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THERMOELECTRIC LEG PRODUCT SPECIFICATION (TELPs) FINAL TECHNICAL REPORT

Volume 2-Specifications and Procedures

ADVANCED NUCLEAR SYSTEMS OPERATION

GENERAL ELECTRIC

**MISSILE AND SPACE DIVISION
Valley Forge Space Technology Center**

PO BOX 8061 PHILADELPHIA, PENNA. 19101

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Volume 2-Specifications and Procedures

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1. THERMOELECTRIC LEG PRODUCT SPECIFICATION

P-TYPE TPM 206, LOT 10

1.1 GENERAL

1.1.1 SCOPE

This specification covers acceptance parameters and criteria for P-type TPM 206, Lot 10, lead tin telluride thermoelectric legs produced for the SNAP-27 Program. Engineering values of leg parameters are included in paragraph 1.6 (Attachment A). Required acceptance procedures are included in Section 3 of this volume.

1.1.1.1 Effectivity

This specification may be implemented at the conclusion of manufacture and Quality Control acceptance of TPM 206, Lot 10, for the SNAP-27 Program.

1.1.1.2 Revision Procedures

This specification is subject to the normal revision procedures used on the SNAP-27 Program, that is, engineering documents may be revised upon recommendation of the seller and approval by the buyer. A record of reissuance will be included on the title page of the re-issued document.

1.1.2 DEFINITIONS

Seebeck Voltage (1090-520), E_s , is defined as the potential difference in millivolts developed by a thermocouple consisting of the test specimen and a thermocouple grade iron wire when said couple is subjected to a temperature differential of 1090 °F to 520 °F. By convention, N-type test specimens produce negative Seebeck voltages relative to the iron reference, while P-type test specimens produce positive Seebeck voltages.

Ingradient Resistivity (1090-520), ρ , of a thermoelectric leg is defined as the product of the leg resistance in microhms and the A/L geometry ratio of the leg in in²/in when the leg is subjected to a temperature difference of 1090 °F to 520 °F under conditions of one-dimensional axial heat flow and negligible internally generated Joule and Thomson heats.

Thermal Conductance (1090-520), $K \Delta T$, is defined as the product of the measured rate of heat flow in watts and the L/A geometry ratio of the leg in in/in^2 when the leg is subjected to a temperature difference of 1090°F to 520°F under conditions of one-dimensional axial heat flow and no electrical current flow.

1.2 APPLICABLE DOCUMENTS

(Reference Only)

<u>NUMBER</u>	<u>TITLE</u>
MMM8406-0233	Task 2.2 TELPS Work Statement Characterization Test Plan
MMM8406-1172	Task 3 Thermoelectric Performance Test Plan

1.3 REQUIREMENTS

1.3.1 RESTRICTIONS

The mean values, deviations, and specification limits for each parameter specified in paragraph 1.4, and the resulting acceptance plans, are based upon limited testing of TPM 206, Lot 10*, PbSnMnTe thermoelectric material. Subsequent additional testing of this material may indicate changes in statistical parameters which will result in adjustments of the specification limits.

1.3.2 IDENTIFICATION

Positive identification of each leg shall be maintained relative to its basic leg batch, inspection and electrical testing requirements. However, a leg shall at no time be physically marked.

1.3.3 SAMPLING METHODS

1.3.3.1 Use of Sequential Sampling Plan

All sampling plans used in this specification are of the variable sequential type. Sequential sampling is a technique whereby items are tested one at a time and after each test the cumulative results are compared to tabulated values in order to make a decision. After a test,

*This lot designation refers to a specific vendor production instruction and completely defines the resulting product.

three decisions are possible:

- a. Reject batch
- b. Continue testing
- c. Accept batch

Each sampling plan contains four columns of tabulated values. Each value defines a decision zone as shown below. Undefined values are used at present and a specific case will subsequently be illustrated.

SAMPLE NUMBER	REJECT	CONTINUE TESTING	ACCEPT	CONTINUE TESTING	REJECT
n	$S < N_1$	$S \leq N_1$	$S < N_2$	$S \leq N_2$	$S < N_3$
					$S \leq N_3$
					$S < N_4$
					$S \leq N_4$
					$S < N_5$
					$S \leq N_5$

The tabulated values are used as follows:

If the cumulative sum S of the test results of n measurements is:*

- a. Less than N_1 - reject
- b. Up to but not including N_2 - continue testing
- c. From N_2 to N_3 - accept
- d. Greater than N_3 to N_4 - continue testing
- e. Greater than N_4 - reject

Numerical Example: Sampling Plan for P-Leg Density

Assume the following test results were found. It is understood that the tests were run one at a time. Each time the sum of all test results to that point were compared to the tabulated for that sample number.

*An asterisk denotes that the decision indicated by the column heading cannot be made with this sample size.

SAMPLE NUMBER	TEST RESULT	SUM	DECISION	REMARKS
Batch A				
1	109	109	Continue	107.6673<109<112.1927
2	108	217	Continue	216.6963<217<219.1186
3	109	326	Continue	325.7253<326<328.1476
4	108	434	<u>Reject</u>	434<434.7543
Batch B				
1	110	110	Continue	107.6673<110<112.1927
2	110	220	<u>Accept</u>	219.1186<220<220.6014
Batch C				
1	106	106	<u>Reject</u>	106<107.6673

1.4 QUALITY PROVISIONS

1.4.1 SPECIFICATION LIMITS

CHARACTERISTIC	MINIMUM	MEAN VALUE	MAXIMUM	NUMBER OF MEASUREMENTS
Length, inches	0.3923	0.3989	0.4055	1,440
Diameter, inches	0.2447	0.2458	0.2469	1,440
Density, gm/in ³	108.51	109.93	111.35	1,440
Seebeck Voltage (1090-520 °F) mv	63.11	67.09	71.07	16
Ingradient Resistivity (1090-520 °F) μ Ω-inches	1237.	1548.	1860.	16
Thermal Conductance Q L/A (1090-520 °F) mwatt/inch	8.51	10.38	12.26	16
Oxygen Content ppm	50.	383.	716.	12

1.4.2 TESTING

1.4.2.1 Order of Inspection

- a. Visual inspection per paragraph 1.4.2.4.1. Reject defective legs.
- b. Length, diameter and density determination per paragraph 1.4.2.4.2(a). Accept/reject batch in accordance with variables sequential sampling plan applied to random samples of batch.
- c. Oxygen content determination per paragraph 1.4.2.4.2(b). Accept/reject batch in accordance with variables sequential sampling plan applied to random sample of batch.
- d. Seebeck voltage, ingradient resistance and thermal conductivity determination per paragraph 1.4.2.4.2(c). Accept/reject batch in accordance with variables sequential sampling plan applied to random sample of batch. Each of the three properties are to be determined simultaneously on the same sample.
- e. If batch fails any tests, hold batch for disposition per paragraph 1.4.2.2.
- f. If batch passes all tests, release to production.

1.4.2.2 Rejected Batch

Whenever a batch is rejected, the supplier shall mark the batch "NSQ", place it in storage and notify the buyer. Disposition of the batch will be jointly determined by MRB action.

1.4.2.3 Significance of Numbers

The test plans in this specification are computer-generated with no provision for rounding nonsignificant numbers. Significance should be judged according to paragraph 1.4.1. Tolerances throughout this specification are ± 10 percent unless otherwise indicated.

1.4.2.4 Test Levels

TEST TITLE	PARAGRAPH NO.	QUALITY REQUIREMENTS 100 PERCENT	NOTES
Visual	1.4.2.4.1	X	
Dimensions and Density	1.4.2.4.2(a)	Variable Sequential Plan	2
Oxygen	1.4.2.4.2(b)	VS	1,2
E _s , R, Q L/A	1.4.2.4.2(c)	VS	2

1. This test is destructive.

2. All variable sequential plans are based on an AQL of 2.5 percent and an LTPD of 10.0 percent.

1.4.2.4.1 Visual Inspection - Visual standards to be mutually adopted by supplier and buyer prior to order placement under this specification.

- a. Corner chipping on a thermoelectric leg shall not be in excess of a mutually approved visual standard which normally corresponds to a maximum allowable decrease in the leg end surface area of 5 percent.
- b. Surface pitting on a thermoelectric leg shall not be in excess of a mutually approved visual standard with a maximum allowable pit depth of 0.015 inch.
- c. Localized surface deposits of lead and carbon shall not exceed that shown in a mutually approved visual standard.
- d. There shall be no evidence of leg surface cracking when examined with the unaided eye, that is, without magnification.

1.4.2.4.2 Acceptance Requirements

- a. Length and diameter shall be determined using a micrometer with a 0 to 1.0-inch range and a 0.0001-inch resolution. Weight should be measured on a balance with a resolution of a milligram. Density shall be determined by:

$$\text{Density} = \frac{4 \times \text{Weight}}{\text{length} \times \text{diameter}^2} \quad \frac{(\text{grams})}{\text{in.}^3}$$

Sampling plans for the dimensions and density are listed in tables following this paragraph.

- b. Oxygen content shall be determined by the Leco Test Method as described in Section 3 of this volume, according to the following sampling plan. Specification limits are based on data listed in paragraph 1.4.1.
- c. Seebeck Voltage, Ingradient Resistivity and Thermal Conductance shall be determined according to the test method described in Section 3 of this volume, using the following sampling plans. Specification limits are based on data listed in paragraph 1.6 (Attachment A).

LENGTH

Double One-Sided Variables Sequential Sampling Plan for Upper and Lower Limits on Length

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500 BETA = 0.1000 SIGMA = 0.002
 LI = 0.395 LO = 0.397 UO = 0.401 U1 = 0.402

SAMPLE NUMBER	REJECT BATCH IF LESS THAN	ACCEPT BATCH IN THIS RANGE ***** *****		REJECT BATCH IF GREATER THAN
1	.3859	*	*	.4118
2	.7821	*	*	.8134
3	1.1783	1.1967	1.1967	1.2215
4	1.5746	1.5929	1.5929	1.6166
5	1.9708	1.9891	1.9899	2.0181
6	2.367	2.3854	2.4015	2.4197
7	2.7632	2.7816	2.803	2.8213
8	3.1594	3.1778	3.2046	3.2229
9	3.5557	3.574	3.6062	3.6244
10	3.9519	3.9702	4.0078	4.026
11	4.3481	4.3665	4.4093	4.4276
12	4.7443	4.7627	4.8109	4.8292
13	5.1405	5.1589	5.2125	5.2307
14	5.5368	5.5551	5.6141	5.6323
15	5.933	5.9513	6.0156	6.0339
16	6.3292	6.3476	6.4172	6.4355
17	6.7254	6.7438	6.8188	6.837
18	7.1216	7.14	7.2204	7.2386
19	7.5179	7.5362	7.6219	7.6402
20	7.9141	7.9324	8.0235	8.0418
21	8.3103	8.3287	8.4251	8.4433
22	8.7065	8.7249	8.8267	8.8449
23	9.1027	9.1211	9.2282	9.2465
24	9.499	9.5173	9.6298	9.6481
25	9.8952	9.9135	10.0314	10.0496
26	10.2914	10.3097	10.433	10.4512
27	10.6876	10.706	10.8345	10.8528
28	11.0838	11.1022	11.2361	11.2544
29	11.48	11.4984	11.6377	11.6559
30	11.8763	11.8946	12.0393	12.0575
31	12.2725	12.2909	12.4402	12.4591
32	12.6687	12.6871	12.8424	12.8607
33	13.0649	13.0833	13.244	13.2622
34	13.4612	13.4795	13.6456	13.6638
35	13.8574	13.8757	14.0471	14.0654
36	14.2536	14.272	14.4487	14.467
37	14.6498	14.6682	14.8503	14.8685
38	15.046	15.0644	15.2519	15.2701
39	15.4423	15.4606	15.6534	15.6717
40	15.8385	15.8568	16.055	16.0733
41	16.2347	16.2531	16.4566	16.4748
42	16.6309	16.6493	16.8582	16.8764
43	17.0271	17.0455	17.2597	17.278
44	17.4234	17.4417	17.6613	17.6796
45	17.8196	17.8379	18.0629	18.0811
46	18.2158	18.2342	18.4645	18.4827
47	18.612	18.6304	18.866	18.8843
48	19.0082	19.0266	19.2676	19.2859
49	19.4045	19.4228	19.6692	19.6874
50	19.8007	19.819	20.0708	20.089

* CANNOT ACCEPT LOT WITH THIS SAMPLE SIZE.

DIAMETER

Double One-Sided Variable Sequential Sampling Plan for Upper and Lower Limits on Diameter

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500 BETA = 0.1000 SIGMA = 0.000
L1 = 0.245015 LO = 245182 UO = 0.2464178 U1 = 0.2465847

SAMPLE NUMBER	REJECT BATCH IF LESS THAN	ACCEPT BATCH IN THIS RANGE ***** *****	REJECT BATCH IF GREATER THAN
1	.2441	*	.2475
2	.4891	.491	.4941
3	.7342	.7361	.7406
4	.9793	.9812	.9871
5	1.2244	1.2263	1.2336
6	1.4695	1.4714	1.4801
7	1.7146	1.7165	1.7266
8	1.9597	1.9616	1.9731
9	2.2048	2.2067	2.2196
10	2.4499	2.4518	2.4661
11	2.695	2.6969	2.7126
12	2.9401	2.942	2.9591
13	3.1852	3.1871	3.2056
14	3.4303	3.4322	3.4521
15	3.6754	3.6773	3.6986
16	3.9205	3.9224	3.9451
17	4.1656	4.1675	4.1916
18	4.4107	4.4126	4.4381
19	4.6558	4.6577	4.6846
20	4.9009	4.9028	4.9311
21	5.146	5.1479	5.1776
22	5.3911	5.393	5.4241
23	5.6362	5.6381	5.6706
24	5.8813	5.8832	5.9171
25	6.1264	6.1283	6.1636
26	6.3715	6.3734	6.4101
27	6.6166	6.6185	6.6566
28	6.8617	6.8636	6.9031
29	7.1068	7.1087	7.1496
30	7.3519	7.3538	7.3961
31	7.597	7.5989	7.6426
32	7.8421	7.844	7.8891
33	8.0872	8.0891	8.1337
34	8.3323	8.3342	8.3802
35	8.5774	8.5793	8.6267
36	8.8225	8.8244	8.8732
37	9.0676	9.0695	9.1197
38	9.3127	9.3146	9.3662
39	9.5578	9.5597	9.6146
40	9.8029	9.8048	9.8592
41	10.048	10.0499	10.1057
42	10.2931	10.295	10.3522
43	10.5382	10.5401	10.5987
44	10.7833	10.7851	10.8452
45	11.0284	11.0302	11.0917
46	11.2735	11.2753	11.3332
47	11.5186	11.5204	11.5847
48	11.7637	11.7655	11.8312
49	12.0088	12.0106	12.0777
50	12.2539	12.2557	12.3242

* CANNOT ACCEPT LOT WITH THIS SAMPLE SIZE.

DENSITY

Double One-Sided Variables Sequential Sampling Plan for Upper and Lower Limits on Density

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500 BETA = 0.1000 SIGMA = 0.319
L1 = 108.921 LO = 109.137 UO = 110.939

SAMPLE NUMBER	REJECT BATCH IF LESS THAN	ACCEPT BATCH IN THIS RANGE ***** *****	REJECT BATCH IF GREATER THAN
1	107.6673	*	*
2	216.6963	219.1186	220.6014
3	325.7253	328.1476	331.4324
4	434.7543	437.1766	442.2634
5	543.7833	546.2056	553.0944
6	652.8123	655.2346	663.9254
7	761.8413	764.2636	774.7564
8	870.8703	873.2926	885.5874
9	979.8993	982.3216	996.4184
10	1088.9283	1091.3506	1107.2494
11	1197.9573	1200.3796	1218.0804
12	1306.9863	1309.4086	1328.9114
13	1416.0153	1418.4376	1439.7424
14	1525.0443	1527.4666	1550.5734
15	1634.0733	1636.4956	1661.4044
16	1743.1023	1745.5246	1772.2354
17	1852.1313	1854.5536	1883.0664
18	1961.1603	1963.5826	1993.8974
19	2070.1893	2072.6116	2104.7284
20	2179.2183	2181.6406	2215.5594
21	2288.2473	2290.6696	2326.3904
22	2397.2763	2399.6986	2437.2214
23	2506.3053	2508.7276	2548.0524
24	2615.3343	2617.7566	2658.8834
25	2724.3633	2726.7856	2769.7144
26	2833.3923	2835.8146	2880.5454
27	2942.4213	2944.8436	2991.3764
28	3051.4503	3053.8726	3102.2074
29	3160.4793	3162.9016	3213.0384
30	3269.5083	3271.9306	3323.8694
31	3378.5373	3380.9596	3434.7004
32	3487.5663	3489.9886	3545.5314
33	3596.5953	3599.0176	3656.3624
34	3705.6243	3708.0466	3767.1934
35	3814.6533	3817.0756	3878.0244
36	3923.6823	3926.1046	3988.8554
37	4032.7113	4035.1336	4099.6864
38	4141.7403	4144.1626	4210.5174
39	4250.7693	4253.1916	4321.3484
40	4359.7983	4362.2206	4432.1794
41	4468.8273	4471.2496	4543.0104
42	4577.8563	4580.2786	4653.8414
43	4686.8853	4689.3076	4764.6724
44	4795.9143	4798.3366	4875.5034
45	4904.9433	4907.3656	4986.3344
46	5013.9723	5016.3946	5097.1654
47	5122.0013	5125.4236	5207.9964
48	5231.0303	5234.4526	5318.8274
49	5340.0593	5343.4816	5429.6584
50	5449.0883	5452.5106	5540.4894

* CANNOT ACCEPT LOT WITH THIS SAMPLE SIZE.

TYPE: 0=SCOTT, 1=RESCOTT

SEEBECK VOLTAGE (1090-520°F)

Double One-Sided Variables Sequential Sampling Plan for Upper and Lower Limits on Seebeck Voltage

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500 BETA = 0.1000 SIGMA = 0.564
L1 = 63.834 LO = 64.217 UO = 69.964 U1 = 70.347

SAMPLE NUMBER	REJECT BATCH IF LESS THAN	ACCEPT BATCH IN THIS RANGE ***** *****	REJECT BATCH IF GREATER THAN
1	61.6246	65.896	68.2848
2	125.6503	129.9217	138.4403
3	189.6761	193.9475	208.5958
4	253.7018	257.9732	278.7513
5	317.7276	321.999	348.9068
6	381.7533	386.0247	419.0623
7	445.7791	450.0505	489.2178
8	509.8048	514.0762	559.3733
9	573.8306	578.102	629.5288
10	637.8563	642.1277	699.6843
11	701.8821	706.1535	769.8398
12	765.9078	770.1792	839.9953
13	829.9336	834.205	910.1508
14	893.9593	898.2307	980.3063
15	957.9851	962.2565	1050.4618
16	1022.0108	1026.2822	1120.6173
17	1086.0366	1090.308	1190.7728
18	1150.0623	1154.3337	1260.9283
19	1214.0881	1218.3595	1331.0838
20	1278.1138	1282.3852	1401.2393
21	1342.1396	1346.411	1471.3948
22	1406.1653	1410.4367	1541.5503
23	1470.1911	1474.4625	1611.7058
24	1534.2168	1538.4882	1681.8613
25	1598.2426	1602.514	1752.0168
26	1662.2683	1666.5397	1822.1723
27	1726.2941	1730.5655	1892.3278
28	1790.3198	1794.5912	1962.4833
29	1854.3456	1858.617	2032.6388
30	1918.3713	1922.6427	2102.7943
31	1982.3971	1986.6685	2172.9498
32	2046.4228	2050.6942	2243.1053
33	2110.4486	2114.72	2313.2608
34	2174.4743	2178.7457	2383.4163
35	2238.5001	2242.7715	2453.5718
36	2302.5258	2306.7972	2523.7273
37	2366.5516	2370.823	2593.8827
38	2430.5773	2434.8487	2664.0383
39	2494.6031	2498.8745	2734.1938
40	2558.6288	2562.9002	2804.3493
41	2622.6546	2626.926	2874.5048
42	2686.6803	2690.9517	2944.6603
43	2750.7061	2754.9775	3014.8158
44	2814.7318	2819.0032	3084.9713
45	2878.7576	2883.029	3155.1268
46	2942.7833	2947.0547	3225.2823
47	3006.8091	3011.0805	3295.4378
48	3070.8348	3075.1062	3365.5933
49	3134.8606	3139.132	3435.7488
50	3198.8863	3203.1577	3505.9043

* CANNOT ACCEPT LOT WITH THIS SAMPLE SIZE.

INGRADIENT RESISTIVITY (1090-520°F)

Double One-Sided Variables Sequential Sampling Plan for Upper and Lower Limits on In-
gradient Resistance

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500 BETA = 0.1000 SIGMA = 49.410
LI = 1299.81 LO = 1333.42 UO = 1762.82 UI = 1796.41

SAMPLE NUMBER	REJECT BATCH IF LESS THAN	ACCEPT BATCH IN THIS RANGE ***** *****	REJECT BATCH IF GREATER THAN
1	1106.6655	1480.1433	1989.6895
2	2423.2805	2796.7583	3769.3045
3	3739.8955	4113.3733	5548.9195
4	5056.5104	5429.9883	7328.5345
5	6373.1254	6746.6033	9108.1495
6	7689.7404	8063.2183	10887.764
7	9006.3554	9379.8333	12667.379
8	10322.97	10696.448	14446.994
9	11639.585	12013.063	16226.609
10	12956.20	13329.678	18006.224
11	14272.815	14646.293	19785.839
12	15589.43	15962.908	21565.454
13	16906.045	17279.523	23345.769
14	18222.66	18596.138	25124.684
15	19539.275	19912.753	26904.299
16	20855.89	21229.368	28683.914
17	22172.505	22545.983	30463.529
18	23489.12	23862.598	32243.144
19	24805.735	25179.213	34022.759
20	26122.35	26495.828	35802.374
21	27438.965	27812.443	37581.989
22	28755.58	29129.058	39361.604
23	30072.195	30445.673	41141.219
24	31388.81	31762.288	42920.834
25	32705.425	33078.903	44700.449
26	34022.04	34395.518	46480.064
27	35338.655	35712.133	48259.679
28	36655.27	37028.748	50039.294
29	37971.885	38345.363	51818.909
30	39288.50	39661.978	53598.524
31	40605.115	40978.593	55378.139
32	41921.73	42295.208	57157.754
33	43238.345	43611.823	58937.369
34	44554.96	44928.438	60716.984
35	45871.575	46245.053	62496.599
36	47188.19	47561.668	64276.214
37	48504.805	48878.283	66055.829
38	49821.42	50194.898	67835.444
39	51138.035	51511.513	69615.059
40	52454.65	52828.128	71394.674
41	53771.265	54144.743	73174.289
42	55087.88	55461.358	74953.904
43	56404.495	56777.973	76733.519
44	57721.11	58094.588	78513.134
45	59037.725	59411.203	80292.749
46	60354.34	60727.818	82072.364
47	61670.955	62044.433	83851.979
48	62987.57	63361.048	85631.594
49	64304.185	64677.663	87411.209
50	65620.80	65994.278	89190.824

* CANNOT ACCEPT LOT WITH THIS SAMPLE SIZE.

THERMAL CONDUCTANCE (1090-520°F)

Double One-Sided Variables Sequential Sampling Plan for Upper and Lower Limits on Thermal Conductance

Average sample size at limits is 15 and is less for all other values of sample mean

ALPHA = 0.0500 BETA = 0.1000 SIGMA = 0.459
L1 = 9.094 LO = 9.405 UO = 11.360 U1 = 11.672

SAMPLE NUMBER	REJECT BATCH IF LESS THAN	ACCEPT BATCH IN THIS RANGE ***** *****		REJECT IF GREATER THAN
1	7.2945	*	*	13.4711
2	16.5441	20.0222	21.509	24.9871
3	25.7938	29.2718	33.025	36.503
4	35.0434	38.5215	44.5409	48.019
5	44.2931	47.7711	56.0569	59.5349
6	53.5427	57.0208	67.5728	71.0509
7	62.7924	66.2704	79.0888	82.5668
8	72.042	75.5201	90.6047	94.0828
9	81.2917	84.7697	102.1207	105.5987
10	90.5413	94.0194	113.6366	117.1147
11	99.791	103.269	125.1526	128.6306
12	109.0406	112.5187	136.6685	140.1466
13	118.2903	121.7683	148.1845	151.6625
14	127.5399	131.018	159.7004	163.1785
15	136.7896	140.2676	171.2164	174.6944
16	146.0392	149.5173	182.7323	186.2104
17	155.2889	158.7669	194.2483	197.7263
18	164.5385	168.0166	205.7642	209.2423
19	173.7882	177.2662	217.2802	220.7582
20	183.0378	186.5159	228.7961	232.2742
21	192.2875	195.7655	240.3121	243.7901
22	201.5371	205.0152	251.828	255.3061
23	210.7868	214.2648	263.344	266.822
24	220.0364	223.5145	274.8599	278.338
25	229.2861	232.7641	286.3759	289.8539
26	238.5357	242.0138	297.8918	301.3699
27	247.7854	251.2634	309.4078	312.8858
28	257.035	260.5131	320.9237	324.4018
29	266.2847	269.7627	332.4397	335.9177
30	275.5343	279.0124	343.9556	347.4337
31	284.784	288.262	355.4716	358.9496
32	294.0336	297.5117	366.9875	370.4656
33	303.2833	306.7613	378.5035	381.9815
34	312.5329	316.011	390.0194	393.4975
35	321.7826	325.2606	401.5354	405.0134
36	331.0322	334.5103	413.0513	416.5294
37	340.2819	343.7599	424.5673	428.0453
38	349.5315	353.0096	436.0832	439.5613
39	358.7812	362.2592	447.5992	451.0772
40	368.0308	371.5089	459.1151	462.5932
41	377.2805	380.7585	470.6311	474.1091
42	386.5301	390.0082	482.147	485.6251
43	395.7798	399.2578	493.663	497.141
44	405.0294	408.5075	505.1789	508.657
45	414.2791	417.7571	516.6949	520.1729
46	423.5287	427.0068	528.2108	531.6889
47	432.7784	436.2564	539.7268	543.2048
48	442.028	445.5061	551.2427	554.7208
49	451.2777	454.7557	562.7587	566.2367
50	460.5273	464.0054	574.2746	577.7527

* CANNOT ACCEPT LOT WITH THIS SAMPLE SIZE.

