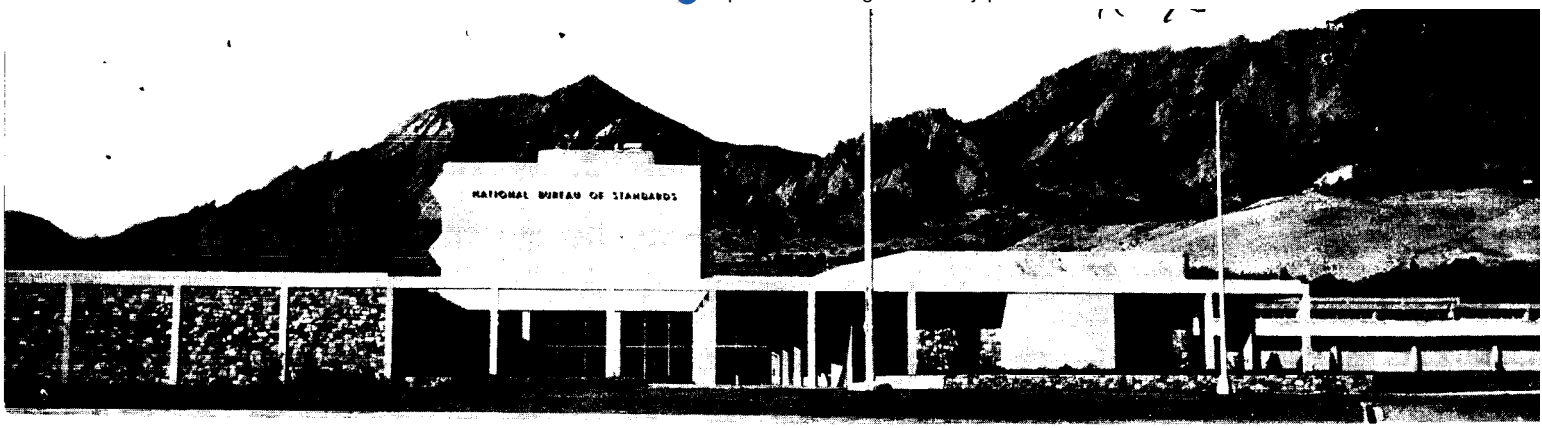


NBS REPORT

8750

AVAILABLE LOW TEMPERATURE THERMOCOUPLE INFORMATION AND SERVICES

by

L. L. Sparks and R. L. Powell

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado

THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. Its responsibilities include development and maintenance of the national standards of measurement, and the provisions of means for making measurements consistent with those standards; determination of physical constants and properties of materials; development of methods for testing materials, mechanisms, and structures, and making such tests as may be necessary, particularly for government agencies; cooperation in the establishment of standard practices for incorporation in codes and specifications; advisory service to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; assistance to industry, business, and consumers in the development and acceptance of commercial standards and simplified trade practice recommendations; administration of programs in cooperation with United States business groups and standards organizations for the development of international standards of practice; and maintenance of a clearinghouse for the collection and dissemination of scientific, technical, and engineering information. The scope of the Bureau's activities is suggested in the following listing of its four Institutes and their organizational units.

Institute for Basic Standards. Electricity. Metrology. Heat. Radiation Physics. Mechanics. Applied Mathematics. Atomic Physics. Physical Chemistry. Laboratory Astrophysics.* Radio Standards Laboratory: Radio Standards Physics; Radio Standards Engineering.** Office of Standard Reference Data.

Institute for Materials Research. Analytical Chemistry. Polymers. Metallurgy. Inorganic Materials. Reactor Radiations. Cryogenics.** Office of Standard Reference Materials.

Central Radio Propagation Laboratory.** Ionosphere Research and Propagation. Troposphere and Space Telecommunications. Radio Systems. Upper Atmosphere and Space Physics.

Institute for Applied Technology. Textiles and Apparel Technology Center. Building Research. Industrial Equipment. Information Technology. Performance Test Development. Instrumentation. Transport Systems. Office of Technical Services. Office of Weights and Measures. Office of Engineering Standards. Office of Industrial Services.

---

* NBS Group, Joint Institute for Laboratory Astrophysics at the University of Colorado.
** Located at Boulder, Colorado.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
31503-12-3150532	February 15, 1965	8750

AVAILABLE LOW TEMPERATURE THERMOCOUPLE INFORMATION AND SERVICES

by

L. L. Sparks and R. L. Powell

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

I. "STANDARD" TABLES

The Cryogenic Data Center of the National Bureau of Standards maintains "standard" tables of voltage vs. temperature for ten thermocouple pairs frequently used at low temperatures. These tables contain interim values which will be useful until national NBS, ASTM, and ASA tables are established for cryogenic temperatures. The "standard" tables now available are slightly different than the previously published tables. The differences are caused by adjusting the older tables to obtain smoother first and second differences of the voltages and sensitivities. The materials, ISA designations, temperature ranges of the data, and literature references are shown below.

