BUREAU INTERNATIONAL DES POIDS ET MESURES

TECHNIQUES FOR APPROXIMATING THE INTERNATIONAL TEMPERATURE SCALE OF 1990

1997

Pavillon de Breteuil, F-92312 Sèvres

Organisation intergouvernementale de la Convention du Mètre

TECHNIQUES FOR APPROXIMATING

THE INTERNATIONAL TEMPERATURE SCALE OF 1990

1997 reprinting of the 1990 first edition

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When this monograph, prepared by Working Group 2 of the Comité Consultatif de Thermométrie (CCT), was published in 1990, it was expected that a revised and updated edition would follow in five to seven years. This intended revision is still a few years away. Consequently, for this reprinting of the first edition, the CCT felt that it was necessary to include a list of amendments to various items in the text that have been made obsolete (or obsolescent) by events in thermometry since 1990. At the same time we list all of the errata in the first edition that have been brought to our attention. Of these latter, happily, there have been very few.

This group of inserted pages contain these errata and amendments keyed to the pages in the text to which they pertain.

R. E. Bedford
Chairman, Working Group 2

T.J. Quinn
Director, BIPM
President, CCT

July 1997

Errata

1. Page (iii), item 3.3.1: change to read “Copper 28.1 % Silver 71.9 % Eutectic Alloy”.
2. Page 2, penultimate line of text: “Appendix A” should read “Appendix B”.
3. Page 20, line 7 of text: delete “the calibration approximates that state” and insert “that state is approximated during the calibration”.
4. Page 35, Sec. 3.3.1 title: should read “Copper 28.1 % Silver 71.9 % Eutectic Alloy”.
5. Page 35, Sec. 3.3.1, line 4: should read “Cu 28.1 % Ag 71.9 %”.

Amendments

1. Page 4, line 12: The reference Bedford et al (1984) should be updated to Bedford et al (1996).
2. Page 4, line 14: The sentence beginning “The value of ...” should be deleted.
3. Page 5, lines 15-16: Note that there are now revised values for (t_{90} – t_{68}) in the temperature range 630 °C to 1064 °C [Rusby et al (1994), and item 14 below].
4. Page 5, lines 29-31: These specifications and tables have now been published (see items 10 and 12 below).
5. Pages 20-24, Sections 3.1.1 and 3.1.2: The superconductive devices SRM767 and SRM768 are no longer available from the NIST.
6. Page 24, Section 3.1.3: Vapour pressure thermometers are discussed in detail by Pavese and Molinar (1992).
7. Page 27, Table 3.4: Revised values for some of the table entries appear in Table 2.1 (page 46) of Pavese and Molinar (1992).
8. Page 60, Section 6: Vapour pressure thermometry is discussed in detail by Pavese and Molinar (1992).
9. Page 96, lines 21-22: New thermocouple reference tables for types R, S and B based upon the ITS-90 have been published [Burns et al (1992a); Burns et al (1992b); Guthrie et al (1992); Burns et al (1993); IEC(1995a)]. See item 17 below.
10. Page 139, Section 16.3: New international specifications for industrial platinum resistance thermometers that relate the thermometer resistance R to t_{90} have been published by the IEC (1995b). The equations relating R to t_{90} are identical in form to equations (16.5) and (16.6) (on page 139) with t_{90} replacing t_{68}. For IPRTs with

W(100 °C) = 1.385 (exact value for calculational purposes 1.385 055) the values for the coefficients A, B, Care:

$A = 3.9083 \times 10^{-3}\ °C^{-1}$

$B = -5.775 \times 10^{-7}\ °C^{-2}$

$C = -4.183 \times 10^{-12}\ °C^{-4}$.

The range of Eq. (16.5) is 0 °C to 850 °C and of Eq. (16.6) is –200 °C to 0 °C.

No mention is made in IEC (1995b) of IPRTs with W(100 °C) = 1.391.

11. Page 142, Table 16.3: This table should be replaced by an equivalent one with entries generated from the (new) equations (16.5) and (16.6) of item 10 above [see IEC(1995b)].
12. Page 147, Section 18.1: New international thermocouple reference tables for Type R, S, B, J, T, E, K, N based upon the ITS-90 have been published [Burns et al (1994); IEC (1995a)]. See item 17 below.
13. Page 169, Section 20: The following additional references should be included in Section 20:

Bedford, R.E., Bonnier, G., Maas, H. and Pavese, F. (1996): Recommended Values of Temperature on the International Temperature Scale of 1990 for a Selected Set of Secondary Reference Points; Metrologia 33, 133-154.