OXYGEN

Double One-Sided Variables Sequential Sampling Plan for Upper and Lower Limits of Oxygen

Content

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500 BETA = 0.1000 SIGMA = 100.850
L1 = 178.950 LO = 247.370 UO = 518.630 U1 = 587.050

SAMPLE REJECT ACCEPT BATCH IN THIS RANGE REJECT BATCH
NUMBER BATCH ***** IF GREATER THAN
IF LESS THAN *****

1	-216.4975	*	*	982.4975
2	-3.3375	760.9775	771.0225	1535.3375
3	209.8225	974.1375	1323.8625	2088.1775
4	422.9825	1187.2975	1876.7025	2641.0175
5	636.1425	1400.4575	2429.5425	3193.8575
6	849.3025	1613.6175	2982.3825	3746.6975
7	1062.4625	1826.7775	3535.2225	4299.5375
8	1275.6225	2039.9375	4088.0625	4852.3775
9	1488.7825	2253.0975	4640.9025	5405.2175
10	1701.9425	2466.2575	5193.7425	5958.0575
11	1915.1025	2679.4175	5746.5825	6510.8975
12	2128.2625	2892.5775	6299.4225	7063.7375
13	2341.4224	3105.7375	6852.2625	7616.5775
14	2554.5824	3318.8975	7405.1025	8169.4175
15	2767.7424	3532.0575	7957.9425	8722.2575
16	2980.9024	3745.2175	8510.7825	9275.0975
17	3194.0624	3958.3775	9063.6225	9827.9375
18	3407.2224	4171.5375	9616.4625	10380.777
19	3620.3824	4384.6975	10169.302	10933.617
20	3833.5424	4597.8575	10722.142	11486.457
21	4046.7024	4811.0174	11274.982	12039.297
22	4259.8624	5024.1774	11827.822	12592.137
23	4473.0224	5237.3374	12380.662	13144.977
24	4686.1824	5450.4975	12933.502	13697.817
25	4899.3424	5663.6574	13486.342	14250.657
26	5112.5024	5876.8174	14039.182	14803.497
27	5325.6624	6089.9774	14592.022	15356.337
28	5538.8224	6303.1375	15144.862	15909.177
29	5751.9824	6516.2974	15697.702	16462.017
30	5965.1424	6729.4574	16250.542	17014.857
31	6178.3024	6942.6174	16803.382	17567.697
32	6391.4624	7155.7774	17356.222	18120.537
33	6604.6224	7368.9374	17909.062	18673.377
34	6817.7824	7582.0975	18461.902	19226.217
35	7030.9424	7795.2574	19014.742	19779.057
36	7244.1024	8008.4174	19567.582	20331.897
37	7457.2624	8221.5774	20120.422	20884.737
38	7670.4224	8434.7374	20673.262	21437.577
39	7883.5824	8647.8974	21226.102	21990.417
40	8096.7424	8861.0574	21778.942	22543.257
41	8309.9024	9074.2174	22331.782	23096.097
42	8523.0624	9287.3774	22884.622	23648.937
43	8736.2224	9500.5374	23437.462	24201.777
44	8949.3824	9713.6974	23990.302	24754.617
45	9162.5424	9926.8574	24543.142	25307.457
46	9375.7024	10140.017	25095.982	25860.297
47	9588.8624	10353.177	25648.822	26413.137
48	9802.0224	10566.337	26201.662	26965.977
49	10015.182	10779.497	26754.502	27518.817
50	10228.342	10992.657	27307.342	28071.657

* CANNOT ACCEPT LOT WITH THIS SAMPLE SIZE.

1.5 PACKAGING

Thermoelectric legs shall be packaged in polyurethane or styrofoam trays sealed in clean polyethylene wrapping material. The leg serial identification number shall be marked on the tray adjacent to the individual thermoelectric leg. Legs shall be handled only with finger cots, white lint-free gloves or tweezers to prevent contamination.

1.6 ENGINEERING DATA

See Attachment A for values of other properties of legs covered by this specification.

1.7 REFERENCE

The correct identification for a thermoelectric leg covered by this specification is:

Leg, Thermoelectric, PbSnMnTe, TPM 206, Lot 10.

1.8 APPROVED VENDOR

Minnesota Mining and Manufacturing Company

2501 Hudson Road

St. Paul, Minnesota

ATTACHMENT A

1.6 ENGINEERING DATA

TABLE 1.6-1.

SUMMARY OF LIFE PERFORMANCE OF LOT 10 P-TYPE PbSnMnTe AT $T_h = 1090^\circ\text{F}$ and $T_c = 520^\circ\text{F}$

Sample	Time	E_s mv	R m Ω	P Watts	Time	E_s mv	R m Ω	P Watts	
10 4A 927	30.55	64.41	10.18	.1019	2220.9	55.07	7.35	.1031	
10 4A 945	30.55	65.72	11.50	.0939	2220.9	53.82	7.23	.1001	
10 4A 929	30.55	66.44	11.69	.0944	2220.9	55.84	9.68	.0805	
10 5A 927	41.38	68.12	12.00	.0967	2220.9	59.64	8.42	.1056	
10 5A 929	30.70	69.49	13.02	.0927	2220.9	57.52	8.67	.0954	
10 6B 027	30.55	65.81	12.38	.0874	2220.9	55.23	7.38	.1033	
10 6B 028	30.55	66.47	11.64	.0949	2220.9	65.95	8.77	.124	
10 6B 029	30.96	68.44	13.23	.0885	2269.4	57.18	8.16	.1001	
10 7B 027	30.97	67.99	12.77	.0905	2269.4	56.58	12.47	.0642	
10 7B 028	30.97	66.88	12.19	.0917	2269.4	55.12	7.56	.1004	
10 7B 029	30.97	67.60	11.85	.0965	2269.4	57.56	8.05	.1029	
10 20A 027	30.97	67.02	12.93	.0868	2269.4	54.55	7.25	.1026	
10 20A 028	30.97	67.25	12.02	.0941	2269.4	54.58	6.54	.1138	
10 20A 029	30.97	67.25	11.81	.0958	2269.4	55.69	8.11	.0955	
10 5A 936	30.97	68.75	13.01	.0909	2279.4	55.53	10.55	.0731	
10 26B 040	30.55	64.08	11.20	.0917	2219	51.93	6.79	.0993	(Control)
10 5A 928	30.55	68.71	12.71	.0928	broken				
$\bar{X}$		67.0841	12.1253	9.30118×10^{-2}		56.3619	8.31125	9.77437×10^{-2}	
EST TRU VAR		2.23489	.621002	1.40499×10^{-5}		9.64272	2.31772	2.11973×10^{-4}	
EST TRU σ		1.49495	.788037	3.74832×10^{-3}		3.10527	1.52241	1.45593×10^{-2}	
N		17	17	17		16	16	16	

TABLE 1.6-2.

GROSS CHEMICAL ANALYSIS - P-TYPE

	Batch No.	$\bar{X}$	σ	Number of Samples
Weight % Pb	Scrap*	29.77	.0883	3
	16A	29.7925	.2377	4
	25A	29.8325	.1717	4
	Overall	29.8009	.16599	11
Weight % Te	Scrap*	45.452	.1276	5
	16A	45.675	.0266	4
	25A	45.7375	.0172	4
		45.6085	.1478	13
Weight % Mn	Scrap*	1.264	.0269	5
	16A	1.320	.0216	4
	25A	1.255	.0173	4
	Overall	1.2785	.0351	13
Weight % Sn	Scrap*	23.1175	.1724	4
	16A	22.9725	.0378	4
	25A	22.955	.1063	4
	Overall	23.015	.1239	12

*Note: Experimental runs on scrap samples

TABLE 1.6-3.

SHEAR STRENGTH - P-TYPE

	Batch No.	$\bar{X}$	σ	Number of Samples
Room Temp Shear Strength (psi)	1A	1620	212	3
	2A	1541	311	3
	3A	1650	125	3
	3B	1514	59	3
	4A	1421	146	3
	4B	1466	141	3
	Overall	1535	183	18
Shear Strength @ 525°F (psi)	1A	2010	271	3
	2A	1927	186	3
	3A	2051	408	3
	3B	2017	337	3
	4A	2192	554	3
	4B	2141	428	3
	Overall	2056	383	18

Note:

TABLE 1.6-4.

COEFFICIENT OF LINEAR EXPANSION

Characteristic	Batch No.	$\bar{X}(\times 10^{-5})$	$\sigma_x(\times 10^{-7})$	Number of Samples
*Coefficient of Linear Expansion	8A	2.01605	4.97445	3
	11B	2.03396	4.79954	3
	13A	2.08406	6.44798	3
	Overall	2.04469	5.62673	9

Note:

*TPM 15 Lot 5

TABLE 1.6-5.

THERMOELECTRIC PROPERTIES

Characteristic	P-TYPE			Number of Samples
	Batch No.	$\bar{X}$	σ	
Seebeck (520-1090°F) mv	7B	63.329	.340	4
	3B	63.1844	.959	4
	2A	60.9583	1.463	4
	22A	64.427	1.127	4
	Overall	62.9747	1.6066	16
Ingradient Resistivity (520-1090°F) μ Ω -inches	7B	1596.84	35.5897	4
	3B	1544.84	30.7705	4
	2A	1443.36	64.052	4
	22A	1607.33	58.741	4
	Overall	1548.1143	80.3372	16
Thermal Conductance (520-1090°F) mW/inch	7B	10.598	0.380	4
	3B	10.040	0.354	4
	2A	10.607	0.208	4
	22A	10.218	0.746	4
	Overall	10.366	0.488	16

Figure 1.6-1. Seebeck Coefficient Versus Temperature for Lot 10 P-Type PbSnMnTe

Figure 1.6-2. Resistivity Versus Temperature for Lot 10 P-Type PbSnMnTe

Figure 1.6-3. Thermal Conductivity for Lot 10 P-Type PbSnMnTe

Figure 1.6-4. Figure of Merit (ZT) for Lot 10 P-Type PbSnMnTe

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2. THERMOELECTRIC LEG PRODUCT SPECIFICATION N-TYPE TPM 211, LOT 9

2.1 GENERAL

2.1.1 SCOPE

This specification covers acceptance parameters and criteria for N-type TPM 211, Lot 9, lead telluride thermoelectric legs produced for the SNAP-27 Program. Engineering values of leg parameters are included in paragraph 2.6 (Attachment A). Required Acceptance procedures are included in Section 3 of this volume.

2.1.1.1 Effectivity

This specification may be implemented at the conclusion of manufacture and Quality Control acceptance of TPM 211, Lot 9, for the SNAP-27 Program.

2.1.1.2 Revision Procedures

This specification is subject to the normal revision procedures used on the SNAP-27 Program, that is, engineering documents may be revised upon recommendation of the seller and approval by the buyer. A record of reissuance will be included on the title page of the re-issued document.

2.1.2 DEFINITIONS

Seebeck Voltage (1090-520), E_s , is defined as the potential difference in millivolts developed by a thermocouple consisting of the test specimen and a thermocouple grade iron wire when said couple is subjected to a temperature differential of 1090°F to 520°F. By convention, N-type test specimens produce negative Seebeck voltages relative to the iron reference, while P-type test specimens produce positive Seebeck voltages.

Ingradient Resistivity (1090-520), ρ , of a thermoelectric leg is defined as the product of the leg resistance in microhms and the A/L geometry ratio of the leg in in²/in when the leg is subjected to a temperature difference of 1090°F to 520°F under conditions of one-dimensional axial heat flow and negligible internally generated Joule and Thomson heats.

Thermal Conductance (1090-520), $K \Delta T$, is defined as the product of the measured rate of heat flow in watts and the L/A geometry ratio of the leg in in^2 when the leg is subjected to a temperature difference of 1090°F to 520°F under conditions of one-dimensional axial heat flow and no electrical current flow.

2.2 APPLICABLE DOCUMENTS

(Reference Only)

NUMBER	TITLE
MMM8406-0233	Task 2.2 TELPS Work Statement Characterization Test Plan
MMM8406-1172	Task 3 Thermoelectric Performance Test Plan

2.3 REQUIREMENTS

2.3.1 RESTRICTIONS

The mean values, deviations, and specification limits for each parameter specified in paragraph 2.4, and the resulting acceptance plans, are based upon limited testing of TPM 211, Lot 9*, PbTe thermoelectric material. Subsequent additional testing of this material may indicate changes in statistical parameters which will result in adjustments of the specification limits.

2.3.2 IDENTIFICATION

Positive identification of each leg shall be maintained relative to its basic leg batch, inspection and electrical testing requirements. However, a leg shall at no time be physically marked.

2.3.3 SAMPLING METHODS

2.3.3.1 Use of Sequential Sampling Plan

All sampling plans used in this specification are of the variable sequential type. Sequential sampling is a technique whereby items are tested one at a time and after each test the cumulative results are compared to tabulated values in order to make a decision.

*This Lot designation refers to a specific vendor production instruction and completely defines the resulting product.

After a test, three decisions are possible:

- a. Reject batch
- b. Continue Testing
- c. Accept batch

Each sampling plan contains four columns of tabulated values. Each value defines a decision zone as shown below. Undefined values are used at present and a specific case will subsequently be illustrated.

SAMPLE NUMBER	REJECT	CONTINUE TESTING	ACCEPT	CONTINUE TESTING	REJECT
n	$S < N_1$	$\leq S < N_2$	$\leq S \leq N_3$	$< S \leq N_4$	$< S$

The tabulated values are used as follows:

If the cumulative sum S of the test results of n measurements is:*

- a. Less than N_1 — reject
- b. Up to but not including N_2 — continue testing
- c. From N_2 to N_3 — accept
- d. Greater than N_3 to N_4 — continue testing
- e. Greater than N_4 — reject

Numerical Example: Sampling Plan for P-Leg Density

Assume the following test results were found. It is understood that the tests were run one at a time. Each time the sum of all test results to that point were compared to the tabulated for that sample number.

*An asterisk denotes that the decision indicated by the column heading cannot be made with this sample size.

SAMPLE NUMBER	TEST RESULT	SUM	DECISION	REMARKS
Batch A				
1	109	109	Continue	107.6673<109<112.1927
2	108	217	Continue	216.6963<217<219.1186
3	109	326	Continue	325.7253<326<328.1476
4	108	434	<u>Reject</u>	434<434.7543
Batch B				
1	110	110	Continue	107.6673<110<112.1927
2	110	220	<u>Accept</u>	219.1186<220<220.6014
Batch C				
1	106	106	<u>Reject</u>	106<107.6673

2.4 QUALITY PROVISIONS

2.4.1 SPECIFICATION LIMITS

CHARACTERISTIC	MINIMUM	MEAN VALUE	MAXIMUM	NUMBER OF MEASUREMENTS
Length, inches	0.3940	0.4015	0.4083	1,435
Diameter, inches	0.2048	0.2063	0.2079	1,435
Density, gm/in. ³	128.84	131.13	133.42	1,435
Seebeck Voltage (1090-520°F)mv	69.37	67.69	61.07	16
Ingradient Resistivity (1090-520°F) μ Ω-inches	928	1157	1386	16
Thermal Conductance Q L/A (1090-520°F) mW/inch	9.53	11.57	13.61	16

2.4.2 TESTING

2.4.2.1 Order of Inspection

- a. Visual inspection per paragraph 2.4.2.4.1. Reject defective legs.
- b. Length, diameter and density determination per paragraph 2.4.2.4.2(a). Accept/reject batch in accordance with variables sequential sampling plan applied to random samples of batch.
- c. Seebeck voltage, ingradient resistance and thermal conductivity determination per paragraph 2.4.2.4.2(b). Accept/reject batch in accordance with variables sequential sampling plan applied to random sample of batch. Each of the three properties are to be determined simultaneously on the same sample.
- d. If batch fails any tests, hold batch for disposition per paragraph 2.4.2.2.
- e. If batch passes all tests, release to production.

2.4.2.2 Rejected Batch

Whenever a batch is rejected, the supplier shall mark the batch "NSQ", place it in storage and notify the buyer. Disposition of the batch will be jointly determined by MRB action.

2.4.2.3 Significance of Numbers

The test plans in this specification are computer-generated with no provision for rounding nonsignificant numbers. Significance should be judged according to paragraph 2.4.1.

Tolerances throughout this specification are $\pm 10\%$ unless otherwise indicated.

2.4.2.4 Test Levels

TEST TITLE	PARAGRAPH	QUALITY REQUIREMENTS	NOTES
Visual	2.4.2.4.1	X	
Dimensions and Density	2.4.2.4.2(a)	Variable Sequential Plan	1
E_s , R, Q L/A	2.4.2.4.2(b)	VS	1

1. All variable sequential plans are based on an AQL of 2.5 percent and an LTPD of 10.0 percent.

2.4.2.4.1 Visual Inspection - Visual standards to be mutually adopted by supplier and buyer prior to order placement under this specification.

- a. Corner chipping on a thermoelectric leg shall not be in excess of a mutually approved visual standard which normally corresponds to a maximum allowable decrease in the leg end surface area of 5 percent.
- b. Surface pitting on a thermoelectric leg shall not be in excess of a mutually approved standard with a maximum allowable pit depth of 0.015 inches.
- c. Localized surface deposits of lead and carbon shall not exceed that shown in a mutually approved visual standard.
- d. There shall be no evidence of leg surface cracking when examined with the unaided eye, that is, without magnification.

2.4.2.4.2 Acceptance Requirements

- a. Length and diameter shall be determined using a micrometer with a 0 to 1.0 inch range and a 0.0001-inch resolution. Weight should be measured on a balance with a resolution of a milligram. Density shall be determined by:

$$\text{Density} = \frac{4 \times \text{Weight}}{\text{length} \times \text{diameter}^2} \quad \frac{(\text{grams})}{(\text{in.}^3)}$$

Sampling plans for the dimensions and density are listed in tables following this paragraph.

- b. Seebeck Voltage, Ingradient Resistivity and Thermal Conductance shall be determined according to the test method described in Section 3 of this volume, using the following sampling plans. Specification limits are based on data listed in paragraph 2.6 (attachment A).

LENGTH

Double One-Sided Variables Sequential Sampling Plan for Upper and Lower Limits on Length

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500

BETA = 0.1000

SIGMA = 0.002

L1 = 0.395

LO = 0.397

UA = 0.401

U1 = 0.402

SAMPLE NUMBER	REJECT BATCH	ACCEPT BATCH IN THIS RANGE *****		REJECT BATCH IF GREATER
	IF LESS THAN	*****		THAN
1	.3874	<	*	.4149
2	.7855	*	*	.8191
3	1.1836	1.2026	1.2043	1.2233
4	1.5817	1.6007	1.6085	1.6275
5	1.9798	1.9988	2.0127	2.0317
6	2.3779	2.3969	2.4169	2.4359
7	2.776	2.795	2.8211	2.8401
8	3.1741	3.1931	3.2253	3.2443
9	3.5722	3.5912	3.6295	3.6485
10	3.9703	3.9893	4.0337	4.0527
11	4.3684	4.3874	4.4379	4.4569
12	4.7665	4.7855	4.8421	4.8611
13	5.1646	5.1836	5.2463	5.2653
14	5.5627	5.5817	5.6505	5.6695
15	5.9608	5.9798	6.0547	6.0737
16	6.3589	6.3779	6.4589	6.4779
17	6.757	6.776	6.8631	6.8821
18	7.1551	7.1741	7.2673	7.2863
19	7.5532	7.5722	7.6715	7.6905
20	7.9513	7.9703	8.0757	8.0947
21	8.3494	8.3684	8.4799	8.4989
22	8.7475	8.7665	8.8841	8.9031
23	9.1456	9.1646	9.2883	9.3073
24	9.5437	9.5627	9.6925	9.7115
25	9.9418	9.9608	10.0967	10.1157
26	10.3399	10.3589	10.5009	10.5199
27	10.738	10.757	10.9051	10.9241
28	11.1361	11.1551	11.3093	11.3283
29	11.5342	11.5532	11.7135	11.7325
30	11.9323	11.9513	12.1177	12.1367
31	12.3304	12.3494	12.5219	12.5409
32	12.7285	12.7475	12.9261	12.9451
33	13.1266	13.1456	13.3303	13.3493
34	13.5247	13.5437	13.7345	13.7535
35	13.9228	13.9418	14.1387	14.1577
36	14.3209	14.3399	14.5429	14.5619
37	14.719	14.738	14.9471	14.9661
38	15.1171	15.1361	15.3513	15.3703
39	15.5152	15.5342	15.7555	15.7745
40	15.9133	15.9323	16.1597	16.1787
41	16.3114	16.3304	16.5639	16.5829
42	16.7095	16.7285	16.9681	16.9871
43	17.1076	17.1266	17.3723	17.3913
44	17.5057	17.5247	17.7765	17.7955
45	17.9038	17.9228	18.1807	18.1997
46	18.3019	18.3209	18.5849	18.6039
47	18.70	18.719	18.9891	19.0081
48	19.0981	19.1171	19.3933	19.4123
49	19.4962	19.5152	19.7975	19.8165
50	19.8943	19.9133	20.2017	20.2207

* CANNOT ACCEPT LOT AT THIS SAMPLE SIZE.

DIAMETER

Double One-Sided Variable Sequential Sampling Plan for Upper and Lower Limits on Diameter

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500

BETA = 0.1000

SIGMA = 0.000

L1 = 0.245015

LO = 245182

UO = 0.2464178 U1 = 0.2465847

SAMPLE NUMBER	REJECT BATCH	ACCEPT BATCH IN THIS RANGE ***** IF LESS THAN *****	REJECT BATCH IF GREATER THAN
1	.2038	*	* .2088
2	.4092	.412	.416
3	.6146	.6174	.6204
4	.82	.8228	.8277
5	1.0253	1.0281	1.0349
6	1.2307	1.2335	1.2421
7	1.4361	1.4389	1.4493
8	1.6415	1.6443	1.6565
9	1.8469	1.8497	1.8638
10	2.0523	2.055	2.071
11	2.2576	2.2604	2.2782
12	2.463	2.4658	2.4854
13	2.6684	2.6712	2.6927
14	2.8738	2.8766	2.8999
15	3.0792	3.082	3.1071
16	3.2845	3.2873	3.3143
17	3.4899	3.4927	3.5215
18	3.6953	3.6981	3.7288
19	3.9007	3.9035	3.936
20	4.1061	4.1089	4.1432
21	4.3115	4.3143	4.3504
22	4.5168	4.5196	4.5576
23	4.7222	4.725	4.7649
24	4.9276	4.9304	4.9721
25	5.133	5.1358	5.1793
26	5.3384	5.3412	5.3865
27	5.5438	5.5466	5.5938
28	5.7491	5.7519	5.801
29	5.9545	5.9573	6.0082
30	6.1599	6.1627	6.2154
31	6.3653	6.3681	6.4226
32	6.5707	6.5735	6.6299
33	6.7761	6.7788	6.8371
34	6.9814	6.9842	7.0443
35	7.1868	7.1896	7.2515
36	7.3922	7.395	7.4587
37	7.5976	7.6004	7.666
38	7.803	7.8058	7.8732
41	8.4191	8.4219	8.4949
42	8.6245	8.6273	8.7021
43	8.8299	8.8327	8.9093
44	9.0353	9.0381	9.1165
45	9.2406	9.2434	9.3237
46	9.446	9.4488	9.531
47	9.6514	9.6542	9.7382
48	9.8568	9.8596	9.9454
49	10.0622	10.065	10.1526
50	10.2676	10.2703	10.3599
			10.3626

* CANNOT ACCEPT LOT WITH THIS SAMPLE SIZE.

DENSITY

Double One-Sided Variables Sequential Sampling Plan for Upper and Lower Limits on Density

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500		BETA = 0.1000		SIGMA = 0.319	
L1 = 108.921		LO = 109.137		UO = 1100.939	
SAMPLE	REJECT	ACCEPT BATCH IN THIS RANGE		REJECT	
NUMBER	BATCH	*****		BATCH	
	IF LESS THAN	*****		IF GREATER THAN	
1	127.2599	*	*	135.0054	
2	257.0717	261.6113	262.9175	267.4583	
3	386.8835	391.4231	395.3704	399.9111	
4	516.6953	521.2349	527.8232	532.364	
5	646.5071	651.0467	660.2761	664.8168	
6	776.3189	780.8585	792.7289	797.2697	
7	906.1307	910.6703	925.1818	929.7225	
8	1035.9425	1040.4821	1057.6346	1062.1753	
9	1165.7543	1170.2939	1190.0875	1194.6282	
10	1295.5661	1300.1057	1322.5403	1327.081	
11	1425.3779	1429.9175	1454.9932	1459.5339	
12	1555.1897	1559.7293	1587.446	1591.9867	
13	1685.0015	1689.5411	1719.8989	1724.4396	
14	1814.8133	1819.3529	1852.3517	1856.8924	
15	1944.6251	1949.1647	1984.8046	1989.3453	
16	2074.4369	2078.9765	2117.2574	2121.7981	
17	2204.2487	2208.7883	2249.7103	2254.251	
18	2334.0605	2338.6001	2382.1631	2386.7038	
19	2463.8723	2468.4119	2514.616	2519.1567	
20	2593.6841	2598.2237	2647.0688	2651.6095	
21	2723.4959	2728.0355	2779.5217	2784.0624	
22	2853.3077	2857.8473	2911.9745	2916.5152	
23	2983.1195	2987.6591	3044.4274	3048.9681	
24	3112.9313	3117.4709	3176.8802	3181.4209	
25	3242.7431	3247.2827	3309.3331	3313.8738	
26	3372.5549	3377.0945	3441.7859	3446.3266	
27	3502.3667	3506.9063	3574.2388	3578.7795	
28	3632.1785	3636.7181	3706.6916	3711.2323	
29	3761.9903	3766.5299	3839.1445	3843.6852	
30	3891.8021	3896.3417	3971.5973	3976.138	
31	4021.6139	4026.1535	4104.0502	4108.5909	
32	4151.4256	4155.9653	4236.503	4241.0437	
33	4281.2374	4285.7771	4368.9559	4373.4966	
34	4411.0492	4415.5889	4501.4087	4505.9494	
35	4540.861	4545.4007	4633.8616	4638.4023	
36	4670.6728	4675.2125	4766.3144	4770.8551	
37	4800.4847	4805.0243	4898.7673	4903.308	
38	4930.2964	4934.8361	5031.2201	5035.7608	
39	5060.1082	5064.6479	5163.6729	5168.2137	
40	5189.92	5194.4597	5296.1258	5300.6665	
41	5319.7318	5324.2715	5428.5787	5433.1194	
42	5449.5436	5454.0833	5561.0315	5565.5722	
43	5579.3554	5583.8951	5693.4844	5698.0251	
44	5709.1672	5713.7068	5825.9372	5830.4779	
45	5838.979	5843.5186	5958.3901	5962.9308	
46	5968.7908	5973.3305	6090.8429	6095.3836	
47	6098.6026	6103.1422	6223.2958	6227.8365	
48	6228.4144	6232.954	6355.7486	6360.2893	
49	6358.2262	6362.7659	6488.2015	6492.7422	
50	6488.038	6492.5776	6620.6543	6625.195	

* CANNOT ACCEPT LOT IF THIS SAMPLE IS *

SEEBECK VOLTAGE (1090-520°F)

Double One-Sided Variables Sequential Sampling Plan for Upper and Lower Limits on
Seebeck Voltage

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500 BETA = 0.1000 SIGMA = 0.564
L1 = 63.834 LO = 64.217 UO = 69.964 U1 = 70.347

SAMPLE	REJECT	ACCEPT BATCH IN THIS RANGE	REJECT BATCH
NUMBER	BATCH	*****	IF GREATER
	IF LESS THAN	*****	THAN

1	-69.993	-68.2054	-67.176	-65.3839
2	-138.9811	-137.1935	-133.5673	-131.7752
3	-207.9692	-206.1816	-199.9586	-198.1665
4	-276.9573	-275.1697	-266.3499	-264.5578
5	-345.9454	-344.1578	-332.7412	-330.9491
6	-414.9335	-413.1459	-399.1325	-397.3404
7	-483.9216	-482.134	-465.5238	-463.7317
8	-552.9097	-551.1221	-531.9151	-530.123
9	-621.8978	-620.1102	-598.3064	-596.5143
10	-690.8859	-689.0983	-664.6977	-662.9056
11	-759.874	-758.0864	-731.089	-729.2969
12	-828.8621	-827.0745	-797.4803	-795.6882
13	-897.8502	-896.0626	-863.8716	-862.0795
14	-966.8383	-965.0507	-930.2629	-928.4708
15	-1035.8264	-1034.0388	-996.6542	-994.8621
16	-1104.8145	-1103.0269	-1063.0455	-1061.2534
17	-1173.8026	-1172.015	-1129.4368	-1127.6447
18	-1242.7907	-1241.0031	-1195.8281	-1194.036
19	-1311.7788	-1309.9912	-1262.2194	-1260.4273
20	-1380.7669	-1378.9793	-1328.6107	-1326.8186
21	-1449.755	-1447.9674	-1395.002	-1393.2099
22	-1518.7431	-1516.9555	-1461.3933	-1459.6012
23	-1587.7312	-1585.9436	-1527.7846	-1525.9925
24	-1656.7193	-1654.9317	-1594.1759	-1592.3838
25	-1725.7074	-1723.9198	-1660.5672	-1658.7751
26	-1794.6955	-1792.9079	-1726.9585	-1725.1664
27	-1863.6836	-1861.896	-1793.3498	-1791.5577
28	-1932.6717	-1930.8841	-1859.7411	-1857.949
29	-2001.6598	-1999.8722	-1926.1324	-1924.3403
30	-2070.6479	-2068.8603	-1992.5237	-1990.7316
31	-2139.636	-2137.8484	-2058.915	-2057.1229
32	-2208.6241	-2206.8365	-2125.3063	-2123.5142
33	-2277.6122	-2275.8246	-2191.6976	-2189.9055
34	-2346.6003	-2344.8127	-2258.0889	-2256.2968
35	-2415.5884	-2413.8008	-2324.4802	-2322.6881
36	-2484.5765	-2482.7889	-2390.8715	-2389.0794
37	-2553.5646	-2551.777	-2457.2628	-2455.4707
38	-2622.5527	-2620.7651	-2523.6541	-2521.862
39	-2691.5408	-2689.7532	-2590.0454	-2588.2533
40	-2760.5289	-2758.7413	-2656.4367	-2654.6446
41	-2829.517	-2827.7294	-2722.828	-2721.0359
42	-2898.5051	-2896.7175	-2789.2193	-2787.4272
43	-2967.4932	-2965.7056	-2855.6106	-2853.8185
44	-3036.4813	-3034.6937	-2922.0019	-2920.2098
45	-3105.4694	-3103.6818	-2988.3932	-2986.6011
46	-3174.4575	-3172.6699	-3054.7845	-3052.9924
47	-3243.4456	-3241.658	-3121.1758	-3119.3837
48	-3312.4337	-3310.6461	-3187.5671	-3185.775
49	-3381.4218	-3379.6342	-3253.9584	-3252.1663
50	-3450.4099	-3448.6223	-3320.3497	-3318.5576

SEEKING FOR THIS SAMPLE SIZE.

