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SNAP-21 PROGRAM, PHASE II

DEEP SEA RADIOISOTOPE - FUELED THERMOELECTRIC GENERATOR POWER SUPPLY SYSTEM

QUARTERLY REPORT NO. 13

P3466

Space and Defense Products
ELECTRICAL PRODUCTS GROUP
3-M CENTER, ST. PAUL, MINN. 55101, PH 633-9400
3M COMPANY

Report No. MMM 3691-57

AEC RESEARCH AND DEVELOPMENT REPORT

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SNAP-21 PROGRAM, PHASE II

DEEP SEA RADIOISOTOPE - FUELED THERMOELECTRIC GENERATOR POWER SUPPLY SYSTEM

QUARTERLY REPORT NO. 13

Period Covered

July 1, 1969 to September 30, 1969

Prepared by

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Issued by

Space and Defense Products

MINNESOTA MINING AND MANUFACTURING COMPANY

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1.0 SUMMARY

Significant technical achievements on the SNAP-21 Program during this quarter include the following items:

- Completed Final Safety Analysis Report.
- Completed Revision 5 of Program Plan.
- Completed updating Task I System Drawings.
- Completed Hydrostatic Test of System S10P4.
- Completed Thermal and Electrical Characterization of System S10P4.
- Began Long-Term Test of System S10P4.
- System S10P3 was implanted off San Clemente Island.
- Continued testing of Phase I and Phase II Thermoelectric Generators.
- Continued testing of Phase II Systems, Power Conditioners and Insulation Systems.
- Phase I six-couple module A4 was removed from test.
- Recommended use of strontium oxide fuel form in 20-watt system.
- Proved feasibility of machine wrapping of a Task I biological shield configuration.
- Developed adjustable tie-rod design for 20-watt insulation system.
- Held Linde-3M Interface Meeting to establish Insulation System Design Parameters.

2.0 TASK I - 10-WATT SYSTEM

2.1 SYSTEMS

2.1.1 Electrically Heated Systems

2.1.1.1 System S10D2

System S10D2 continued on test this past quarter. Table 2-1 shows the thermoelectric generator and system electrical performance. Table 2-2 shows the thermal performance for the system. Figures 2-1 and 2-3 show performance curves for the system and the thermoelectric generator (A10D4). Figure 2-2 shows the system instrumentation locations. Table 2-3 shows the generator history. From the data it can be seen that the system performance is satisfactory.

The internal pressure of the generator continues to decrease but is decreasing at a slower rate than indicated in the previous quarterly report. As of September 23, 1969, the pressure was 18.25 psia as compared to 19.20 psia on June 27, 1969.

An evaluation of the total test history for TEG A10D4 has shown that the unit is performing as expected. During the first five thousand hours, some erratic changes occurred, but after integration into system S10D2 the performance for the TEG has been stable. The major changes (during the first five thousand hours) occurred in the "P" leg. The "N" leg has been fairly stable.

On September 22, 1969, the building power was interrupted for about 30 minutes. At this time periodic maintenance was being conducted on the emergency generator which resulted in a complete lack of power for about 8 minutes. Analysis of the data shows that there were no apparent effects on system S10D2 from this failure.

Table 2-1. System S10D2 Electrical Performance

Item	4/24/68	9/4/68	11/15/68	2/24/69	6/13/69	9/17/69
Test Hours	233	1,771	3,502	6,798	8,542	10,028
System Power Input (corrected-watts)	218	220	220	219	219	213.6
Generator Primary Load Voltage (vdc)	5.32	5.29	5.30	5.30	5.29	5.28
Generator Bias Load Voltage (vdc)	0.739	0.734	0.736	0.736	0.734	0.734
Generator Primary Load Current (amperes)	2.89	2.80	2.78	2.75	2.73	2.62
Generator Bias Load Current (amperes)	0.142	0.138	0.136	0.136	0.138	0.138
Generator Primary Power Output (watts)	15.3	14.8	14.7	14.6	14.4	13.86
Generator Bias Power Output (watts)	0.105	0.101	0.100	0.100	0.101	0.101
Generator Total Power Output (watts)	15.4	14.9	14.8	14.7	14.5	13.96
Conditioner Primary Voltage Input (vdc)	5.31	5.26	5.27	5.27	5.26	5.25
Conditioner Bias Voltage Input (vdc)	0.734	0.724	0.726	0.726	0.724	0.724
Conditioner Primary Current Input (amperes)	2.89	2.80	2.78	2.75	2.73	2.62
Conditioner Bias Current Input (amperes)	0.142	0.138	0.136	0.136	0.138	0.138
Conditioner Primary Power Input (watts)	15.2	14.7	14.6	14.5	14.4	13.78
Conditioner Bias Power Input (watts)	0.104	0.099	0.098	0.098	0.099	0.099
Conditioner Total Power Input (watts)	15.4	14.8	14.7	14.6	14.4	13.88
System Load Voltage (vdc)	24.6	24.5	24.48	24.48	24.49	24.50
System Load Current (amperes)	0.428	0.426	0.426	0.426	0.427	0.426
System Load (ohms)	57.48	57.38	57.5	57.5	57.35	57.51
System Power Output (measured) (watts)	10.5	10.5	10.4	10.4	10.4	10.4
Primary Open Circuit (volts)	9.46	9.40	9.30	9.22	9.16	8.94
Bias Open Circuit (volts)	1.39	1.37	1.37	1.35	1.35	1.31
Internal Resistance (ohms)	1.43	1.46	1.43	1.41	1.41	1.38
Bias Open Circuit (volts)	1.39	1.37	1.37	1.35	1.35	
Bias Load Voltage (volts)	0.739	0.734	0.736	0.736	0.734	
Bias Load Current (amps)	0.142	0.138	0.136	0.136	0.138	
Internal Resistance (ohms)	1.43	1.46	1.43	1.41	1.41	
Total Power Output (watts)	15.4	14.9	14.8	14.7	14.5	

Table 2-2. System S10D2 Temperature Profile in Water

Thermocouple Location (See Figure 2-2)	Identification	Pre Dynamic Test 4/28/68 (°F)	Post-Hydro Test 9/4/68 (°F)	Long-Term Test			
				11/15/68	2/24/69	6/13/69	9/17/69
1	Segmented Ring at Pressure Vessel Wall	39	43	45	40	43	43
2	TEG Mounting Plate (inner)	50	54	56	50	53	53
3	TEG Cold Frame Center (external)	58	63	65	59	62	62
4	TEG Hot Frame Center (external)	1042	1040	1041	1028	1026	1009
5	TEG Hot Frame Edge (external)	1047	1046	1046	1035	1033	1016
6	Emitter Center	1254	1277	1278	1267	1267	1252
7	Emitter Midway	1262	1287	1287	1276	1275	1260
8	Emitter Edge	1305	1332	1332	1321	1319	1303
9	Insulation System Upper	97	103	103	99	100	99
10	TEG Cold Frame Outer (external)	53	59	60	54	56	56
11	TEG Mounting Plate Male	42	47	49	42	45	45
12	Heater Block Bottom	1435	1470	1471	1458	1456	1439
13	Power Conditioner Base	44	41	-	-	-	-
14	Pressure Vessel, Cover Upper	40	40	41	40	41	40
15	Pressure Vessel, Cover Center	40	41	40	40	40	40
16	Pressure Vessel Body Lower	40	41	40	40	41	41
	TEG Hot Frame (internal) – Edge	1012	1014	1009	1002	1002	985
	TEG Hot Frame (internal) – Center	999	998	993	985	986	970
	Hot Button – Edge	999	1001	996	990	990	974
	Hot Button – Center	976	976	971	963	965	949
	Cold Button – Edge	95	98	96	94	96	94
	Cold Button – Center	91	94	93	91	93	92
	Cold Frame (internal) – Edge	82	83	82	80	81	81
	Cold Frame (internal) – Center	74	72	72	70	71	71
	Follower – Edge	81	84	83	81	83	82
	Follower – Center	80	81	81	80	81	80
17	Water – Top	40	40	39	40	40	40
18	Water – Middle	40	40	39	40	40	40
19	Water – Bottom	39	40	39	40	40	40

