically by the user by measuring its resistance at the water TP. The interval of time between verification measurements will depend on the frequency of use; however, once per year should be considered the maximum allowable interval. The best possible reproducibility will be achieved by following a few special procedures during these checks: (1) always make sure the ice mantle of the water TP cell is free to rotate about the re-entrant well and not stuck to the well; (2) always take measurements at two different currents and calculate the zero-power resistance for the most accurate comparison to the previous measurements; (3) fabricate an aluminum bushing to fit loosely over the outside of the glass adapter tube and inside the water TP cell re-entrant well; then use this bushing during water TP measurements with the adapter probe to minimize local heating effects in the SPRT; and (4) allow approximately 30 minutes for the adapter probe to come into equilibrium with the water TP cell before taking measurements. Further information on the preparation and use of the water TP can be found in Reference [3].

REFERENCES

[1] Preston-Thomas, H., "The International Temperature Scale of 1990," *Metrologia*, **27**, pp. 3-10, (1990) and *Metrologia*, **27**, p. 107, (1990).

[2] Tew, W.L., "Standard Reference Material 1750: Standard Platinum Resistance Thermometer, 13.8033 K to 429.7485 K," NIST Special Publication 260-139, U.S. Government Printing Office, Washington DC, (2001).

[3] Mangum, B.W. and Furukawa, G.T., "Guidelines for Realizing The International Temperature Scale of 1990 (ITS-90)," NIST Technical Note 1265, U.S. Government Printing Office, Washington DC, (1990).

[4] Strouse, G.F. and Tew, W.L., "Assessment of Uncertainties of Calibration of Resistance Thermometers at the National Institute of Standards and Technology," NISTIR **5319**, p. 16, (1994).

[5] Tew, W.L. and Mangum, B.W., "New Procedures and Capabilities for the Calibration of Cryogenic Resistance Thermometers at NIST," in *Advances in Cryogenic Engineering*, **39B**, p. 1019, P. Kittel, editor, Plenum Press, New York, (1994).

[6] Tew, W.L., Strouse, G.F., Meyer, C.W., and Furukawa, G.T., "Recent Advances in the Realization and Dissemination of the ITS-90 below 83.8058 K at NIST," Advances in Cryogenic Engineering, **43B**, P. Kittel, editor, Plenum Press, New York, (1998).

[7] Tew, W.L., Strouse, G.F., and Meyer, C.W., "A Revised Assessment of Calibration Uncertainties for Capsule-Type Standard Platinum and Rhodium-Iron Resistance Thermometers," NISTIR **6138**, p. 36, (1998).

Users of this SRM should ensure that the certificate in their possession is current. This can be accomplished by contacting the SRM Program at: telephone (301) 975-6776; fax (301) 926-4751; e-mail srminfo@nist.gov; or via the Internet http://www.nist.gov/srm.

Table 2. Certified values[a] of the ITS-90 deviation function coefficients for the sub-ranges 1 and 10 using 0 mA and 1.0 mA excitations, and sub-range 1 using a 2.0 mA excitation. The most recent (as of 2/1/2001) values of the triple point of water resistance for those same currents are also shown in ohms.

0 mA Calibration		1.0 mA Calibration		2.0 mA Calibration	
a_1 =	−1.044358E-04	a_1 =	−1.040972E-04	a_1 =	−1.031219E-04
b_1 =	2.567947E-05	b_1 =	2.924072E-05	b_1 =	3.977980E-05
c_1 =	2.369853E-06	c_1 =	3.446202E-06	c_1 =	6.630464E-06
c_2 =	1.418234E-06	c_2 =	2.072775E-06	c_2 =	4.007001E-06
c_3 =	3.501131E-07	c_3 =	5.063624E-07	c_3 =	9.675856E-07
c_4 =	3.964964E-08	c_4 =	5.663556E-08	c_4 =	1.067215E-07
c_5 =	1.716392E-09	c_5 =	2.418340E-09	c_5 =	4.485994E-09
a_{10} =	−1.406230E-04	a_{10} =	−1.414005E-04		
R(273.16 K)=	25.42669 ohms[a]	R(273.16 K)=	25.42672 ohms[a]	R(273.16 K)=	25.42678 ohms[a]

[a] The resistance values are not certified values and are provided for information purposes only.

The coefficients a_1, b_1, c_1, c_2, c_3, c_4, and c_5 are used in the deviation equation for sub-range 1 (13.8033 K to 273.16 K) as given by,

$$\Delta W_1(T_{90}) \equiv a_1\left[W(T_{90})-1\right]+b_1\left[W(T_{90})-1\right]^2+\sum_{i=1}^{5} c_i\left\{\ln\left[W(T_{90})\right]\right\}^{i+2}. \quad (1)$$

The coefficient a_{10} is used in the deviation equation for sub-range 10 (273.15 K to 429.7485 K) as given by,

$$\Delta W_{10}(T_{90}) \equiv a_{10}\left[W(T_{90})-1\right]. \quad (2)$$

Equations 1 and 2 are used in conjunction with the ITS-90 definitions,

$$\Delta W(T_{90}) \equiv W(T_{90}) - W_{\mathrm{r}}(T_{90}). \quad (3)$$

and

$$W(T_{90}) \equiv \frac{R(T_{90})}{R(273.16\ \mathrm{K})} \quad (4)$$

where $W_r(T_{90})$ is the upper range reference function in the case of sub-range 10, or the lower range reference function in the case of sub-range 1. Given a measured value of $W(T_{90})$, the equations may be solved by iteration to find the temperature T_{90}. For additional information on the ITS-90 reference functions and a full description of the scale, see NIST Technical Note 1265.