Burns, G.W., Strouse, G.F., Mangum, B.W., Croarkin, M.C., Guthrie, W.F., Marcarino, P., Battuello, M., Lee, H.K.; Kim, J.C., Gam, K.S., Rhee, C., Chattle, M., Arai, M., Sakurai, H., Pokhodun, A.I., Moiseeva, N.P., Perevalova, S.A., de Groot, M.J., Zhang, J., Fan, K., Wu, S. (1992a): New Reference Function for Platinum - 10 % Rhodium versus Platinum (Type S) Thermocouples based on the ITS-90, Part I and Part II; Temperature, Its Measurement and Control in Science and Industry (American Institute of Physics, New York) 6, 537-546.

Burns, G.W.; Strouse, G.F.; Mangum, B.W.; Croarkin, M.C.; Guthrie, W.F.; Chattle, M. (1992b): New Reference Functions for Platinum - 13 % Rhodium versus Platinum (Type R) and Platinum - 30 % Rhodium versus Platinum - 6 % Rhodium (Type B) Thermocouples based on the ITS-90; Temperature, Its Measurement and Control in Science and Industry (American Institute of Physics, New York), 6, 559-564.

Burns, G.W.; Scroger, M.G.; Strouse, G.F.; Croarkin, M.C.; Guthrie, W.F. (1993): Temperature-Electromotive Force Reference Functions and Tables for the Letter Designated Thermocouple Types Based on the ITS-90; National Institute of Standards and Technology (U.S.) Monograph 175.

Guthrie, W.F.; Croarkin, M.C.; Burns, G.W.; Strouse, G.F.; Marcarino, P.; Battuello, M.; Lee, H.K., Kim, J.C.; Gam, K.S.; Rhee, C.; Chattle, M.; Arai, M.; Sakurai, H.; Pokhodun, A.I.; Moiseeva, N.P.; Perevalova, S.A.; de Groot, M.J.; Zhang, J.; Fan, K.; Wu, S. (1992): Statistical Analysis of Type S Thermocouple Measurements on the International Temperature Scale of 1990; Temperature, Its Measurement and Control in Science and Industry (American Institute of Physics, New York) 6, 547-552.

IEC (1995a): Thermocouples, Part 1: Reference Tables; International Electrotechnical Commission, IEC International Standard, Publication 584-1, 2nd edition 1995-09. (Central Bureau of the International Electrotechnical Commission, Geneva.)

IEC (1995b): Industrial Platinum Resistance Thermometer Sensors, IEC Standard, Publication 751, 1st edition 1983, Amendment 2, 1995-07. (Central Bureau of the International Electrotechnical Commission, Geneva.)

Pavese, F. and Molinar, G. (1992): Modern Gas-Based Temperature and Pressure Measurements; (Plenum Press, New York and London).

Rusby, R.L.,Hudson, R.P. and Durieux, M. (1994): Revised Values for (t_{90} – t_{68}) from 630 °C to 1064 °C; Metrologia 31, 149-153.

14. Page, 189, Appendix A: The values of (t_{90} – t_{68}) in the range 630 °C to 1064 °C have been revised [Rusby et al (1994)]. These revised values may be obtained from the following equation:

$$(t_{90} - t_{68}) / °C = \sum_{i=o}^{5} b_i (t_{90} / °C)^i$$

where $b_0 = 7.868\,720\,9 \times 10^{1}$

$b_1 = -4.713\,599\,1 \times 10^{-1}$

$b_2 = 1.095\,471\,5 \times 10^{-3}$

$b_3 = -1.235\,788\,4 \times 10^{-6}$

$b_4 = 6.773\,658\,3 \times 10^{-10}$

$b_5 = -1.445\,808\,1 \times 10^{-13}$

15. Page 191, Appendix B: Two entries should be deleted: Amt für Standardisierung Messwesen und Warenprüfung and Kamerlingh Onnes Laboratorium. Four other entries should be changed, as follows:

National Institute of Standards and Technology
Process Measurements Division
Chemical Science and Technology Laboratory
Gaithersburg, Maryland 20899
U.S.A.