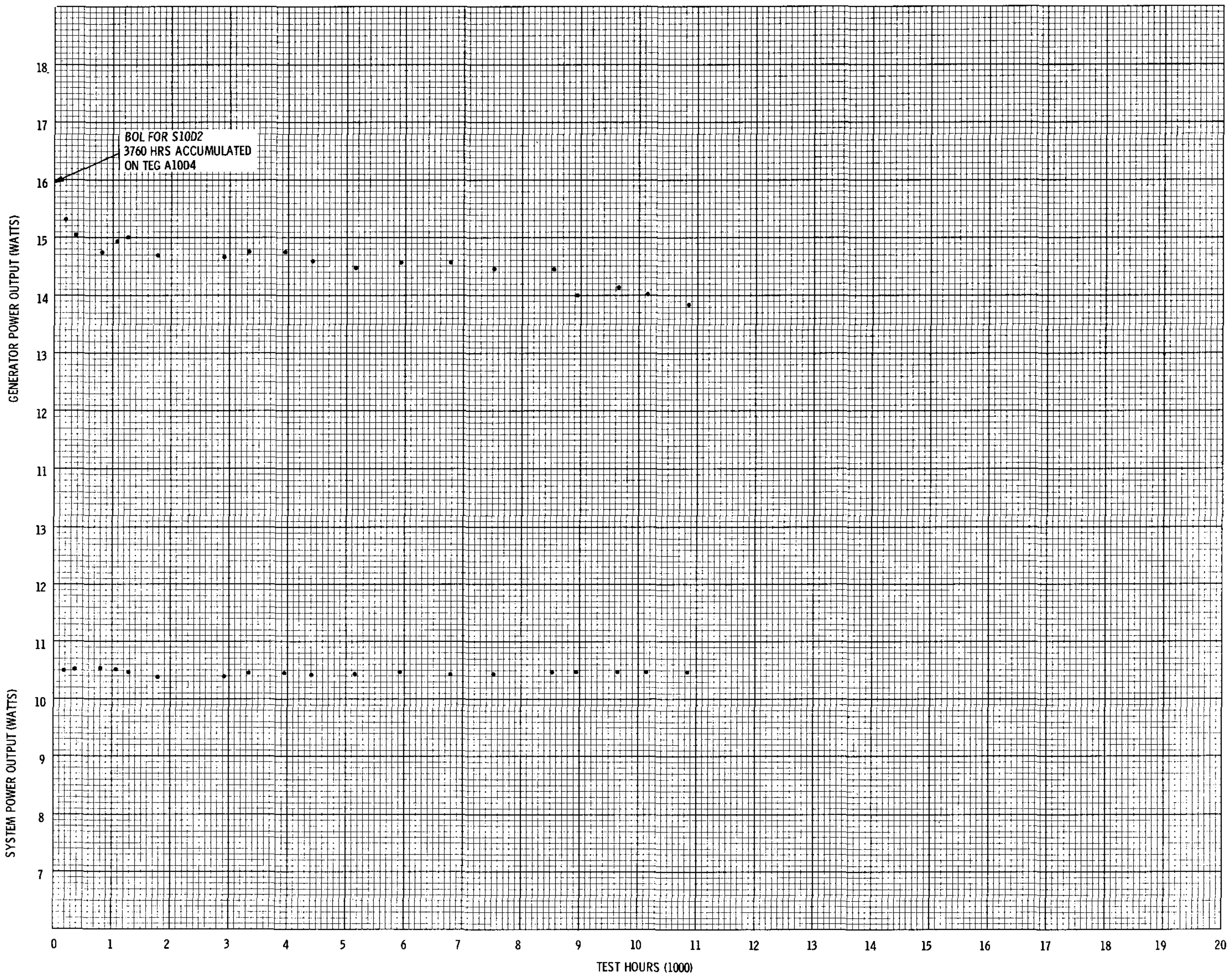


Figure 2-1. System S10D2 Performance

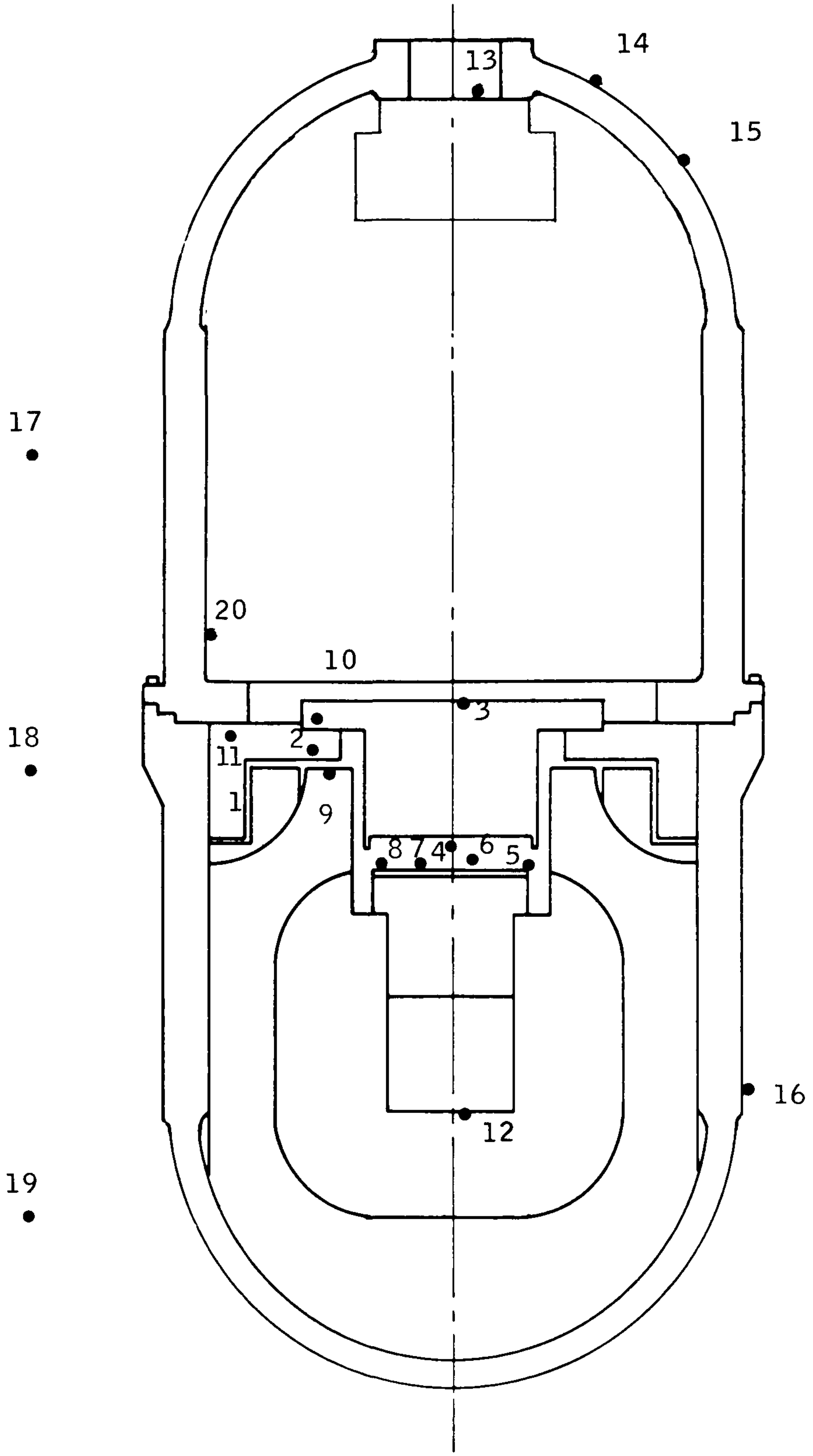


Figure 2-2. System S10D2 Instrumentation

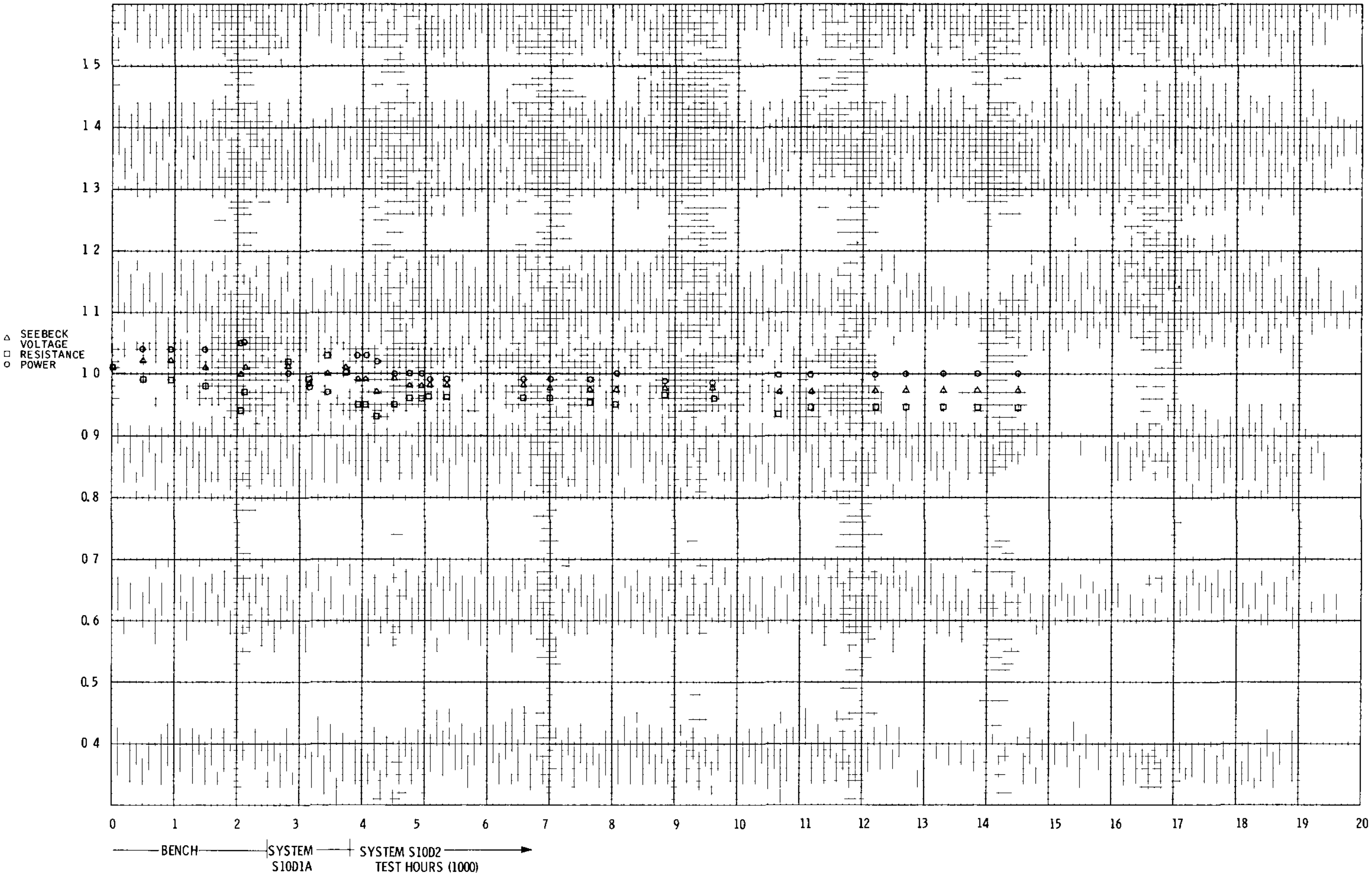


Figure 2-3. SNAP-21 Thermoelectric Generator A10D4 Normalized Data

Table 2-3. Generator A10D4 History

Date	Remarks
9/22/67	Power on BOL
9/25/67	TEG backfilled
9/26/67 – 9/29/67	Conax fittings retorqued daily and TEG backfilled on 9/28/69
10/7/67 – 10/9/67	TEG mapping
10/18/67	Conax fittings retorqued
10/25/67	Conax fittings retorqued
10/30/67	Conax fittings retorqued
12/20/67	Power turned off for integration into System S10D1(A)
1/19/68	TEG integrated into System S10D1(A)
3/11/68	TEG removed from A10D1(A)
3/19/68	Installed into efficiency fixture
4/1/68	Removed from efficiency fixture and awaited integration into System S10D2
4/18/68	Integrated into System S10D2

2.1.2 Fueled Systems

All 10-watt system drawings have been updated to reflect the actual configuration of the four fueled systems (S10P1, P2, P3, and P4).

2.1.2.1 System S10P1

See performance data in Section 2.10.

2.1.2.2 System S10P2

See performance data in Section 2.10.

2.1.2.3 System S10P3

System S10P3 was shipped to NRDL, Long Beach, California, on July 30, 1969. System identification, handling manuals, certifications and data accompanied the shipment. The performance data is shown in Section 2.10.

2.1.2.4 System S10P4

After shock and vibration was completed at Sandia, the system was shipped to Southwest Research Institute for hydrostatic testing. Testing was conducted on July 9, 1969. The system passed the hydrostatic test satisfactorily.

Upon completion of hydrostatic testing, the system was sent to 3M Company. At 3M Company S10P4 underwent System Load and Environmental Characteristics test and upon completion of these tests the system was put on long-term test.