Table 3. Certified Values of $W(T_{90})$ versus Temperature in kelvins (K) for the SRM 1750 SPRT at 0 mA.

T_{90}	0	1	2	3	4	5	6	7	8	9
10					0.00133413	0.00161734	0.00196426	0.00238291	0.00288090	0.00346544
20	0.00414317	0.00492018	0.00580185	0.00679288	0.00789724	0.00911812	0.01045797	0.01191852	0.01350078	0.01520509
30	0.01703116	0.01897814	0.02104462	0.02322874	0.02552820	0.02794035	0.03046220	0.03309052	0.03582185	0.03865255
40	0.04157886	0.04459692	0.04770283	0.05089263	0.05416239	0.05750820	0.06092618	0.06441253	0.06796352	0.07157553
50	0.0752450	0.0789686	0.0827429	0.0865648	0.0904313	0.0943394	0.0982863	0.1022694	0.1062861	0.1103341
60	0.1144110	0.1185147	0.1226431	0.1267943	0.1309664	0.1351578	0.1393669	0.1435920	0.1478319	0.1520850
70	0.1563503	0.1606264	0.1649124	0.1692072	0.1735098	0.1778193	0.1821349	0.1864559	0.1907814	0.1951109
80	0.1994438	0.2037793	0.2081171	0.2124566	0.2167973	0.2211388	0.2254809	0.2298229	0.2341648	0.2385061
90	0.2428466	0.2471860	0.2515241	0.2558606	0.2601955	0.2645284	0.2688593	0.2731880	0.2775144	0.2818383
100	0.2861596	0.2904783	0.2947943	0.2991075	0.3034178	0.3077252	0.3120296	0.3163310	0.3206293	0.3249246
110	0.3292168	0.3335058	0.3377917	0.3420745	0.3463541	0.3506306	0.3549039	0.3591741	0.3634412	0.3677051
120	0.3719659	0.3762236	0.3804783	0.3847299	0.3889784	0.3932239	0.3974665	0.4017060	0.4059426	0.4101763
130	0.4144071	0.4186350	0.4228600	0.4270823	0.4313017	0.4355184	0.4397323	0.4439436	0.4481522	0.4523581
140	0.4565614	0.4607620	0.4649602	0.4691558	0.4733488	0.4775394	0.4817276	0.4859133	0.4900966	0.4942775
150	0.4984560	0.5026323	0.5068062	0.5109779	0.5151473	0.5193145	0.5234795	0.5276423	0.5318029	0.5359614
160	0.5401178	0.5442721	0.5484243	0.5525745	0.5567226	0.5608688	0.5650129	0.5691551	0.5732953	0.5774336
170	0.5815699	0.5857044	0.5898370	0.5939677	0.5980965	0.6022236	0.6063488	0.6104722	0.6145938	0.6187136
180	0.6228317	0.6269481	0.6310627	0.6351755	0.6392867	0.6433962	0.6475040	0.6516101	0.6557146	0.6598174
190	0.6639186	0.6680181	0.6721161	0.6762124	0.6803072	0.6844003	0.6884919	0.6925819	0.6966704	0.7007573
200	0.7048427	0.7089266	0.7130089	0.7170897	0.7211690	0.7252469	0.7293232	0.7333981	0.7374715	0.7415434
210	0.7456139	0.7496829	0.7537504	0.7578166	0.7618813	0.7659446	0.7700065	0.7740669	0.7781260	0.7821836
220	0.7862399	0.7902948	0.7943483	0.7984005	0.8024512	0.8065006	0.8105487	0.8145954	0.8186408	0.8226848
230	0.8267275	0.8307689	0.8348089	0.8388476	0.8428851	0.8469212	0.8509560	0.8549895	0.8590217	0.8630526
240	0.8670823	0.8711106	0.8751377	0.8791635	0.8831880	0.8872113	0.8912334	0.8952541	0.8992736	0.9032919
250	0.9073089	0.9113247	0.9153392	0.9193525	0.9233646	0.9273754	0.9313850	0.9353934	0.9394006	0.9434065
260	0.9474112	0.9514147	0.9554170	0.9594180	0.9634179	0.9674165	0.9714139	0.9754101	0.9794051	0.9833989
270	0.9873915	0.9913828	0.9953730	0.9993619	1.0033495	1.0073358	1.0113209	1.0153048	1.0192875	1.0232689
280	1.0272492	1.0312282	1.0352060	1.0391826	1.0431580	1.0471322	1.0511051	1.0550768	1.0590474	1.0630167
290	1.0669848	1.0709516	1.0749173	1.0788818	1.0828450	1.0868070	1.0907679	1.0947275	1.0986859	1.1026431
300	1.1065991	1.1105538	1.1145074	1.1184598	1.1224109	1.1263609	1.1303096	1.1342571	1.1382034	1.1421485
310	1.1460925	1.1500352	1.1539767	1.1579169	1.1618560	1.1657939	1.1697306	1.1736660	1.1776003	1.1815334
320	1.1854652	1.1893959	1.1933253	1.1972536	1.2011806	1.2051065	1.2090311	1.2129546	1.2168768	1.2207978
330	1.2247177	1.2286363	1.2325537	1.2364700	1.2403850	1.2442988	1.2482115	1.2521229	1.2560331	1.2599422
340	1.2638500	1.2677566	1.2716621	1.2755663	1.2794694	1.2833712	1.2872719	1.2911713	1.2950696	1.2989666
350	1.3028625	1.3067571	1.3106506	1.3145429	1.3184340	1.3223238	1.3262125	1.3301000	1.3339863	1.3378714
360	1.3417553	1.3456380	1.3495195	1.3533999	1.3572790	1.3611569	1.3650337	1.3689092	1.3727836	1.3766567
370	1.3805287	1.3843995	1.3882690	1.3921374	1.3960046	1.3998706	1.4037355	1.4075991	1.4114615	1.4153228
380	1.4191828	1.4230417	1.4268993	1.4307558	1.4346111	1.4384652	1.4423181	1.4461699	1.4500204	1.4538697
390	1.4577179	1.4615649	1.4654106	1.4692552	1.4730986	1.4769409	1.4807819	1.4846217	1.4884604	1.4922979
400	1.4961341	1.4999692	1.5038031	1.5076359	1.5114674	1.5152978	1.5191269	1.5229549	1.5267817	1.5306073
410	1.5344318	1.5382550	1.5420771	1.5458979	1.5497176	1.5535361	1.5573535	1.5611696	1.5649846	1.5687983
420	1.5726109	1.5764223	1.5802326	1.5840416	1.5878495	1.5916562	1.5954617	1.5992660	1.6030691	1.6068711
430	1.6106719									