Centre for Quantum Metrology
National Physical Laboratory
Teddington, TW11 OLW U.K.
Fax: +44 181 943 6755

Institute for National Measurement Standards
National Research Council of Canada
Ottawa, Canada, K1A OR6

Nederlands Meetinstituut
P.O. Box 654
2600 AR Delft (NL)
Schoemakerstraat 97
2628 VK Delft (NL)
Fax: +31 15 261 2971

16. Page 194, Appendix C: There are four (known) changes of address:

Scientific Instruments
4400 W. Tiffany Drive
Mangonia Park
West Palm Beach, Florida 33407
U.S.A.
Fax: 1 (516) 881-8556

Cryogenic Ltd.
Unit 30, Acton Park Estate
London W3 7QE
U.K.
Fax: +44 181 749 5315

H. Tinsley and Co. Ltd.
275 King Henry's Drive
Croydon CRO OAE
U.K.
Fax: +44 1689 800 405

Oxford Instruments Inc.
Scientific Research Division
Old Station Way
Eynsham Witney
Oxford OX8 1TL
U.K.
Fax: +44 1865 881 567

Additionally, the Fax numbers for the first two firms listed are:

Cryo Cal
Fax: 1 (612) 646-8718

Lake Shore
Fax: 1 (614) 891-1392

17. Page 200, Appendix F: The original Appendix F should be deleted and replaced by the following new Appendix F.

Appendix F

Interpolation Polynomials for Standard Thermocouple Reference Tables

i) All tables are for a reference temperature of 0 °C.
ii) Throughout, E is in mV and t_{90} is in °C.
iii) All of the polynomials (except one for Type K as noted below) are of the form $E = \sum_{i=0}^{n} d_i (t_{90})^i$. The values of n and of the coefficients d_i are listed for each thermocouple type and each range.

1. Type T

a) temperature range from –270 °C to 0 °C: n = 14

d_0	=	0.0	d_7	=	$3.607\ 115\ 420\ 5 \times 10^{-13}$
d_1	=	$3.874\ 810\ 636\ 4 \times 10^{-2}$	d_8	=	$3.849\ 393\ 988\ 3 \times 10^{-15}$
d_2	=	$4.419\ 443\ 434\ 7 \times 10^{-5}$	d_9	=	$2.821\ 352\ 192\ 5 \times 10^{-17}$
d_3	=	$1.184\ 432\ 310\ 5 \times 10^{-7}$	d_{10}	=	$1.425\ 159\ 477\ 9 \times 10^{-19}$
d_4	=	$2.003\ 297\ 355\ 4 \times 10^{-8}$	d_{11}	=	$4.876\ 866\ 228\ 6 \times 10^{-22}$
d_5	=	$9.013\ 801\ 955\ 9 \times 10^{-10}$	d_{12}	=	$1.079\ 553\ 927\ 0 \times 10^{-24}$
d_6	=	$2.265\ 115\ 659\ 3 \times 10^{-11}$	d_{13}	=	$1.394\ 502\ 706\ 2 \times 10^{-27}$
			d_{14}	=	$7.979\ 515\ 392\ 7 \times 10^{-31}$

b) temperature range from 0 °C to 400 °C: n = 8

d_0	=	0.0	d_4	=	$-2.188\ 225\ 684\ 6 \times 10^{-9}$
d_1	=	$3.874\ 810\ 636\ 4 \times 10^{-2}$	d_5	=	$1.099\ 688\ 092\ 8 \times 10^{-11}$
d_2	=	$3.329\ 222\ 788\ 0 \times 10^{-5}$	d_6	=	$-3.081\ 575\ 877\ 2 \times 10^{-14}$
d_3	=	$2.061\ 824\ 340\ 4 \times 10^{-7}$	d_7	=	$4.547\ 913\ 529\ 0 \times 10^{-17}$
			d_8	=	$-2.751\ 290\ 167\ 3 \times 10^{-20}$