Material	Letter Designations	Temp Range	References
Copper vs Constantan	TP-TN	1-300°K	1,2
Copper vs Gold-cobalt	None	1-300°K	1,2
Copper vs "normal" Silver	None	1-300°K	1,2
Chromel* vs Alumel*	KP-KN	1-280°K	2
Chromel* vs Constantan	EP-EN	1-280°K	- -
Chromel* vs Gold-cobalt	None	1-280°K	- -
Iron vs Constantan (modified 1913)	JP-JN	1-280°K	2
Iron vs Constantan (R. P. 1080)	YP-YN	1-280°K	2
"Normal" Silver vs Constantan	None	1-300°K	- -
"Normal" Silver vs Gold-cobalt	None	1-300°K	- -

* Registered Trademark

II. MODIFICATIONS OF "STANDARD" TABLES

Users should recognize that a particular thermocouple pair will not normally generate voltages identical to those listed in the "standard" tables. For example, if two copper vs. constantan thermocouples are made from two different spools of constantan, the voltages produced by these thermocouples will be different, and neither will be in exact agreement with the "standard" copper vs. constantan table.

To overcome this difficulty and achieve the best possible accuracy in the use of thermocouples the user generally resorts to a spot calibration. The spot calibration establishes a voltage for a given thermocouple for a definite temperature difference. The ratio of voltage (measured) to voltage ("standard" table) is then applied as a factor to the existing "standard" table voltage. The result is a working table for a particular thermocouple. A working calibration table could be established for every thermocouple in use; however, it will generally suffice to have one working table for all of the thermocouples made from one spool of wire.

Calibrations and certifications of thermocouple materials in some temperature ranges can be obtained from the Temperature Physics Section of the Institute for Basic Standards, National Bureau of Standards, Washington, D. C. The Cryogenics Division of the Institute for Materials Research does not perform spot calibrations or thermocouple certifications.

III. AVAILABLE SERVICES AND DATA

The Cryogenic Data Center will furnish, at cost, the following materials or services upon request.

1. "Standard" thermocouple tables. "Standard" thermocouple tables are available for the ten materials listed in part I. These printed tables contain the following information: temperature (one degree Kelvin or Celsius intervals), voltage (microvolts), sensitivity (microvolts per degree), and the first differences in the voltages (microvolts). Samples of the tabular data are shown in examples 1 and 2. Example 1 is in degrees Kelvin with a 0.0 degree Kelvin reference temperature and example 2 is in degrees Celsius with a 0.0 degree Celsius reference temperature. References 1 and 2 are also available in reprint form.

2. "Standard" thermocouple data decks. The data on the computer cards is the same as that in the printed tables except that the voltage first differences are omitted and the cards have only degree Kelvin intervals with a 0.0 degree Kelvin reference temperature. The card decks are color striped to agree as nearly as possible with ISA's recommended color code for positive thermocouple extension wire. Example 3 is a typical data card.

3. A program deck, FACTOR, written in FORTRAN II or IV. FACTOR was developed to adjust the "standard" data to fit a particular thermocouple. This program will be discussed in detail in Appendix A of this report.

4. Computer modified tables and data decks. The Cryogenic Data Center will process, on the NBS computer, spot calibration[2] data furnished by the user. The Data Center will then supply the user with any combination of adjusted working tables and data decks. The following information must be given by the user in order to produce a working table or card deck for a particular thermocouple:

a) Users name (1 to 12 characters)

b) Company or laboratory (1 to 15 characters)

c) Thermocouple material

d) Lot identification (1 to 6 characters)

e) Temperature units (degree Kelvin or degrees Celsius)

f) Reference temperature (same units as in (e))

g) Spot calibration high temperature (same units as in (e))

h) Spot calibration low temperature (same units as in (e))

i) Resulting voltage (absolute value in microvolts)

j) Test date (1 to 14 characters)

k) Output form: Tables only or tables and cards

Support necessary for the development of the services described in this paper has been supplied by NASA, Marshall Space Flight Center, Huntsville, Alabama. The Cryogenic Data Center will assume the responsibility of maintaining the services on a cost basis.

THERMOCOUPLE TABLE FOR COPPER VS AUCO , ISA TYPE UNDESIG., BASED ON NAT. BUR. OF STANDARDS PUB. R-188 WITH CALC. MULT. FACTOR OF 1.000.
GENERAL , LOT ANY . USERS REFERENCE TEMPERATURE 0. DEG. K
TEST DATE SEPTEMBER 1,60 BY POWELL,BUNCH