THERMAL CONDUCTANCE (1090-520°F)

Double One-Sided Variables Sequential Sampling Plan for Upper and Lower Limits on
Thermal Conductance

Average sample size at limits is 15 and is less for all other values of sample mean.

ALPHA = 0.0500 BETA = 0.1000 SIGMA = 0.459
L1 = 9.094 LO = 9.405 UO = 11.360 U1 = 11.672

SAMPLE NUMBER	REJECT BATCH	ACCEPT BATCH IN THIS RANGE ***** IF LESS THAN *****	REJECT BATCH IF GREATER THAN
------------------	-----------------	---	------------------------------------

1	780.5994	*	*	1533.7206
2	1799.0994	2222.2992	2404.9408	2828.1406
3	2817.5994	3240.7992	3700.0608	4123.2606
4	3836.0994	4259.2992	4995.1808	5418.3806
5	4854.5994	5277.7992	6290.3007	6713.5006
6	5873.0994	6296.2992	7585.4208	8008.6206
7	6891.5994	7314.7992	8880.5407	9303.7406
8	7910.0994	8333.2992	10175.661	10598.861
9	8928.5994	9351.7992	11470.781	11893.981
10	9947.0994	10370.299	12765.901	13189.101
11	10965.599	11388.799	14061.021	14484.221
12	11984.099	12407.299	15356.141	15779.341
13	13002.599	13425.799	16651.261	17074.461
14	14021.099	14444.299	17946.381	18369.581
15	15039.599	15462.799	19241.501	19664.701
16	16058.099	16481.299	20536.621	20959.821
17	17076.599	17499.799	21831.741	22254.941
18	18095.099	18518.299	23126.861	23550.061
19	19113.599	19536.799	24421.981	24845.181
20	20132.099	20555.299	25717.101	26140.301
21	21150.599	21573.799	27012.221	27435.421
22	22169.099	22592.299	28307.341	28730.541
23	23187.599	23610.799	29602.461	30025.661
24	24206.099	24629.299	30897.581	31320.781
25	25224.599	25647.799	32192.701	32615.901
26	26243.099	26666.299	33487.821	33911.021
27	27261.599	27684.799	34782.941	35206.141
28	28280.099	28703.299	36078.061	36501.261
29	29298.599	29721.799	37373.181	37796.381
30	30317.099	30740.299	38668.301	39091.501
31	31335.599	31758.799	39963.421	40386.621
32	32354.099	32777.299	41258.541	41681.741
33	33372.599	33795.799	42553.661	42976.861
34	34391.099	34814.299	43848.781	44271.981
35	35409.599	35832.799	45143.901	45567.101
36	36428.099	36851.299	46439.021	46862.221
37	37446.599	37869.799	47734.141	48157.341
38	38465.099	38888.299	49029.261	49452.461
39	39483.599	39906.799	50324.381	50747.581
40	40502.099	40925.299	51619.501	52042.701
41	41520.599	41943.799	52914.621	53337.821
42	42539.099	42962.299	54209.741	54632.941
43	43557.599	43980.799	55504.861	55928.061
44	44576.099	44999.299	56799.981	57223.181
45	45594.599	46017.799	58095.101	58518.301
46	46613.099	47036.299	59390.221	59813.421
47	47631.599	48054.799	60685.341	61108.541
48	48650.099	49073.299	61980.461	62403.661
49	49668.599	50091.799	63275.581	63698.781
50	50687.099	51110.299	64570.701	64993.901

* CANNOT ACCEPT LOT WITH THIS SAMPLE SIZE.

2.5 PACKAGING

Thermoelectric legs shall be packaged in polyurethane or styrofoam trays sealed in clean polyethylene wrapping material. The leg serial identification number shall be marked on the tray adjacent to the individual thermoelectric leg. Legs shall be handled only with finger cots, white lint-free gloves or tweezers to prevent contamination.

2.6 ENGINEERING DATA

See Attachment A for values of other properties of legs covered by this specification.

2.7 REFERENCE

The correct identification for a thermoelectric leg covered by this specification is:

Leg, Thermoelectric, PbTe, TPM 211, Lot 9.

2.8 APPROVED VENDOR

Minnesota Mining and Manufacturing Company
2501 Hudson Road
St. Paul, Minnesota

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ATTACHMENT A
2.6 ENGINEERING DATA

TABLE 2.6-1.

SUMMARY OF LIFE PERFORMANCE OF LOT 9 - N-TYPE PbTe AT $T_h = 1090^\circ\text{F}$ and $T_c = 520^\circ\text{F}$

<u>Sample</u>	<u>Time Hours</u>	<u>E_s mv</u>	<u>R mΩ</u>	<u>P Watts</u>	<u>Time Hours</u>	<u>E_s mv</u>	<u>R mΩ</u>	<u>P Watts</u>
9 4B 927		*	*	*	2211.7	65.94	*	*
9 4B 928	30.55	69.90	12.66	.0965	2211.7	64.10	13.12	.0783
9 4B 929	30.55	67.14	12.34	.0913	2211.7	56.42	9.18	.0867
9 6A 927	30.55	65.96	12.58	.0865	2211.7	62.51	11.93	.0819
9 6A 928	30.55	67.16	12.53	.0900	2211.7	62.10	11.22	.0859
9 6A 929	30.55	68.23	12.40	.0939	2211.7	62.38	12.13	.0802
9 7B 927	30.55	67.37	12.58	.0902	2211.7	64.41	11.76	.0882
9 7B 928	30.55	67.68	12.55	.0912	2211.7	64.64	11.68	.0894
9 7B 929		*	*	*	2269.4	65.67	12.87	.0838
9 11B 027	30.97	67.44	13.41	.0848	2269.4	64.44	13.46	.0772
9 11B 028	30.97	67.09	12.96	.0869	2269.4	56.37	9.34	.0851
9 11B 029	30.97	67.12	12.98	.0868	2269.4	61.51	12.06	.0785
9 14A 027	30.97	67.15	12.19	.0925	2269.4	62.46	11.63	.0838
9 14A 028	30.97	67.28	12.73	.0890	2269.4	61.49	11.96	.0791
9 14A 029	30.97	66.78	12.67	.0881	2269.4	63.49	12.36	.0815
9 20B 040	38.55	67.71	13.02	.0881	2220	67.83	12.87	.0894 (Control)
-								
X		67.4293		.0897		62.86	11.838	8.32667×10^{-2}
			12.6857					
EST TRU VAR		.764522		1.02293×10^{-5}		9.3646	1.47115	
			.100997					1.70124×10^{-5}
EST TRU σ		.874369	.3178	3.19832×10^{-3}		3.06016		4.12461×10^{-3}
							1.21291	
N		14	14	14		16	15	15

* Value lost due to fixture malfunction.

TABLE 2.6-2

GROSS CHEMICAL ANALYSIS, N-TYPE

	Batch No.	$\bar{X}$	σ	Number of Samples
Weight % Pb	25B	62.302	.0386	4
	21A	62.285	.0581	4
	5B	62.345	.0603	4
	5A	62.31	.044	4
	Overall	62.3106	.0510	16
Weight % Te	25B	37.66	.0337	4
	21A	37.598	.0263	4
	5B	37.682	.0172	4
	5A	37.622	.0359	4
	Overall	37.6406	.0428	16
Weight % Pb	* Test-scrap	62.206	.0237	10
Weight % Te	* Test-scrap	37.69	.0478	10

Note: * 10 samples taken from one solution - 40 ml aliquots

TABLE 2.6-3

SHEAR STRENGTH - "N" TYPE

	Batch No.	$\bar{X}$	σ	Number of Samples
Shear - Room Temp Psi	5A	2417	130	3
	5B	1727	399	3
	6A	2111	225	3
	6B	1732	304	3
	7A	1923	50	3
	1E	2991	307	3
	3A	2299	267	3
	3B	2164	145	3
	1A	2322	622	3
	4A	2176	184	3
	Overall	2186	305	30
Shear Strength - 525°F Psi	5B	1892	116	3
	6A	1705	76	3
	6B	1664	198	3
	7A	1724	72	3
	1A	2589	307	3
	1B	2380	315	3
	3A	2173	278	3
	3B	2012	121	3
	4A	2016	126	3
	5A	1599	63	3
	Overall	1974	192	30

TABLE 2.6-4.

COEFFICIENT OF LINEAR EXPANSION

Characteristic	Batch No.	$\bar{X}(\times 10^{-5})$	$\sigma(\times 10^{-7})$	Number of Samples
*Coefficient of Linear Expansion	8A	1.92442	5.72303	3
	14A	1.93911	6.90452	3
	15B	1.97199	4.54202	3
Overall		1.94517	5.4509	9

Note:

*TPM 10 Lot 4

TABLE 2.6-5.

THERMOELECTRIC PROPERTIES

N-TYPE

Characteristic	Batch No.	$\bar{X}$	σ	Number of Samples
Seebeck (520-1090°F) mv	5B	48.3998	.219	4
	1A	49.4228	.052	4
	6B	49.4715	.197	4
	25A	49.4774	.343	4
	Overall	49.1929	.5152	16
Ingradient Resistivity (520-1090°F) $\mu\Omega$ -inches	5B	1117.15	33.00	4
	1A	1155.68	75.68	4
	6B	1206.22	52.42	4
	25A	1148.18	54.45	4
	Overall	1156.8066	60.0	16
Thermal Conductance (520-1090°F) mW/inch	5B	11.335	0.221	4
	1A	11.621	0.126	4
	6B	11.395	0.314	4
	25A	12.031	0.877	4
	Overall	11.596	0.516	16

Figure 2.6-1. Seebeck Coefficient Lot 9 N-Type PbTe

Figure 2.6-2. Resistivity Versus Temperature
of Lot 9 N-Type PbTe

Figure 2.6-3. Thermal Conductivity of
Lot 9 N-Type PbTe

Figure 2.6-4. Figure of Merit (ZT) of
Lot 9 N-Type PbTe

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3. TEST PROCEDURES

3.1 INGRADIENT TEST PROCEDURES

3.1.1 TEST STATION – PRETEST OPERATIONS

After each individual test station has been assembled (Figure 3-1), complete with quartz tube and protective shield, it must be preprocessed to remove water vapor, oxide layers and other possible deleterious contaminants from the system. The following operation must be performed:

- a. Evacuate station with mechanical fore pump to $< 100\mu\text{Hg}$ as indicated on the station thermocouple vacuum gauge. Use of a refrigerated trap in the vacuum system will expedite processing time.
- b. Turn on hot block and cold block heaters controlling the heating rate so as not to exceed $\sim 100\mu\text{Hg}$ pressure.
- c. Continue Step b until both blocks reach 600°F and the indicated pressure drops below $100\mu\text{Hg}$.
- d. Back fill fixture with a gas mixture of 15 percent H_2 - 85 percent A.
- e. Adjust heaters to reach 1350°F on the hot block while not exceeding 600°F on the cold block. Oxide films which are reduceable in hydrogen at these temperatures should visibly disappear during this operation.
- f. Re-evacuate fixture and back-fill with the 15 percent H_2 - 85 percent A several times, noting each time the time required to reach $100\mu\text{Hg}$. When no further change in evacuation rate is observed, proceed to step g.
- g. Refill fixture with the above gas mixture and turn off heater.
- h. Remove safety screen and quartz tube after $T_h \leq 200^\circ\text{F}$. Forced air convection cooling may be used to accelerate cooling.
- i. Clean inner and outer surfaces of quartz tube by scrubbing with water, a stiff bristle brush, and laboratory glass cleaning compound. Rinse thoroughly and wipe dry with clean lint-free cloth.
- j. Dry the internal surfaces of quartz tubes by placing in a drying oven or by using an internally applied hot air torch.
- k. While still warm, replace the quartz tube on the fixture and re-evacuate.

- l. Heat entire fixture uniformly to approximately 200°F while repeating Step f. This heating can conveniently be performed by means of a flexible heater tape, spirally wrapped around the entire quartz tube fixture base and valve assembly.
- m. When no further improvement in pump down time is noted, consider the processing to be complete. If not placed into immediate service, the station should either be maintained under kinetic vacuum or backfilled with 99 percent Ar, 1 percent He and isolated from both the gas and vacuum manifolds by closing the valves. Avoid prolonged exposure of internal portion of the test fixture to the atmosphere.

3.1.2 TEST STATION – THERMOCOUPLE CALIBRATION

3.1.2.1 Calibration

A calibrated inspection standard thermocouple assembly will be used to check the calibration of the sheathed hot and cold junction thermocouples by a direct comparison technique. With the standard thermocouple assembly installed on a fixture, readings will be taken of the output of each of the three thermocouples while the hot and cold block portions of the fixture are heated isothermally by an external electric oven. Because of the temperature limitations of the cold block material (aluminum), the calibration will be limited to not over 600°F.

3.1.2.2 Correction

If the thermocouple output agrees with the Bureau of Standards tabulated value within the manufacturer's claimed tolerances, no correction to the readings will be applied. If however, a significant difference exists between measured and expected values for any given thermocouple, the true mv reading for a thermocouple will be calculated by: *

$$T_{\text{(true)}} = T_{\text{(meas)}} + A_0 + A_1 T_{\text{(meas)}} + A_2 T_{\text{(meas)}}^2$$

Where the constants A_0 , A_1 and A_2 are calculated by a second order least squares fit of the error difference versus measured thermocouple output. These constants, if different from zero, will be stored in the data analysis program entitled "TELPS 7" in Section 4.

* See "COMPAR", Section 4

3.1.3 INGRADIENT PERFORMANCE TESTS

After fixture bake-out procedures have been completed, or at the completion of a preceding ingradient test, the procedure for removing the previous test specimen and installing a new sample consists of the following steps:

- a. If fixture is not already at room temperature, turn off the hot and cold block heaters and accelerate fixture cooling by forced air convection on the outside of the quartz tube.
- b. Ascertain that the fixture is removed from the balance of the series circuit by closing the shorting switch located at that station. Failure to do so will result in the constant current source current being interrupted by the breaking of an arc between the sample and the graphite electrode which could damage both the fixture and the test specimen.
- c. Prior to removing the safety screen and quartz tube, evacuate the test chamber and back-fill with air by actuating the handle on the pressure relief valve.
- d. Using gloves or rubber finger tips to avoid contaminating fixture interior surfaces, raise the top thermocouple a fraction of an inch and wedge in raised position using a suitable shaped metal wedge.
- e. Lower the cold block by first depressing the lower thermocouple by its midlock fitting. Initially, the thermocouple compression spring will be completely compressed, whereafter further depression of the thermocouple will start to compress the main cold block compression springs, freeing the previous test specimen for easy removal by tweezers.
- f. Install a new test specimen by reversing the procedure of Step e. Install the new test specimen by centering it by eye on the graphite cold block current electrode. Slowly release the downward pressure applied to the lower thermocouple, allowing first for the cold block to raise up to provide compressive loading of the test specimen against the graphite hot block electrode. Continued release of downward pressure on the lower thermocouple will cause the thermocouple spring assembly to apply thermocouple pressure to the center of the lower face of the test specimen.
- g. Remove temporary wedge holding upper thermocouple and allow it to contact the center of the upper face of the test specimen. Check for thermocouple contact by feel as well as by ohmmeter indication of continuity across the sheaths of both thermocouples.
- h. Replace quartz cover and safety screen. Use care to avoid accidental tube breakage while resecuring the hold down ring by properly centering the quartz tube and by seeing that no foreign objects or sample chips have fallen onto the neoprene gasket.

- i. Open vacuum valve and evacuate chamber to $< 50\mu$ Hg. Hold-down ring can be snugged down an additional $\sim 1/4$ turn at this time.
- j. Close vacuum valve and crack open gas valve to flush with ~ 1 atm of the 99 percent Ar, 1 percent He fill gas.
- k. Close gas valve and open vacuum valve to again evacuate test chamber to $< 50\mu$ Hg.
- l. Close vacuum valve and open gas valve to refill station to 10 psig with the 99 percent Ar, 1 percent He mixture.
- m. Close gas valve and turn on the hot and cold block heaters. It may be necessary to occasionally "top off" the stations in the event there is any leakage past the valves. This may be accomplished simply by momentarily opening and closing the station's gas valve.
- n. Monitor hot and cold junction temperatures and adjust variance to provide the required test conditions.
- o. For each station in sequence measure:
 1. The hot junction thermocouple mv output
 2. The cold junction thermocouple mv output
 3. The mv drop across a 50 mv-2 ampere shunt in series with all stations and a constant current source
 4. The closed circuit voltage
 5. The open circuit voltage

Collect data on the data acquisition system on punched paper tape. Collect a data cycle at least once each two hours.

- p. Submit the data, together with properly formatted sample identification, previously accumulated test hours, most recent start time, and appropriate resistance and voltage correction coefficients, to the time share computer terminal for data reduction using the program "TELPs 7".

3.1.4 CALCULATIONS

From the measured values of hot and cold thermocouple outputs, current shunt voltages, closed circuit voltage V , and open circuit voltage E , the following calculations will be made by "TELPs 7".

- a. Hot and cold junction temperatures will be calculated from 5th order polynomial curve fit formula relating temperature in °F to handbook values of iron-constantan thermocouple outputs. These values will be further corrected as required by a second order correction formula previously described.

- b. Resistance

$$R_{\text{meas}} = \frac{E - V}{I} \times \alpha \times 1.17847$$

where I is the current. The factor α given by the equation $\alpha = (1 + 5.23 \times 10^{-5}) \times (T_h - T_c)$ is an empirically obtained correction factor required to account for convective and radiative heat loss from the sides of the test specimen. Under design temperature operating condition, α accounts for a three percent correction factor. The factor 1.17847 is a theoretically derived correction factor determined by the size and shape of the test specimen as well as the current electrodes of the test fixture.**

- c. Normalized Voltage *

$$E = E_{\text{meas}} = \frac{\int_{520}^{1090} SdT}{\int_{T_c}^{T_h} SdT}$$

- d. Normalized Resistance *

$$R = R_{\text{meas}} = \frac{\int_{520}^{1090} KpdT \int_{T_c}^{T_h} KdT}{\int_{520}^{1090} Kdt \int_{T_c}^{T_h} KpdT}$$

- e. Normalized Power

$$P = \frac{E^2}{4R}$$

- f. These data will be plotted versus elapsed test hours. For fixtures equipped with thermal conductivity heat flow transducers (Figure 3-2) the foregoing procedure may be extended to include measurements of thermal conductance. To do so requires that the scan circuit be modified to measure the potential drop E_Q across

* See Section 4

** See Vol. 1, Section 7.5

the standard during air open circuit conduction in addition to the previously measured quantity. Thermal equilibrium may be obtained under either open circuit or closed circuit conditions and test results so qualified. Normalized values of $Q \frac{L}{A}$ are obtained by

$$Q \frac{L}{A}_{\text{norm}} = Q \frac{L}{A}_{\text{meas}} * \frac{\int_{520}^{1090} K dt}{\int_{T_c}^{T_h} K dt}$$

where $Q = C \times E_Q$

and where C is the empirically determined calibration coefficient for the test future.

3.2 INGRADIENT SOAK TESTS

Preprocessing and operation of the ingradient soak test fixtures (Figure 3-3) is identical to that stated for the ingradient performance station except for the following differences:

- a. The hot junction on monitoring thermocouple location in the graphite electrode corresponding to the No. 1 leg position (Figure 3-3), and cold junction thermocouple location in the graphite cold electrode attached to the No. 1 follower, is such that no separate handling procedures are required as specified for the ingradient performance fixture.
- b. Loading and unloading of test specimens is accomplished by depressing the individual followers instead of the cold block.
- c. A total of eight legs may be soaked in one fixture at any one time in multiples of two starting at position No. 1. If an odd number of legs requires ingradient soaking, a spare leg must be used to complete the pair so as to complete the electric circuit. The banana plug jack on the fixture base must be located as so to short out any unused positions in the fixture. Furthermore, each fixture must be shorted out completely during loading and unloading to prevent arc damage to the test specimen or the fixture and to avoid the shock hazard.

TABLE 3-1. SCAN SEQUENCE

SCANNER POSITION	TEST STATION TIME RECORDED *	CIRCUIT	CONTACTS	QUANTITY
0				
1	1	Closed	1-2	T _h
2	1	Closed	3-4	T _c
3	Shunt	Closed	5-6	I
4	1	Closed	4-2	V
5	1	Open	4-2	L
6	2	Closed	1-2	T _h
7	2	Closed	3-4	T _c
8	Shunt	Closed	5-6	I
9	2	Closed	4-2	V
10	2	Open	4-2	E
11	3	Closed	1-2	T _h
12	3	Closed	3-4	T _c
13	Shunt	Closed	5-6	I
14	3	Closed	4-2	V
15	3	Open	4-2	E

* See section 4

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ITEM	DN	DRWG. NO.	REQ.	MAT'L	COM'L	NAME
1	X	PD-45-6001 PD-45-6101	1	Quartz		Ass'y Ingradient Performance Fixture Tube
2	X	PD-45-6102	1			Insulation Blanket
3		PD-45-6039	1	304 S/S		Screen Assembly
4		PD-45-6104	1	Iron Con- stanan wires In- comel sheath	X	Thermocouple Sheath
5		PD-45-6105	2	303 S/S	X	Midlock fitting
6		PD-45-6106	1	Armco Iron		Thermocouple Weight
7		PD-45-6007	1			Ass'y T/C Support Tube
8		PD-45-6108	5	Molybdenum		Upper Shield
9		PD-45-6109	2	Nickel		Heater Leads
10		PD-45-6110-P, 99	1	Alumina-AD 99	X	Insulator Sleeve Thermocouple Return

ISSUE	DATE AND CHANGE RECORD	BY: W. H. Nelson	REV.	CH.
A	June 22, 1966			
B	July 16, 1966 Design Modification		WHN	HNH
C	November 22, 1966 Delete Items 2, 7, 20, 22, 27, 37, 38, 58, 59, 51, 29, 16, 18, Added Items 60 thru 84 Item 3 was PD-45-6103 Screen Item 10 was PD-45-6110 Item 40 was PD-45-6198 Item 55 was PD-45-6197 Item 34 was Boron Nitride Item 45 was PD-45-6145-Base Req. Item 13 was 2, Req. Item 33 was 8 Req. Item 35 was 2 Req. Item 50 was 2 Req. Item 30 was 3		WJK	WJK
D	Add items 80, 81 Delete Items 71, 74, 75, 57, 39 <div style="border: 1px solid black; padding: 5px; display: inline-block;"> RELEASED PD 06. 11-29-66 Prod _____ </div> ITEM 39 ON PD-45-6019 ITEM 8 WAS QTY = 10		WJK	WJK

USED ON	TITLE Ass'y Ingradient Performance Fixture
	DIVISION <u>I.P.R.</u>
	PROJ. SHEET 1 OF 6 SHEETS

ITEM	BN	DRWG. NO.	REQ.	MAT'L	COM'L	NAME			
ISSUE		DATE AND CHANGE RECORD				BY:		REV.	CH.
E		Changed Item 46, Delete Item 71, 74, 75, Add Item 85						WJK	
F		JAN. 13, 1967							
USED ON						TITLE			
						DIVISION			
						PROJ. SHEET 2 OF 6 SHEETS			

ITEM	DN	DRWG. NO.	REQ.	MAT'L	COM'L	NAME
11		PD-45-6111	3	Inconel Sheath Ceramic Seal - 2" Solid Nickel	X	Heater
12		PD-45-6112	3	" " "	X	Heater
13		PD-45-6113	1	Boron Nitride		Thermocouple Support Plug
14		PD-45-6114	1	Armco Iron		Block
15		PD-45-6115	1	Alum. (6061-T6)		Block
16		PD-45-6116	1	Graphite		Block
17		PD-45-6117	1	Graphite		Socket
18		PD-45-6118	1	Boron Nitride		Thermocouple Sleeve
19		PD-45-6119	1	Armco Iron		Threaded Plug
20		PD-45-6120	3	Armco Iron		Knockout Plug
21		PD-45-6121	3	304 S/S (Threaded)		Support Rod
22		PD-45-6122	3	316L S/S		Support Tube
23		PD-45-6123	1	Iron Con- stantan Wires In- conel Sheath	X	Thermocouple Sheath
24	X	PD-45-6002	1	" " "		Inspection Standard Ass'y
25		PD-45-6125	1	Armco Iron		Thermocouple Spring Retainer
26		PD-45-6126	1	304 S/S		Thermocouple Support Spring
27		PD-45-6127	10	Molybdenum		Lower Shield
28		PD-45-6128	1	316L S/S		Current Ring
29		PD-45-6129	3	Boron Nitride		Spring Block (Upper)
30		PD-45-6130	6	Fired Lava		Spring Block (Lower)
31		PD-45-6131	3	304 S/S		Support Spring
SHEET 3 OF 6 SHEETS						