2. Type J

a) temperature range from -210 °C to 760 °C: n = 8

d_0 =	0.0	d_4 =	$1.322\,819\,529\,5 \times 10^{-10}$
d_1 =	$5.038\,118\,781\,5 \times 10^{-2}$	d_5 =	$-1.705\,295\,833\,7 \times 10^{-13}$
d_2 =	$3.047\,583\,693\,0 \times 10^{-5}$	d_6 =	$2.094\,809\,069\,7 \times 10^{-16}$
d_3 =	$-8.568\,106\,572\,0 \times 10^{-8}$	d_7 =	$-1.253\,839\,533\,6 \times 10^{-19}$
		d_8 =	$1.563\,172\,569\,7 \times 10^{-23}$

b) temperature range from 760 °C to 1200 °C: n = 5

d_0 =	$2.964\,562\,568\,1 \times 10^{2}$	d_3 =	$-3.184\,768\,670\,10 \times 10^{-6}$
d_1 =	-1.497 612 778 6...	d_4 =	$1.572\,081\,900\,4 \times 10^{-9}$
d_2 =	$3.178\,710\,392\,4 \times 10^{-3}$	d_5 =	$-3.069\,136\,905\,6 \times 10^{-13}$

3. Type E

a) temperature range from -270 °C to 0 °C: n = 13

d_0 =	0.0	d_7 =	$-1.028\,760\,553\,4 \times 10^{-13}$
d_1 =	$5.866\,550\,870\,8 \times 10^{-2}$	d_8 =	$-8.037\,012\,362\,1 \times 10^{-16}$
d_2 =	$4.541\,097\,712\,4 \times 10^{-5}$	d_9 =	$-4.397\,949\,739\,1 \times 10^{-18}$
d_3 =	$-7.799\,804\,868\,6 \times 10^{-7}$	d_{10} =	$-1.641\,477\,635\,5 \times 10^{-20}$
d_4 =	$-2.580\,016\,084\,3 \times 10^{-8}$	d_{11} =	$-3.967\,361\,951\,6 \times 10^{-23}$
d_5 =	$-5.945\,258\,305\,7 \times 10^{-10}$	d_{12} =	$-5.582\,732\,872\,1 \times 10^{-26}$
d_6 =	$-9.321\,405\,866\,7 \times 10^{-12}$	d_{13} =	$-3.465\,784\,201\,3 \times 10^{-29}$

b) temperature range from 0 °C to 1000 °C: n = 10

d_0 =	0.0	d_6 =	$-1.919\,749\,550\,4 \times 10^{-16}$
d_1 =	$5.866\,550\,871\,0 \times 10^{-2}$	d_7 =	$-1.253\,660\,049\,7 \times 10^{-18}$
d_2 =	$4.503\,227\,558\,2 \times 10^{-5}$	d_8 =	$2.148\,921\,756\,9 \times 10^{-21}$
d_3 =	$2.890\,840\,721\,2 \times 10^{-8}$	d_9 =	$-1.438\,804\,178\,2 \times 10^{-24}$
d_4 =	$-3.305\,689\,665\,2 \times 10^{-10}$	d_{10} =	$3.596\,089\,948\,1 \times 10^{-28}$
d_5 =	$6.502\,440\,327\,0 \times 10^{-13}$		

4. Type K

a) temperature range from -270 °C to 0 °C: n = 10

d_0	=	0.0	d_6	=	$-5.741\ 032\ 742\ 8 \times 10^{-13}$
d_1	=	$3.945\ 012\ 802\ 5 \times 10^{-2}$	d_7	=	$-3.108\ 887\ 289\ 4 \times 10^{-15}$
d_2	=	$2.362\ 237\ 359\ 8 \times 10^{-5}$	d_8	=	$-1.045\ 160\ 936\ 5 \times 10^{-17}$
d_3	=	$-3.285\ 890\ 678\ 4 \times 10^{-7}$	d_9	=	$-1.988\ 926\ 687\ 8 \times 10^{-20}$
d_4	=	$-4.990\ 482\ 877\ 7 \times 10^{-9}$	d_{10}	=	$-1.632\ 269\ 748\ 6 \times 10^{-23}$
d_5	=	$-6.750\ 905\ 917\ 3 \times 10^{-11}$			

b) temperature range from 0 °C to 1372 °C:

The polynominal has the form

$$E = \sum_{i=0}^{9} d_i (t_{90})^i + b_0 \exp\left[b_1 (t_{90} - 126.9686)^2\right]$$

d_0	=	$-1.760\ 041\ 368\ 6 \times 10^{-2}$	d_5	=	$-5.607\ 284\ 488\ 9 \times 10^{-13}$
d_1	=	$3.892\ 120\ 497\ 5 \times 10^{-2}$	d_6	=	$5.607\ 505\ 905\ 9 \times 10^{-16}$
d_2	=	$1.855\ 877\ 003\ 2 \times 10^{-5}$	d_7	=	$-3.202\ 072\ 000\ 3 \times 10^{-19}$
d_3	=	$-9.945\ 759\ 287\ 4 \times 10^{-8}$	d_8	=	$9.715\ 114\ 715\ 2 \times 10^{-23}$
d_4	=	$3.184\ 094\ 571\ 9 \times 10^{-10}$	d_9	=	$-1.210\ 472\ 127\ 5 \times 10^{-26}$
b_0	=	$1.185\ 976 \times 10^{-1}$			
b_1	=	$-1.183\ 432 \times 10^{-4}$			

5. Type S

a) temperature range from -50 °C to 1064.18 °C: n = 8

d_0	=	0.0	d_4	=	$3.220\ 288\ 230\ 36 \times 10^{-11}$
d_1	=	$5.403\ 133\ 086\ 31 \times 10^{-3}$	d_5	=	$-3.314\ 651\ 963\ 89 \times 10^{-14}$
d_2	=	$1.259\ 342\ 897\ 40 \times 10^{-5}$	d_6	=	$2.557\ 442\ 517\ 86 \times 10^{-17}$
d_3	=	$-2.324\ 779\ 686\ 89 \times 10^{-8}$	d_7	=	$-1.250\ 688\ 713\ 93 \times 10^{-20}$
			d_8	=	$2.714\ 431\ 761\ 45 \times 10^{-24}$

b) temperature range from 1064.18 °C to 1664.5 °C: n = 4

d_0	=	1.329 004 440 85...	d_3	=	$-1.648\ 562\ 592\ 09 \times 10^{-9}$
d_1	=	$3.345\ 093\ 113\ 44 \times 10^{-3}$	d_4	=	$1.299\ 896\ 051\ 74 \times 10^{-14}$
d_2	=	$6.548\ 051\ 928\ 18 \times 10^{-6}$			

c) temperature range from 1664.5 °c to 1768.1 °C: n = 4

d_0 = 1.466 282 326 36 x 10^{2}

d_1 = -2.584 305 167 52 x 10^{-1}

d_2 = 1.636 935 746 41 x 10^{-4}

d_3 = -3.304 390 469 87 x 10^{-8}

d_4 = -9.432 236 906 12 x 10^{-15}

6. Type B

a) temperature range from 0° C to 630.615 °C: n=6

d_0 = 0.0

d_1 = -2.465 081 834 6 x 10^{-4}

d_2 = 5.904 042 117 1 x 10^{-6}

d_3 = -1.325 793 163 6 x 10^{-9}

d_4 = 1.566 829 190 1 x 10^{-12}

d_5 = -1.694 452 924 0 x 10^{-15}

d_6 = 6.299 0347 09 4 x 10^{-19}

b) temperature range from 630.615 °C to 1820 °C: n = 8

d_0 = -3.893 816 862 1 ...