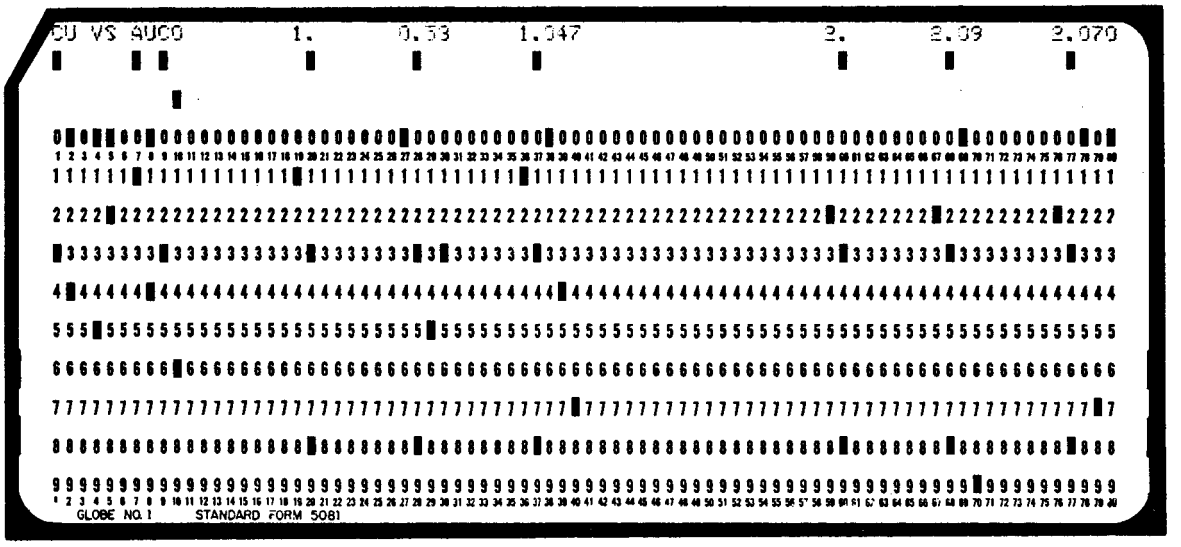
TEMP DEG K	EMF MIC V	DELEMF MIC V	DE/DT MIC V/DGK	TEMP DEG K	EMF MIC V	DELEMF MIC V	DE/DT MIC V/DGK
1	0.53	0.53	1.047	41	640.6	26.4	26.600
2	2.09	1.56	2.070	42	667.4	26.8	26.963
3	4.66	2.57	3.069	43	694.6	27.2	27.317
4	8.22	3.56	4.044	44	722.1	27.5	27.662
5	12.74	4.52	4.994	45	749.9	27.8	27.998
6	18.20	5.46	5.920	46	778.1	28.2	28.326
7	24.57	6.37	6.822	47	806.6	28.5	28.646
8	31.83	7.26	7.700	48	835.4	28.8	28.958
9	39.96	8.13	8.554	49	864.5	29.1	29.262
10	48.93	8.97	9.383	50	893.9	29.4	29.558
11	58.72	9.79	10.188	51	923.6	29.7	29.846
12	69.30	10.58	10.969	52	953.6	30.0	30.127
13	80.65	11.35	11.726	53	983.9	30.3	30.402
14	92.75	12.10	12.458	54	1014.4	30.5	30.669
15	105.6	12.9	13.165	55	1045.2	30.8	30.929
16	119.1	13.5	13.848	56	1076.2	31.0	31.183
17	133.2	14.1	14.513	57	1107.5	31.3	31.430
18	148.0	14.8	15.165	58	1139.1	31.6	31.671
19	163.5	15.5	15.803	59	1170.9	31.8	31.906
20	179.6	16.1	16.427	60	1202.9	32.0	32.134
21	196.4	16.8	17.038	61	1235.1	32.2	32.356
22	213.7	17.3	17.635	62	1267.5	32.4	32.573
23	231.6	17.9	18.219	63	1300.2	32.7	32.784
24	250.1	18.5	18.791	64	1333.1	32.9	32.989
25	269.2	19.1	19.349	65	1366.2	33.1	33.189
26	288.8	19.6	19.893	66	1399.5	33.3	33.384
27	308.9	20.1	20.424	67	1433.0	33.5	33.574
28	329.6	20.7	20.941	68	1466.7	33.7	33.759
29	350.8	21.2	21.446	69	1500.5	33.8	33.938
30	372.5	21.7	21.938	70	1534.5	34.0	34.112
31	394.7	22.2	22.417	71	1568.7	34.2	34.280
32	417.3	22.6	22.884	72	1603.1	34.4	34.442
33	440.4	23.1	23.340	73	1637.6	34.5	34.599
34	464.0	23.6	23.785	74	1672.3	34.7	34.753
35	488.0	24.0	24.218	75	1707.1	34.8	34.905
36	512.4	24.4	24.640	76	1742.1	35.0	35.056
37	537.3	24.9	25.052	77	1777.2	35.1	35.205
38	562.6	25.3	25.454	78	1812.5	35.3	35.352
39	588.2	25.6	25.846	79	1847.9	35.4	35.497
40	614.2	26.0	26.228	80	1883.5	35.6	35.641

EXAMPLE I

THERMOCOUPLE TABLE FOR COPPER VS AUCO , ISA TYPE UNDESIG., BASED ON
NAT. BUR. OF STANDARDS PUB. R-188 WITH CALC. MULT. FACTOR OF 1.000.
GENERAL , LOT ANY . USERS REFERENCE TEMPERATURE 0. DEG. C
TEST DATE SEPTEMBER 1,60 BY POWELL,BUNCH