Table 4. Certified Values of $W(T_{90})$ versus Temperature in kelvins (K) for the SRM 1750 SPRT at 1.0 mA.

T_{90}	0	1	2	3	4	5	6	7	8	9
10					0.00133413	0.00161736	0.00196427	0.00238290	0.00288090	0.00346543
20	0.00414317	0.00492018	0.00580186	0.00679289	0.00789724	0.00911811	0.01045794	0.01191847	0.01350070	0.01520498
30	0.01703103	0.01897798	0.02104444	0.02322853	0.02552797	0.02794010	0.03046194	0.03309025	0.03582157	0.03865226
40	0.04157857	0.04459664	0.04770255	0.05089236	0.05416214	0.05750796	0.06092596	0.06441232	0.06796334	0.07157536
50	0.0752449	0.0789685	0.0827428	0.0865648	0.0904312	0.0943394	0.0982863	0.1022694	0.1062862	0.1103342
60	0.1144111	0.1185148	0.1226432	0.1267945	0.1309666	0.1351581	0.1393671	0.1435923	0.1478322	0.1520853
70	0.1563506	0.1606268	0.1649128	0.1692076	0.1735102	0.1778197	0.1821354	0.1864563	0.1907819	0.1951114
80	0.1994443	0.2037798	0.2081176	0.2124571	0.2167978	0.2211394	0.2254814	0.2298235	0.2341654	0.2385067
90	0.2428472	0.2471866	0.2515247	0.2558613	0.2601961	0.2645291	0.2688600	0.2731886	0.2775150	0.2818389
100	0.2861603	0.2904790	0.2947950	0.2991082	0.3034185	0.3077259	0.3120303	0.3163317	0.3206300	0.3249253
110	0.3292174	0.3335065	0.3377924	0.3420752	0.3463548	0.3506312	0.3549046	0.3591748	0.3634418	0.3677057
120	0.3719666	0.3762243	0.3804789	0.3847305	0.3889790	0.3932246	0.3974671	0.4017066	0.4059432	0.4101769
130	0.4144077	0.4186356	0.4228606	0.4270829	0.4313023	0.4355190	0.4397329	0.4439442	0.4481527	0.4523586
140	0.4565619	0.4607626	0.4649607	0.4691563	0.4733494	0.4775399	0.4817281	0.4859138	0.4900971	0.4942780
150	0.4984565	0.5026328	0.5068067	0.5109784	0.5151478	0.5193149	0.5234799	0.5276427	0.5318033	0.5359618
160	0.5401182	0.5442725	0.5484247	0.5525749	0.5567230	0.5608692	0.5650133	0.5691555	0.5732957	0.5774339
170	0.5815703	0.5857048	0.5898373	0.5939680	0.5980969	0.6022239	0.6063491	0.6104725	0.6145941	0.6187139
180	0.6228320	0.6269483	0.6310629	0.6351758	0.6392870	0.6433964	0.6475042	0.6516104	0.6557148	0.6598176
190	0.6639188	0.6680184	0.6721163	0.6762126	0.6803074	0.6844005	0.6884921	0.6925821	0.6966706	0.7007575
200	0.7048429	0.7089267	0.7130091	0.7170899	0.7211692	0.7252470	0.7293234	0.7333982	0.7374716	0.7415435
210	0.7456140	0.7496830	0.7537506	0.7578167	0.7618814	0.7659447	0.7700065	0.7740670	0.7781261	0.7821837