Based on the System Load and Environmental Characteristic data, electrical and thermal performance of the final fueled 10-watt system was predicted for a range of "off-design" conditions. These predictions are analytical extrapolations of actual system test data. The analytical method used in making these predictions is fully described in Quarterly Report No. 12, 3691-52.

The system load and environmental test results are presented in Table 2-4. These curves which characterize the system both thermally and electrically are shown in Appendix A. Table 2-5 shows the performance history of system S10P4 and Figure 2-4 shows the general system instrumentation locations. The performance for the system has been stable.

2.2 BIOLOGICAL SHIELD

Upon completion of refurbishing of shield serial number 008 interface dimensions were checked and data forwarded to Manufacturing Engineering. (Shield is from destructed insulation system B10DL3.)

2.3 INSULATION SYSTEMS

2.3.1 Insulation System B10DL6

This insulation system continued on test this past quarter. Table 2-6 shows performance data for this unit. Refer to Figure 2-5 for location of the thermocouples. The power input was reduced to simulate the yearly fuel decay for generator A10P1 which is mated with this insulation system.

On September 22, 1969, the building power was interrupted for about 30 minutes. At this time periodic maintenance was being conducted on the emergency generator which resulted in a lack of power for about 8 minutes. Analysis of the data shows that there was no apparent effects on HTVIS B10DL6 from this failure.

2.4 THERMOELECTRIC GENERATOR

2.4.1 Phase I

Data collection and analysis of the Phase I 6-couple modules and prototype generators continued during this quarter. Performance data for 6-couple modules A1, A3, and A4 is given in Table 2-7 and Figures 2-6 through 2-8. Data from prototypes P5, P6, and P7 are given in Tables 2-8 through 2-10 and Figures 2-9 through 2-11.