TEMP DEG C	EMF MIC V	DELEMF MIC V	DE/DT MIC V/DGC	TEMP DEG C	EMF MIC V	DELEMF MIC V	DE/DT MIC V/DGC
-272	-9871.05	0.70	1.202	-232	-9227.2	26.4	26.655
-271	-9869.34	1.71	2.221	-231	-9200.3	26.9	27.017
-270	-9866.62	2.72	3.217	-230	-9173.0	27.3	27.369
-269	-9862.91	3.71	4.188	-229	-9145.5	27.5	27.713
-268	-9858.25	4.66	5.134	-228	-9117.6	27.9	28.048
-267	-9852.65	5.60	6.057	-227	-9089.4	28.2	28.375
-266	-9846.15	6.50	6.955	-226	-9060.8	28.6	28.693
-265	-9838.75	7.40	7.830	-225	-9032.0	28.8	29.004
-264	-9830.50	8.25	8.680	-224	-9002.9	29.1	29.307
-263	-9821.40	9.10	9.505	-223	-8973.4	29.5	29.602
-262	-9811.49	9.91	10.307	-222	-8943.7	29.7	29.889
-261	-9800.80	10.69	11.084	-221	-8913.6	30.1	30.169
-260	-9789.33	11.47	11.837	-220	-8883.3	30.3	30.442
-259	-9777.11	12.22	12.566	-219	-8852.7	30.6	30.708
-258	-9764.2	12.9	13.269	-218	-8821.9	30.8	30.968
-257	-9750.6	13.6	13.949	-217	-8790.9	31.0	31.220
-256	-9736.4	14.2	14.612	-216	-8759.5	31.4	31.467
-255	-9721.5	14.9	15.262	-215	-8727.9	31.6	31.707
-254	-9705.9	15.6	15.897	-214	-8696.1	31.8	31.941
-253	-9689.7	16.2	16.520	-213	-8664.0	32.1	32.168
-252	-9672.8	16.9	17.128	-212	-8631.8	32.2	32.389
-251	-9655.4	17.4	17.723	-211	-8599.4	32.4	32.605
-250	-9637.4	18.0	18.306	-210	-8566.6	32.8	32.815
-249	-9618.8	18.6	18.876	-209	-8533.7	32.9	33.019
-248	-9599.6	19.2	19.431	-208	-8500.6	33.1	33.219
-247	-9580.0	19.6	19.974	-207	-8467.2	33.4	33.413
-246	-9559.8	20.2	20.502	-206	-8433.7	33.5	33.602
-245	-9539.0	20.8	21.018	-205	-8400.0	33.7	33.786
-244	-9517.7	21.3	21.521	-204	-8366.2	33.8	33.964
-243	-9495.9	21.8	22.011	-203	-8332.1	34.1	34.138
-242	-9473.7	22.2	22.488	-202	-8297.9	34.2	34.305
-241	-9451.0	22.7	22.953	-201	-8263.5	34.4	34.466
-240	-9427.8	23.2	23.408	-200	-8229.0	34.5	34.622
-239	-9404.2	23.6	23.851	-199	-8194.2	34.8	34.776
-238	-9380.1	24.1	24.282	-198	-8159.4	34.8	34.928
-237	-9355.6	24.5	24.702	-197	-8124.4	35.0	35.078
-236	-9330.7	24.9	25.113	-196	-8089.3	35.1	35.227
-235	-9305.3	25.4	25.513	-195	-8054.0	35.3	35.374
-234	-9279.7	25.6	25.904	-194	-8018.5	35.5	35.519
-233	-9253.6	26.1	26.284	-193	-7982.9	35.6	35.663

EXAMPLE 2



EXAMPLE 3

APPENDIX A

The Program FACTOR:

To help the user prepare working tables for given thermocouples a computer program called FACTOR has been developed. In order to use the FACTOR program to generate his own "working" data the user is presumed to have:

1. The program FACTOR (card deck),
2. The appropriate "standard" thermocouple card deck,
3. Results from the user's spot calibration (to be punched as data cards), and
4. Access to a computer which will accept either FORTRAN II or IV.

The FORTRAN II version of FACTOR was written for an IBM model 7090, but should be compatible with IBM models 7070/7074, 705 and 704. FACTOR may be compatible as written or easily adapted to some other types of computers. When ordering a FACTOR program, the type of computer to be used should be specified.

The FACTOR program calculates the proper ratio of voltage (measured) to voltage ("standard" table), applies it to the existing "standard" thermocouple table and produces a working table for a particular thermocouple. FACTOR is designed to allow any number of data decks to be processed at one time, and any number of adjustments to be made on any or all of the decks. The options available in the FACTOR program are:

1. FACTOR program in either FORTRAN II or FORTRAN IV language,
2. Output in degrees Kelvin, °K, reference temperature in °K,

3. Output in degrees Celsius, °C, reference temperature in °C,
4. Output in the form of printed tables,
5. Output in the form of printed tables and punched data cards,
6. The reference temperature (emf zero) may be any temperature that falls within the range of the "standard" tables.

These options are selected by the user by punching cards as described below.

Description of User Punched Cards:

There are three cards with which the user must concern himself. Two cards must be punched by the user for each set of output (tables or tables and cards in either °K or °C with one reference temperature).