220	0.7862400	0.7902949	0.7943484	0.7984005	0.8024513	0.8065007	0.8105488	0.8145955	0.8186408	0.8226849
230	0.8267275	0.8307689	0.8348090	0.8388477	0.8428851	0.8469212	0.8509560	0.8549895	0.8590217	0.8630526
240	0.8670823	0.8711106	0.8751377	0.8791635	0.8831881	0.8872113	0.8912334	0.8952541	0.8992736	0.9032919
250	0.9073089	0.9113247	0.9153392	0.9193525	0.9233646	0.9273754	0.9313850	0.9353934	0.9394006	0.9434065
260	0.9474112	0.9514147	0.9554170	0.9594180	0.9634179	0.9674165	0.9714139	0.9754101	0.9794051	0.9833989
270	0.9873915	0.9913828	0.9953730	0.9993619	1.0033495	1.0073358	1.0113209	1.0153048	1.0192875	1.0232689
280	1.0272492	1.0312282	1.0352060	1.0391826	1.0431580	1.0471321	1.0511051	1.0550768	1.0590473	1.0630166
290	1.0669847	1.0709516	1.0749173	1.0788817	1.0828450	1.0868070	1.0907678	1.0947274	1.0986858	1.1026430
300	1.1065990	1.1105538	1.1145073	1.1184597	1.1224108	1.1263608	1.1303095	1.1342570	1.1382033	1.1421484
310	1.1460923	1.1500350	1.1539765	1.1579168	1.1618559	1.1657938	1.1697304	1.1736659	1.1776002	1.1815332
320	1.1854651	1.1893957	1.1933252	1.1972534	1.2011805	1.2051063	1.2090310	1.2129544	1.2168766	1.2207977
330	1.2247175	1.2286361	1.2325536	1.2364698	1.2403848	1.2442986	1.2482113	1.2521227	1.2560329	1.2599420
340	1.2638498	1.2677564	1.2716619	1.2755661	1.2794692	1.2833710	1.2872716	1.2911711	1.2950693	1.2989664
350	1.3028622	1.3067569	1.3106504	1.3145426	1.3184337	1.3223236	1.3262123	1.3300998	1.3339860	1.3378711
360	1.3417550	1.3456377	1.3495193	1.3533996	1.3572787	1.3611566	1.3650334	1.3689089	1.3727833	1.3766564
370	1.3805284	1.3843992	1.3882687	1.3921371	1.3960043	1.3998703	1.4037351	1.4075988	1.4114612	1.4153224
380	1.4191825	1.4230413	1.4268990	1.4307555	1.4346108	1.4384649	1.4423178	1.4461695	1.4500200	1.4538694
390	1.4577175	1.4615645	1.4654103	1.4692549	1.4730983	1.4769405	1.4807815	1.4846214	1.4884600	1.4922975
400	1.4961338	1.4999688	1.5038028	1.5076355	1.5114670	1.5152974	1.5191265	1.5229545	1.5267813	1.5306069
410	1.5344313	1.5382546	1.5420766	1.5458975	1.5497172	1.5535357	1.5573530	1.5611692	1.5649841	1.5687979
420	1.5726105	1.5764219	1.5802321	1.5840412	1.5878490	1.5916557	1.5954612	1.5992655	1.6030687	1.6068706
430	1.6106714									

Table 5. Certified Values of $W(T_{90})$ versus Temperature in kelvins (K) for the SRM 1750 SPRT at 2.0 mA.