Table 2-4. System Environmental and Characteristics Test Data – S10P4

		Thermoelectric Generator						System		
Water Temp	System Load (Ω)	Hot Frame Temp °F	Cold Frame Temp °F	Primary Load Voltage (V)	Primary Load Current (A)	Resis-tance (Ω)	Primary Power Out (W)	Load Voltage (V)	Load Current (A)	Power Out (W)
	37.0	1049	64	4.53	3.18	1.56	14.41	21.9	0.588	12.88
	42.0	1053	65	4.82	3.03	1.57	14.60	23.5	0.556	13.07
	47.0	1055	65	4.97	2.93	1.57	14.56	24.4	0.516	12.59
40°	51.1	1055	65	4.97	2.93	1.57	14.56	24.4	0.475	11.59
	57.6	1055	65	4.97	2.93	1.57	14.56	24.4	0.425	10.37
	65.0	1055	66	4.97	2.93	1.57	14.56	24.5	0.374	9.16
	80.0	1055	65	4.97	2.93	1.57	14.56	24.5	0.306	7.50
	37.0	1065	82	4.51	3.18	1.62	14.34	21.7	0.583	12.65
	42.0	1069	84	4.79	3.00	1.63	14.37	23.3	0.552	12.86
	47.0	1071	83	4.98	2.90	1.63	14.44	24.4	0.516	12.59
60°	51.1	1071	84	4.97	2.90	1.63	14.41	24.5	0.475	11.64
	57.6	1070	85	4.97	2.90	1.63	14.41	24.5	0.425	10.41
	65.0	1070	84	4.97	2.90	1.63	14.41	24.5	0.374	9.16
	80.0	1069	82	4.98	2.90	1.63	14.44	24.5	0.306	7.50
	37.0	1079	102	4.45	3.13	1.70	13.93	21.4	0.576	12.33
	42.0	1083	102	4.74	2.98	1.69	14.13	23.1	0.545	12.59
	47.0	1085	101	4.97	2.85	1.70	14.16	24.5	0.516	12.64
80°	51.1	1084	101	4.97	2.85	1.70	14.16	24.5	0.475	11.64
	57.6	1083	102	4.97	2.85	1.69	14.16	24.5	0.425	10.41
	65.0	1084	102	4.98	2.85	1.69	14.19	24.5	0.374	9.16
	80.0	1083	101	4.98	2.85	1.69	14.19	24.5	0.305	7.47

Table 2-5. Performance Data for System S10P4

Parameter	Pre Environmental BOL Performance	Stable Reference Performance	Stable Reference Performance	Pre Z Axis Shock and Vibration	Post Z Axis Shock and Vibration	Post Y Axis Shock and Vibration	Post Y Axis Shock and Vibration	Stable Reference Performance	Stable Reference Performance	Hydrostatic Pressure Test	Stable Reference Performance	Stable Reference Performance	Post Environmental BOL Performance	Long Term Performance	Thermocouple No Per Figure
Date Month/Day/Year	5/28/69	5/29/69	6/11/69	6/12/69	6/12/6[illegible]	6/12/69	6/13/6[illegible]	6/16/69	7/8/69	7/9/69	7/11/69	7/16/69	7/24/69	9/11/69	
System Fuel Input watts (t)	210 4	210 4	210 0	210 0	210 0	210 0	210 0	210 0	209 7	209 7	209 7	209 7	209 5	208 7	
Generator Primary Open Circuit (volts)	9 64	10 0	10 0	9 91	9 78	9 83	9 82	10 12	10 01	9 73	10 04	9 95	9 59	9 53	
Generator Bias Open Circuit (volts)	1 41	1 46	1 46	1 4[illegible]	1 44	1 44	1 44	1 48	1 46	1 42	1 46	1 45	1 40	1 40	
Generator Primary Load Voltage (vdc)	4 98	4 99	4 99	5 00	4 99	4 [illegible]8	4 [illegible]	4 99	5 00	5 01	5 00	4 97	4 97	4 97	
Generator Bias Load Voltage (vdc)	0 701	0 696	0 692	0 700	0 699	0 698	0 700	0 692	0 691	0 695	0 693	0 689	0 701	0 699	
Generator Primary Load Current (amps)	2 88	2 8[illegible]	2 83	[illegible] 90	2 88	2 88	2 88	2 83	2 85	3 00	2 85	2 85	2 93	2 93	
Generator Bias Load Current (amps)	0 118	0 124	0 1[illegible]4	0 12	0 122	0 122	0 122	0 126	0 126	0 118	0 126	0 124	0 120	0 120	
Generator Primary Power Output (watts)	14 3	14 2	14 1	14	14 4	14 3	14 4	14 1	14 2	15 0	14 2	14 2	14 6	14 6	
Generator Bias Power Output (watts)	0 083	0 086	0 086	0 085	0 08[illegible]	0 08[illegible]	0 08[illegible]	0 087	0 087	0 082	0 087	0 085	0 084	0 084	
Generator Total Power Output (watts)	14 4	14 3	14 2	14 6	14 [illegible]	14 4	14 [illegible]	14 2	14 3	15 1	14 3	14 3	14 7	14 7	
Generator Internal Resistance (ohms)	1 61	1 7[illegible]	1 77	1 68	1 65	1 67	1 67	1 80	1 75	1 56	1 76	1 73	1 57	1 55	
Conditioner Total Power Input (watts)	14 3	14 2	14 1	14 [illegible]	14 4	14 4	14 4	14 2	14 2	1[illegible] 0	14 2	14 2	14 6	14 6	
System Load Voltage (vdc)	24 5	24 5	24 6	24 [illegible]	[illegible]4 [illegible]	[illegible]4 4	24 [illegible]	24 6	24 6	24 6	24 6	24 4	24 4	24 4	
System Load Current (amps)	0 426	0 426	0 426	0 426	0 426	0 426	0 4[illegible]6	0 426	0 427	0 426	0 426	0 425	0 425	0 425	
System Power Output (watts)	10 4	10 4	10 5	10 4	10 4	10 4	10 4	10 5	10 5	10 5	10 5	10 4	10 4	10 4	
System Load Resistance (ohms)	57 5	57 5	57 7	[illegible]7 [illegible]	57 [illegible]	[illegible]7 3	57 [illegible]	57 7	57 6	57 7	57 7	57 4	57 4	57 4	
Seg Ret Ring at Pressure Vessel Wall (°F)	44	83	90	62	63	64	61	99	90	39	90	89	44	43	1
Seg Ret Ring Inner (°F)	57	96	10	78	79	80	77	111	101	51	101	101	57	[illegible]6	2
TEG Cold Frame Center (Ext) (°F)	6[illegible]	103	110	8[illegible]	87	87	8	119	109	58	109	108	6	64	3
TEG Hot Frame Center (Ext) (°F)	10[illegible]8	10[illegible]4	10 4	107	1071	107	1071	1103	1088	1048	1091	1090	1049	1045	4
TEG Hot Frame Edge (Ext) (°F)	1070	1106	110	108	1081	1083	1082	1112	1097	1059	1100	1100	1060	1054	5
Emitter Plate Center (°F)	1258	1 83	1284	1276	1270	1 70	1271	1292	1281	1254	1[illegible]84	1282	1258	1253	6
Reference (°F)	41	84	8[illegible]	68	69	6[illegible]	6	98	88	–	88	87	–	–	7
Water Top (°F)	40	–	–					–		39	–		42	40	8
Water Center (°F)	40	–								39	–	–	42	40	9
Water Bottom (°F)	40		–	–				–	–	39	–	–	42	40	10
Average Cold Junction (Estimated) (°F)	93	131	138	113	11[illegible]	11[illegible]	113	147	137	86	137	137	93	92	
Average Hot Junction (Estimated) (°F)	1004	1040	1041	1024	1017	10	1018	1049	1033	994	1306	1036	995	990	
Ambient (°F)	70	66	7	6	74	7[illegible]	74	77	70	87	70	74	–	–	
Test Hours	9	117	43	4 4	4 7	463	480	550	1103	1133	1173	1298	1585 5	2752 5	