ITEM	BM	DRWG. NO.	REQ.	MAT'L	COM'L	NAME
32		PD-45-6132	1	304 S/S		Support Plate
33		PD-45-6133	4	304 S/S	X	Attach Screws
34		PD-45-6134	6	Alum. (6061-T6)		Washer
35		PD-45-6135	1	Viton	X	Seal
36		PD-45-6136	1	Teflon		Pressure Ring
37		PD-45-6137	1	Alum. (6061-T6)		Cap
38		PD-45-6138	2	Alum. (6061-T6)		Knockout Plug
39		PD-45-6139	2	303 S/S	X	Packing Glands
40		PD-45-6110-P122	2	Alumina		Insulator Sleeve - Heater Lead
41		PD-45-6141	1	Nickel		Current Ring Lead
42		PD-45-6008	1			Ass'y T/C Support Tube
43		PD-45-6143	2	Nickel		Heater Leads
44		PD-45-6144	1	Graphite		Insert
45		PD-45-6019	1	304 S/S		Base Assembly
46		PD-45-6314	18	St. Stl	X	Nut
47		PD-45-6147	1	Nickel		Support Rod Lead
48		PD-45-6148	4	S/S	X	Capscrews
49		PD-45-6149	4	S/S	X	Bolt
50		PD-45-6150	1	304 S/S		Support Leg
51		PD-45-6006	2		X	Terminal Board Ass'y
52		PD-45-6170	4	S/S	X	Capscrews
53		PD-45-6160	1			Vacuum Gage
54		PD-45-6154	1			Relief Valve
55		PD-45-6110-P11	2	Alumina AO-99		Insulator - Heater Lead
56		PD-45-6199	2	St. Stl.		Knurled Nut
SHEET 4 OF 6 SHEETS						

ITEM	SM	DRWG. NO.	REQ.	MAT'L	COM'L	NAME
57		PD-45-6189	3	St. Stl.		Support Spring
58		PD-45-6009				Ass'y Gas Connection
59		PD-45-6010				Ass'y Vacuum Connection
60		PD-45-6110-P14	1	Alumina Ad-99		Insulator Sleeve - T/C Probe Support
61		PD-45-6326	1	Neoprene		Washer, Flat Rubber
62		PD-45-6315	1	St. Stl.		Spacer
63		PD-45-6319	1	St. Stl.		Bolt - Rad. Shield
64		PD-45-6317	1	St. Stl.		Support Weldment
65		PD-45-6324	1	St. Stl.		Support Leg
66		PD-45-6110-P13	1	Alumina Ad-99	x	Insulator Sleeve - Heater Lead
67		PD-45-6110-P12	2	Alumina Ad-99	x	Insulator Sleeve - Heater Lead
68		PD-45-6110-P5	1	Alumina Ad-99	x	Insulator Sleeve - Heater Lead
69		PD-45-6110-P4	4	Alumina Ad-99	x	Insulator Sleeve - Rad. Shield
70		PD-45-6311	1	St. Stl.	x	Screw - Terminal
71		PD-45-6329	4	Nickel Plt.	x	Ring Tongue Connector
72		PD-45-6316	1	Boron Nitride		Thermocouple Support Plug (Upper)
73		PD-45-6328	500	Ceramic	x	Ceramic Bead
74		PD-45-6330	4	Cad. Plate	x	Screw - Heater Connection
75		PD-45-6331	4	Cad. Plate Stl.	x	Nut - Heater Connection
76		PD-45-6042	1		x	Term. Strip Assembly - Long
77		PD-45-6043	1		x	Term. Strip Assembly - Short
78		PD-45-6332	2	St Stl.	x	Nut - Rad. Shield
79		PD-45-6334	1	Boron Nitride		Plug - Insert
SHEET 5 OF 6 SHEETS						

ITEM	BM	DRWG. NO.	REQ.	MAT'L	COM'L	NAME
80		PD-45-6340	2	St. Stl.	x	Nut - Heater Connection
81		PD-45-6341	2	St. Stl.		Screw - Heater Connection
82		PD-45-6343	4	Ceramic	x	Shield Spacer
83	*	PD-45-6047	1			Block Ass'y.
84	*	PD-45-6046	1			Insert Ass'y.
85	*	PD-45-6045	1			Ass'y Thermal Conductivity Insert
		(PD-45-6045	will be used	on only 2 fixtures)		
SHEET 6 OF 6 SHEETS

Figure 3-2. Assembly of Thermal Conductivity Insert
45-6045

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- 52 ASSY OF CALIBRATION STANDARD PD 45 6002
- 64 ASSY GAS CONNECTION PD 45 6009
- 65 ASSY VACUUM CONNECTION PD 45 6010

Figure 3-3. Ingradient Soak Test Fixture
45-6003

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ITEM	QTY	DRWG. NO.	REQ.	MATL	COM'L	NAME		
1		PD-45-6003 PD-45-6101	1	Quartz		Ass'y Soak Ingradient Fixture Tube		
2	X	PD-45-6102	1			Insulation Blanket		
3	X	PD-45-6039	1	304 S/S		Screen Assembly		
4		PD-45-6110-LP	1	Alumina-AD-99		Insulator Sleeve - T/C Return		
5		PD-45-6104	1	Iron Con- Stantan Wires	X	Thermocouple Sheath		
6		PD-45-6151	5	Molybdenum		Upper Shield		
7		PD-45-6156	1	Armco Iron		Hot Block		
8		PD-45-6155	4	Inconel Sheath Ceramic Seal-2" Solid Nickel Leads-Cen- terless Gnd X		heater 1/2".L. 125 W		
ISSUE		DATE AND CHANGE RECORD			BY: W. J. Nelson		REV.	CH.
A		June 22, 1966						
B		Design Modification						
		July 16, 1966					WhN	hNH
C		November 22, 1966						
		Delete Items 2, 9, 15, 18, 19, 24, 26, 35, 37, 38, 39, 40, 41, 42, 43, 44, 45, 53, 60, 63, 64, 65, 47					WJK	WJK
		Added Items 66 thru 85, Added Item 82, 89, 90						
		Item 4 was PD-45-6110						
		Item 42 was PD-45-6180						
		Item 58 was PD-45-6186						
		Item 61 was PD-45-6195						
		Item 62 was PD-45-6196						
		Item 22 was Boron Nitride						
		Item 3 was Screen 6103						
		Item 60 was Nickel						
		Item 27 was PD-45-6145 Base						
		Req. Item 6 was 10						
		Req. Item 29 was 2						
		Req. Item 32 was 2						
		Req. Item 36 was 8						
		Req. Item 42 was 16						
D		Added Items 86, 91, 87, 88 Deleted Items 77, 80, 81					WJK	WJK
USED ON				Req Item 75 was 16				
TITLE				Ass'y Soak Ingradient Fixture				
DIVISION								
PROJ.				SHEET 1 OF 6 SHEETS				

RELEASED

PD 44 11-29-66

Prod

ITEM	BN	DRWG. NO.	REQ.	MAT'L	COM'L	NAME			
ISSUE		DATE AND CHANGE RECORD				BY:		REV.	CH.
E	January 10, 1967 Changed Req'd. on Items 12, 13, 14, 46, 61, 62 Item 28 now on PD-45-6019 Delete Items 77, 80, 81								
F	JAN. 13, 1967								
USED ON						TITLE			
						DIVISION			
						PROJ.			
						SHEET 2 OF 6 SHEETS			

ITEM	BM	DRWG. NO.	REQ.	MAT'L	COM'L	NAME
9		PD-45-6171	4	Armco Iron		Knockout Plug
10		PD-45-6157	1	Boron Nitride		Insulation Plate
11		PD-45-6158	1	Boron Nitride		Insulation Collar
12		PD-45-6159	1	Graphite		Disk
13		PD-45-6161	1	Graphite		Cap
14		PD-45-6162	1	Alum (6061-T6)		Follower
15		PD-45-6172	1	Alum (6061-T6)		Knockout Plug
16		PD-45-6111	1	Inconel Sheath Ceramic Seal-2" Solid Nickel Leads Centerless Ground	X	Heater
17		PD-45-6165	1	316L S/S .063 I.D. X .125 O.D.		Support Tube
18		PD-45-6146	16	S/S		Nut
19		PD-45-6166	2	304 S/S		Support Rods
20		PD-45-6153	8	304 S/S		Spring Block
21		PD-45-6168	8	302 S/S		Support Spring
22		PD-45-6191	8	Fired Lava		Spring Block
23		PD-45-6152	1	Iron Constantan Wires Inconel Sheath	X	Thermocouple Sheath (Ungrounded)
24		PD-45-6137	1	Alum. (6061-T6)		Cap
25		PD-45-6133	4	304 S/S	X	Attach Screws
26		PD-45-6132	1	304 S/S		Support Plate
SHEET 3 OF 6 SHEETS						

ITEM	SM	DRWG. NO.	REQ.	MAT'L	COM'L	NAME
27		PD-45-6019	1	304 S/S		Base Assembly
28		PD-45-6139	2	303 S/S	X	Packing Glands
29		PD-45-6150	1	304 S/S		Support Leg
30		PD-45-6167	1	304 S/S		Upper Plate
31		PD-45-6136	1	Teflon		Pressure Ring
32		PD-45-6135	1	Viton	X	Seal
33		PD-45-6149	4	S/S	X	Bolt
34		PD-45-6148	4	S/S	X	Capscrews
35		PD-45-6173	10	Molybdenum		Shield
36		PD-45-6174	3	S/S		Current Washer
37		PD-45-6175	13	Boron Nitride		Plug
38		PD-45-6176	4			Support Spring
39		PD-45-6177	8	Alumina-Ad-99		Insulator Support Tube
40		PD-45-6178	4	Alumina-Ad-99		Insulator Base Support
41		PD-45-6179		Alumina-Ad-99		Insulator - Upper Base
42		PD-45-6180	4	Alumina-Ad-99		Insulator Sleeve - Shield Spacer
43		PD-45-6181	4	Alumina-Ad-99		Insulator - Lower Block
44		PD-45-6182	4	Alumina-Ad-99		Insulator - Middle Spacer
45		PD-45-6183	2	Alumina-Ad-99		Insulator - Upper
46		PD-45-6109	4	Nickel		Heater Lead
47		PD-45-6008	2		X	Terminal Board Ass'y.
48		PD-45-6170	4	S/S	X	Capscrew
49		PD-45-6105	1	303 S/S	X	Midlock Fitting
SHEET 4 OF 6 SHEETS						

ITEM	BM	DRWG. NO.	REQ.	MAT'L	COM'L	NAME
50		PD-45-6160	1		X	Vacum Cage
51		PD-45-6154	1		X	Relief Valve
52	X	PD-45-6002	1			Inspection Std. Thermocouple Ass'y
53		PD-45-6121	2	St. Stl.		Support Rod
54		PD-45-6184	7	St. Stl. 304		Follower Support
55		PD-45-6185	7	Alum. 6061		Follower
56		PD-45-6186	7	Graphite		Cap
57		PD-45-6187	3	Graphite		Disk
58		PD-45-6110-P8	1	Alum. AD-99		Insulator Sleeve - T/C Probe
59		PD-45-6163	1	Alum.		Cold Block
60		PD-45-6169	5	Copper	X	Follower Leads
61		PD-45-6110-P9	2	Alumina Ad-99		Insulator Sleeve - Heater Leads
62		PD-45-6110-P10	2	" "		Insulator Sleeve - Heater Leads
63		PD-45-6190	8	S. Ste.		Soak Follower Support
64		PD-45-6009				Ass'y Gas Connection
65		PD-45-6010				Ass'y Vacuum Connection
66		PD-45-6318	4	St Stl 304		Support - Upper Plate & Cold Block
67		PD-45-6323	2	St. Stl.		Current Washer
68		PD-45-6322	8	Boron Nitride		Spacer
69		PD-45-6320	1	A-286 Super Alloy		Stud
70		PD-45-6315	1	St. Stl.		Spacer
71		PD-45-6326-	1	Neoprene		Washer, Flat Rubber
72		PD-45-6321	1	St. Stl.		Support Plate
73		PD-45-6325	1	St. Stl.		Support Leg
74		PD-45-6314	1	St. Stl.	x	Nut - Stud
75		PD-45-6313	12	St. Stl.	x	Screw - Support
SHEET 5 OF 6 SHEETS						

ITEM	BN	DRWG. NO.	REQ.	MAT'L	COM'L	NAME
76		PD-45-6312	4	St. Stl.	x	Screw - Insulation Plate
77		PD-45-6329	4	Nickel Plt.	x	Ring Tongue Connector
78		PD-45-6332	17	St. Stl.	x	Nut
79		PD-45-6328	700	Ceramic	x	Ceramic Bead
80		PD-45-6330	4	Cad. Plate	x	Screw - Heater Connection
				Stl.		
81		PD-45-6331	4	Cad. Plate	x	Nut - Heater Connection
				Stl.		
82		PD-45-6106	1	Armco Iron		Thermocouple Weight
83		PD-45-6042	1		x	Term. Strip Ass'y - Long
84		PD-45-6043	1		x	Term. Strip Ass'y - Short
85		PD-45-6044	5		x	Bdg. Post Assembly
86		PD-45-6340	2	St. Stl.	x	Nut - Heater Connection
87		PD-45-6341	2	St. Stl.		Screw - Heater Connection
88		PD-45-6342	4	St. Stl.	x	Screw - Support Plate
89		PD-45-6343	4	Ceramic	x	Shield Spacer
90		PD-45-6344	6	Glass	x	Glass Sleeving
91		PD-45-6346	1	ST. STL.		RETAINER
SHEET 5 OF 6 SHEETS						

3.2.1 POST-TEST OPERATIONS

At the conclusion of cycle on each test specimen, the legs will be returned to their respective REPAMMI containers. The containers themselves will remain at each station to aid in sample identification. The following will then be performed:

- a. The physical dimensions will be measured and recorded.
- b. Spot checks of the density will be made.

3.3 DETERMINATION OF THE THERMOELECTRIC PROPERTIES

3.3.1 DISCUSSION OF GENERAL CASE

The thermoelectric properties of practical importance are the Seebeck coefficient S , the electrical resistivity ρ , and the thermal conductivity K , all of which are functions of the temperature. A thermoelectric leg having a length/area ratio L/A operating in a temperature gradient will exhibit a Seebeck voltage E relative to a given reference material (that is, iron), a resistance R , and conduct heat at the rate of Q watts. The values observed depend upon the thermoelectric properties of the material and the junction temperatures. From a number of such observations made at a series of junction temperatures it is possible to determine values for S , ρ , and K as point functions of temperature.

It will be convenient to first treat a general case described by the definite integral

$$\phi(a) = \int_{u_0(a)}^{u_1(a)} f(x, a) dx \quad (1)$$

Applying Leibniz' Rule for differentiation of a definite integral to Equation (1) we obtain:

$$\frac{d\phi}{da} = f(u_1, a) \frac{du_1}{da} - f(u_0, a) \frac{du_0}{da} + \int_{u_0(a)}^{u_1(a)} \left[\frac{\partial f(x, a)}{\partial a} \right] dx \quad (2)$$

These mathematical procedures can now be applied to the determination of the thermoelectric properties.

3.3.2 SEEBECK COEFFICIENT

The voltage E developed across the thermoelectric leg having a Seebeck Coefficient S , operating between a cold junction temperature T_c and a hot junction temperature T_h is given by

$$E = \int_{T_c}^{T_h} S(t) dt \quad (3)$$

Applying Equation (2) to Equation (3) below:

$$\frac{dE}{dT_h} = S(T_h) \frac{dT_h}{dT_h} - S(T_c) \frac{dT_c}{dT_h} + \int_{T_c}^{T_h} \left[\frac{\partial S(T)}{\partial T_h} \right] dt \quad (4)$$

Since S is a property of the system, $\frac{\partial S(T)}{\partial T_h} = 0$ and Equation (4) becomes

$$S(T_h) = \frac{dE}{dT_h} + S(T_c) \frac{dT_c}{dT_h} \quad (5)$$

3.3.3 THERMAL CONDUCTIVITY

It will be assumed that the heat flow is one dimensional. Convective and radiative heat losses can be effectively eliminated by providing suitable large area hot and cold junction surfaces to act as thermal guards in combination with the microquartz insulating blanket to prevent convective losses.

$$Q = K(T)A \frac{dT}{dx} \quad (6)$$

$$T = T_c \text{ at } X = 0$$

and

$$T = T_h \text{ at } X = L$$

$$Qdx = K(T)AdT \quad (7)$$

$$Q \frac{L}{A} = \int_{T_c}^{T_h} K(T) dT \quad (8)$$

Equation (8) is of the same form as Equation (3). The left hand side of each equation is the experimentally observed quantity which is a function of the independent variables T_h and T_c , the limits of intergration, and the argument of the integral which is the quantity to be determined. Applying Leibniz' rule to Equation (8) gives:

$$\left(\frac{L}{A}\right) \frac{dQ}{dT_h} = K(T_h) \frac{dT_h}{dT_h} - K(T_c) \frac{dT_c}{dT_h} + \int_{T_c}^{T_h} \left[\frac{\partial K(T)}{\partial T_h} \right] dt \quad (9)$$

$$K(T_h) = \left(\frac{L}{A}\right) \frac{dQ}{dT_h} + K(T_c) \frac{dT_c}{dT_h} \quad (10)$$

3.3.4 ELECTRICAL RESISTIVITY

The resistance R of a leg of length L is given by

$$R = \frac{1}{A} \int_0^L \rho(T) dx \quad (11)$$

If a temperature difference exists across the leg then Equation (11) cannot be used to determine $\rho(T)$ unless the explicit relation between T and X is known. The independent variable in (11) can be changed from X to T to give

$$R = \left(\frac{1}{A}\right) \int_{T_c}^{T_h} \rho(T) \frac{dx}{dT} dT \quad (12)$$

By solving equation (6) for dx/dT and substituting (12) we get

$$R = \frac{1}{Q} \int_{T_c}^{T_h} \rho(t) K(T) dT$$

or

$$RQ = \int_{T_c}^{T_h} \rho(T)K(T)dt \quad (13)$$

which again is of the same form as Equation (3) and Equation (8). The experimentally observed quantities are the RQ product and the junction temperatures. Differentiating Equation (17) by Leibniz' rule gives:

$$\frac{d(RQ)}{dT} = \rho(T_h) \bullet K(T_h) \frac{dT_h}{dT} - \rho(T_c) \bullet K(T_c) \frac{dT_c}{dT} + \int_{(T_c)}^{T_h} \frac{\partial}{\partial T_h} \left[\rho(T) \bullet K(T) \right] dt \quad (14)$$

Since the $\rho(T) \bullet K(T)$ product is a property of the system

$$\frac{\partial}{\partial T_h} \left[\rho(T) \bullet K(T) \right] = 0$$

$$\rho(T_h) \bullet K(T_h) = \frac{d(RQ)}{dT} + \rho(T_c) \bullet K(T_c) \frac{dT_c}{dT_h} \quad (15)$$

3.3.5 EXPERIMENTAL PROCEDURE

The experimental procedure consists of obtaining data from a series of pseudo-equilibrium observations made on a thermoelectric leg subjected to a series of successively higher thermal gradients. An abbreviated outline of the experimental steps consists of the following:

- a. Mount test specimen in an ingradient performance fixture which has been modified to include a thermal heat flux meter in the cold block (Figure 3-2). Follow the procedure and observe the precautions detailed in Section 3.
- b. Surround the test specimen with microquartz pad insulation which has been previously baked at 1600°F for one hour to remove absorbed water.

- c. Evacuate to $<100\mu\text{Hg}$, flush, re-evacuate, and backfill the fixture with 99% A, 1% He gas to a pressure of 10 psig.
- d. Using the automatic data acquisition system measure the following six quantities:

Quantity	Circuit Condition
1. $T_h = \text{mv output of hot junction thermocouple}$	Open
2. $T_c = \text{mv output of cold junction thermocouple}$	Open
3. $E_Q = \mu\text{v output of an iron-constantan differential thermocouple heat flux standard in thermal series with test specimen}$	Open
4. $E_s = \text{Seebeck voltage relative to the iron wires of the hot and cold junction thermocouples}$	Open
5. $V = \text{Closed circuit voltage relative to the iron wires of the hot and cold junction thermocouples}$	Closed
6. $I = \text{mv drop across a 50 mv 2 ampere shunt in series with test specimen}$	Closed

- e. Start experiment with hot and cold junction at or near room temperature by taking a set of readings as set forth in (3.3.5d).
- f. Adjust the hot block heater variac to apply 10 volts, ac to the hot block heater, raising it 10 volts each six minutes thereafter until the full output of the variac is reached, recording a series of six readings once each six minutes.
- g. Continue readings once each six minutes until the maximum desired hot junction temperature has been reached (that is, 1200°F). This should require about 95 minutes.
- h. Submit the resulting punched data tape to the computer for analysis using the data reduction programs entitled "SKRHO1" and "SKRHO2", Section 4.

3.3.6 ANALYTIC PROCEDURE

The data reduction program entitled "SKRHO1" performs the function of evaluating the quantities S , K , and $(\rho \cdot K)$ as point functions of temperature by solving for the appropriate quantities in Equations (5), (10) and (15). The ratio $(\rho \cdot K)/K$ gives the resistivity. Approximate values of dE/dT_h , dQ/dT_h , of the finite differences $\frac{d(R \cdot Q)}{dT_h}$, and dT_c/dT_h are given

by the ratios $\Delta \dot{E}/\Delta T_h$, $\Delta Q/\Delta T_h$, $\frac{\Delta(R \bullet Q)}{\Delta T_h}$, and $\frac{\Delta T_c}{\Delta T_h}$ respectively, and are evaluated at the average temperature in the interval ΔT_h between two adjacent readings.

It will be noted that except in the special case where the cold junction temperature is held constant, Equations (5), (8) and (19) are transcendental. Solutions may readily be found by using a method of numerical analysis as in SKRHO1 which utilizes the results of proceeding calculations to estimate the value of the parameter evaluated at a cold junction temperature corresponding to a particular hot junction temperature.

3.4 OXYGEN ANALYSIS

3.4.1 PRINCIPLE OF OPERATION

The sample will be placed in a graphite crucible and heated in an induction furnace which will liberate any oxygen present and convert it to CO. The CO will be oxidized to CO₂ and swept into a Ba(OH)₂ solution where it will react to form BaCO₃. The change in conductivity of the Ba(OH)₂ solution will be measured as a function of oxygen content. The following reactions prevail:

3.4.2 EQUIPMENT USED

LECO Induction Furnace No. 537

LECO Oxygen Analyzer No. 534-300

3.4.3 PROCEDURE

The procedures used follow the instruction manuals (dated 1958) supplied with the equipment, except as noted below:

3.4.3.1 Solution Preparation

In order to obtain a $\text{Ba}(\text{OH})_2$ solution saturated with BaCO_3 , 17 grams of anhydrous $\text{Ba}(\text{OH})_2$, reagent grade will be dissolved in ~ 600 ml of boiling distilled water and added to 17 liters of distilled water without filtering off any BaCO_3 present. This solution will be agitated by drawing air through it for 1/2 hour. Preferably the solution will be allowed to settle several days before using. No further reagents will be added.

3.4.3.2 Blanking the New Crucible

The new crucible assembly will be packed as described and placed in the induction furnace. The temperature control knob will be set at 180-200 ma and, with an argon flow of about 120 bubbles/minute, the crucible will be allowed to out-gas at about 800-1000°C overnight. The following morning, the catalyst furnace will be turned on and the temperature raised to complete the outgassing as described in the manual.

3.4.3.3 Establishing the Graph

LECO standards made of potassium acid phthalate will be used. The amount of carbon and oxygen in each standard sample will be stated on the bottle. The graph will be plotted showing ohms versus milligrams O_2 . The furnace temperature will be set at approximately 2000°C by setting the temperature control knob at 500 ma. (It has been advantageous to leave the furnace on continuously at this temperature, rather than cycle the temperature as outlined in the instruction manual.)

The time interval from the time the sample is dropped into the crucible until the reading is taken will be ten minutes, as measured with a stop watch. Sample size will be 1/2 gram, of a suitable size lump to pass through the loading stopcock, but not crushed.

3.5 NORMALIZATION PROCEDURES

A meaningful comparison of voltage, resistance, and data points obtained on different samples or on any individual sample at different observation times requires that a normalization procedure be used which corrects for the influence of hot and cold junction temperature deviations from their intended fixed reference values. Initially, a first order correction procedure was used of this form:

$$E_{(1090-520)} = E_{(T_h - T_c)} - \frac{\partial E}{\partial T_h} (T_h - 1090) - \frac{\partial E}{\partial T_c} (T_c - 520) \quad (1)$$

and

$$R_{(1090-520)} = R_{(T_h - T_c)} - \frac{\partial R}{\partial T_h} (T_h - 1090) - \frac{\partial R}{\partial T_c} (T_c - 520) \quad (2)$$

where T_h and T_c are the actual measured hot and cold junction temperatures. The partial derivatives of E and R with respect to hot and cold junction temperature are evaluated by a multiple regression analysis of data obtained during a temperature cycling experiment. Details of this procedure are set forth in the Test Plan for Task 3, document MMM 8406-1172 Section 6 and Appendix D.

This method of normalization is adequate for small temperature excursions, but is subject to serious limitations. The partial derivatives of E and R with respect to T_c and T_h are single valued and are correct only for the average T_h and average T_c observed during the series of readings taken in the temperature cycling experiment and not necessarily 1090°F and 520°F, respectively. In P-type PbSnMnTe, for example, $\frac{\partial E}{\partial T_c}$ and $\frac{\partial R}{\partial T_c}$ vary by -0.38% and +0.24% per degree change in T_h , respectively, while $\frac{\partial E}{\partial T_h}$ and $\frac{\partial R}{\partial T_h}$ vary by +0.24% and +0.18% per degree change in T_c , respectively. Eqs (1) and (2) do not compensate for this variation. Furthermore, this normalization scheme does not provide any procedure for adjustment to be made to compensate for gradual changes in leg properties with time, short of repetition of the time-consuming temperature cycling experiment which could adversely effect the outcome of the life test.