1. Card A contains the information from the spot calibration.
2. Card B identifies the material, user, date, etc.

Card Punching Detail:

Card A

Columns 1 - 6:	System of units; either DEG. K or DEG. C. The space between the period and K or C is required.
Columns 11 - 20:	High temperature of spot calibration; must include a decimal point (number of decimal points carried is users option) and units must be consistent with system of units chosen in columns 1 - 6.
Columns 21 - 30:	Low temperature of spot calibration; same form as used in columns 11 - 20 (number of decimal places need not be the same).

Columns 31 - 40: Voltage from spot calibration; units must be microvolts. There must be a decimal point.

Columns 41 - 50: Reference temperature; there must be a decimal point and must be in the units chosen in columns 1 - 6.

Columns 58 - 60: Punch YES if punched cards are desired in addition to a printed table. Punch NO in columns 58 - 59 if only a table is wanted.

Card B

Columns 1 - 15: Company or laboratory name; may be any length up to 15 letters.

Columns 21 - 26: Material lot number; may be any coding desired to identify the particular spool of wire in question, and may be any length up to six characters.

Columns 31 - 42: Users name; may be any length up to 12 characters.

Columns 51 - 64: Date of test; may be written in any form desired within the given space, and may be any length up to 14 characters.

The third card is called REPEAT card and is used as follows: the repeat card is used only when more than one set of output is desired for the same material. If the user wishes to process two or more thermocouples of the same material in one machine run he must punch a REPEAT card as described below for each extra thermocouple.

REPEAT Card

Columns 1 - 21:	Punch REPEAT LAST T.C. DECK
Column 50	Punch 0 (Ed. zero)
Columns 55 - 60:	Punch DEG. K; must punch DEG. K regardless of units wanted. There must be a space between the period and K.
Columns 68 - 70:	Punch YES

Example:

As an example of how the FACTOR program may be used suppose the user has two "standard" thermocouple decks - one of type XP-XN and the other of type ZP-ZN. The temperature range of the "standard" deck for the X material is 0 - 300°K and for the Z material it is 0 - 280°K. The user has three spools of the X material and two spools of the Z material. The user identifies the three spools of X material as 001, 002, and 003; the two spools of Z material are identified as 101 and 102.

Spot calibrations are made on each spool in question (5 tests). Each spot calibration was done with a high temperature of 273.15°K (0.0°C) and a low temperature of 76.7°K (-196.95°C). The data taken in each test was the high and low temperatures and the resulting voltage in microvolts.

Let us further suppose that the user is JOHN DOE of DUMMY COMPANY, and that the test date was JANUARY 3, 1965.

XP-XN Material

Spool 001:	The output is to be a table in °K with a 90.0°K reference temperature (first set of output). The user would also like a table and punched cards in °C with a 0.0°C reference temperature. (second set of output).

Spool 002: The output is to be a table in °K with 0.0°K reference temperature (third set of output).

Spool 003: The output is to be a table and punched cards in °K with a 77.0°K reference temperature (fourth set of output).

Spool 101: The output is to be a table in °C with a reference temperature of -167.90°C (fifth set of output).