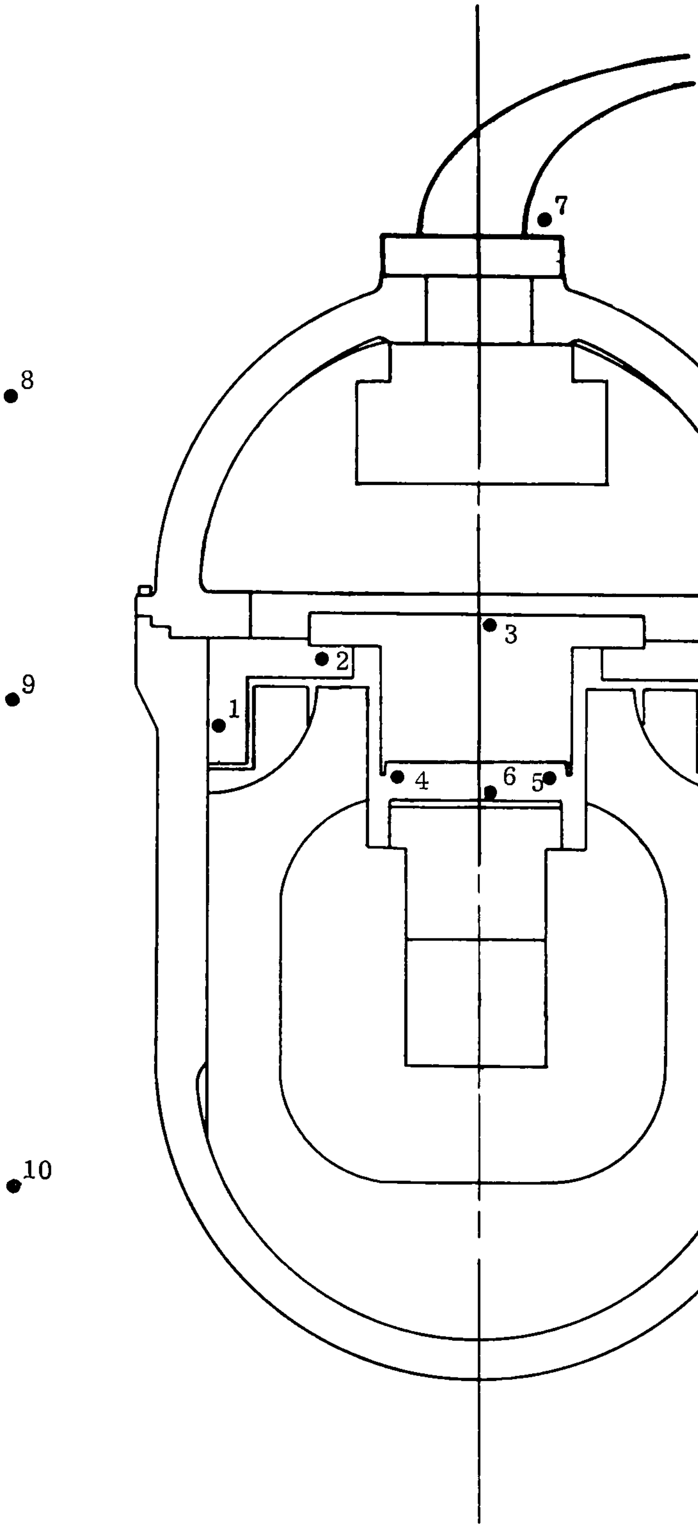
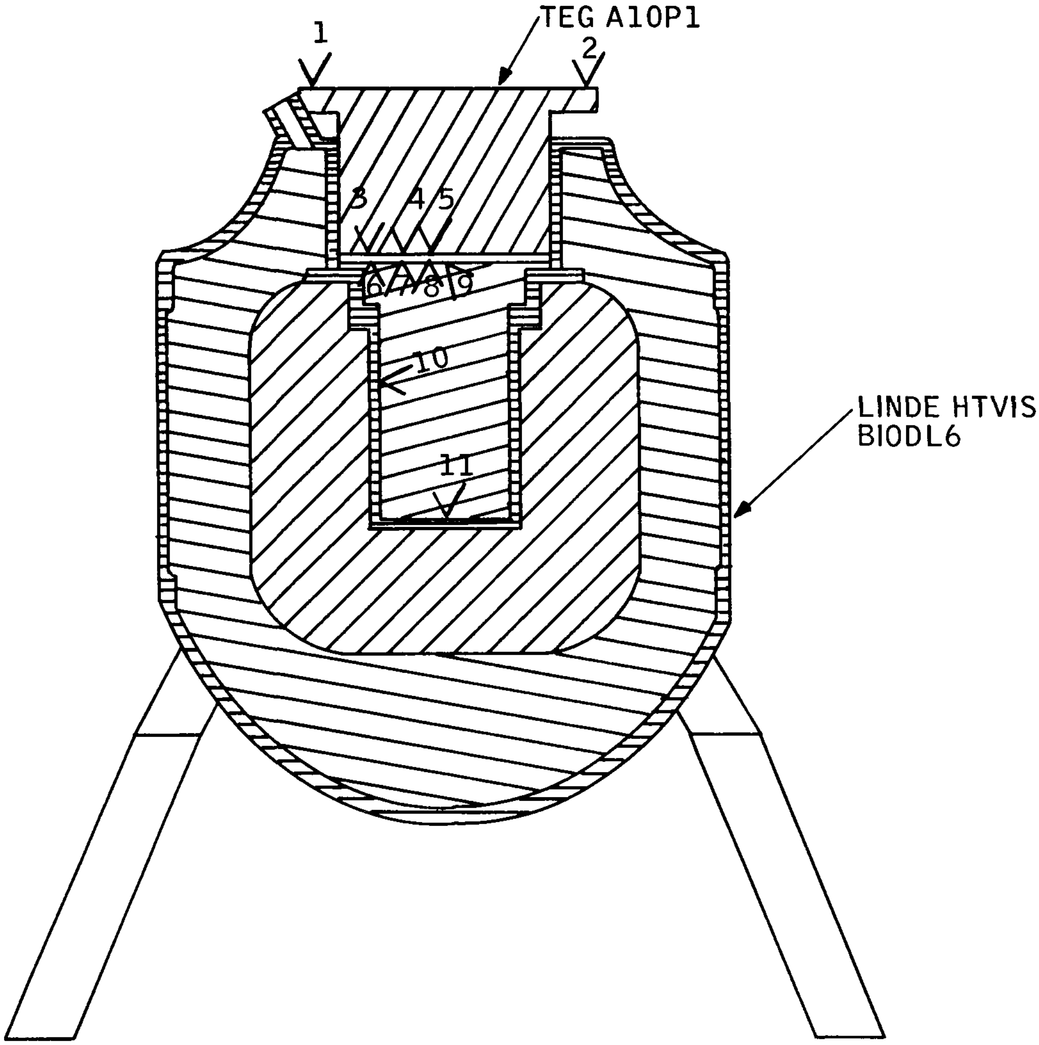


Figure 2-4. General System Instrumentation

Table 2-6. HTVIS B10DL6 Thermal Performance Data

Thermocouple Number Refer to Figure 2-9	Location	Performance Data			
		4/30/69	5/20/69	6/24/69	9/18/69
# 1	Cold Frame	83	88	81	81
# 2	Cold Frame	83	88	81	81
# 3	Hot Frame External Edge	1050	1043	1032	1013
# 4	Hot Frame External Middle	1068	1065	1053	1035
# 5	Hot Frame External Center	1046	1042	1028	1009
# 6	Emitter Top Edge	1249	1244	1233	1219
# 7	Emitter Top Middle	1266	1260	1250	1236
# 8	Emitter Top Center	1253	1248	1237	1223
# 9	Emitter Bottom Center	1273	1268	1257	1243
#10	Heater Block Side	1392	1387	1377	1362
#11	Heater Block Bottom	1406	1401	1391	1376
	Power Input	208	206	208*	203
	Test Hours	1344.5	1824	2664.5	4715.5

* Watt transducer was calibrated on 6/16/69 and was found to be reading 1.5 watts high.