In view of the above-mentioned shortcomings, an improved procedure was adopted which is applicable over large ranges of junction temperature deviations and which largely compensates for possible changes in thermoelectric characteristics with time. The method is illustrated for the example of normalization of the Seebeck voltage. The Seebeck coefficient of a thermoelectric leg at beginning of life is shown by the upper curve in Figure 3-4. This parameter has been measured repeatedly and can be expressed as a function of temperature by a power series

$$S = S_0 + S_1 T + S_2 T^2 + \dots + S_N T^N \quad (3)$$

Figure 3-4. Typical Seebeck Coefficient Versus Temperature for Two Times

where the coefficients $S_0, S_1, \dots, S_N$ are evaluated by the method of least squares. The Seebeck voltage which would be developed by such a leg between junction temperatures T_h and T_c is obtained by integration term by term.

$$E_{(T_h - T_c)} = S_0 (T_h - T_c) + \frac{S_1 (T_h^2 - T_c^2)}{2} + \dots + \frac{S_N (T_h^{N+1} - T_c^{N+1})}{N+1} \quad (4)$$

Assume that at some later time, the Seebeck coefficient has shifted as shown by the lower curve of Figure 3-4, such that a measured Seebeck voltage between T_h and T_c is given by the area ABCD. We wish to normalize this to $T_h = 1090$ and $T_c = 520$, or $E_{\text{NORM}} = \text{EFGH}$. To do this, we must subtract the sum of areas ABFE and HGCD. This sum is estimated by adjusting the sum of areas AIJE and HKLD by the ratio of observed to theoretical Seebeck voltages $\frac{\text{ABCD}}{\text{AILD}}$.

Or, mathematically:

$$E_{\text{NORM}} = E_{\text{MEAS}} - \left[\int_{T_c}^{520} SdT + \int_{1090}^{T_h} SdT \right] \frac{E_{\text{MEAS}}}{\int_{T_c}^{T_h} SdT} \quad (5)$$

$$E_{\text{NORM}} = E_{\text{MEAS}} \left[1 - \frac{\int_{T_c}^{T_h} SdT - \int_{520}^{1090} SdT}{\int_{T_c}^{T_h} SdT} \right] \quad (6)$$

$$E_{\text{NORM}} = E_{\text{MEAS}} \frac{\int_{520}^{1090} SdT}{\int_{T_c}^{T_h} SdT} \quad (7)$$

Similarly, it follows that for the thermal conductances

$$\left(Q \frac{L}{A} \right)_{\text{NORM}} = \left(Q \frac{L}{A} \right)_{\text{MEAS}} \times \frac{\int_{520}^{1090} KdT}{\int_{T_c}^{T_h} KdT} \quad (8)$$

) and for the resistance

$$R_{\text{NORM}} = R_{\text{MEAS}} \times \frac{\int_{520}^{1090} K \rho dT \int_{T_c}^{T_h} K dT}{\int_{520}^{1090} K dT \int_{T_c}^{T_h} K \rho dT} \quad (9)$$

Thus, for all three thermoelectric performance parameters, E , $Q \frac{L}{A}$, and R , a multiplicative correction factor F can be determined which is function of both T_h and T_c . The data reduction program "TELPs 7" Section 4 has utilized this normalization scheme. Tables of F have been included in this section for reference and for manual normalization purposes. Normalized values of matched load power and efficiency can be calculated, utilizing the normalized values of E , R , and $Q \frac{L}{A}$.

These factors are intended for use in normalizing leg performance data when contact resistance is negligible. This method can be extended to apply to couples or modules having a finite extraneous resistance. If the fraction α of the total measured resistance which is due to temperature-independent extraneous factors can be estimated a corrected value of F for resistance normalization is given by

$$F_{\text{CORRECTED}} = \left[F - \alpha (F - 1) \right]$$

In an ingradient leg performance test in which the extraneous resistance is suspected of being a significant portion, α can be determined experimentally by making two resistance measurements at different sets of junction temperatures (designated by subscripts 1 and 2) and comparing their normalized values.

$$R_1 \left[F_1 - \alpha (F_1 - 1) \right] = R_2 \left[F_2 - \alpha (F_2 - 1) \right]$$

Solving for α given

$$\alpha = \frac{R_1 F_1 - R_2 F_2}{R_1 (F_1 - 1) - R_2 (F_2 - 1)}$$

Example:

A pair of measurements yielded the following data:

$$1) \quad T_h = 1070^\circ\text{F}, \quad T_c = 500^\circ\text{F}, \quad R_{\text{MEASURED}} = 12.45 \text{ m}\Omega$$

$$2) \quad T_h = 1110^\circ\text{F}, \quad T_c = 540^\circ\text{F}, \quad R_{\text{MEASURED}} = 13.55 \text{ m}\Omega$$

From the Tables on the following pages, $F_1 = 1.048$ and $F_2 = 0.956$

Thus,

$$\alpha = \frac{12.45 \times 1.048 - 13.55 \times 0.956}{12.45 \times 0.048 - 13.55 \times (-0.044)} = \frac{0.0916}{1.194}$$

$$\alpha = 0.0767$$

or 7.67% of the normalized resistance is independent of temperature.

SEEBECK VOLTAGE NORMALIZATION FACTOR FOR TH=1090 AND TC=520
DEGS F FOR P-TYPE P3SNMTE TYPE TPM-206

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	490	495	500	505	510	515	520
1060	1.021	1.028	1.034	1.041	1.048	1.055	1.062
1065	1.011	1.017	1.024	1.03	1.037	1.044	1.051
1070	1.001	1.007	1.014	1.02	1.027	1.034	1.041
1075	.991	.997	1.004	1.01	1.017	1.023	1.03
1080	.982	.988	.994	1.	1.007	1.013	1.02
1085	.973	.978	.984	.991	.997	1.003	1.01
1090	.963	.969	.975	.981	.987	.994	1.
1095	.955	.96	.966	.972	.978	.984	.99
1100	.946	.951	.957	.963	.969	.975	.981
1105	.937	.943	.948	.954	.96	.966	.972
1110	.929	.934	.94	.945	.951	.957	.963
1115	.921	.926	.931	.937	.942	.948	.954
1120	.912	.918	.923	.928	.934	.939	.945

SEEBECK VOLTAGE NORMALIZATION FACTOR FOR TH=1090 AND TC=520
DEGS F FOR P-TYPE P3SNMTE TYPE TPM-206

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	525	530	535	540	545	550	555
1060	1.07	1.077	1.085	1.093	1.101	1.109	1.118
1065	1.059	1.066	1.073	1.081	1.089	1.097	1.106
1070	1.048	1.055	1.062	1.07	1.078	1.086	1.094
1075	1.037	1.044	1.051	1.059	1.066	1.074	1.082
1080	1.027	1.034	1.041	1.048	1.056	1.063	1.071
1085	1.017	1.023	1.03	1.037	1.045	1.052	1.06
1090	1.007	1.013	1.02	1.027	1.034	1.042	1.049
1095	.997	1.003	1.01	1.017	1.024	1.031	1.038
1100	.987	.994	1.	1.007	1.014	1.021	1.028
1105	.978	.984	.991	.997	1.004	1.011	1.018
1110	.969	.975	.981	.988	.994	1.001	1.008
1115	.96	.966	.972	.978	.985	.992	.998
1120	.951	.957	.963	.969	.976	.982	.989

Note: These tables were generated by "NORMAL" - Section 4, Paragraph 4.1.5.

RESISTANCE NORMALIZATION FACTOR FOR TH=1090 AND TC=520
FOR N-TYPE PBTE TYPE TPM-211.

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	490	495	500	505	510	515	520
1060	1.074	1.068	1.062	1.056	1.05	1.044	1.039
1065	1.067	1.061	1.055	1.049	1.043	1.038	1.032
1070	1.06	1.054	1.048	1.042	1.037	1.031	1.026
1075	1.053	1.047	1.041	1.036	1.03	1.025	1.019
1080	1.046	1.04	1.035	1.029	1.024	1.018	1.013
1085	1.039	1.033	1.028	1.022	1.017	1.012	1.006
1090	1.032	1.027	1.021	1.016	1.011	1.005	1.
1095	1.026	1.02	1.015	1.01	1.004	.999	.994
1100	1.019	1.014	1.009	1.003	.998	.993	.988
1105	1.013	1.008	1.002	.997	.992	.987	.982
1110	1.007	1.001	.996	.991	.986	.981	.976
1115	1.	.995	.99	.985	.98	.975	.97
1120	.994	.989	.984	.979	.974	.969	.964

RESISTANCE NORMALIZATION FACTOR FOR TH=1090 AND TC=520
FOR N-TYPE PBTE TYPE TPM-211.

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	525	530	535	540	545	550	555
1060	1.033	1.028	1.022	1.016	1.011	1.006	1.
1065	1.027	1.021	1.016	1.01	1.005	.999	.994
1070	1.02	1.015	1.009	1.004	.998	.993	.988
1075	1.014	1.008	1.003	.998	.992	.987	.982
1080	1.007	1.002	.997	.991	.986	.981	.976
1085	1.001	.996	.99	.985	.98	.975	.97
1090	.995	.99	.984	.979	.974	.969	.964
1095	.989	.983	.978	.973	.968	.963	.958
1100	.983	.977	.972	.967	.962	.958	.953
1105	.977	.972	.967	.962	.957	.952	.947
1110	.971	.966	.961	.956	.951	.946	.941
1115	.965	.96	.955	.95	.945	.941	.936
1120	.959	.954	.949	.945	.94	.935	.931

THERMAL CONDUCTANCE NORMALIZATION FACTOR FOR TH=1090 AND TC=520 DEGS F
FOR N-TYPE PATE TYPE TPM-211.

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	490	495	500	505	510	515	520
1060	1.005	1.015	1.025	1.036	1.046	1.056	1.067
1065	.995	1.005	1.015	1.025	1.035	1.045	1.056
1070	.985	.994	1.004	1.014	1.024	1.034	1.044
1075	.975	.984	.994	1.003	1.013	1.023	1.033
1080	.965	.974	.983	.993	1.002	1.012	1.022
1085	.955	.964	.973	.982	.992	1.001	1.011
1090	.946	.954	.963	.972	.981	.991	1.
1095	.936	.945	.953	.962	.971	.98	.989
1100	.927	.935	.944	.952	.961	.97	.979
1105	.917	.926	.934	.942	.951	.96	.968
1110	.908	.916	.924	.933	.941	.949	.958
1115	.899	.907	.915	.923	.931	.94	.946
1120	.89	.898	.906	.913	.922	.93	.933

THERMAL CONDUCTANCE NORMALIZATION FACTOR FOR TH=1090 AND TC=520 DEGS F
FOR N-TYPE PATE TYPE TPM-211.

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	525	530	535	540	545	550	555
1060	1.078	1.089	1.1	1.111	1.123	1.135	1.147
1065	1.066	1.077	1.088	1.099	1.11	1.122	1.133
1070	1.055	1.065	1.076	1.087	1.098	1.109	1.12
1075	1.043	1.053	1.064	1.074	1.085	1.096	1.107
1080	1.032	1.042	1.052	1.062	1.073	1.084	1.094
1085	1.021	1.03	1.04	1.05	1.061	1.071	1.082
1090	1.01	1.019	1.029	1.039	1.049	1.059	1.069
1095	.999	1.008	1.018	1.027	1.037	1.047	1.057
1100	.988	.997	1.006	1.016	1.026	1.035	1.045
1105	.977	.986	.995	1.005	1.014	1.024	1.033
1110	.967	.976	.985	.994	1.003	1.012	1.022
1115	.957	.965	.974	.983	.992	1.001	1.01
1120	.946	.955	.963	.972	.981	.99	.999

SEEBECK VOLTAGE NORMALIZATION FACTOR FOR TH=1090 AND TC=520
DEGS F FOR N-TYPE P8TE TYPE TPM 211.

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	490	495	500	505	510	515	520
1060	1.014	1.021	1.028	1.036	1.044	1.051	1.059
1065	1.004	1.011	1.019	1.026	1.033	1.041	1.049
1070	.995	1.002	1.009	1.016	1.024	1.031	1.039
1075	.986	.992	.999	1.007	1.014	1.021	1.029
1080	.977	.983	.99	.997	1.004	1.012	1.019
1085	.968	.974	.981	.988	.995	1.002	1.009
1090	.959	.966	.972	.979	.986	.993	1.
1095	.951	.957	.964	.97	.977	.984	.991
1100	.942	.949	.955	.961	.968	.975	.982
1105	.934	.94	.947	.953	.959	.966	.973
1110	.926	.932	.938	.945	.951	.958	.964
1115	.918	.924	.93	.936	.943	.949	.956
1120	.911	.916	.922	.928	.935	.941	.947

SEEBECK VOLTAGE NORMALIZATION FACTOR FOR TH=1090 AND TC=520
DEGS F FOR N-TYPE P8TE TYPE TPM 211.

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	525	530	535	540	545	550	555
1060	1.068	1.076	1.085	1.093	1.102	1.111	1.121
1065	1.057	1.065	1.074	1.082	1.091	1.1	1.109
1070	1.047	1.055	1.063	1.071	1.08	1.089	1.098
1075	1.037	1.044	1.052	1.061	1.069	1.078	1.086
1080	1.027	1.034	1.042	1.05	1.058	1.067	1.075
1085	1.017	1.024	1.032	1.04	1.048	1.056	1.065
1090	1.007	1.015	1.022	1.03	1.038	1.046	1.054
1095	.998	1.005	1.013	1.02	1.028	1.036	1.044
1100	.989	.996	1.003	1.011	1.018	1.026	1.034
1105	.98	.987	.994	1.001	1.009	1.016	1.024
1110	.971	.978	.985	.992	.999	1.007	1.015
1115	.962	.969	.976	.983	.99	.998	1.005
1120	.954	.961	.967	.974	.981	.989	.996

RESISTANCE NORMALIZATION FACTOR FOR TH=1090 AND TC=520
FOR P-TYPE PBSNMNTE TYPE TPM-206.

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	490	495	500	505	510	515	520
1060	1.05	1.046	1.042	1.037	1.033	1.029	1.024
1065	1.046	1.042	1.037	1.033	1.029	1.024	1.02
1070	1.042	1.037	1.033	1.029	1.024	1.02	1.016
1075	1.037	1.033	1.029	1.024	1.02	1.016	1.012
1080	1.033	1.029	1.024	1.02	1.016	1.012	1.008
1085	1.029	1.024	1.02	1.016	1.012	1.008	1.004
1090	1.024	1.02	1.016	1.012	1.008	1.004	1.
1095	1.02	1.016	1.012	1.008	1.004	1.	.996
1100	1.016	1.012	1.008	1.004	1.	.996	.992
1105	1.012	1.008	1.004	1.	.996	.992	.989
1110	1.008	1.004	1.	.996	.993	.989	.985
1115	1.004	1.	.997	.993	.989	.985	.981
1120	1.001	.997	.993	.989	.985	.981	.978

RESISTANCE NORMALIZATION FACTOR FOR TH=1090 AND TC=520
FOR P-TYPE PBSNMNTE TYPE TPM-206.

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	525	530	535	540	545	550	555
1060	1.02	1.016	1.012	1.008	1.004	1.	.995
1065	1.016	1.012	1.008	1.004	1.	.996	.992
1070	1.012	1.008	1.004	1.	.996	.992	.988
1075	1.008	1.004	1.	.996	.992	.988	.984
1080	1.004	1.	.996	.992	.988	.984	.98
1085	1.	.996	.992	.988	.984	.98	.976
1090	.996	.992	.988	.984	.98	.977	.973
1095	.992	.988	.984	.981	.977	.973	.969
1100	.988	.985	.981	.977	.973	.969	.966
1105	.985	.981	.977	.973	.97	.966	.962
1110	.981	.977	.973	.97	.966	.962	.959
1115	.977	.974	.97	.966	.963	.959	.955
1120	.974	.97	.966	.963	.959	.956	.952

THERMAL CONDUCTANCE NORMALIZATION FACTOR FOR TH=1090 AND TC=520 DEGS F
FOR P-TYPE PBSNMNTE TYPE TPM-206.

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	490	495	500	505	510	515	520
1060	1.012	1.021	1.03	1.04	1.05	1.06	1.07
1065	1.001	1.01	1.019	1.029	1.038	1.048	1.058
1070	.99	.999	1.008	1.017	1.027	1.036	1.046
1075	.98	.988	.997	1.006	1.015	1.025	1.034
1080	.969	.978	.987	.995	1.004	1.013	1.023
1085	.959	.967	.976	.985	.993	1.002	1.011
1090	.949	.957	.965	.974	.982	.991	1.
1095	.939	.947	.955	.963	.972	.98	.989
1100	.929	.937	.945	.953	.961	.97	.978
1105	.919	.927	.935	.943	.951	.959	.967
1110	.91	.917	.925	.933	.94	.948	.956
1115	.9	.907	.915	.923	.93	.938	.946
1120	.891	.898	.905	.913	.92	.928	.935

THERMAL CONDUCTANCE NORMALIZATION FACTOR FOR TH=1090 AND TC=520 DEGS F
FOR P-TYPE PBSNMNTE TYPE TPM-206.

TSUBH	C O L D J U N C T I O N T E M P E R A T U R E S						
	525	530	535	540	545	550	555
1060	1.08	1.09	1.101	1.112	1.123	1.134	1.145
1065	1.068	1.078	1.088	1.099	1.109	1.12	1.131
1070	1.056	1.066	1.076	1.086	1.096	1.107	1.118
1075	1.044	1.053	1.063	1.073	1.084	1.094	1.104
1080	1.032	1.041	1.051	1.061	1.071	1.081	1.091
1085	1.02	1.03	1.039	1.049	1.058	1.068	1.078
1090	1.009	1.018	1.027	1.037	1.046	1.056	1.065
1095	.998	1.007	1.016	1.025	1.034	1.043	1.053
1100	.986	.995	1.004	1.013	1.022	1.031	1.04
1105	.975	.984	.993	1.001	1.01	1.019	1.028
1110	.965	.973	.981	.99	.999	1.007	1.016
1115	.954	.962	.97	.979	.987	.996	1.004
1120	.943	.951	.959	.967	.976	.984	.993

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VOLUME 2, SECTION 4
COMPUTER PROGRAMS

The following computer programs were used in the reduction and analysis of TELPS data. Each listing is preceded by a discussion of how it may be used. This listing does not include preliminary programs which were superseded by improved versions.

EXPLANATORY NOTES

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4. COMPUTER PROGRAMS

EXPLANATORY NOTES

LANGUAGE: BASIC

4.1 PROGRAM: SKRHO 1

LENGTH: 3000 CHAR.

This program reduces the data obtained during simultaneous operation of Fixtures 23 and 24 for the purpose of obtaining the thermoelectric properties: S, K, ρ , ZT, and EPS as point functions of temperature. The raw data tape from the data acquisition system is edited by means of a control tape to give the following data input format:

```

500  DATA    108, +046976,
501  DATA    111, +007977, 112, -007807, 113, +000467, 114,
      +013477, 115, -036307,
502  DATA    116, -021577, 117, -021407, 118, +000047, 119,
      +000787, 120, -026067,
503  DATA    108, +047006,
504  DATA    111, +007977, 112, . . . . . etc. for all additional readings:
  
```

CHANNEL IDENTIFICATION

	I	T_h	T_c	E_q	E_s	V
Conduc- tivity	mv. across 50 mv 2_A shunt	mv	mv	mv	mv	mv
P	108	111	112	113	114	115
N	108	116	117	118	119	120

In addition, sample description is entered as:

```

2  DATA    (Sample Number), (Length), (Diameter)
  
```

The output is formatted to facilitate direct paper tape input to the SKRHO 2 curve fit routine.

SKRH01

```
2 DATA 10260123,.4,.250,9111123,.123,.123
4 READ N,L,D,Q,Q,Q
6 DEF FNC(Y)=(ABS(Y)/Y)*INT(.1*ABS(Y))*10+(-(ABS(Y)-10*INT(.1*ABS(Y)))-4))
8 DEF FNT(Y)=F(0)+F(1)*Y+F(2)*Y^2+F(3)*Y^3+F(4)*Y^4+F(5)*Y^5
10 DEF FNN(Y)=.0001*INT(10000*Y+.5)
12 DIM A(1,2),F(5),H(1,2),C(1,2),B(38,2),X(39,10),Y(39,5)
14 LET Z=5
16 LET G=4
18 MAT READ F(5),A(1,2),H(1,2),C(1,2)
20 DATA 32.0432,35.7115,-.385149,2.02802 E-2,-4.61086 E-4,3.46189 E-6
22 DATA 2.46245 E-2,5.09814,-.592593,7.84652 E-3,3.56545,-.393462
24 DATA 3.81926,-.353417,2.39280 E-3,-.260272,-7.72102 E-2,-2.34209 E-3
26 DATA 1.29492,-.254517,-2.29292 E-3,1.72302,-.331263,-1.82750 E-3
28 LET M=INT(N/1000000)
30 PRINT "THERMOELECTRIC PROPERTIES OF LOT" M "BATCH";
32 PRINT (INT(INT((N-1000000*M)/10000)));
34 IF (INT(N/1000)-10*INT(N/10000))=1 THEN 40
36 PRINT "A      SAMPLE";
38 GO TO 42
40 PRINT "B      SAMPLE";
42 PRINT (N-1000*INT(N/1000))
44 PRINT
46 PRINT " TAG      TEMP      S      K      RH0      ZT";
48 PRINT "      EPS"
50 PRINT "      DEG F      MIC V/F      MW/IN F      MICOHMIN      --";
52 PRINT "      ---"
54 PRINT
56 LET M=10-M
58 FOR J=1 TO 99 STEP 2
60 READ L(0),X(J,0)
62 IF L(0)=0 THEN 80
64 FOR K=1 TO 10
66 READ L(K),X(J,K)
68 NEXT K
70 LET Y(J,0)=FNC(X(J,0))
72 FOR K=1 TO 5
74 LET Y(J,K)=FNC(X(J,K+5*M))
76 NEXT K
78 NEXT J
80 FOR W=1 TO Z STEP 2
82 LET X(W,1)=FNT(Y(W,1)+3.41403)+H(M,0)+H(M,1)*Y(W,1)+H(M,2)*Y(W,1)^2
84 LET X(W,2)=FNT(Y(W,2)+3.41403)+C(M,0)+C(M,1)*Y(W,2)+C(M,2)*Y(W,2)^2
86 LET X(W,3)=A(M,0)+A(M,1)*Y(W,3)+A(M,2)*Y(W,3)^2
88 LET X(W,4)=Y(W,4)
90 LET X(W,5)=1.17847*25*X(W,3)*(Y(W,4)-Y(W,5))/Y(W,0)
92 LET X(W,3)=1.2732395*L*X(W,3)/D^2
94 IF W<3 THEN 146
96 LET X(W-1,1)=.5*(X(W,1)+X(W-2,1))
98 LET X(W-1,2)=.5*(X(W,2)+X(W-2,2))
100 LET U=(X(W,2)-X(W-2,2))/(X(W,1)-X(W-2,1))
```

```

102 FOR I=0 TO 2
104 LET P(I)=(X(W,I+3)-X(W-2,I+3))/(X(W,I)-X(W-2,I))
106 NEXT I
108 IF Z>5 THEN 122
110 FOR I=0 TO 2
112 LET B(W-1,I)=P(I)/(1-U)
114 NEXT I
116 IF W=3 THEN 146
118 LET Z=J-2
120 GOTO 80
122 IF X(W-1,2)<X(G,1) THEN 126
124 LET G=G+2
126 FOR I=0 TO 2
128 LET R=(X(G-2,1)-X(W-1,2))/(X(G,1)-X(G-2,1))
130 LET S(I)=B(G-2,I)-(B(G,I)-B(G-2,I))*R
132 LET B(W-1,I)=P(I)+S(I)*U
134 NEXT I
136 PRINT 500+(W-1)/2"DATA"X(W-1,1),"1000*(1-2*M)*B(W-1,1)",",",
138 PRINT 1000*B(W-1,0),"1000*B(W-1,2)/B(W-1,0)",",",
140 LET F=.001*(B(W-1,1)+2)*(X(W-1,1)+460)/B(W-1,2)
142 LET E=(SQR(1+F)-1)/(SQR(1+F)+1)
144 PRINT FNN(F),"FNN(E)
146 NEXT W
148 PRINT
150 PRINT 500"DATA"N","(W-1)/2","3
152 IF M=1 THEN 999
154 FOR J=0 TO 40
156 PRINT
158 NEXT J
160 RESTORE
162 READ N,L,D,N,L,D
164 GO TO 14
998 DATA 0,0
999 END

```

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EXPLANATORY NOTES

LANGUAGE: BASIC

4.2 PROGRAM: SKRHO 2

LENGTH: 3600 CHAR.

SKRHO 2 consists of a third order least squares polynomial curve fit to the Seebeck coefficient, thermal conductivity and the $K \cdot RHO$ product versus temperature in degrees F. The input data tape is received from SKRHO 1 and entered beginning at data line 500. The polynomial coefficients for each parameter for both the N and P type sample being processed are punched on paper tape to be used as an input to SKRHO 3.