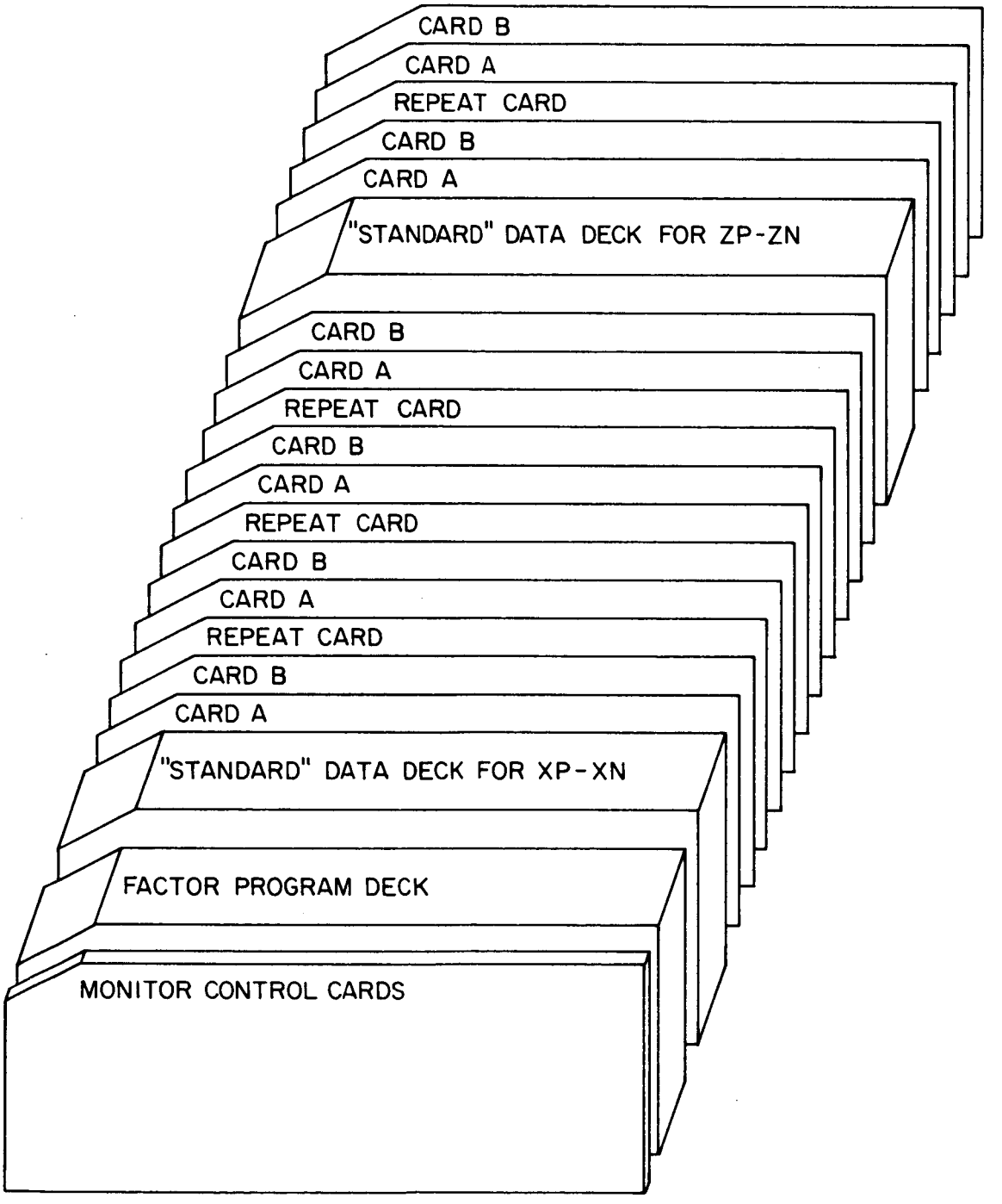
Spool 102: The output is to be a table and cards in °K with a 20.0°K reference temperature (sixth set of output).

The deck arrangement and the "user punched cards" for this example are illustrated on the following pages.

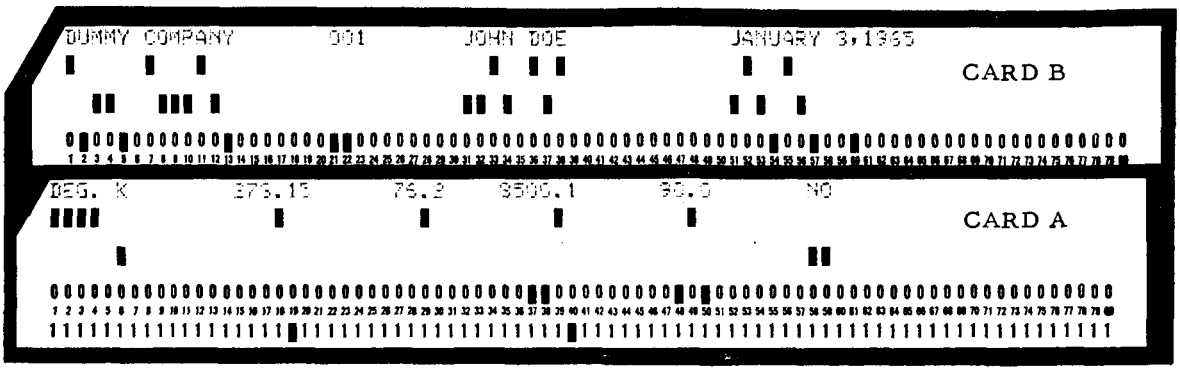
The MONITOR CONTROL CARDS shown in the deck arrangement will differ to some degree for most computer installations. Information concerning what cards are necessary and how to punch them should be available from the particular computer facilities.

The "standard" data deck for each thermocouple material will consist of KEY CARD 1, KEY CARD 2, and the thermocouple data. These KEY cards are already punched and must not be changed.