T_{90}	0	1	2	3	4	5	6	7	8	9
10					0.00133416	0.00161742	0.00196430	0.00238291	0.00288088	0.00346542
20	0.00414317	0.00492019	0.00580188	0.00679292	0.00789725	0.00911807	0.01045786	0.01191832	0.01350047	0.01520467
30	0.01703064	0.01897750	0.02104388	0.02322791	0.02552729	0.02793936	0.03046116	0.03308943	0.03582073	0.03865141
40	0.04157772	0.04459580	0.04770173	0.05089157	0.05416139	0.05750725	0.06092529	0.06441172	0.06796279	0.07157488
50	0.0752445	0.0789681	0.0827425	0.0865646	0.0904311	0.0943393	0.0982863	0.1022695	0.1062864	0.1103344
60	0.1144114	0.1185152	0.1226437	0.1267950	0.1309673	0.1351588	0.1393679	0.1435931	0.1478330	0.1520863
70	0.1563516	0.1606279	0.1649139	0.1692087	0.1735114	0.1778210	0.1821367	0.1864577	0.1907833	0.1951129
80	0.1994458	0.2037814	0.2081192	0.2124587	0.2167995	0.2211411	0.2254831	0.2298252	0.2341671	0.2385085
90	0.2428490	0.2471884	0.2515265	0.2558631	0.2601980	0.2645309	0.2688619	0.2731906	0.2775169	0.2818409
100	0.2861622	0.2904810	0.2947969	0.2991101	0.3034204	0.3077278	0.3120322	0.3163336	0.3206320	0.3249272
110	0.3292194	0.3335084	0.3377944	0.3420771	0.3463567	0.3506332	0.3549065	0.3591767	0.3634437	0.3677077
120	0.3719685	0.3762262	0.3804808	0.3847324	0.3889809	0.3932264	0.3974689	0.4017085	0.4059451	0.4101787
130	0.4144095	0.4186374	0.4228624	0.4270846	0.4313041	0.4355207	0.4397346	0.4439459	0.4481544	0.4523603
140	0.4565636	0.4607642	0.4649623	0.4691579	0.4733509	0.4775415	0.4817296	0.4859153	0.4900986	0.4942795
150	0.4984580	0.5026342	0.5068081	0.5109798	0.5151492	0.5193163	0.5234813	0.5276440	0.5318047	0.5359631
160	0.5401195	0.5442738	0.5484260	0.5525761	0.5567242	0.5608703	0.5650145	0.5691566	0.5732968	0.5774350
170	0.5815714	0.5857058	0.5898384	0.5939690	0.5980979	0.6022249	0.6063501	0.6104734	0.6145950	0.6187148
180	0.6228329	0.6269492	0.6310638	0.6351766	0.6392878	0.6433972	0.6475050	0.6516111	0.6557155	0.6598183
190	0.6639195	0.6680190	0.6721169	0.6762133	0.6803080	0.6844011	0.6884927	0.6925827	0.6966711	0.7007580
200	0.7048434	0.7089272	0.7130095	0.7170904	0.7211697	0.7252475	0.7293238	0.7333986	0.7374720	0.7415439
210	0.7456143	0.7496833	0.7537509	0.7578170	0.7618817	0.7659450	0.7700068	0.7740673	0.7781263	0.7821840
220	0.7862402	0.7902951	0.7943486	0.7984007	0.8024515	0.8065009	0.8105489	0.8145956	0.8186410	0.8226850
230	0.8267277	0.8307690	0.8348091	0.8388478	0.8428852	0.8469213	0.8509561	0.8549896	0.8590218	0.8630527
240	0.8670823	0.8711107	0.8751377	0.8791635	0.8831881	0.8872114	0.8912334	0.8952541	0.8992736	0.9032919
250	0.9073089	0.9113247	0.9153392	0.9193525	0.9233646	0.9273754	0.9313850	0.9353934	0.9394005	0.9434065
260	0.9474112	0.9514147	0.9554169	0.9594180	0.9634179	0.9674165	0.9714139	0.9754101	0.9794051	0.9833989
270	0.9873915	0.9913828	0.9953730	0.9993619						

APPENDIX A. Total Calibration Uncertainty

The NIST assessment of uncertainties in the ITS-90 calibration of an SPRT involves the decomposition of uncertainty into Type A and Type B components. The Type A component, s, is a combined uncertainty from standard deviations of only those measurements under direct statistical process control. The Type B components, u_j, are the estimated standard uncertainties for each known component in the measurement process that cannot be directly measured. In addition, uncertainties are described by a coverage factor, k, for a specific level of confidence. The Type A and Type B uncertainties at each of the SPRT calibration points, "x", are combined in quadrature and expanded by the coverage factor, k, to form the expanded fixed-point uncertainty, U_x, given by

$$U_\mathrm{x} \equiv k\sqrt{s^2 + \sum u_j^2} \ . \qquad \text{(A-1)}$$

In general, each fixed-point uncertainty U_x will propagate over the calibration sub-range with a specific form of temperature dependence. The NIST total calibration uncertainty, $U_\mathrm{cal}(T_{90})$, is then calculated as a root-sum-square (RSS) from the propagation of these individual fixed-point uncertainties as given on page 1 of this certificate,

$$U_\mathrm{cal}(T_{90}) \equiv \sqrt{\sum U_\mathrm{x}^2} \qquad \text{(A-2)}$$

where the summation is over all the fixed points required for the sub-range.