√ CHROMEL-ALUMEL THERMOCOUPLES

Figure 2-5. Instrumentation for HTVIS B10DL6 and TEG A10P1

Table 2-7. Performance Data of SNAP-21 6-Couple Modules

Module	Date	T_h (°F, est)	T_c (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (milliohms)	P_I (watts)	Hours
A1	8-4-64	1100	115	1.31	0.66	1.96	1.29	342	38.0	192
	2-25-65	1100	114	1.35	0.68	2.09	1.41	323	39.0	5,112
	7-23-65	1100	114	1.35	0.67	2.00	1.34	341	37.0	8,664
	10-7-65	1100	113	1.35	0.68	1.97	1.33	342	38.0	10,488
	10-9-65			Power Input Reduced						
	10-9-65	1080	114	1.33	0.67	1.94	1.29	340	36.0	10,536
	4-14-66	1080	113	1.33	0.65	1.91	1.25	352	36.0	15,021
	10-13-66	1080	113	1.33	0.65	1.88	1.21	364	36.0	19,389
	10-13-66			Power Input Reduced						
	10-17-66	1060	113	1.29	0.64	1.84	1.17	355	36.0	19,485
	6-23-67	1060	115	1.29	0.63	1.83	1.15	361	36.0	25,581
	10-16-67	1060	115	1.30	0.64	1.86	1.18	356	36.0	28,341
	10-19-67			Power Input Reduced						
	10-25-67	1040	115	1.27	0.63	1.82	1.15	351	35.0	28,557
	3-20-68	1040	113	1.26	0.62	1.76	1.09	365	35.0	32,085
	8-27-68	1040	114	1.28	0.63	1.73	1.10	373	32.0	35,879
	9-16-68	1040	116	1.27	0.63	1.73	1.09	369	32.0	36,359
	10-21-68	1040	114	1.27	0.63	1.73	1.09	369	32.0	37,199
	11-25-68	1040	115	1.27	0.63	1.72	1.09	370	32.0	38,039
	12-9-68	1040	115	1.27	0.63	1.71	1.08	374	32.0	38,375
	12-9-68			Power Input Reduced						
	12-11-68	1020	116	1.24	0.62	1.67	1.03	374	35.0	38,423
	1-7-69	1020	115	1.24	0.62	1.71	1.06	362	35.0	39,071
	2-10-69	1020	116	1.24	0.63	1.69	1.06	364	35.0	39,887

Table 2-7. Performance Data of SNAP-21 6-Couple Modules (Continued)

Module	Date	T_h (°F, est)	T_c (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (milliohms)	P_I (watts)	Hours
A1	3-11-69	1020	115	1.24	0.62	1.69	1.05	367	35.0	40,583
	4-24-69	1020	115	1.24	0.62	1.69	1.05	367	35.0	41,639
	5-9-69	1020	115	1.24	0.61	1.67	1.03	375	35.0	41,999
	6-13-69	1020	115	1.24	0.61	1.67	1.02	375	35.0	42,839
	7-17-69	1020	115	1.24	0.62	1.68	1.04	371	35.0	43,655
	7-24-69	1020	115	1.24	0.62	1.68	1.04	371	35.0	43,823
	8-14-69	1020	115	1.24	0.61	1.66	1.02	378	35.0	44,327
	8-27-69	1020	115	1.24	0.61	1.66	1.02	378	35.0	44,663
	9-4-69	1020	115	1.24	0.61	1.67	1.02	375	34.0	44,855
	9-17-69	1020	115	1.24	0.62	1.67	1.03	374	34.0	45,167

Table 2-7. Performance Data of SNAP-21 6-Couple Modules (Continued)

Module	Date	T_h (°F, est)	T_c (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (milliohms)	P_I (watts)	Hours
A3	9-17-64	1106	114	1.35	0.65	1.93	1.26	360	–	72
	1-21-65	1100	111	1.35	0.69	2.10	1.44	316	45.0	3,096
	10-7-65	1100	119	1.35	0.67	1.91	1.27	359	47.0	9,312
	10-9-65			Power Input Reduced						
	10-9-65	1080	118	1.33	0.66	1.90	1.25	351	46.0	9,360
	5-27-66	1080	120	1.32	0.66	1.86	1.23	356	46.0	14,877
	10-13-66	1080	118	1.33	0.66	1.86	1.22	361	47.0	18,213
	10-13-66			Power Input Reduced						
	10-17-66	1060	118	1.30	0.65	1.84	1.20	353	46.5	18,309
	5-13-67	1060	119	1.30	0.65	1.84	1.20	356	47.0	23,241
	10-18-67	1060	119	1.31	0.65	1.82	1.18	364	47.0	27,081
	10-19-67			Power Input Reduced						
	10-25-67	1040	120	1.27	0.63	1.77	1.12	360	45.5	27,225
	5-10-68	1040	119	1.28	0.65	1.78	1.15	355	46.5	31,931
	8-13-68	1040	117	1.30	0.65	1.76	1.14	372	46.5	34,211
	9-16-68	1040	119	1.29	0.64	1.76	1.13	367	46.5	35,027
	10-21-68	1040	119	1.31	0.64	1.77	1.14	376	46.5	35,867
	11-7-68	1040	118	1.31	0.65	1.77	1.14	375	47.0	36,275
	12-9-68	1040	120	1.30	0.65	1.77	1.14	370	47.0	37,043
	12-9-68			Power Input Reduced						
	12-11-68	1020	117	1.28	0.63	1.74	1.10	371	45.5	37,091
	1-7-69	1020	117	1.28	0.63	1.74	1.10	372	45.5	37,739
	2-10-69	1020	117	1.28	0.64	1.71	1.09	374	45.5	38,555

Table 2-7. Performance Data of SNAP-21 6-Couple Modules (Continued)

Module	Date	T_h (°F, est)	T_c (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (milliohms)	P_I (watts)	Hours
A3	3-11-69	1020	116	1.28	0.64	1.72	1.10	371	45.5	39,251
	4-23-69	1020	116	1.29	0.64	1.71	1.10	379	46.0	40,283
	5-9-69	1020	115	1.29	0.64	1.71	1.10	378	46.5	40,643
	6-13-69	1020	115	1.30	0.64	1.72	1.11	382	46.5	41,483
	7-17-69	1020	115	1.31	0.65	1.72	1.11	387	47.0	42,299
	7-24-69	1020	115	1.31	0.65	1.72	1.11	387	47.0	42,467
	8-14-69	1020	115	1.29	0.64	1.70	1.08	384	46.0	42,971
	8-27-69	1020	115	1.29	0.64	1.70	1.08	384	46.0	43,283
	9-4-69	1020	115	1.29	0.64	1.70	1.08	385	46.0	43,475
	9-17-69	1020	115	1.28	0.63	1.70	1.08	381	46.0	43,787

Table 2-7. Performance Data of SNAP-21 6-Couple Modules (Continued)