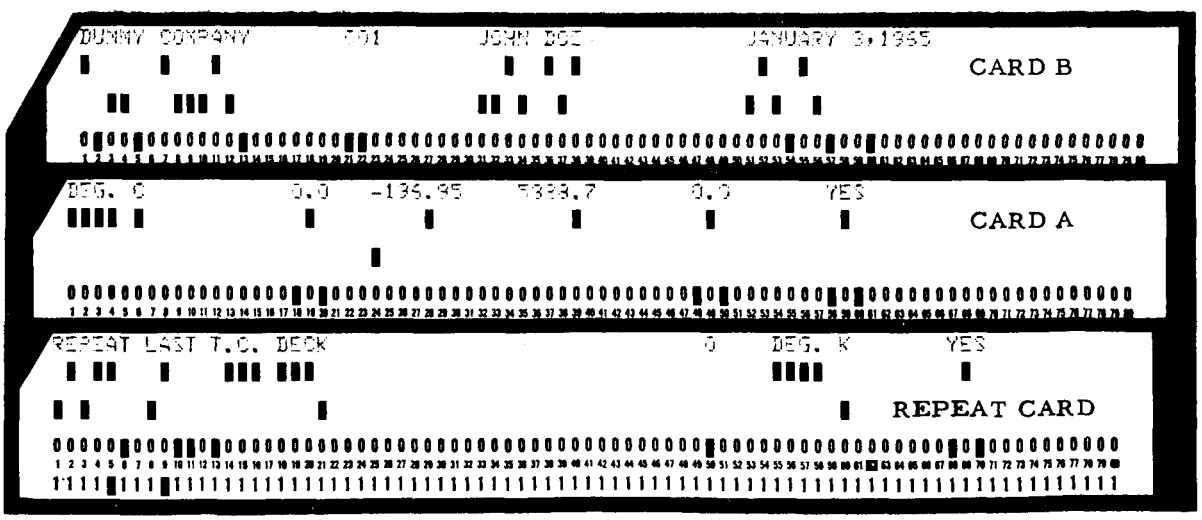
NOTE: The monitors used in some computer facilities will differ to some extent from the standard IBM monitor for which FACTOR was written. The FACTOR program uses tape five as a peripheral read unit, tape six as a peripheral print unit, and tape seven as a peripheral punch unit. If the monitor being used utilizes different tape units for these functions the program must be altered to indicate the tape units needed. As it is now written the FACTOR program uses the read units in statements 100, 105, 120, 140 and 150, the print unit in statements 665, 680, 690, 700, 725, 735, 800, 810, 865, 870, 880, 890, 955, 965, 1020 and 1030, and the punch unit in statements 1095 and 1097.



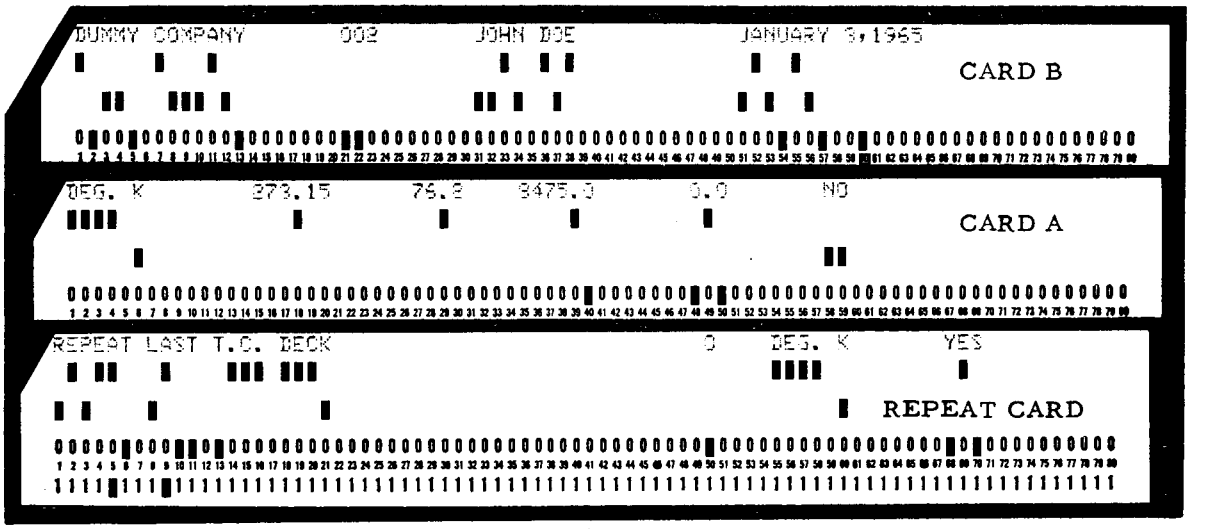
EXAMPLE DECK ARRANGEMENT



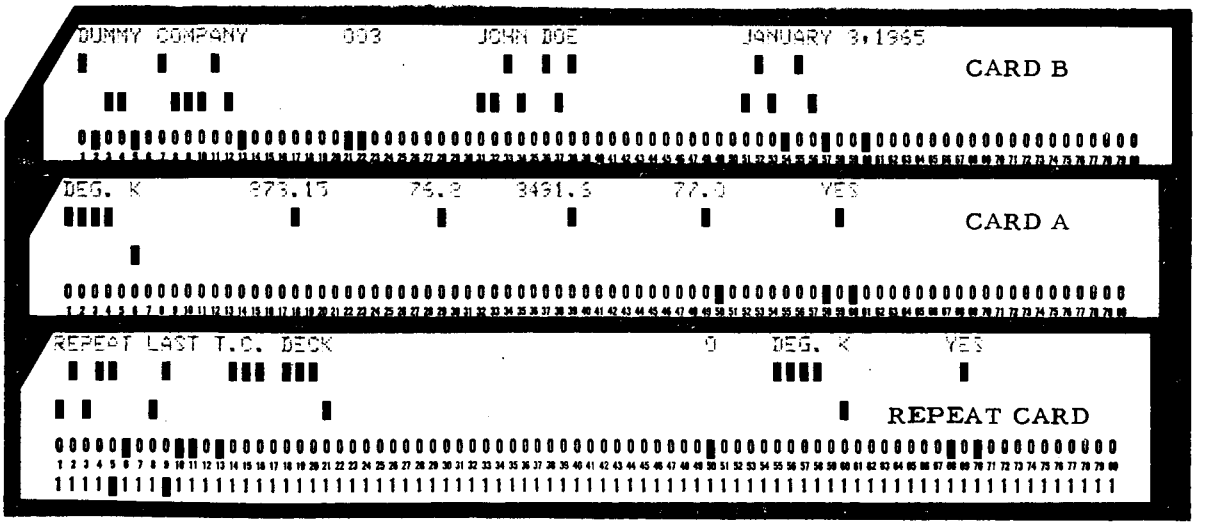
These cards immediately follow the data deck of the XP-XN material. They furnish the FACTOR program with the data required to generate the first set of output from spool 001.