The curves in Figure A-1 show $U_\mathrm{cal}(T_{90})$, expressed in units of mK, for all temperatures in the SPRT calibration range for SRM 1750. The $U_\mathrm{cal}(T_{90})$ uncertainty is expanded for a coverage factor of $k = 2$, so that the two curves as shown in Figure A-1 represent a bounded interval having a confidence level of approximately 95 %.

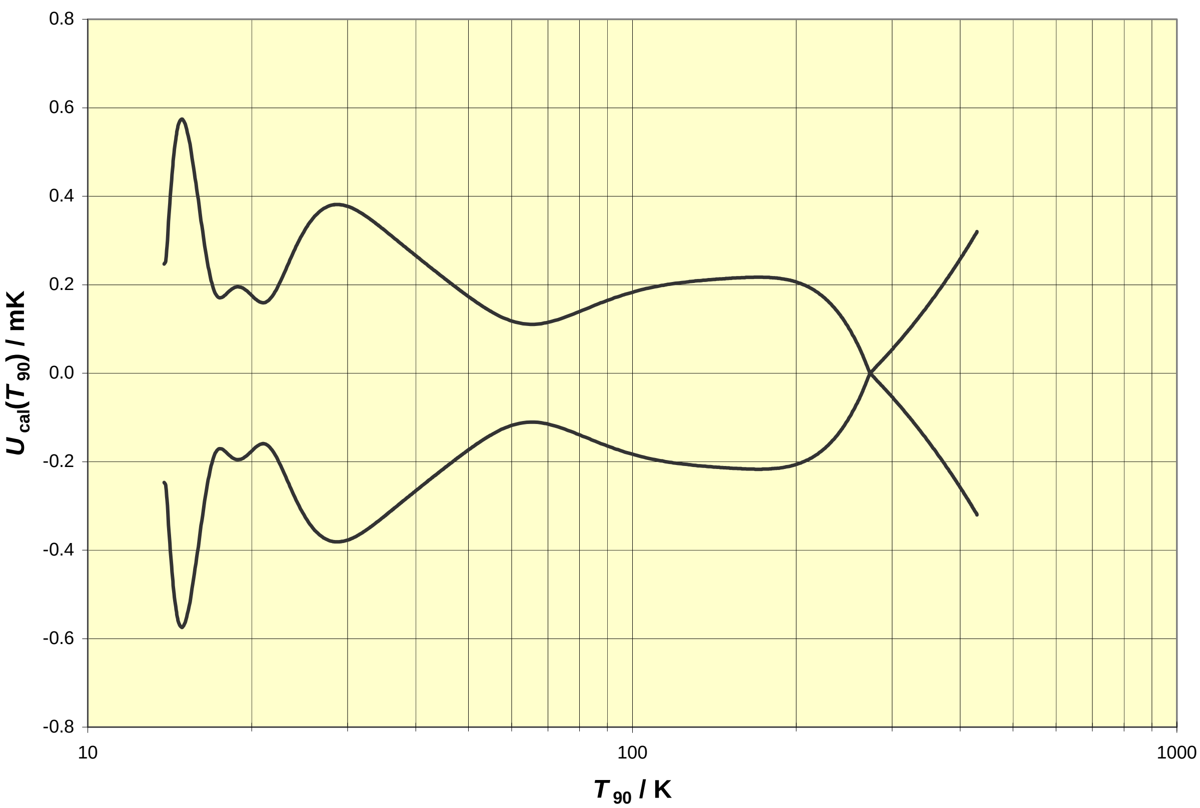

Figure A-1. The NIST total calibration uncertainty for the SRM 1750 SPRT. The curves represent a bounded interval with a confidence level of 95 %. The interval is constrained to be zero at 273.16 K (see text).

As a consequence of the definition of $W(T_{90})$, the uncertainty of the NIST realization of the water TP is already included in the stated uncertainties for the other fixed points. Hence, the curves for $U_{cal}(T_{90})$, are constrained to be zero at the water TP in order to avoid overestimating the uncertainty contribution from the NIST water TP realization. However, in order to use the SPRT to determine temperature, the user must account for an additional uncertainty contribution from the user's realization of the water TP. This additional user's uncertainty component, $u_{WTP}(T_{90})$, will propagate throughout the calibration temperature range with a temperature dependence as shown in Figure A-2. The size of u_{WTP}(273.16 K) is assumed to be 0.1 mK in Figure A-2. For a specific user's application, however, this will depend on a variety of factors including the resolution of the user's measurement system for a resistance of 25.5 Ω.