Module	Date	T_h (°F, est)	T_c (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (milliohms)	P_I (watts)	Hours
A4	10-29-64	1099	115	1.39	0.70	2.22	1.54	312	45.0	240
	1-5-65	1100	114	1.39	0.72	2.30	1.66	291	48.0	1,872
	4-2-65	1100	115	1.39	0.70	2.36	1.64	294	47.0	3,960
	7-7-65	1100	116	1.39	0.69	2.16	1.50	322	46.0	6,264
	8-25-65	1100	114	1.39	0.69	2.15	1.48	327	45.0	7,440
	10-7-65	1100	117	1.39	0.68	2.14	1.46	330	44.0	8,472
	10-9-65			Power Input Reduced						
	10-9-65	1080	116	1.36	0.68	2.10	1.42	326	43.0	8,520
	11-16-65	1080	115	1.36	0.68	2.11	1.43	324	42.0	9,432
	1-27-66	1080	115	1.36	0.67	2.09	1.40	330	41.0	11,160
	5-26-66	1080	116	1.36	0.66	2.03	1.35	343	40.0	14,013
	10-13-66	1080	116	1.36	0.63	1.89	1.18	387	40.0	17,373
	10-13-66			Power Input Reduced						
	10-17-66	1060	117	1.31	0.62	1.87	1.15	373	39.0	17,469
	6-23-67	1060	117	1.29	0.66	2.30	1.52	274	39.0	23,385
	10-16-67	1060	117	1.30	0.68	2.38	1.63	259	40.0	26,169
	10-19-67			Power Input Reduced						26,241
	10-25-67	1040	116	1.27	0.64	2.44	1.55	259	39.0	26,385
	3-14-68	1040	118	1.25	0.60	2.26	1.36	287	39.0	29,769
	8-13-68	1040	117	1.24	0.62	2.28	1.42	271	39.5	33,571
	10-21-68	1040	119	1.24	0.61	2.20	1.33	288	39.5	35,027
	12-9-68	1040	117	1.24	0.56	2.04	1.15	332	39.5	36,203
	12-9-68			Power Input Reduced						
	12-11-68	1020	112	1.22	0.56	2.03	1.13	327	38.8	36,251

Table 2-7. Performance Data of SNAP-21 6-Couple Modules (Continued)

Module	Date	T_h (°F, est)	T_c (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (milliohms)	P_I (watts)	Hours
A4	1-17-69	1020	115	1.22	0.61	1.44	0.871	427	37.5	37,139
	2-26-69	1020	115	1.23	0.45	0.993	0.450	782	37.0	38,099
	3-11-69	1020	115	1.22	0.04	0.081	0.003	14,590	37.0	38,411
	3-18-69	1020	115	1.22	0.03	0.061	0.002	18,880	37.0	38,579
	4-9-69	1020	115	1.05	0.51	0.743	0.378	730	37.0	39,107
	4-23-69	Shorted Out Couple No. 1 Because of High Resistance								
	4-24-69	1020	114	1.03	0.087	0.413	0.036	2,280	37.0	39,467
	4-30-69	1020	115	1.01	0.015	0.073	0.001	13,630	37.0	39,611
	5-9-69	1020	114	1.00	0.006	0.029	0.0002	34,280	37.0	39,827
	5-20-69	1020	116	1.02	0.0075	0.036	0.0003	28,130	37.0	40,091
	6-13-69	1020	115	0.977	0.0026	0.013	0.00003	74,950	37.0	40,667
	6-18-69	1020	115	0.978	0.0025	0.012	0.00003	81,290	37.0	40,787
	7-17-69	1020	115	0.959	0.0017	0.008	0.00001	119,600	37.0	41,483
	7-24-69	1020	115	0.960	0.0018	0.009	0.00001	106,470	37.0	41,651
	7-24-69	Power Turned Off (Test Terminated)								