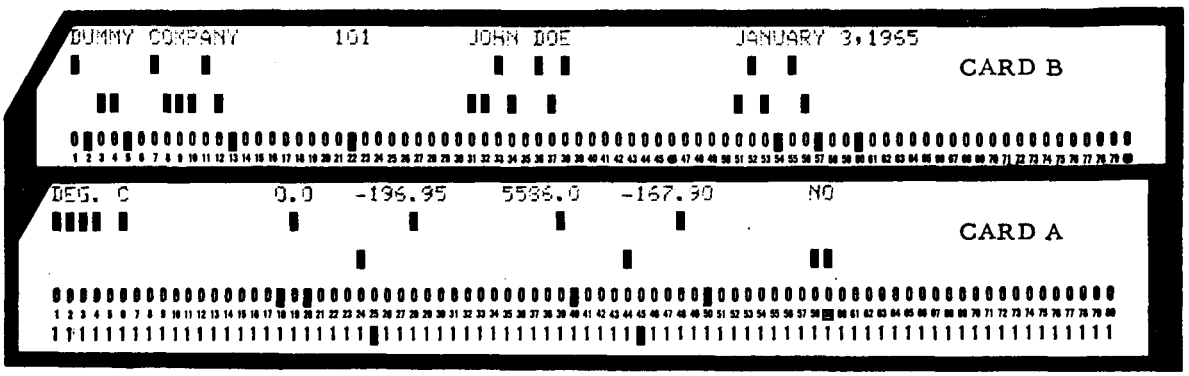
Information for the second set of output from spool 001 is supplied by these three cards.



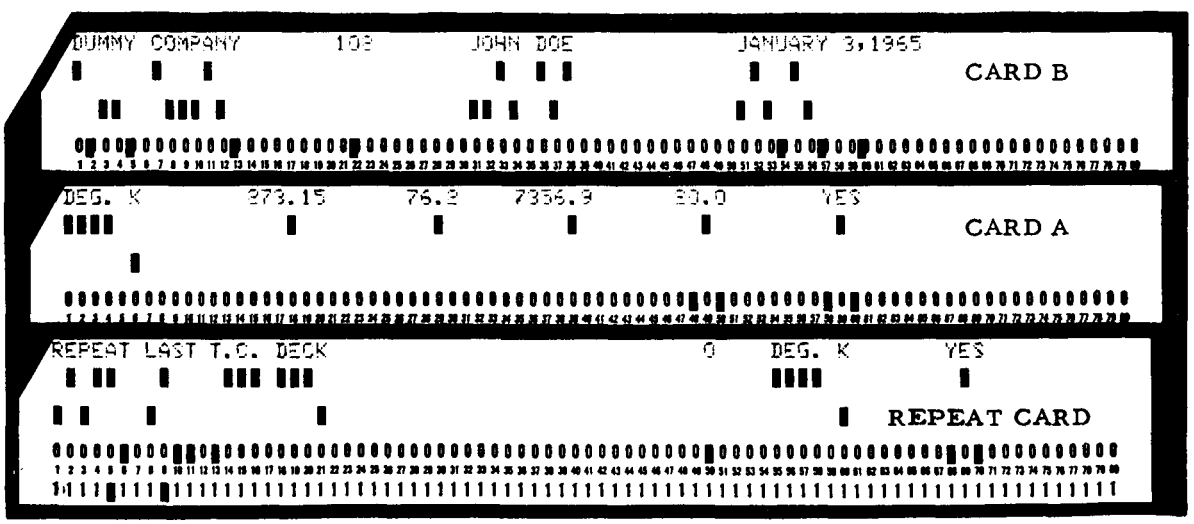
Third set of output



Fourth set of output



These cards follow the "standard" data deck for the ZP-ZN material. Generate the fifth set of output.



Sixth and final set of output.

References

1. Powell, R. L., Bunch, M. D., and Corruccini, R. J., "Low-Temperature Thermocouples-1. Gold-Cobalt or Constantan vs. Copper or 'Normal' Silver", Cryogenics 1, 139 (1961).

2. Powell, R. L., Caywood, L. P., and Bunch, M. D., "Low-Temperature Thermocouples" in a Book Temperature, Its Measurement and Control in Science and Industry, Vol. 3, Part 2 (Reinhold, New York, 1963).