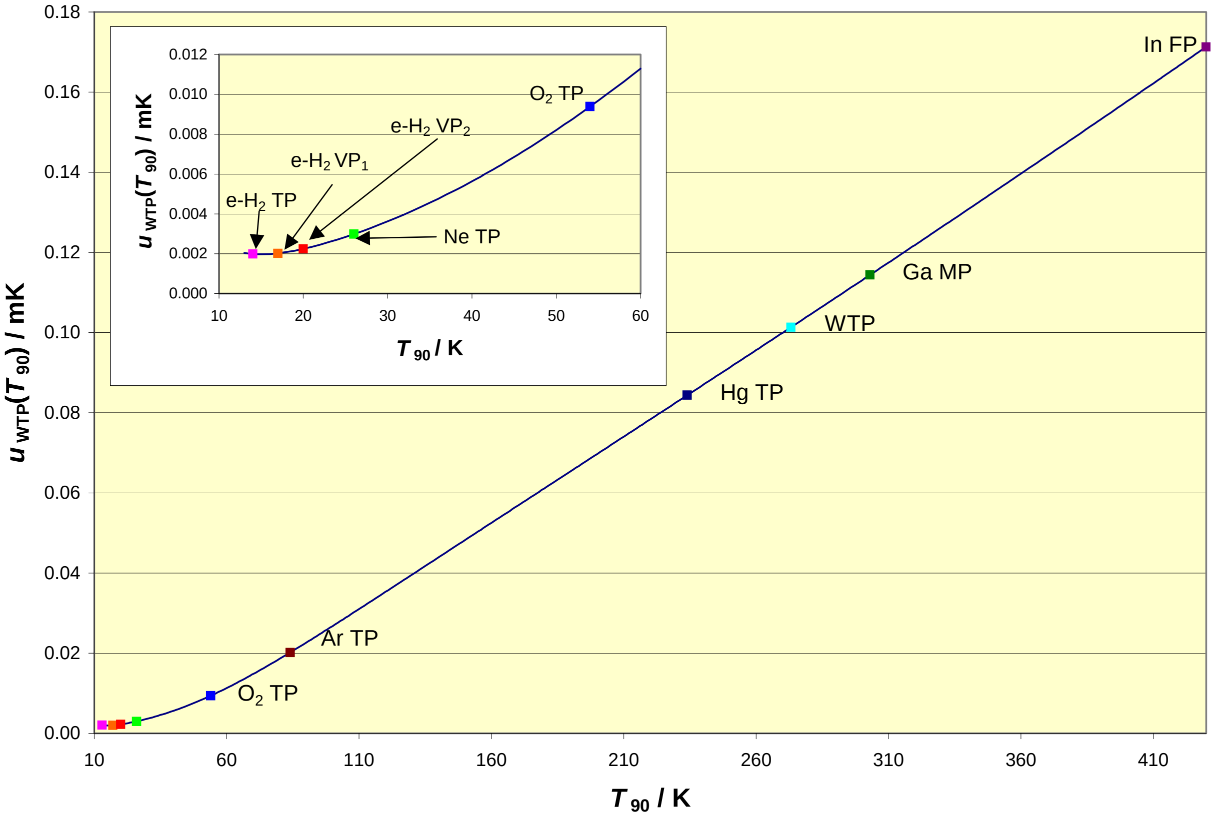

Figure A-2. The propagation of an uncertainty of 0.1 mK at the water triple point (WTP) as incurred by the user for the SRM 1750 SPRT. The relative location of the fixed-point temperatures are shown for reference only.

Finally, the user must determine the uncertainty with which the user's measurement system can determine the resistance ratio $W(T_{90})$ of the SPRT for all of the resistance values in the calibration range. This uncertainty, expressed in units of mK, would then be added in quadrature to both $u_{WTP}(T_{90})$ and $U_{cal}(T_{90})$ in order to determine the user's total expanded uncertainty for the determination of temperature with the SPRT.

APPENDIX B. Use of the Glass Adapter Probe

The glass adapter probe assembly of SRM 1750 is very simple to use with the SPRT; however, **the user must read and understand the contents of this appendix before attempting to load the probe assembly**.

Referring to Figure B-1, the probe is made from a 60 cm long precision-bore borosilicate glass tube of 5.8 mm ID and 7.5 mm OD which is custom made to fit the SRM 1750 SPRT. A nylon tee header is included to terminate the open end of the tube. This header is slightly oversized for the tube, so a teflon front-ferrule must be used for that connection. The teflon ferrule has sufficient compliance to accommodate the slight mismatch in diameters. This connection should be made snug by finger tightening only, over-tightening the nut onto the tube will break the glass. The other two connections on the nylon tee accommodate the four-wire polarized plug and a 3 mm diameter hose nipple.

The wiring harness consists of four 32 AWG phosphor-bronze lead wires that are polyimide insulated. The wires are bonded together as a ribbon by a polyvinyl butral bonding film. The harness is terminated with four #22 socket contacts made from gold-plated beryllium-copper. These contacts mate onto the pin contacts located on the ends of the SPRT platinum lead wires. Three short pieces of polytetrafluoroethylene (PTFE) tubing serve to insulate these contacts from each other while the entire assembly is loaded inside the glass tube.

When loading and unloading the SPRT into and out of the glass adapter tube, several critical precautions must be taken in order to minimize the risk of accidental mechanical shocks to the SPRT. Follow the procedures described below for loading and unloading the SPRT.