d_1 = 2.857 174 747 0 x 10^{-2}

d_2 = -8.488 510 478 5 x 10^{-5}

d_3 = 1.578 528 016 4 x 10^{-7}

d_4 = -1.683 534 486 4 x 10^{-10}

d_5 = 1.110 979 401 3 x 10^{-13}

d_6 = -4.451 543 103 3 x 10^{-17}

d_7 = 9.897 564 082 1 x 10^{-21}

d_8 = -9.379 133 028 9 x 10^{-25}

7. Type N

a) temperature range from -270°C to 0 °C: n = 8

d_0 = 0.0

d_1 = 2.615 910 596 2 x 10^{-2}

d_2 = 1.095 748 422 8 x 10^{-5}

d_3 = -9.384 111 155 4 x 10^{-8}

d_4 = -4.641 203 975 9 x 10^{-11}

d_5 = -2.630 335 771 6 x 10^{-12}

d_6 = -2.265 343 800 3 x 10^{-14}

d_7 = -7.608 930 079 1 x 10^{-17}

d_8 = -9.341 966 783 5 x 10^{-20}

b) temperature range from 0 °C to 1300 °C: n = 10

d0 = 0.0

d1 = 2.592 939 460 1 x 10^{-2}

d2 = 1.571 014 188 0 x 10^{-5}

d3 = 4.382 562 723 7 x 10^{-8}

d4 = -2.526 116 979 4 x 10^{-10}

d5 = 6.431 181 933 9 x 10^{-13}

d6 = -1.006 347 151 9 x 10^{-15}

d7 = 9.974 533 899 2 x 10^{-19}

d8 = -6.086 324 560 7 x 10^{-22}

d9 = 2.084 922 933 9 x 10^{-25}

d10 = -3.068 219 615 1 x 10^{-29}

8. Type R

a) temperature range from -50 °C to 1064.18 °C: n = 9

d_0 = 0.0

d_1 = $5.289\,617\,297\,65 \times 10^{-3}$

d_2 = $1.391\,665\,897\,82 \times 10^{-5}$

d_3 = $-2.388\,556\,930\,17 \times 10^{-8}$

d_4 = $3.569\,160\,010\,63 \times 10^{-11}$

d_5 = $-4.623\,476\,662\,98 \times 10^{-14}$

d_6 = $5.007\,774\,410\,34 \times 10^{-17}$

d_7 = $-3.731\,058\,861\,91 \times 10^{-20}$

d_8 = $1.577\,164\,823\,67 \times 10^{-23}$

d_9 = $-2.810\,386\,252\,51 \times 10^{-27}$

b) temperature range from 1064.18 °C to 1664.5 °C: n = 5

d_0 = 2.951 579 253 16...

d_1 = $-2.520\,612\,513\,32 \times 10^{-3}$

d_2 = $1.595\,645\,018\,65 \times 10^{-5}$

d_3 = $-7.640\,859\,475\,76 \times 10^{-9}$

d_4 = $2.053\,052\,910\,24 \times 10^{-12}$

d_5 = $-2.933\,596\,681\,73 \times 10^{-16}$

c) temperature range from 1664.5 °C to 1768.1 °C: n = 4

d_0 = $1.522\,321\,182\,09 \times 10^{2}$

d_1 = $-2.688\,198\,885\,45 \times 10^{-1}$

d_2 = $1.712\,802\,804\,71 \times 10^{-4}$

d_3 = $-3.458\,957\,064\,53 \times 10^{-8}$

d_4 = $-9.346\,339\,710\,46 \times 10^{-15}$

Foreword

This monograph, published by the Bureau International des Poids et Mesures (BIPM), has been compiled by the Comité Consultatif de Thermométrie, one of the eight consultative committees established by the Comité International des Poids et Mesures.

The approximations to the International Temperature Scale of 1990 described here provide levels of accuracy that are adequate for the great majority of thermometric requirements, and in general do so with greater convenience or at lower cost than would be the case in realizing the ITS-90 itself. Thermometrists who do require the accuracy only available from, or the imprimatur of, the ITS-90 are referred to the text of that scale and, more particularly, to the companion monograph to this one: "Supplementary Information for the ITS-90", also published by the BIPM in 1990. The Comité Consultatif de Thermométrie expects to update both monographs periodically, probably at intervals of the order of five to eight years.

H. PRESTON- THOMAS
President, CCT

T.J. QUINN
Director, BIPM

July 1990

Acknowledgments

This monograph has been prepared by the Working Group of the Comité Consultatif de Thermométrie (CCT) identified hereunder. Although a large part of the material originated with members of this Working Group, much also was originally contributed by colleagues, either in our laboratories, or in other National Standards Laboratories. In addition, (parts of) various drafts underwent critical review by some members of the CCT and thermometry groups. We thank all of these people for their assistance, and express special appreciation to H. Ronsin (Institut National de Métrologie, France), B. Fellmuth (Amt für Standardisierung Messwesen und Warenprüfung, German Democratic Republic), L. Crovini (Istituto di Metrologia "G. Colonnetti", Italy), R.P. Hudson (then of Bureau International des Poids et Mesures, Paris), R. Rusby (National Physical Laboratory, United Kingdom), and members of the Temperature and Pressure Section (National Bureau of Standards, United States of America). We also thank Mrs. P. Vineham (National Research Council of Canada) for having typed so excellently and so patiently the several successive drafts of this monograph.

Working Group 2: R.E. Bedford, National Research Council of Canada
Chairman
G. Bonnier, Institut National de Métrologie, France
H. Maas, Amt für Standardisierung Messwessen und Warenprüfung, German Democratic Republic
F. Pavese, Istituto di Metrologia “G. Colonnetti”, Italy.