SKRH02

```
2 READ D,M,N
4 PRINT "LEAST SQUARES POLYNOMIAL CURVE FITS TO THE SEEBECK";
6 PRINT " COEFFICIENT, THERMAL"
8 PRINT "CONDUCTIVITY, AND THE K*RHO PRODUCT VS TEMPERATURE IN DEGS F."
9 PRINT
10 PRINT
11 PRINT
12 DIM A(15),B(15),S(15),G(15),U(15,4)
14 DIM C(40),P(40),Q(40),X(40),Y(40),Z(40,4)
16 FOR I=1 TO M
18 READ X(I),Z(I,0),Z(I,1),Z(I,2),Z(I,3),Z(I,4)
20 LET Z(I,2)=Z(I,2)*Z(I,1)*.001
22 NEXT I
24 FOR G=0 TO 2
26 LET Z=0
28 LET Q=1
30 LET K=12
32 LET N=N+1
34 LET T7=Z
36 LET T8=Z
38 LET W7=Z
40 FOR I=1 TO M
42 LET W7=W7+X(I)
44 LET T7=T7+Z(I,G)
46 LET T8=T8+Z(I,G)*2
48 NEXT I
50 LET T9=(M*T8-T7*2)/(M*2-M)
52 IF G=1 THEN 60
54 IF G=2 THEN 64
56 PRINT "SEEBECK COEFFICIENT OF SAMPLE"D
58 GO TO 66
60 PRINT "THERMAL CONDUCTIVITY OF SAMPLE"D
62 GO TO 66
64 PRINT"K*RHO PRODUCT OF SAMPLE"D
66 PRINT
70 PRINT "          NUMBER OF POINTS =" ;M
72 PRINT "          MEAN VALUE OF X =" ;W7/M
74 PRINT "          MEAN VALUE OF Y =" ;T7/M
76 PRINT "          STD ERROR OF Y =" ;SQR(T9)
82 FOR I=1 TO M
84 LET P(I) = Z
86 LET Q(I)=0
88 NEXT I
90 FOR I = 1 TO 11
92 LET A(I) = Z
94 LET B(I) = Z
96 LET S(I) = Z
98 NEXT I
100 LET E1=Z
102 LET F1=Z
104 LET W1=M
106 LET N4=K
108 LET I=1
```

```

110 LET K1=2
112 IF N=0 THEN 116
114 LET K1=N4
116 LET W=Z
118 FOR L=1 TO M
120 LET W=W+Z(L,G)+Q(L)
122 NEXT L
124 LET S(I)=W/W1
126 IF I-N4>=0 THEN 164
128 LET E1=Z
130 FOR L=1 TO M
132 LET E1=E1+X(L)*Q(L)*Q(L)
134 NEXT L
136 LET E1=E1/W1
138 LET A(I+1)=E1
140 LET W=Z
142 FOR L=1 TO M
144 LET V=(X(L)-E1)*Q(L)-F1*P(L)
146 LET P(L)=Q(L)
148 LET Q(L)=V
150 LET W=W+V*V
152 NEXT L
154 LET F1= W/W1
156 LET B(I+2)=F1
158 LET W1=W
160 LET I=I+1
162 GOTO 116
164 FOR L=2 TO 11
166 LET G(L)=Z
168 NEXT L
170 LET G(1)=0
172 FOR J=1 TO N
174 LET S1 =Z
176 FOR L=1 TO N
178 IF L=1 THEN 182
180 LET G(L)=G(L)-A(L)*G(L-1)-B(L)*G(L-2)
182 LET S1=S1+S(L)*G(L)
184 NEXT L
186 LET U(J,G)=S1
188 LET L=N
190 FOR I2=2 TO N
192 LET G(L)=G(L-1)
194 LET L=L-1
196 NEXT I2
198 LET G(1)=Z
200 NEXT J
202 PRINT
204 LET T=Z
206 FOR L=1 TO M
208 LET C(L)=Z
210 LET J=N
212 FOR I2=1 TO N
214 LET C(L)=C(L)+X(L)+U(J,G)
216 LET J=J-1
218 NEXT I2
220 LET T3=Z(L,G)-C(L)
222 LET T=T+T3*2

```

```

224 NEXT L
226 IF M<>N THEN 232
228 LET T5=0
230 GOTO 234
232 LET T5=T/(M-N)
234 LET Q7=1-(T5/T9)
236 PRINT
238 PRINT "POLYFIT OF DEGREE"N-1;
240 PRINT "INDEX OF DETERMINATION ="Q7
242 PRINT
244 PRINT "TERM","COEFFICIENT"
246 FOR J=1 TO N
248 LET I2=J-1
250 PRINT I2,U(J,G)
252 NEXT J
254 PRINT
256 PRINT "X-ACTUAL","Y-ACTUAL","Y-CALC","DIFF","PCT-DIFF"
258 PRINT
260 FOR L=1 TO M
262 LET Q8=Z(L,G)-C(L)
264 PRINT X(L),Z(L,G),C(L),Q8,
266 IF C(L)=0 THEN 272
268 PRINT 100*Q8/C(L)
270 GOTO 274
272 PRINT "INFINITE"
274 NEXT L
276 PRINT
278 PRINT "          STD ERROR OF ESTIMATE FOR Y ="SQRT(T5)
280 FOR J=1 TO 50-(N+M)
282 PRINT
284 NEXT J
286 LET N=N-1
288 NEXT G
290 PRINT
292 PRINT "O=NO  I=YES  IS PUNCH ON";
294 INPUT F
296 IF F=0 THEN 294
298 PRINT "DATA"D","
300 FOR G=0 TO 2
302 PRINT "DATA"; U(1,G);","U(2,G);","U(3,G);","U(4,G)
304 NEXT G
9999 END

```

EXPLANATORY NOTES

4.3 PROGRAM: SKRHO 3

LANGUAGE: BASIC

LENGTH: 6200 CHAR.
(Includes data for
16 samples)

The purpose of SKRHO 3 is to conveniently summarize the thermoelectric properties of either N or P type material based on measurements made on a given number of SNAP-27 legs. Data is input as follows:

500 DATA (Sample No.), (S_0), (S_1), (S_2), (S_3)

501 DATA (K_0), (K_1), (K_2), (K_3)

502 DATA ($K\rho_0$), ($K\rho_1$), ($K\rho_2$), ($K\rho_3$)

. . . etc.

In addition to regenerating values of each parameter for each sample at convenient 100°F intervals, a statistical summary including mean, variance, standard deviations and $\pm 3\sigma$ limits is given.

SKRH03

```
1 DIM U(40,12),S(1,12),N(100)
2 DEF FNB(Z)=.1*INT(10*Z+.5)
3 DEF FNC(Z)=.01*INT(100*Z+.5)
4 DEF FNN(Z)=.0001*INT(10000*Z+.5)
5 DEF FNV(Z)=.01*INT(100000000*Z+.5)
6 FOR I=1 TO 100
7 READ N(I)
8 IF N(I)=0 THEN 13
9 FOR J=1 TO 12
10 READ U(I,J)
11 NEXT J
12 NEXT I
13 LET N=N-1
14 IF U(1,1)>0 THEN 17
15 PRINT "SUMMARY OF THERMOELECTRIC PROPERTIES OF TYPE 2N PBTE BASED ON"
16 GO TO 19
17 PRINT "SUMMARY OF THERMOELECTRIC PROPERTIES OF TYPE 3P PBSNTE BASED";
18 PRINT " ON"
19 PRINT "MEASUREMENTS MADE ON THE FOLLOWING" N " SNAP-27 T/E LEGS:"
20 PRINT
21 FOR T=75 TO 1300 STEP 100
22 GOSUB 74
23 PRINT
24 MAT S=ZER(1,5)
25 FOR I=1 TO N
26 MAT X=ZER(5)
27 FOR J=1 TO 4
28 LET X(0)=X(0)+U(I,J)*T*(J-1)
29 LET X(1)=X(1)+U(I,J+4)*T*(J-1)
30 LET X(2)=X(2)+U(I,J+8)*T*(J-1)
31 NEXT J
32 LET X(3)=1000*X(2)/X(1)
33 LET X(4)=.000001*(X(0)+2)*(T+460)/X(2)
34 LET X(5)=(SQR(1+X(4))-1)/(SQR(1+X(4))+1)
35 PRINT T;" ";FNC(X(0));" ";FNC(X(1));" ";FNB(X(3));" ";FNN(X(4));" ";
36 PRINT FNN(X(5)),N(I)
37 FOR P=0 TO 5
38 LET S(0,P)=S(0,P)+X(P)
39 LET S(1,P)=S(1,P)+X(P)*X(P)
40 NEXT P
41 NEXT I
42 FOR P=0 TO 5
43 IF P=2 THEN 48
44 LET A(P)=S(0,P)/N
45 LET V(P)=(S(1,P)-A(P)*S(0,P))/N
46 LET W(P)=V(P)*N/(N-1)
47 LET D(P)=SQR(W(P))
48 NEXT P
49 PRINT
50 PRINT T;" ";FNC(A(0));" ";FNC(A(1));" ";FNB(A(3));" ";FNN(A(4));" ";
51 PRINT FNN(A(5));" "," MEAN"
52 PRINT T;" ";FNC(W(0));" ";FNC(W(1));" ";FNB(W(3));
53 PRINT FNV(W(4));"E-6";FNV(W(5));"E-6 EST TRU VAR"
54 PRINT T;" ";FNC(D(0));" ";FNC(D(1));" ";FNB(D(3));" ";FNN(D(4));" ";
55 PRINT FNN(D(5));" "," STD DEV"
```

```

56 PRINT T;" "FNC(A(0)+3*D(0))" "FNC(A(1)+3*D(1))" "
57 PRINT FNC(A(3)+3*D(3))" "FNC(A(4)+3*D(4))" "FNC(A(5)+3*D(5))" "
58 PRINT " MEAN+3 SIGMA"
59 PRINT T;" "FNC(A(0)-3*D(0))" "FNC(A(1)-3*D(1))" "
60 PRINT FNC(A(3)-3*D(3))" "FNC(A(4)-3*D(4))" "FNC(A(5)-3*D(5))" "
61 PRINT " MEAN-3 SIGMA"
62 PRINT
63 IF T=75 THEN 69
64 IF (T/200)-INT(T/200)=0 THEN 70
65 FOR I=1 TO 66-2*(N+10)
66 PRINT
67 NEXT I
68 IF T>75 THEN 70
69 LET T=T-75
70 NEXT T
71 PRINT
72 PRINT
73 GO TO 79
74 PRINT "TEMP          S          K          RH0          ZT          EPS",
75 PRINT " SAMPLE"
76 PRINT "DEG F  MIC V/F      MW/IN F      MICOHMIN      ---      ---",
77 PRINT " NUMBER"
78 RETURN
79 DATA 10071060,17.1519,8.60577 E-2,1.69493 E-4,-1.40733 E-7
80 DATA 24.3435,-8.35404 E-3,-2.60324 E-5,3.04013 E-8
81 DATA 8.09628,1.80464 E-2,-3.18220 E-5 ,4.58531 E-8
82 DATA 10071061,16.7789,8.11322 E-2,1.80558 E-4,-1.46542 E-7
83 DATA 18.2961,2.40534 E-2,-7.12696 E-5,4.87317 E-8
84 DATA 7.37302,1.80944 E-2,-1.71839 E-5,3.33671 E-8
85 DATA 10071062,16.8921,8.70222 E-2,1.68790E-4,-1.40799 E-7
86 DATA 21.5963,1.78947 E-2,-7.47130 E-5,5.72466 E-8
87 DATA 7.23016,3.04031 E-2,-5.59891 E-5,6.19998 E-8
88 DATA 10071063,10.1485,.120537,1.16769 E-4,-1.15903 E-7
89 DATA 34.9274,-4.64751 E-2,2.27355 E-5,1.07204 E-8
90 DATA 14.8936,-1.71939 E-2,3.22431 E-5,1.30021 E-8
91 DATA 10031960,18.2389,7.80322 E-2,1.86601 E-4,-1.49498 E-7
92 DATA 25.2627,-1.06721 E-2,-1.90790 E-5,2.42933 E-8
93 DATA 9.47033 ,5.28533 E-3,-1.80146 E-6,2.72828 E-8
94 DATA 10031961,16.5155,7.74343 E-2,1.76998 E-4,-1.38559 E-7
95 DATA 22.6886,1.31962 E-2,-6.97372 E-5,5.34322 E-8
96 DATA 5.32284,4.02314 E-2,-7.89542 E-5,7.21323 E-8
97 DATA 10031962,16.8895,8.23304 E-2,1.82513 E-4,-1.48746 E-7
98 DATA 26.2353,-1.17937 E-2,-2.36236 E-5,2.94158 E-8
99 DATA 8.71381,1.70539 E-2,-3.24235 E-5,4.57750 E-8
100 DATA 10031963,15.0205,9.15373 E-2,1.67104 E-4,-1.42619 E-7
101 DATA 23.3609,3.21675 E-3,-5.57851 E-5,4.84632 E-8
102 DATA 7.12053,3.04367 E-2,-6.39318 E-5,6.41712 E-8
103 DATA 10020955,15.8397 , 8.64756 E-2 , 1.57803 E-4 , -1.28498 E-7
104 DATA 20.3849 , 1.53441 E-2 , -5.39393 E-5 , 3.72107 E-8
105 DATA 7.85519 , .011194 , -5.54280 E-6 , 2.51350 E-8
106 DATA 10020955, 16.0722 , 9.69832 E-2 , 1.43360 E-4 , -1.24595 E-7
107 DATA 16.0666 , 2.69753 E-2 , -6.37823 E-5 , 3.97511 E-8
108 DATA 9.10997 , -1.48296 E-5 , 1.93027 E-5 , 1.14313 E-8
109 DATA 10020955, 15.3859 , 8.79195 E-2 , 1.52470 E-4 , -1.24572 E-7
110 DATA 20.1149 , 1.52903 E-2 , -4.96103 E-5 , 3.35903 E-8

```

111 DATA 7.63449 , 9.61308 E-3 , 5.22073 E-7 , 2.08686 E-8
 112 DATA 10020957,16.2248 , 7.29537 E-2 , 1.63936 E-4 , -1.23601 E-7
 113 DATA 21.3988 , 3.80555 E-3 , -3.00314 E-5 , 2.44213 E-8
 114 DATA 7.16515 , 1.00305 E-2 , -8.00248 E-6 , 2.61140 E-8
 115 DATA 10020958,16.7922 , 6.92511 E-2 , 1.85862 E-4 , -1.41173 E-7
 116 DATA 21.8663 , 1.85286 E-2 , -6.85396 E-5 , 4.80248 E-8
 117 DATA 6.80894 , 2.89072 E-2 , -4.65658 E-5 , 4.96242 E-8
 118 DATA 10020959,15.0405 , 9.85252 E-2 , 1.40207 E-4 , -1.23748 E-7
 119 DATA 18.8501 , 1.57607 E-2 , -4.78987 E-5 , 3.37982 E-8
 120 DATA 8.63348 , 4.07292 E-3 , 4.92461 E-6 , 2.04256 E-8
 121 DATA 10220060,17.3568 , 8.78943 E-2 , 1.77836 E-4 , -1.51500 E-7
 122 DATA 19.1062 , 3.23632 E-2 , -9.48640 E-5 , 6.31101 E-8
 123 DATA 7.61871 , 1.88763 E-2 , -2.36877 E-5 , 3.85320 E-8
 124 DATA 10220061,17.2191 , 8.00868 E-2 , 1.72346 E-4 , -1.35924 E-7
 125 DATA 22.41 , 1.88725 E-2 , -7.47472 E-5 , 5.42758 E-8
 126 DATA 5.5083 , 3.98748 E-2 , -7.35017 E-5 , 6.97711 E-8
 127 DATA 10220062,17.3064 , 9.25376 E-2 , 1.66930 E-4 , -1.44290 E-7
 128 DATA 23.1784 , 2.61737 E-3 , -5.50515 E-5 , 4.75426 E-8
 129 DATA 8.674 , 2.07154 E-2 , -4.17572 E-5 , 5.01558 E-8
 130 DATA 10220063,17.1905 , 8.97808 E-2 , 1.75565 E-4 , -1.50019 E-7
 131 DATA 17.623 , 4.05357 E-2 , -1.12145 E-4 , 7.48568 E-8
 132 DATA 6.36914,3.16856 E-2,-5.31859 E-5,5.81215 E-8
 998 DATA 0,
 999 END

EXPLANATORY NOTES

LANGUAGE: BASIC

4.4 PROGRAM: SKRHO 4

LENGTH: 2400 CHAR.

This program summarizes the polynomial coefficients of the thermoelectric properties of either N or P type SNAP-27 legs. The output contains, first of all, the 0th, 1st, 2nd, and 3rd order terms for each sample, for the Seebeck coefficient, thermal conductivity, and the $K \cdot \rho$ product, giving a mean for each term. In addition, pseudo operational characteristics are calculated for typical Q.C. test conditions as well as SNAP-27 temperature gradient conditions. Data input format is identical with that of SKRHO 3.

SKRMB4

```
5 DIM U(40,12),S(1,12),N(100),T(3,4)
10 FOR I=1 TO 100
15 READ N(I)
20 IF N(I)=0 THEN 45
25 FOR J=1 TO 12
30 READ U(I,J)
35 NEXT J
40 NEXT I
45 LET N=N-I
50 IF U(1,1)>0 THEN 65
55 PRINT "SUMMARY OF INGRADIENT PROPERTIES OF TYPE 2N PBTE BASED ON"
60 GO TO 70
65 PRINT "SUMMARY OF INGRADIENT PROPERTIES OF TYPE 3P PBSNMNTE BASED ON"
70 PRINT "MEASUREMENTS MADE ON THE FOLLOWING" N " SNAP-27 T/E LEGS:"
75 PRINT
80 MAT S=ZER(1,12)
85 FOR K=1 TO 9 STEP 4
90 IF K=5 THEN 110
95 IF K=9 THEN 120
100 PRINT "COEFFICIENTS OF SEEBECK COEFFICIENT"
105 GO TO 125
110 PRINT "COEFFICIENTS OF THERMAL CONDUCTIVITY"
115 GO TO 125
120 PRINT "COEFFICIENTS OF K*RH0 PRODUCT"
125 PRINT
130 PRINT "SAMPLE","0TH ORDER","1ST ORDER","2ND ORDER","3RD ORDER"
135 PRINT "NUMBER","1ST TERM","2ND TERM","3RD TERM","4TH TERM"
140 PRINT
145 FOR I=1 TO N
150 PRINT N(I),
155 FOR J=K TO K+3
160 PRINT U(I,J),
165 LET S(0,J)=S(0,J)+U(I,J)
170 NEXT J
175 NEXT I
180 PRINT
185 PRINT "MEAN",
190 FOR J=K TO K+3
195 LET U(N+1,J)=S(0,J)/N
200 PRINT U(N+1,J),
205 NEXT J
210 PRINT
215 PRINT
220 NEXT K
225 MAT T=ZER(3,4)
230 FOR J=1 TO 4
235 LET T(1,J)=(675+J-75+J)/J
240 LET T(2,J)=(875+J-75+J)/J
245 LET T(3,J)=(1090+J-520+J)/J
250 NEXT J
255 PRINT "SAMPLE"," SEEBECK MV"," SEEBECK MV"," RA/L MOHMIN"
260 PRINT " QL/A W/IN "," PL/A W/IN"," EFFICIENCY"
265 PRINT "NUMBER"," REF DELTA T"," (1090-520)"," (1090-520)"
270 PRINT " (1090-520)"," (1090-520)"," (1090-520)"
```

```

275 PRINT
280 FOR I=1 TO N+1
285 MAT X=ZER(9)
290 FOR J=1 TO 4
295 FOR K=1 TO 3
300 LET X(K)=X(K)+U(I,J)*T(K,J)
305 NEXT K
310 LET X(4)=X(4)+U(I,J+4)*T(3,J)
315 LET X(5)=X(5)+U(I,J+8)*T(3,J)
320 NEXT J
325 LET X(9)=1000*X(5)/X(4)
330 LET X(6)=.00000025*X(3)*X(3)/X(9)
335 LET X(7)=SQR(1+ (.001265*X(3)*X(3))/(570*X(5)))
340 LET X(8)=(570/1550)*(X(7)-1)/(X(7)+980/1550)
345 IF I=N+1 THEN 365
350 PRINT N(I);.001*X(INT(.000001*N(I))-8);.001*X(3);X(9);.001*X(4);X(6);
355 PRINT X(8)
360 NEXT I
365 PRINT
370 PRINT " MEAN      ";.001*X(INT(.000001*N(I-1))-8);.001*X(3);X(9);
375 PRINT .001*X(4);X(6);X(8)
998 DATA 0
999 END

```


EXPLANATORY NOTES

LANGUAGE: BASIC

4.5 PROGRAM: TELPS 7

LENGTH: 3800 CHAR.

This program accepts raw data from ingradient tests via the data acquisition system. It then analyzes the data to calculate values of the dependent variables R and E for various values of the independent variables T_h and T_c . The analysis of the raw data is corrected for both geometry factor and lateral radiation heat loss. The calculated values are then included in the output which is normalized for resistance, voltage and power output to the nominal operating temperatures. Data input is as follows:

For Sample Identifications:

471 DATA (Operating Temperature), (Sample No.), (Total Elapsed Hours),
(Time at Beginning of Preceding Soak), (Time at End of Preceding
Soak, (Time at beginning of present performance)

472 DATA Continue for each succeeding sample in order of DAS scan.

Data for each scan is entered as follows, using the output tape from the DAS along with a control tape:

500 DATA (Time)

501 DATA (Channel), (T_h), (Channel), (T_c), (Channel), (I), (Channel),
(V), (Channel), (E)

502 DATA Repeat for each sample scanned.

TELP57

```

5 DEF FNR(Z)=(ABS(Z)/Z)*INT(.1*ABS(Z))*10+(-(ABS(Z)-10*INT(.1*ABS(Z))-4))
10 DEF FNC(Z)=2*INT(Z/2)-Z+1
15 DEF FNA(Z)=.01*INT(100*Z+.5)
20 DEF FNB(Z)=.1*INT(10*Z+.5)
25 DEF FND(Z)=INT(Z/10000)
30 DEF FNH(Z)=INT(Z/100)-100*INT(Z/10000)
35 DEF FNM(Z)=Z-100*INT(Z/100)
40 DIM C(2,24),H(2,24),S(24),F(5),T(24),A(24),E(1,3),Q(1,3),R(1,3)
45 DIM D(24),B(24),G(24),K(24)
50 MAT READ E(1,3),Q(1,3),R(1,3),F(5)
55 DATA 16.2258,8.70273 E-2,1.65841 E-4,-1.37293 E-7
60 DATA 46.6471,6.39145 E-2,1.18836 E-4,-1.01378 E-7
65 DATA 22.095,9.50997 E-3,-5.37841 E-5,4.21826 E-8
70 DATA 39.9441,-3.97937 E-2,-3.04405 E-6,2.46979 E-8
75 DATA 7.97766,1.76285 E-2,-2.65198 E-5,4.07646 E-8
80 DATA 1.95306,3.23819 E-2,-6.06917 E-5,6.17310 E-8
85 DATA 32.0432,35.7115,-.385149,2.02802 E-2,-4.61086 E-4,3.46189 E-6
90 FOR Y=1 TO 24
95 LET C(0,Y)=.8904489
100 LET C(1,Y)=-.258252115
105 LET C(2,Y)=.000227980
110 LET H(0,Y)=C(0,Y)
115 LET H(1,Y)=C(1,Y)
120 LET H(2,Y)=C(2,Y)
125 NEXT Y
130 FOR X=1 TO 24
135 READ K(X),S(X),D(X),B(X),G(X),T(X)
140 IF K(X)=999 THEN 150
145 NEXT X
150 LET X=X-1
155 PRINT
160 PRINT "ANALYSIS OF TELPS LEG PERFORMANCE DATA CORRECTED FOR BATH"
165 PRINT "GEOMETRY FACTOR AND LATERAL RADIATION HEAT LOSS. (REV 6/27/67)"
170 PRINT
175 PRINT "FIXTURE LOT BATCH SAMPLE DAYS/HRS/MIN D/HRS/MIN,INIT";
180 PRINT " ELAPSED HRS"
185 PRINT "TSUBH-DEG F TSUBC-DEG F RESIST-MOHMS SEEBECK-MV";
190 PRINT " MAX PWR-WATTS"
195 PRINT "*****"
200 PRINT "*****"
205 PRINT
210 READ I
215 LET T=T+0
220 FOR J=1 TO X
225 LET D=D+(FND(G(J))-FND(B(J))+FND(T)-FND(T(J)))
230 LET D=D+(FNH(G(J))-FNH(B(J))+FNH(T)-FNH(T(J)))
235 LET D=D+(FNM(G(J))-FNM(B(J))+FNM(T)-FNM(T(J)))/60
240 READ L(1),H,L(2),C,L(3),I,L(4),V,L(5),E
245 IF K(J)=0 THEN 430
250 LET Y=L(5)/5
255 LET M=FNC(Y)
260 GOSUB 440
265 LET I=FNR(I)
270 LET V=FNR(V)
275 LET E=FNR(E)
280 PRINT " ";Y;" ";
285 LET A(J)=INT(S(J)/1000000)
290 PRINT A(J);

```

```

295 PRINT (INT(INT((S(J)-1000000*A(J))/10000)));
300 IF (INT(S(J)/1000)-10*INT(S(J)/10000))=1 THEN 315
305 PRINT "A"; " ";
310 GØ TØ 320
315 PRINT "B"; " ";
320 PRINT (S(J)-1000*INT(S(J)/1000)),T,T(J),FNA(D)
335 LET R=(1+5.23 E-5*(H-C))*1.17847*25*(E-V)/I
340 LET W=INT((10*E+2/(4*R))+.5)/10000
345 PRINT FNB(H),FNB(C),FNA(R),FNA(E),W
350 MAT X=ZER(5)
355 FØR L=0 TØ 3
360 LET M(L)=(H+(L+1)-C+(L+1))/(L+1)
361 LET N(L)=(K(J)+(L+1)-520+(L+1))/(L+1)
362 LET X(0)=X(0)+E(M,L)*(M(L)-N(L))
364 LET X(1)=X(1)+E(M,L)*M(L)
366 LET X(2)=X(2)+Q(M,L)*(M(L)-N(L))
368 LET X(3)=X(3)+Q(M,L)*M(L)
370 LET X(4)=X(4)+R(M,L)*(M(L)-N(L))
372 LET X(5)=X(5)+R(M,L)*M(L)
380 NEXT L
385 LET E=E*(1-X(0)/X(1))
390 LET R=R*(1-X(4)/X(5))/(1-X(2)/X(3))
395 LET P=INT((10*E+2/(4*R))+.5)/10000
400 PRINT K(J)," 520",FNA(R),FNA(E),P
405 PRINT
410 IF ABS((W-P)/W)<.1 THEN 430
415 PRINT "POWER CORRECTION FACTØR ØN PRECEEDING DATA =" P/W;
420 PRINT ". CHECK FIXTURE"
425 PRINT
430 NEXT J
435 GØ TØ 999
440 LET H=FNR(H)+3.41403
445 LET C=FNR(C)+3.41403
450 LET A=F(0)+F(1)*H+F(2)*H+2+F(3)*H+3+F(4)*H+4+F(5)*H+5
455 LET H=A+H(0,Y)+H(1,Y)*H+H(2,Y)*H+2
460 LET B=F(0)+F(1)*C+F(2)*C+2+F(3)*C+3+F(4)*C+4+F(5)*C+5
465 LET C=B+C(0,Y)+C(1,Y)*C+C(2,Y)*C+2
470 RETURN
471 DATA 1090,10061029,464.817,231725,760930,761530
472 DATA 1090,9071929,464.817,231725,760930,761530
473 DATA 1090,10071027,464.817,231725,760930,761530
474 DATA 1090,9111027,464.817,231725,760930,761530
475 DATA 1090,10071028,464.817,231725,760930,761530
476 DATA 1090,9111028,464.817,231725,760930,761530
477 DATA 0,0,0,0,0,0
478 DATA 1090,9111029,464.817,231725,760930,761530
479 DATA 1090,10071029,464.817,231725,760930,761530
480 DATA 1090,9140027,464.817,231725,760930,761530
481 DATA 1090,10200027,464.817,231725,760930,761530
482 DATA 1090,9140028,464.817,231725,760930,761530
483 DATA 1090,10200028,464.817,231725,760930,761530
484 DATA 1090,9140029,464.817,231725,760930,761530
485 DATA 1090,10200029,464.817,231725,760930,761530
486 DATA 0,0,0,0,0,0
487 DATA 1090,10261040,0,0,0,1700
488 DATA 1090,9201040,0,0,0,12127
489 DATA 1090,10050936,474.817,231725,760930,761530
499 DATA 999,0,0,0,0,0
999 END

```


EXPLANATORY NOTES

LANGUAGE: BASIC

4.6 PROGRAM: COMPAR

LENGTH: 3000 CHAR.

This program converts temperature to $^{\circ}\text{F}$ from the mv readings obtained on the hot junction thermocouple, cold junction thermocouples and a comparison standard thermocouple when all those are operated isothermally. The data input normally consists of the following:

```
500 DATA (Time)

501 DATA (Ch), (Tstd), (Ch), (Thot), (Ch), (Tcold)

502 DATA . . . and so on for the entire temperature range of interest.
      Statement 290 would normally be as follows:

290 READ T, L(1), T(J, 3), L(2), T(J, 1), L(3), T(J, 2)
```

In the examples shown, the input format was modified to make possible the calibration of fixture #23. In this case (T_{std}) was measured on Channel 108, (T_{hot}) on Channel 111 and (T_{cold}) on Channel 112. The arrangement of input terminals to the DAS necessitated the modification shown.