Loading: For loading, first prepare a horizontal working surface with approximately 1.2 m of clearance in one direction and cover the surface with a soft cushioning foam. Disconnect the nylon tee from the glass tube and remove the wiring harness. Lay the glass tube and the SPRT on the foam horizontally in such a way that they are prevented from rolling. Next, connect the pins on the SPRT leads to the sockets on the end of the wiring harness, keeping the SPRT fixed on the foam surface. To prevent shorting of the SPRT leads at the pin-to-socket connection, be sure to overlap a short section of PTFE tubing over the exposed sections of the connectors for three out of four of the pin-to-socket pairs. Then insert the bottom end of the SPRT into the glass tube and begin to slowly slide the entire assembly of the SPRT and wiring harness further inside. It should be possible to continue to slide the assembly and keep the SPRT horizontal by gently pushing the wire into the glass until the SPRT reaches the bottom of the tube. At this point, there will be very little, if any, slack in the wiring harness left and the nylon tee may then be re-connected to the tube. Tighten the nut on the nylon tee with fingers only (**DO NOT** use a wrench). Once the SPRT is resting firmly at the bottom of the tube and the nylon tee reconnected, the entire assembly may then be picked up and held in a vertical orientation suitable for insertion into a fixed-point cell. Always support the assembly by holding onto the glass tube; never hold it using the nylon tee alone.

Unloading: Unloading the SPRT can be accomplished by disconnecting the nylon tee from the glass tube and gently pulling on the wiring harness to retract the SPRT. Once the SPRT has been removed from the tube, disconnect the pins and sockets and place the SPRT in its wooden case for storage and/or transport. As with the loading operation, the unloading operation should be done with the glass tube held horizontally, resting entirely on the foam cushion. Never hold the tube more than a few degrees off horizontal or otherwise allow the SPRT to accelerate freely towards either end of the tube when loading and unloading.

If the probe has been accidentally overheated during its use, a section of the wiring harness' bonding film will often soften and then stick to the inner surface of the glass tubing upon cooling. This section of adhered wire must be mechanically dislodged from the inner glass surface before the SPRT can be safely unloaded. This can be accomplished by using a small gauge piece of tempered steel, such as piano wire, with a small hook fashioned on one end. Use the steel wire hook to gently lift the section of adhered wiring harness off of the inner glass wall. **DO NOT** pull or yank on the wiring harness until all sections are free. After dislodging the wire, all four leads in the harness should then be inspected for any permanent damage and the insulation resistance between each lead checked. If the insulation resistances between all lead wires are still greater than 100 MΩ, then it should be possible to re-use the wiring.

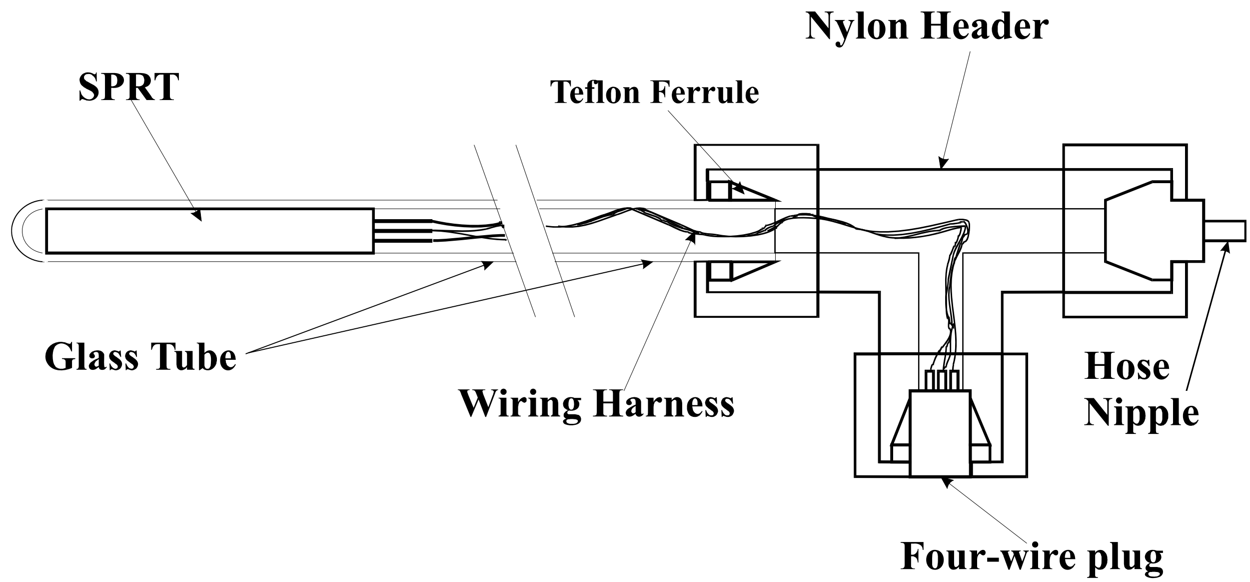

Figure B-1. The glass adapter probe shown as a cross-section with the SPRT in the properly loaded position.