The output produces an error table for each thermocouple which shows for each mv reading obtained the corresponding temperature difference in degrees F between the standard and the thermocouples in question. The output tables are formatted such that they may be directly input via paper tape to a standard least squares polynomial curve fit routine to obtain error curve correction coefficient.

COMPAR

```

100 REM THIS PROGRAM COMPARES HOT AND COLD JUNCTION THERMOCOUPLE
110 REM READINGS WITH A COMPARISON STANDARD OPERATED ISOTHERMALLY.
120 REM ENTER DATA AT LINE 500, USING OUTPUT OF DAS TO GIVE
130 REM TIME, CHANNEL, TH, CHANNEL, TC, CHANNEL, TS. TYPE 'RUN'
140 REM AND TURN ON PUNCH. OUTPUT TAPE IS THEN INPUT TO POLFIT**
150 REM FOR CURVE FIT TO 2ND ORDER.
160 DEF FNR(Z)=(ABS(Z)/Z)*INT(.1*ABS(Z))*10+(-(ABS(Z)-10*INT(.1*ABS(Z))-4))
170 LET F(0)=32.0432
180 LET F(1)=35.7115
190 LET F(2)=-.385149
200 LET F(3)=2.02802 E-2
210 LET F(4)=-4.61086 E-4
220 LET F(5)=3.46189 E-6
230 LET S(0)=.292042
240 LET S(1)=1.00000
250 LET S(2)=-1.54483 E-5
260 LET S(3)=7.76042 E-9
270 DIM X(100,3),Y(100,3),T(100,3)
280 FOR J=1 TO 100
290 READ T,L(1),T(J,3),L(2),A,L(3),A,L(9),T(J,1),L(10),T(J,2)
300 FOR I=1 TO 3
310 LET T(J,I)=FNR(T(J,I))+3.41403
320 NEXT I
330 IF T=0 THEN 350
340 NEXT J
350 FOR I=1 TO 2
360 MAT X=ZER(100,3)
370 MAT Y=ZER(100,3)
380 PRINT"10 DATA"J-1",2"
390 FOR L=1 TO J-1
400 FOR K=0 TO 5
410 LET X(L,I)=X(L,I)+F(K)*T(L,I)*K
420 LET X(L,3)=X(L,3)+F(K)*T(L,3)*K
430 NEXT K
440 FOR K=0 TO 3
450 LET Y(L,3)=Y(L,3)+S(K)*X(L,3)*K
460 NEXT K
470 PRINT 100+L;"DATA";T(L,1);",";"Y(L,3)-X(L,1)
480 NEXT L
490 NEXT I
500 DATA 271220,
501 DATA 108,+270847,109,+121176,110,+148146,111,+271037,112,+268587
502 DATA 271240,108,+239147,109,+124276,110,+144806,111,+239317
503 DATA 112,+237307, 271300,108,+208947,109,+121746,110,+144646
504 DATA 111,+209157,112,+207307, 271320,108,+181887,109,+138756
505 DATA 110,+162576,111,+182097,112,+180347, 271340,108,+158457
506 DATA 109,+155626,110,+189216,111,+158647,112,+156907, 271400
507 DATA 108,+138197,109,+107436,110,+127576,111,+138357,112,+136727
508 DATA 271420,108,+120437,109,+137396,110,+166276,111,+120567
509 DATA 112,+118957, 271440,108,+104687,109,+039175,110,+052915
510 DATA 111,+104787,112,+094307, 271500,108,+090877,109,+039905
511 DATA 110,+053785,111,+090947,112,+080507, 271520,108,+074567
512 DATA 109,+040375,110,+054425,111,+074557,112,+064597,71540
513 DATA 108,+064477,109,+043225,110,+058635,111,+064457,112,+053837
514 DATA 271600,108,+055497,109,+039545,110,+053925,111,+055477

```

515 DATA 112,+045807, 271620,108,+045587,109,+036815,110,+049735
516 DATA 111,+045487,112,+036777, 271640,108,+025477,109,+035455
517 DATA 110,+048675,111,+025337,112,+017737, 271700,108,+011007
518 DATA 109,+033125,110,+044835,111,+010887,112,+003537, 271800
519 DATA 108,-009647,109,+032025,110,+043495,111,-009687,112,-016777
520 DATA 271853,108,-015977,109,+032185,110,+043475,111,-015997
521 DATA 112,-023077,
998 DATA 0,0,0,0,0,0,0
999 END

EXPLANATORY NOTES

LANGUAGE: BASIC

LENGTH: ABOUT
2400 CHAR.

4.7 PROGRAM: EXPFT*

This program performs a least squares curve fit to an equation of the form

$$\left[\frac{X_t - X_1}{X_0 - X_1} \right] = e^{-\frac{t}{\tau}}$$

where the data input consists of a series of observed values of X_t and t . Assuming X_t changes exponentially with time from an initial value X_0 to an asymptote X_1 at a rate governed by the time constant τ , the program iteratively adjusts X_0 and X_1 for a best straight line fit to:

$$\ln \left[\frac{X_t - X_1}{X_0 - X_1} \right] = -\frac{t}{\tau}$$

When convergence to a preset desired level has been obtained, values of X_0 , X_1 and τ are printed out as well as a regenerated Table comparing actual with calculated values of

$$\left[\frac{X_t - X_1}{X_0 - X_1} \right] \text{ vs time.}$$

To operate:

- a. Input data starting at statement number 900 as follows:

900 DATA (t_1) , (X_{t1}) , (t_2) , (X_{t2}) , (t_3) , (X_{t3})

- b. Type "RUN"
- c. Input initial step size for ΔX_1 , τ convergence criteria, and X_1 convergence criteria when requested.

EXPFT*

```

100 REM  USER -- E. H. MCCALL
120 DIM T(250),X(250),Y(250)
130 FOR I=1 TO 1000
140 READ T(I),X(I)
150 IF T(I)>=9 E 50 THEN 170
160 NEXT I
170 LET N=I-1
190 PRINT "INPUT INITIAL STEP SIZE, TAU CONV CRIT, X-INF CONV CRIT."
200 INPUT S,D1,D5
210 PRINT
211 PRINT "INPUT INITIAL X0? TYPE 1 IF YES, 0 IF NO"
212 INPUT I9
213 PRINT
214 IF I9=0 THEN 220
215 PRINT "INPUT INITIAL X0"
216 INPUT X9
217 PRINT
220 LET C0=0.0
230 LET X0=X(1)
240 LET X1=X(N)
245 IF X0>=X1 THEN 247
246 LET S=-S
247 IF I9=1 THEN 249
248 LET X0=X0 + S
249 LET X1=X1 - S
250 LET X2=X0
260 LET D9=0.0
262 IF I9=0 THEN 270
265 LET X0=X9
270 LET S0=0.0
280 LET S1=0.0
290 LET S2=0.0
300 LET S3=0.0
310 LET S4=0.0
320 FOR I=1 TO N
330 LET Y(I)=LOG((X(I) - X1)/(X0 - X1))
340 LET Y1=Y(I)
350 LET S0=S0 + Y1
360 LET S1=S1 + Y1*Y1
370 LET T1=T(I)
380 LET S2=S2 + T1
390 LET S3=S3 + T1*T1
400 LET S4=S4 + T1*Y1
410 NEXT I
420 LET D2=N*S3 - S2*S2
430 LET D=(S0*S3 - S4*S2)/D2
440 LET D3=N*S4 - S2*S0
450 LET M=D3/D2
460 LET C=D3/(SQR(D2*(N*S1 - S0*S0)))
470 LET C1=ABS(C)
480 LET T3=-1.0/M
481 PRINT X0,X1,T3,C
490 IF ABS(T3-T0)<=D1 THEN 570
500 LET T0=T3
510 IF D<D9 THEN 540
520 LET X0=(X0 - X1)*EXP(ABS(D)) + X1

```

```

530 GO TO 550
540 LET X0=(X0 - X1)*EXP(-ABS(D)) + X1
550 LET D9=D
560 GO TO 270
570 IF C0<C1 THEN 580
572 IF ABS(X2-X1)<=D5 THEN 650
574 LET X2=X1
576 LET S=-S/2.0
580 LET X1=X1-S
585 LET C0=C1
590 GO TO 260
650 PRINT "SYSTEM CONVERGED"
655 PRINT
660 PRINT "FOR TAU CONV. CRIT. = "D1;"AND X-INF CONV. CRIT = "D5;"THEN"
670 PRINT "X0 = "X0;"X-INF = "X1;"TAU = "T3;"C = "C
675 PRINT
680 PRINT "T","X(T) DATA","X(T) CALC","DIFF","PRCNT DIFF"
690 FOR I=1 TO N
700 LET X3=(X0-X1)*EXP(M*T(I))+X1
710 LET D3=X(I)-X3
720 PRINT T(I),X(I),X3,D3,100.0*D3/X(I)
730 NEXT I
740 PRINT
750 PRINT
760 PRINT
770 PRINT "LEAST SQUARES FIT"
780 PRINT
790 PRINT "T","X","Y(T) DATA","Y(T) CALC","DIFF","PRCNT DIFF"
800 PRINT
810 FOR I=1 TO N
820 LET Y3=M*T(I)+D
830 LET D3=Y(I)-Y3
840 PRINT T(I),X(I),Y(I),Y3,D3,100.0*D3/Y(I)
850 NEXT I
860 PRINT
870 PRINT
880 PRINT
890 STOP
900 DATA 10,9.09365,20,8.3516,30,7.74406,
910 DATA 40,7.24664,50,6.8394,60,6.50597
920 DATA 70,6.23298,80,6.00948,90,5.82649,
930 DATA 100,5.67668,110,5.55402
9998 DATA 9 E 50,9 E 50
9999 END

```


EXPLANATORY NOTES

LANGUAGE: BASIC

4.8 PROGRAM: STATS 1

LENGTH: 3600 CHAR.

This program calculates the mean, variance, and standard deviation for each of several sets of individual values or frequency distributions. Data for each set of individual values is entered into the program as follows:

```
1 DATA N, X(1), X(2), X(3), . . . . X(N)
```

Where the N values of the set are X(1) through X(N). Additional data statements are available as needed up to data statement 299. The data input for grouped values has the following format:

```
1 DATA 0, N, X(1), F(1), X(2), F(2), . . . . , X(N), F(N)
```

Where the initial zero signals grouped data, the N is the number of different values to be given, and the F(1) are the number of times the X(1) occur. Here again, data statements 1-299 are available for input data.

STATS1

```

1 DATA 3,.4897,.2876,.393,3,2.029,1.933,1.945,3,1.87,2.418,2.055,
2 DATA 3,.4475,.3987,.409,3,1.95,1.924,1.942,3,1.899,2.225,2.015,
3 DATA 3,.4237,.295,.437,3,2.02,1.946,1.96,3,2.123,2.26,1.958,
4 DATA 9,.4897,.2876,.393,.4475,.3987,.409,.4237,.295,.437,
5 DATA 9,2.029,1.933,1.945,1.95,1.924,1.942,2.02,1.946,1.96,
6 DATA 9, 1.87,2.418,2.055,1.899,2.225,2.015,2.123,2.26,1.958,
8 DATA 3,1.945,1.942,1.96,6,2.029,1.933,1.95,1.924,
9 DATA 2.02,1.946
10 PRINT"D. HOWARD"
300 LET H=0
305 PRINT
310 PRINT
315 PRINT "ARITHMETIC MEAN, VARIANCE, AND"
320 PRINT "          STANDARD DEVIATION"
325 PRINT
330 READ C
335 LET H=H+1
340 IF C=9ES0 THEN 795
345 LET S1=0
350 LET S2 = 0
355 IF C <> 0 THEN 435
360 PRINT
365 PRINT "FOR GROUPED DATA SET";H
370 PRINT
375 READ Q
380 LET N = 0
385 PRINT "X-VALUE","FREQUENCY"
390 PRINT
395 FOR P = 1 TO Q
400 READ X, M
405 LET N = N + M
410 LET S1 = S1 + M*X
415 LET S2 = S2 + M*X*X
420 PRINT X, M
425 NEXT P
430 GOTO 500
435 PRINT
440 PRINT
445 PRINT "INDIVIDUAL SET NUMBER";H
450 PRINT
455 PRINT "INPUT VALUES: ";
460 LET N = C
465 FOR P = 1 TO N
470 READ X
475 LET S1 = S1 + X
480 LET S2 = S2 + X*X
485 PRINT X;
490 NEXT P
495 PRINT
500 LET A = S1/N
505 LET V=(S2-S1*S1/N)/(N-1)
510 LET V1=V*N/(N-1)
515 LET D = SQR(V)
516 LET D1 = SQR(V1)

```

```

520 PRINT
525 PRINT "      NUMBER OF VALUES = ";N
530 PRINT "      ARITHMETIC MEAN = ";A
535 PRINT "      STANDARD DEVIATION = ";D
540 PRINT "      SAMPLE VARIANCE = ";V
545 PRINT "      EST TRUE VARIANCE = ";V1
546 PRINT "      EST TRUE STD DEV. = "; D1
550 PRINT
555 PRINT
560 GOTO 330
565 PRINT
570 PRINT "THIS PROGRAM CALCULATES THE MEAN, VARIANCE, AND STANDARD"
575 PRINT "DEVIATION FOR EACH OF SEVERAL SETS OF INDIVIDUAL VALUES"
580 PRINT "OR FREQUENCY DISTRIBUTIONS."
585 PRINT
590 PRINT "DATA FOR EACH SET OF INDIVIDUAL VALUES IS ENTERED INTO"
595 PRINT "THE PROGRAM AS FOLLOWS:"
600 PRINT
605 PRINT "      1 DATA N, X(1), X(2), X(3),....., X(N)"
610 PRINT
615 PRINT "WHERE THE N VALUES OF THE SET ARE X(1) THRU X(N). IF"
620 PRINT "NEEDED, ADDITIONAL DATA STATEMENTS MAY BE USED TO GIVE"
625 PRINT "THE ENTIRE LIST OF VALUES. ADDITIONAL CASES MAY BE"
630 PRINT "GIVEN IN SUBSEQUENT DATA STATEMENTS IN THE SAME FORMAT."
635 PRINT
640 PRINT "THE INPUT FOR GROUPED VALUES HAS THE FOLLOWING FORMAT:"
645 PRINT
650 PRINT "      1 DATA O, N, X(1), F(1), X(2), F(2),...., X(N), F(N)"
655 PRINT
660 PRINT "WHERE THE INITIAL ZERO SIGNALS GROUPED DATA, THE N IS"
665 PRINT "THE NUMBER OF DIFFERENT VALUES TO BE GIVEN, AND THE F(1)"
670 PRINT "ARE THE NUMBER OF TIMES THE X(1) OCCUR. DATA STATEMENTS"
675 PRINT "FOLLOWING MAY BE USED TO EXTEND THE LIST AS NECESSARY,"
680 PRINT "AND BLOCKS OF GROUPED DATA MAY BE INTERMIXED FREELY"
685 PRINT "WITH STRAIGHT LISTS DESCRIBED ABOVE."
690 PRINT
695 PRINT "AS AN EXAMPLE, SUPPOSE WE WERE INTERESTED IN THE MEAN"
700 PRINT "AND STANDARD DEVIATION OF THE NUMBERS 1,5,4,2,6,7,4,7"
705 PRINT "AND ALSO FOR THE DISTRIBUTION CONSISTING OF 5-1'S,"
710 PRINT "3-4'S, 6-7'S, AND 2-11'S. THESE TWO CASES COULD BE RUN"
715 PRINT "BY TYPING THE FOLLOWING:"
720 PRINT
725 PRINT "      1 DATA 8,1,5,4,2"
730 PRINT "      2 DATA 6,7,4,7"
735 PRINT "      3 DATA 0,4,5,1,3,4"
740 PRINT "      4 DATA 6,7,2,11"
745 PRINT "      RUN"
750 PRINT
755 PRINT "OR EQUIVALENTLY:"
760 PRINT
765 PRINT "      1 DATA 8,1,5,4,2,6,7,4,7,0,4,5,1,3,4,6,7,2,11"
770 PRINT "      RUN"
775 PRINT
780 PRINT "NOTE THAT STATEMENT NUMBERS 1 THRU 299 ARE AVAILABLE"
785 PRINT "FOR CONTINUATION OF THE DATA FIELD."
790 DATA 9E50
795 END

```


EXPLANATORY NOTES

LANGUAGE: BASIC

4.9 PROGRAM: STATS 2

LENGTH: 4600 CHAR.

This program is a modification of a polynomial curve fit routine used to determine coefficients of expansion, subtracting the differences found in the iron standard and the effects of the quartz fixture itself. The program maximum is 100 data points with the highest degree of fit being 11.

STATS2

```

2 LET C1=-2.48297 E-4
4 LET C2=1.12347 E-5
6 LET C3=3.50163 E-9
155 DATA 0,0,0,0
160 READ M,N,F,S
165 IF INT(-10000+C1)-M=3 THEN 9999
170 IF M=0 THEN 1970
200 DIM A(15),B(15),S(15),G(15),U(15)
210 DIM Q(100),P(100),X(100),Y(100),C(100)
220 LET Z=0
230 LET Q=1
240 LET K=12
250 LET N=N+1
260 IF N>11 THEN 1760
270 IF M<N THEN 1800
280 IF M>100 THEN 1730
290 LET T7=Z
300 LET T8=Z
310 LET W7=Z
320 FOR I=1 TO M
330 READ X(I),Y(I)
340 LET Y(I)=Y(I)/(F+S)
350 LET T=X(I)
360 LET Y(I)=((F+S)/S)*(Y(I)-(F/(F+S))*(C1+C2*T+C3*T^2))
370 LET W7=W7+X(I)
380 LET T7=T7+Y(I)
390 LET T8=T8+Y(I)^2
400 NEXT I
410 LET T9=(M*T8-T7^2)/(M^2-M)
420 PRINT
430 PRINT "L E A S T - S Q U A R E S   P O L Y N O M I A L S"
440 PRINT
450 PRINT "          NUMBER OF POINTS =" ; M
460 PRINT "          MEAN VALUE OF X =" ; W7/M
470 PRINT "          MEAN VALUE OF Y =" ; T7/M
480 PRINT "          STD ERROR OF Y =" ; SQR(T9)
490 PRINT
500 GO TO 580
510 PRINT "  NOTE:  CODE FOR 'WHAT NEXT?' IS:"
520 PRINT
530 PRINT "          0 = STOP PROGRAM"
540 PRINT "          1 = COEFFICIENTS ONLY"
550 PRINT "          2 = ENTIRE SUMMARY"
560 PRINT "          3 = FIT NEXT HIGHER DEGREE"
570 PRINT
580 PRINT
590 FOR I=1 TO M
600 LET P(I) = Z
610 LET Q(I) = Q
620 NEXT I
630 FOR I = 1 TO 11
640 LET A(I) = Z
650 LET B(I) = Z
660 LET S(I) = Z
670 NEXT I

```

```

680 LET E1=Z
690 LET F1=Z
700 LET W1=M
710 LET N4=K
720 LET I=1
730 LET K1=2
740 IF N=0 THEN 760
750 LET K1=N4
760 LET W=Z
770 FOR L=1 TO M
780 LET W=W+Y(L)*Q(L)
790 NEXT L
800 LET S(I)=W/W1
810 IF I-N4>=0 THEN 1000
820 LET E1=Z
830 FOR L=1 TO M
840 LET E1=E1+X(L)*Q(L)*Q(L)
850 NEXT L
860 LET E1=E1/W1
870 LET A(I+1)=E1
880 LET W=Z
890 FOR L=1 TO M
900 LET V=(X(L)-E1)*Q(L)-F1*P(L)
910 LET P(L)=Q(L)
920 LET Q(L)=V
930 LET W=W+V*V
940 NEXT L
950 LET F1= W/W1
960 LET B(I+2)=F1
970 LET W1=W
980 LET I=I+1
990 GOTO 760
1000 FOR L=2 TO 11
1010 LET G(L)=Z
1020 NEXT L
1030 LET G(1)=0
1040 FOR J=1 TO N
1050 LET S1 =Z
1060 FOR L=1 TO N
1070 IF L=1 THEN 1090
1080 LET G(L)=G(L)-A(L)*G(L-1)-B(L)*G(L-2)
1090 LET S1=S1+S(L)*G(L)
1100 NEXT L
1110 LET U(J)=S1
1120 LET L=N
1130 FOR I2=2 TO N
1140 LET G(L)=G(L-1)
1150 LET L=L-1
1160 NEXT I2
1170 LET G(1)=Z
1180 NEXT J
1190 PRINT
1200 LET T=Z
1210 FOR L=1 TO M
1220 LET C(L)=Z
1230 LET J=N

```

```

1240 FOR I2=1 TO N
1250 LET C(L)=C(L)*X(L)+U(J)
1260 LET J=J-1
1270 NEXT I2
1280 LET T3=Y(L)-C(L)
1290 LET T=T+T3*2
1300 NEXT L
1310 IF M<>N THEN 1340
1320 LET T5=0
1330 GOTO 1350
1340 LET T5=T/(M-N)
1350 LET Q7=1-(T5/T9)
1360 PRINT
1370 PRINT "POLYFIT OF DEGREE";N-1;
1380 PRINT "INDEX OF DETERM =" ;Q7;
1400 PRINT
1410 PRINT
1420 GO TO 1450
1430 IF R=0 THEN 1870
1440 IF R=3 THEN 1700
1450 PRINT "TERM","COEFFICIENT","ALPHA COEFFICIENTS"
1460 PRINT
1470 FOR J=1 TO N
1480 LET I2=J-1
1490 PRINT I2,U(J),J*U(J+1)
1500 NEXT J
1510 IF R=1 THEN 1670
1520 PRINT
1530 PRINT "X-ACTUAL","Y-ACTUAL","Y-CALC","DIFF","PCT-DIFF"
1540 PRINT
1550 FOR L=1 TO M
1560 LET Q8=Y(L)-C(L)
1570 PRINT X(L),Y(L),C(L),Q8,
1580 IF C(L)=0 THEN 1610
1590 PRINT 100*Q8/C(L)
1600 GOTO 1620
1610 PRINT "INFINITE"
1620 NEXT L
1630 PRINT
1640 PRINT "          STD ERROR OF ESTIMATE FOR Y =" ;SQR(T5)
1650 GO TO 1860
1660 IF K=N THEN 1870
1670 PRINT
1690 GOTO 1430
1700 LET N=N+1
1710 IF M<N THEN 1800
1720 GOTO 1000
1730 PRINT
1740 PRINT "PROGRAM SIZE LIMIT IS 100 DATA POINTS."
1750 GO TO 1870
1760 PRINT "ELEVENTH DEGREE IS THE LIMIT."
1770 GO TO 1870
1780 PRINT
1790 GO TO 1870
1800 PRINT
1810 PRINT "TOO FEW POINTS FOR FITTING DEGREE";N-1

```



```
1820 GO TO 1870
1850 RETURN
1860 PRINT
1870 PRINT "TEMP DEG C","REL EXP COEFF","ABS EXP COEFF"
1880 PRINT
1890 FOR T=0 TO 0 STEP 500
1900 LET A=0
1910 FOR J=1 TO N-1
1920 LET A=A+J*U(J+1)*T*(J-1)
1930 NEXT J
1940 PRINT T,A,A+.54 E-6
1950 NEXT T
1960 GO TO 160
1970 LET C1=-3.01397 E-4
1980 LET C2=1.25279 E-5
1990 LET C3=1.24311 E-10
1995 RESTORE
2000 GO TO 160
9999 END
```


EXPLANATORY NOTES

LANGUAGE: BASIC

LENGTH: 3800 CHAR.

4.10 PROGRAM: STAT 3*

STATS 3 gives an analysis of characterization tests by Newman-Keuls sequential range test for significant differences between batch means. The data input begins at data line 1050, listing in order the number of group means, the number of observations per group, the mean, and variance for each group of observations. The program can handle up to 11 group means and a number of observations per mean such that 20 degrees of freedom is not exceeded.

STAT3*

```

100 REM      ENTER ALL DATA STARTING AT STATEMENT 1050 LISTING FIRST
110 REM      THE NUMBER OF GROUP MEANS AND SECOND, THE NUMBER OF OBSER-
120 REM      VATIONS PER GROUP. THEN LIST THE MEAN AND VARIANCE FOR EACH
125 REM      GROUP OF OBSERVATIONS. TYPE 'RUN'.
130 REM      TABLE VI 'UPPER 5 PERCENT POINTS OF THE STUDENTIZED RANGE, Q'
140 REM      IS STORED IN DATA STATEMENTS 840 THROUGH 1030 AND THIS PRO-
150 REM      GRAM CAN PRESENTLY HANDLE UP TO 11 GROUP MEANS AND A NUMBER
160 REM      OF OBSERVATIONS PER MEAN SUCH THAT 20 DEGREES OF FREEDOM IS
170 REM      NOT EXCEEDED.
180 PRINT"ANALYSIS OF CHARACTERIZATION TESTS BY NEWMAN-KEULS SEQUENTIAL";
190 PRINT" RANGE TEST"
200 DIM Q(19,9)
210 MAT READ Q(19,9)
220 READ N,N1
230 PRINT "FOR" N "GROUPS OF OBSERVATIONS WITH" N1 "OBSERVATIONS PER GROUP."
240 PRINT
250 LET Z=0
260 LET S=0
270 FOR I=1 TO N
280 READ Y(I),Z(I)
290 LET Z=Z+Z(I)
300 LET S(I)=Y(I)
310 LET S=S+Y(I)
320 NEXT I
330 LET P=-9E50
340 FOR M=1 TO N
350 FOR L=1 TO N
360 IF S(L)<=P THEN 390
370 LET P=Y(L)
380 LET K=L
390 NEXT L
400 LET R(M)=K
410 LET S(K)=-9E50
420 LET P=-9E50
430 NEXT M
440 PRINT "RANK","GROUP","MEAN","STD DEV","VARIANCE"
450 PRINT
460 FOR M=1 TO N
470 LET J=R(M)
480 LET X(M)=Y(J)
490 LET V(M)=Z(J)
500 PRINT M,J,X(M),SQR(V(M)),V(M)
510 NEXT M
520 PRINT
530 LET X=SQR(Z/(N*N1))
540 PRINT
550 LET N2=(N1-1)*N
560 PRINT
570 PRINT "                                GRAND MEAN="S/N
580 PRINT "STANDARD ERROR OF A SINGLE MEAN=";X
590 PRINT
595 PRINT "TABLE OF STUDENTIZED RANGE, Q"
600 PRINT
610 PRINT " K                                Q(.95)(K,N2)"," W(K)"

```

```

620 PRINT
630 FOR K=2 TO N
640 LET W(K)=X*Q(N2-1,K-2)
650 PRINT K,Q(N2-1,K-2),W(K)
660 NEXT K
670 PRINT
680 PRINT "NUMBER OF DEGREES OF FREEDOM IS"N2
690 PRINT
700 PRINT "RANKS          DIFFERENCE BETWEEN GROUP MEANS"," K","CONCLUSION"
710 PRINT "CONCLUSION"
720 PRINT
730 FOR I=1 TO N
740 FOR J=1 TO N
750 IF X(I)-X(J)<=0 THEN 820
760 PRINT
770 PRINT I,J,X(I)"-"X(J)"="X(I)-X(J),J-I+1,
780 IF (X(I)-X(J))>W(J-I+1) THEN 810
790 PRINT "NO SIG DIFF"
800 GO TO 820
810 PRINT "SIG DIFF"
820 NEXT J
830 NEXT I
840 DATA 18.0,27.0,32.8,37.1,40.4,43.1,45.4,47.4,49.1,50.6
850 DATA 6.09,8.3,9.8,10.9,11.7,12.4,13.0,13.5,14.0,14.4
860 DATA 4.50,5.91,6.82,7.50,8.04,8.48,8.85,9.18,9.46,9.72,
870 DATA 3.93,5.04,5.76,6.29,6.71,7.05,7.35,7.60,7.83,8.03
880 DATA 3.64,4.60,5.22,5.67,6.03,6.33,6.58,6.80,6.99,7.17
890 DATA 3.46,4.34,4.90,5.31,5.63,5.89,6.12,6.32,6.49,6.65
900 DATA 3.34,4.16,4.68,5.06,5.36,5.61,5.82,6.00,6.16,6.30
910 DATA 3.26,4.04,4.53,4.89,5.17,5.40,5.60,5.77,5.92,6.05
920 DATA 3.20,3.95,4.42,4.76,5.02,5.24,5.43,5.60,5.74,5.87
930 DATA 3.15,3.88,4.33,4.65,4.91,5.12,5.30,5.46,5.60,5.72
940 DATA 3.11,3.82,4.26,4.57,4.82,5.03,5.20,5.35,5.49,5.61
950 DATA 3.08,3.77,4.20,4.51,4.75,4.95,5.12,5.27,5.40,5.51
960 DATA 3.06,3.73,4.15,4.45,4.69,4.88,5.05,5.19,5.32,5.43
970 DATA 3.03,3.70,4.11,4.41,4.64,4.83,4.99,5.13,5.25,5.36
980 DATA 3.01,3.67,4.08,4.37,4.60,4.78,4.94,5.08,5.20,5.31
990 DATA 3.00,3.65,4.05,4.33,4.56,4.74,4.90,5.03,5.15,5.26
1000 DATA 2.98,3.63,4.02,4.30,4.52,4.71,4.86,4.99,5.11,5.21
1010 DATA 2.97,3.61,4.00,4.28,4.49,4.67,4.82,4.96,5.07,5.17
1020 DATA 2.96,3.59,3.98,4.25,4.47,4.65,4.79,4.92,5.04,5.14
1030 DATA 2.95,3.58,3.96,4.23,4.45,4.62,4.77,4.90,5.01,5.11
1040 REM          ENTER ALL INPUT DATA AFTER THIS STATEMENT
1050 DATA 4,4
1060 DATA 682.5,3941.6667,663.75,4756.25,698.75,722.9167,678.75,1022.9167
9999 END

```


EXPLANATORY NOTES

LANGUAGE: FORTRAN

LENGTH: 6000 CHAR.

4.11 PROGRAM: COMRAN

COMRAN solves the completely randomized design problem. It allows transforms, tests homogeneity and normality, and prints out the F values and the ANOVA table along with the respective means and variances for each of the groups. Enter data as follows:

```
1000  N, P, XN1, XN2, XN3, . . . . , XNP
```

Where

N = the total number of data points

P = the number of groups

XN1 = number of observations of 1st group

XN2 = number of observations of 2nd group, etc.

Enter all observations of 1st group, then 2nd group, etc. Continue with new line numbers as needed. If more than one set of data is to be analyzed, it should follow the 1st set.

*COMRAN and its associated subroutines SFD, TRANSF, and SORTTEM were originally written by S. Demskey and D. Reilly, General Electric Co., MSD Philadelphia, Pa. These programs as listed here have been modified to make them compatible with the Fortran compiler of the Pillsbury Co./GE 225 Time Share Computer and to somewhat simplify data input and output procedures.

COMRAN

```

1' FOR INFORMATION ON THIS PROGRAM CALL STAN HILLIARD 733-4035
5' THIS PROGRAM SOLVES THE COMPLETELY RANDOMIZED DESIGN PROBLEM
10' IT ALLOWS TRANSFORMS, TESTS HOMOGENEITY AND NORMALITY AND
15' PRINTS OUT THE F VALUE AND THE ANOVA TABLE ALONG WITH
20' THE RESPECTIVE MEANS AND VARIANCES FOR EACH OF THE GROUPS
25'   ENTER DATA AS FOLLOWS:
30'   1000  N,P,XN1,XN2,XN3,...,XNP
35'   WHERE  N=TOTAL NUMBER OF DATA POINTS
40'           P=NUMBER OF GROUPS
45'           XN1=NUMBER OF OBSERVATIONS OF 1ST GROUP
50'           XN2=NUMBER OF OBSERVATIONS OF 2ND GROUP, ETC.
55'   1001  ENTER ALL OBSERVATIONS OF 1ST GROUP, THEN 2ND GROUP, ETC.
60'   1002  CONTINUE WITH NEW LINE NUMBERS AS NEEDED. IF MORE THAN
65'           ONE SET OF DATA IS TO BE ANALYZED IT SHOULD FOLLOW
70'           THE 1ST SET.
75'
80       COMMON W(300),N,B(300),XN(15),VAR(15),XBAR(15),D(300)
85       DIMENSION SD(15),SORT(15)
90       INTEGER TITLE (55)
95       INTEGER P
100      42 FORMAT(55A1)
105      COUNT=1
110      PRINT"ENTER A TITLE",
115      INPUT 42,TITLE
120      43 FORMAT(//////////13HRAW DATA FOR ,55A1/)
125      50 READ,N,P,(XN(J),J=1,P),(B(I),I=1,N)
130      PRINT 43,TITLE
135      PRINT,(B(I),I=1,N),+
140 87986 FORMAT(///"FOR REFERENCE PURPOSES HERE IS TABLE 'A'"/
145 +      25X,"NO TRANSFORM      1"/,25X,"LOG BASE 10      2"/
150 +      25X,"RECIP X 1000      3"/,25X,"SQRTF            4"/
155 +      25X,"LOGLOG BASE 10    5"/,25X,"NLOG((1-Y)/Y)    6"/
160 +      25X,"2ARCSIN(4)        7"/,25X,"SQRTF(Y+CONST)   8"/)
165      70 DO 71 I=1,N
170      71 D(I)=B(I)
175      51 DO 52 I=1,N
180      52 B(I)=D(I)
185      CALL TRANSF(B,N,COUNT)
190'
195'      CALCULATION OF BARTLETS TEST CRITERION.
200'
205      SXN=ERROR=SINV=RHS=LL=0
210      START=1
215      DO 666 J=1,P
220      DUMSUM=SDUMSUM=0
225      SXN=SXN+XN(J)
230      IF(XN(J)-1) 660,660,664
235 664 DO 665 I=START,SXN
240      DUMSUM=DUMSUM+B(I)
245      SDUMSUM=SDUMSUM+B(I)**2
250 665 VAR(J)=(SDUMSUM-DUMSUM**2/XN(J))/(XN(J)-1)
255      XBAR(J)=DUMSUM/XN(J)
260      GO TO 799

```



```

265 660 VAR(J)=0
270 XBAR(J)=B(SXN)
275 799 IF(VAR(J))880,880,800
280 800 RHS=RHS+(XN(J)-1)*LOGF(VAR(J))
285 880 IF(XN(J)-1)666,666,885
290 885 SINV=SINV+(1/(XN(J)-1))
295 LL=LL+1
300 ERROR=ERROR+(VAR(J)*(XN(J)-1))
305 666 START= SXN+1
310 IF(N-P) 60,1221
315 CF=1+(SINV-1/(N-P))/(3*(LL-1))
320 BF=(N-P)*(LOGF(ERROR/(N-P)))-RHS
325 XB=BF/CF
330 XC=3*(LL-1)*(CF-1)
335 1210 FORMAT(///16X,"TEST FOR HOMOGENEITY OF VARIANCE"//,
340 + "BARTLETT'S TEST CRITERION =",F8.3,3X,"WITH",
345 + 14,1X,"DEGREES OF FREEDOM",/,"MFACTOR=",F8.3,3X,"CI=",F8.3)
350
355
360
361 DO 5000 I=2,P
362 IF(XN(I)-XN(I-1)) 1221,5000,1221
363 5000 CONTINUE
365 SUMSORT=0
370 DO 6000 I=1,P
375 6000 SORT(I)=VAR(I)
380 SMAX=-9999999900000000
385 DO 6020 L=1,P
390 IF(SORT(L)-SMAX) 6020,6020,6010
395 6010 SMAX=VAR(L)
400 K=L
405 6020 SUMSORT=SUMSORT+SORT(L)
410 COCHRAN=VAR(K)/SUMSORT
415 6040 FORMAT("COCHRAN'S TEST CRITERION: G=",F3.3," WITH",I2,
420 + " DEGREES OF FREEDOM")
425
430
435
440 1221 K=L=0
445 DO 919 J=1,P
450 K1=K+1
455 K=XN(J)+K
460 L=L+1
465 DO 919 I=K1,K
470 919 W(I)=B(I)-XBAR(L)
475 PRINT 1300
480 1300 FORMAT(/2X,"NORMALITY TEST-ALL OBSERVATIONS-GROUP MEANS"
481 + " TRANSLATED TO ZERO"/)
485 CALL SFD
490 IF (N-P) 60,1222
495 IF(P-1) 60,3336
500 PRINT 1210,XB,LL-1,BF,XC
501 DO 1400 I=2,P
502 IF(XN(I)-XN(I-1)) 1222,1400,1222
503 1400 CONTINUE

```

```

505      PRINT 6040,C0CHRA,LL-1
510
515      CALCULATIONS FOR ANOVA TABLE
520
525      1222 TSUM=TSUMSQ=0
530          DO 20 I=1,N
535          TSUM=TSUM+B(I)
540          TSUMSQ=TSUMSQ+B(I)**2
545      20 CONTINUE
550          TMEAN=TSUM/N
555          TSS=TSUMSQ-(TMEAN*TSUM)
560          AMONG=TSS-ERROR
565          F=(AMONG/ERROR)*((N-P)/(P-1))
570          PRINT 3333
575      3333 FORMAT(// "                                ANALYSIS OF VARIANCE"//)
580          PRINT 3334,AMONG,P-1,AMONG/(P-1),F,
582 +          ERROR,N-P,ERROR/(N-P),
584 +          TSS,N-1
585      3334 FORMAT(22X,"SUM SQ",7X,"DF",7X,"MEAN SQ",8X,"F"//
590 +          "AMONG MEANS",4X,F15.4,4X,I3,F15.4,5X,F4.2//~
594 +          "WITHIN",9X,F15.4,4X,I3,F15.4//
598 +          "TOTAL",10X,F15.4,4X,I3)
600
605      CALCULATION OF BATCH BY BATCH TABLE.
610
615      3336 PRINT 3335
620      3335 FORMAT(///19X,"BATCH BY BATCH ANALYSIS"//,4X,
625 +          "BATCH  SAMPLE SIZE      MEAN",
630 +          8X,"VARIANCE",2X,"STD DEVIATION"//)
635          DO 30 J=1,P
640          IF(VAR(J))25,25
645          SD(J)=SQRTF(VAR(J))
650          GO TO 30
655      25 SD(J)=0.0
660      30 CONTINUE
665          M=P
670          CALL SORTEM(XBAR,N,VAR,SD,XN,M)
680          PRINT 40,
685      40 FORMAT(///"TYPE '1' FOR A TRANSFORM, '2' FOR NEXT DATA",
690 +          1X,"SET, AND '3' FOR HALT.")
695          INPUT,LX
700          GO TO(500,42,60),LX
705      500 COUNT=COUNT+1
710          IF(COUNT-2) 510,510,51
715      510 PRINT 87986
720          GO TO 51
725      60 STOP
735          $USE TRANSF
740          $USE SFD
745          $USE SORTEM
750          $DATA

```

EXPLANATORY NOTES

LANGUAGE: FORTRAN

4.12 PROGRAM: TRANSF

LENGTH: 1200 CHAR.

TRANSF is also a subroutine which is used in COMRAN. It can perform transformations which are selected as options in COMRAN. This subroutine is automatically called up from storage by COMRAN.

TRANSF

```

00005      SUBROUTINE TRANSF(A,N,COUNT)
00010      DIMENSION A(300)
00020      GO TO (730,111,730),COUNT
00030      111 PRINT"SEND TYPE OF TRANSFORM REQUIRED PER TABLE 'A'",
00040      INPUT, MK
00050      GO TO (730,701,703,705,707,709,711,713),MK
00060      701 DO 702 I=1,N
00070      702 A(I)=(LOGF(A(I)))*(.43429448)
00080      GO TO 730
00090      703 DO 704 I=1,N
00100      704 A(I)=1000/A(I)
00110      GO TO 730
00120      705 DO 706 I=1,N
00130      706 A(I)=SQRTF(A(I))
00140      GO TO 730
00150      707 DO 708 I=1,N
00160      708 A(I)=(LOGF((LOGF(A(I)))*(.43429448)))*(.43429448)
00170      GO TO 730
00180      709 DO 710 I=1,N
00190      710 A(I)=LOGF((1-A(I))/A(I))
00200      GO TO 730
00210      711 DO 712 I=1,N
00220      712 A(I)=2*ATANF(SQRTF(A(I)/(1-A(I))))
00230      GO TO 730
00240      713 PRINT 1000
00250      1000 FORMAT("SEND THE CONSTANT IN THE XFORM SQRTF(OBS+CONS)")
00260      INPUT,C0N
00270      DO 714 I=1,N
00280      714 A(I)=SQRTF(A(I)+C0N)
00290      730 RETURN

```

EXPLANATORY NOTES

LANGUAGE: FORTRAN

4.13 PROGRAM: SFD

LENGTH: 1800 CHAR.

SFD is a subroutine which is used in COMRAN. Its purpose is to perform statistical maneuvers such as running sums, running sums of squares, sums of differences squared, cubed, etc. This subroutine is automatically called from memory by COMRAN.

SFD

```

100      SUBROUTINE SFD
110      COMMON XT(300),N
120      DIMENSION R(20)
130      DO 30 J=1,19
140 30    R(J)=0
150      B=N
160      DO 100 J=1,N
170      R(1)=R(1)+XT(J)
180 100   R(19)=R(19)+(XT(J)**2)
190      R(5)=R(1)/B
200      DO 101 J=1,N
210      R(17)=R(17)+ABSF(XT(J)-R(5))
220      R(2)=R(2)+(XT(J)-R(5))**2
230      R(3)=R(3)+(XT(J)-R(5))**3
240 101   R(4)=R(4)+(XT(J)-R(5))**4
250      R(6)=R(2)/(B-1.)
260      R(7)=SQRTF(R(6))
270      R(8)=(B*R(3))/((B-1.)*(B-2.))
280      R(9)=R(8)/R(7)**3
290      R(10)=B*((B+1.)*(R(4))-(3.*(B-1.)*((R(2))**2/
300 +    B)))/((B-1.)*(B-2.)*(B-3.))
310      R(11)=R(10)/R(7)**4
320      R(12)=R(7)/R(5)
330      R(13)=SQRTF((6.*B*(B-1.))/((B-2.)*(B+1.)*(B+3.)))
340      R(14)=SQRTF((24.*B*(B-1.))**2/((B-3.)*(B-2.)*(B+3.)*
350 +    (B+5.)))
360      R(15)=R(9)/R(13)
370      R(16)=R(11)/R(14)
380      R(18)=((R(17)/B)/R(7))*SQRTF(B/(B-1))
390      PRINT 303,N,R(13),R(14)
391      PRINT 306,R(1),R(6),R(9),R(15),R(12),R(2)
392      PRINT 305
393      PRINT 306,R(5),R(7),R(11),R(16),R(18),R(19)
400 303   FORMAT(3X,4HN = ,I4,3X,6HSG1 = ,1PE13.6,3X,
410 +    6HSG2 = ,E13.6//4X,5HSUM X,10X,4HS**2,7X,6HGAMMA1,7X,2HT1,
420 +    8X,2HCV,6X,10HSUM(DEV+2))
460 305   FORMAT(/5X,4HXBAR,11X,1HS,9X,6HGAMMA2,7X,
470 +    2HT2,8X,1HA,7X,8HSUM(X+2))
480 306   FORMAT(1PE13.6,1X,E13.6,1X,E9.2,1X,E9.2,1X,E9.2,1X,E13.6)
500      RETURN

```

EXPLANATORY NOTES

LANGUAGE: FORTRAN

4.14 PROGRAM: SORTEM

LENGTH: 800 CHAR.

SORTEM is another subroutine which is automatically used in COMRAN. Its purpose is to merely rearrange input with the largest value first.

SORTEM

```
1'      FOR INFORMATION ABOUT THIS PROGRAM SEE STAN HILLIARD 733-4035
100      SUBROUTINE SORTEM(XBAR,N,VAR,SD,XN,M)
110      DIMENSION XBAR(100),SORTEM(100),NSEQ(15),VAR(15),SD(15),XN(15)
120      INTEGER P
130      P=M
140      DO 4000 I=1,P
150 4000  SORTEM(I)=XBAR(I)
160      SMAX=-9999999900000000
170      DO 4040 M=1,P
180      DO 4020 L=1,P
190      IF(SORTEM(L)-SMAX) 4020, 4020,4010
200 4010  SMAX=XBAR(L)
210      K=L
220 4020  CONTINUE
230      NSEQ(M)=K
240      SORTEM(K)=-9999999900000000
250      SMAX=-9999999900000000
260 4040  CONTINUE
270      DO 4050 M=1,P
280      J=NSEQ(M)
290 4050  PRINT,J,XN(J),XBAR(J),VAR(J),SD(J)
300      RETURN
```


EXPLANATORY NOTES

LANGUAGE: BASIC

4.15 PROGRAM: NORMAL

LENGTH: 1200 CHAR.

This program produces a table of normalization which can be used similar to the process of normalization used in TELPS 7. More precisely, the table serves as an off-line reference item. Data input at statement 380 consists of the averaged polynomial coefficients determined in SKRHO 4. Three modifications of the program were used to develop the tables shown in Volume 2, Section 3. One version, used to calculate normalization coefficients for resistance, follows this explanation.

NORMAL

```

100 DEF FNA(Z)=.001*INT(1000*Z+.5)
110 PRINT "RESISTANCE NORMALIZATION FACTOR FOR TH=1090 AND TC=520"
120 PRINT "FOR N-TYPE PBTE TYPE TPM-211."
130 PRINT
140 PRINT "TSUBH","C O L D   J U N C T I O N   T E M P E R A T U R E S"
150 PRINT
160 READ K(0),K(1),K(2),K(3),R(0),R(1),R(2),R(3)
170 READ C(0),H(0),H(1)
180 LET X(0)=0
181 LET Y(0)=0
190 FOR L=0 TO 3
200 LET X(0)=X(0)+K(L)*((1090+(L+1))-520+(L+1))/(L+1)
201 LET Y(0)=Y(0)+R(L)*((1090+(L+1))-520+(L+1))/(L+1)
210 NEXT L
220 PRINT "      ";
230 FOR C=C(0) TO C(0)+30 STEP 5
240 PRINT C;
250 PRINT "      ";
260 NEXT C
270 PRINT
280 FOR H=H(0) TO H(1) STEP 5
290 PRINT H;
300 FOR C=C(0) TO C(0)+30 STEP 5
310 LET X(1)=0
311 LET Y(1)=0
320 FOR L=0 TO 3
330 LET X(1)=X(1)+K(L)*((H+(L+1))-C+(L+1))/(L+1)
331 LET Y(1)=Y(1)+R(L)*((H+(L+1))-C+(L+1))/(L+1)
340 NEXT L
350 PRINT FNA((Y(0)/X(0))/(Y(1)/X(1)));
360 NEXT C
370 NEXT H
380 DATA 39.9441,-3.97937 E-2,-3.04405 E-6,2.46979 E-8
385 DATA 1.95306,3.23819 E-2,-6.06917 E-5,6.17310 E-8
390 DATA 490,1060,1120
400 END

```

EXPLANATORY NOTES

LANGUAGE: BASIC

4.16 PROGRAM: SHAPE

LENGTH: 2600 CHAR.

This program performs calculations to evaluate predicted values of physical dimensions, weights, leg geometries, and their time derivatives as function of time and hot junction temperature.

Data Input:

Measured values of dimensional and weight changes with time for a given hot junction temperature are first fit to a second order polynomial using POLFIT***.

Data is input as follows:

For N-Type legs:

740 DATA (Initial average hot junction diameter), (Initial average cold junction diameter), (Initial average length), (Initial average weight)

For T_h 1090°F:

750 DATA $R1_o$, $R1_1$, $R1_2$

760 DATA $R2_o$, $R2_1$, $R2_2$

770 DATA L_o , L_1 , L_2

780 DATA W_o , W_1 , W_2

where the $R1_o$, $R2_o$, L_o , W_o , etc., are the coefficients of the polynomials describing the change in dimension or weight with time.

Next four data statements include listing of coefficients for $T_h = 1220^\circ\text{F}$.

Next four data statements include listing of coefficients for $T_h = 1350^\circ\text{F}$.

Repeat entire data statement format for P-legs.

SHARP

```

90 FOR I=1 TO 6
100 PRINT "THE FOLLOWING PREDICTED PHYSICAL DIMENSIONS, WEIGHTS, AND THEIR"
110 PRINT "TIME AND LENGTH DERIVATIVES ARE BASED ON MEASUREMENTS MADE AT"
120 PRINT "ROOM TEMPERATURE AFTER VARIOUS GRADIENT TEST PERIODS TOTALING"
130 PRINT "ABOUT 2200 HOURS AT THE INDICATED HOT JUNCTION TEMPERATURES."
140 PRINT "LINEAR AND CUBIC TEMPERATURE EXPANSION EFFECTS HAVE NOT BEEN"
141 PRINT "INCLUDED."
142 PRINT
143 PRINT
170 READ X(0,1),X(0,2),X(0,3),X(0,4)
180 FOR K=1 TO 4
190 FOR J=1 TO 3
200 READ X(J,K)
210 NEXT J
220 NEXT K
230 FOR T=0 TO 2500 STEP 500
240 FOR K=1 TO 4
250 LET U(K)=X(0,K)+X(1,K)+X(2,K)*T+X(3,K)*T*T
260 LET V(K)=X(2,K)+2*X(3,K)
270 NEXT K
280 LET R=3.1416/12
290 LET W=(U(1)*U(1)+U(1)*U(2)+U(2)*U(2))
300 LET W1=R*U(3)*(2*U(1)+U(2))
310 LET W2=R*U(3)*(2*U(2)+U(1))
320 LET W3=W/U(3)
330 LET W4=W1*U(1)+W2*U(2)+W3*U(3)
340 LET P=(W*U(4)-U(4)*W4)/(W*W)
350 LET P1=P/U(3)
360 LET A=W/U(3)
370 LET A1=(U(3)*W4-W*U(3))/(U(3)*U(3))
380 LET A2=(A*U(3)-U(3)*A1)/(A*A)
390 IF I=1 THEN 450
400 IF I=2 THEN 470
410 IF I=3 THEN 480
420 IF I=4 THEN 510
430 IF I=5 THEN 530
440 IF I=6 THEN 550
450 PRINT "N-TYPE PRTG AT TH=1090 DEGS F AFTER "T;"HOURS."
460 GOTO 560
470 PRINT "N-TYPE PRTG AT TH=1220 DEGS F AFTER "T;"HOURS."
480 GOTO 560
490 PRINT "N-TYPE PRTG AT TH=1350 DEGS F AFTER "T;"HOURS."
500 GOTO 560
510 PRINT "P-TYPE PRTG AT TH=1090 DEGS F AFTER "T;"HOURS."
520 GOTO 560
530 PRINT "P-TYPE PRTG AT TH=1220 DEGS F AFTER "T;"HOURS."
540 GOTO 560
550 PRINT "P-TYPE PRTG AT TH=1350 DEGS F AFTER "T;"HOURS."
560 PRINT
570 PRINT "HOT END DIAMETER = ";U(1);" INCHES"
580 PRINT "LENGTH = ";U(3);" INCHES"
590 PRINT "L/A = ";U(3)/A;" INCHES/50 INCH"

```

```

600 PRINT "WEIGHT" = ";U(4);" GRAMS"
610 PRINT "VOLUME" = ";V;" "CU INCHES"
620 PRINT "DENSITY" = ";U(4)/V;" GRAMS/CU IN"
630 PRINT "DL/DT" = "W(3);" "INCHES/HOUR"
640 PRINT "D(D-HOT)/DT" = "W(1);" "INCHES/HOUR"
650 PRINT "DV/DT" = ";V4;" "CU IN/HR"
660 PRINT "DP/DT" = ";P;" "GMS/CU IN HR"
670 PRINT "DV/DL" = ";V4/W(3);" "CU INCHES/INCH"
680 PRINT "D(L*A0/LB*A)/DT" = ";A2*A/U(3)"
690 PRINT "DP/DL" = ";P1;" "GMS/INCH+4"
700 PRINT
710 PRINT
720 NEXT T
725 PRINT
726 PRINT
730 NEXT I
740 DATA .206302,.206302,.401496,1.75989774
750 DATA 2.70201E-4,3.03973E-6,-7.29713E-10
760 DATA 1.91693E-6,2.38951E-7,-7.64893E-11
770 DATA -3.21768E-4,-4.32640E-6,3.86831E-10
780 DATA 3.07675E-4,-1.18702E-5,-1.46794E-9
790 DATA .206302,.206302,.401496,1.75989774
800 DATA 2.55092E-4,2.88501E-6,-4.14526E-10
810 DATA 2.83336E-5,1.47437E-7,-7.11872E-11
820 DATA -8.72153E-4,-1.21847E-5,2.48067E-9
830 DATA -2.56712E-3,-8.88042E-5,3.10725E-8
840 DATA .206302,.206302,.401496,1.75989774
850 DATA 6.18344E-4,8.34300E-6,-1.37187E-9
860 DATA 1.43438E-4,4.00619E-7,-1.33671E-10
870 DATA -7.36354E-3,-3.11811E-5,8.83967E-10
880 DATA -3.41275E-2,-2.01205E-4,3.38337E-8
890 DATA .2458,.2458,.3939,2.08082
900 DATA 6.95362E-5,2.01910E-6,-7.23994E-10
910 DATA 3.99731E-5,6.20791E-7,-2.74755E-10
920 DATA -5.09385E-5,-9.16075E-7,6.70779E-11
930 DATA 3.73197E-4,-3.32497E-6,-1.38430E-9
940 DATA .2458,.2458,.3939,2.08082
950 DATA 4.60069E-4,5.65171E-6,-1.91286E-9
960 DATA 5.82532E-5,7.31491E-7,-2.69306E-10
970 DATA -4.02790E-4,-5.40961E-6,7.10360E-10
980 DATA -1.29966E-3,-3.47205E-5,6.36024E-9
990 DATA .2458,.2458,.3939,2.08082
1000 DATA 4.58355E-4,6.32483E-6,-1.95445E-9
1010 DATA 1.63294E-4,7.39769E-7,-2.77701E-10
1020 DATA -1.42255E-3,-2.20266E-5,5.22602E-10
1030 DATA -8.01125E-3,-2.55611E-4,6.39393E-8
1040 END

```