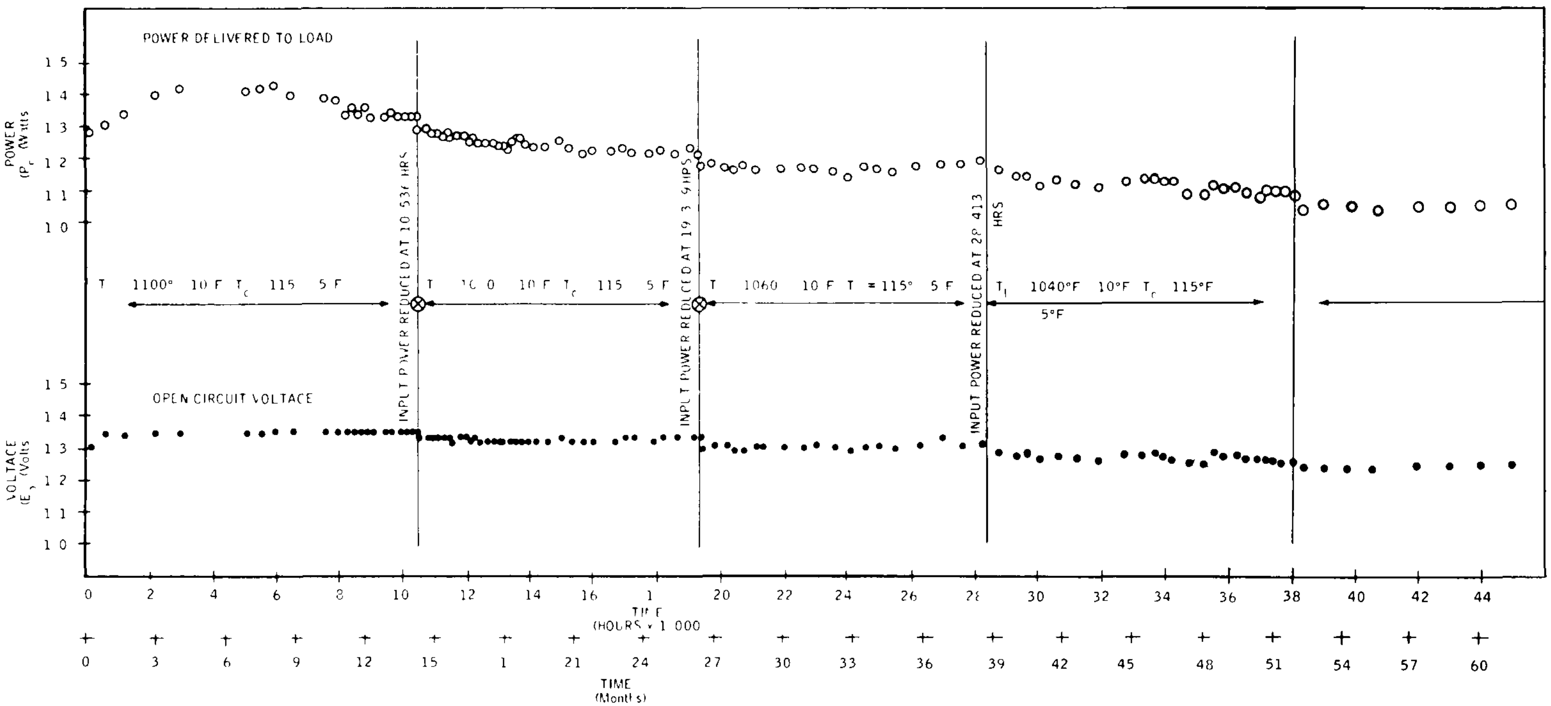


Figure 2-6. SNAP-21B 6-Couple Module A1

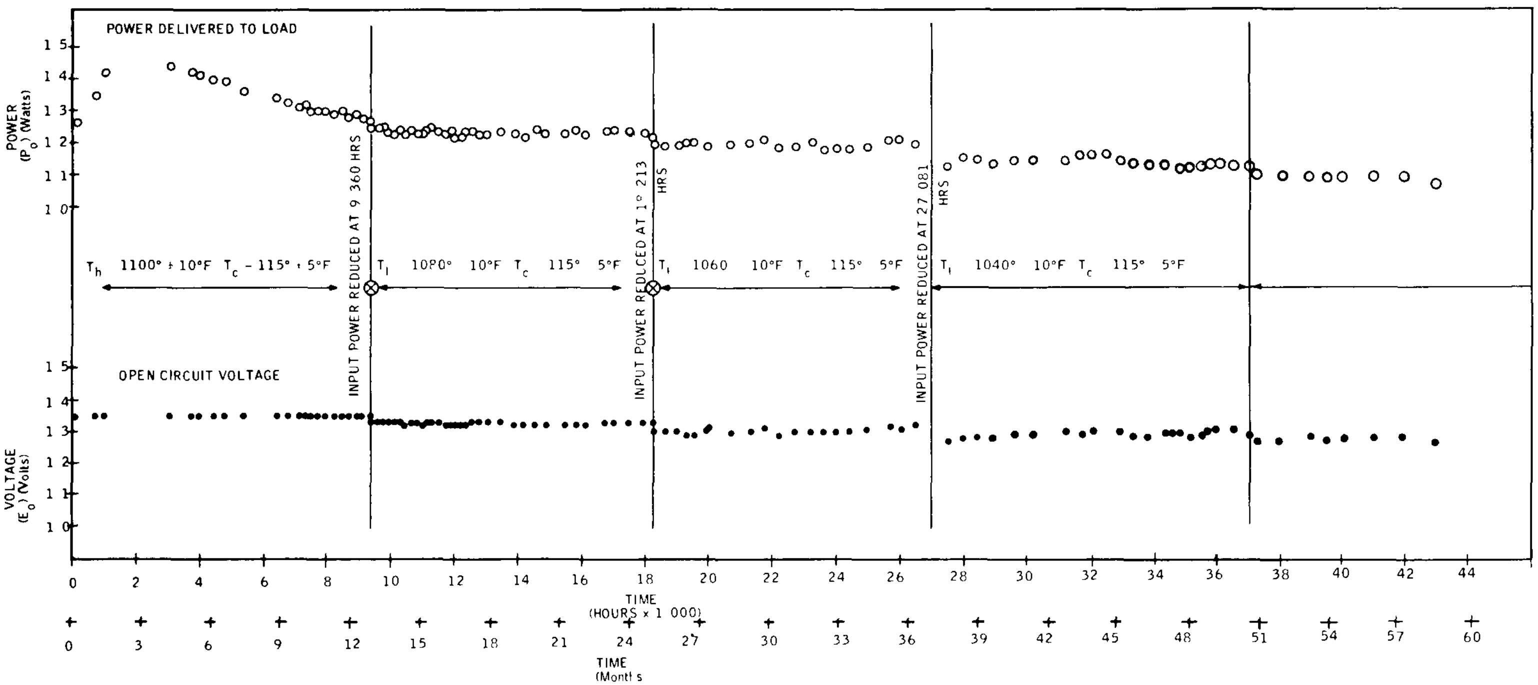


Figure 2-7. SNAP-21B 6-Couple Module A3

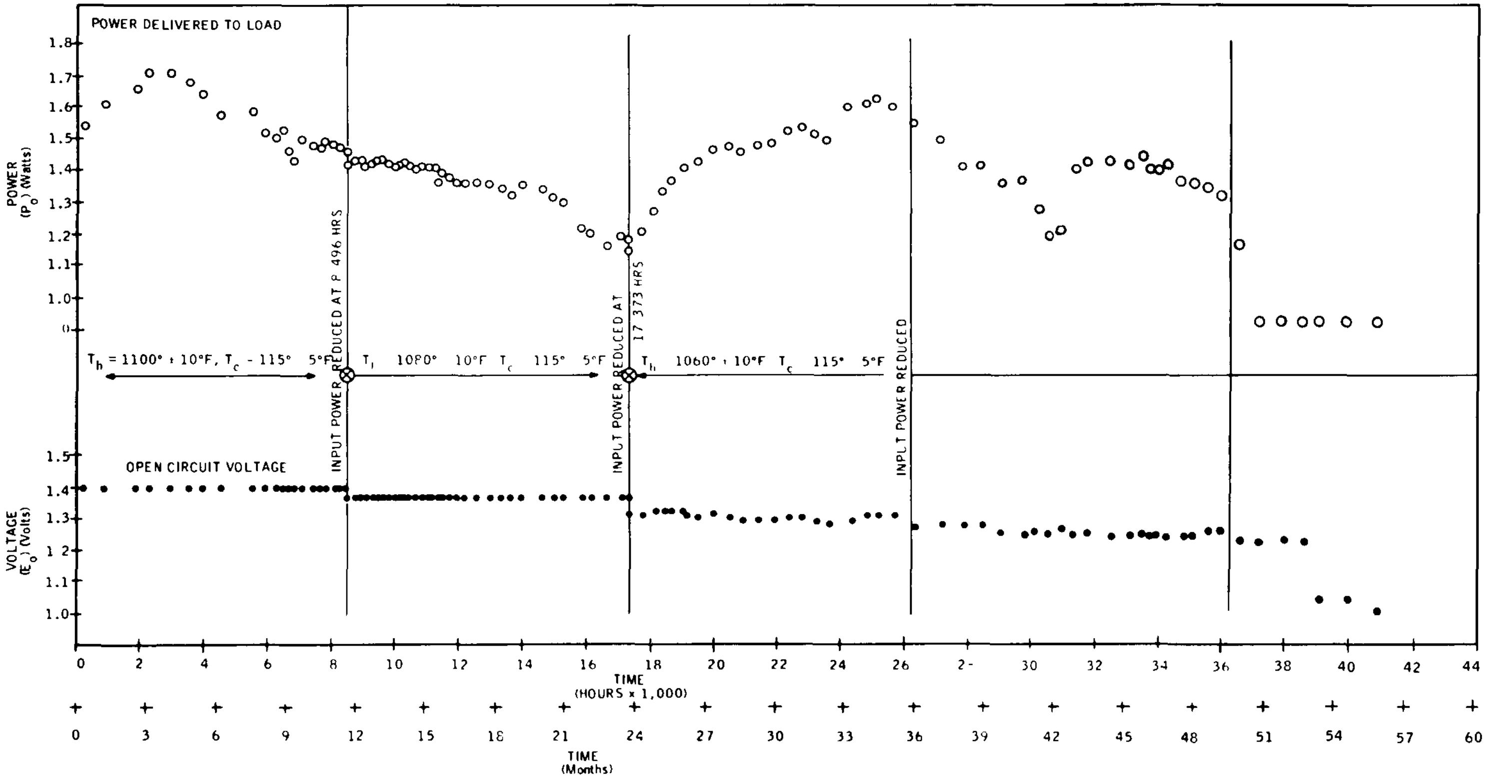


Figure 2-8. SNAP-21B 6-Couple Module A4

Table 2-8. Typical Performance Data SNAP-21B Prototype P5*

Date	T_h[1] (°F)	T_c[2] (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (ohms)	P_I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
4-19-65	1112	117	11.20	5.60	2.04	11.42	2.74	—	0.99	1.26	0.78	24
5-12-65	1115	127	10.92	5.46	2.00	10.92	2.73	—	0.97	1.24	0.77	576
6-30-65	1097	135	10.65	5.32	2.02	10.74	2.64	176	0.97	1.20	0.78	1,320
7-26-65	1097	142	10.68	5.34	2.01	10.72	2.66	176	0.98	1.21	0.79	1,944
9-10-65	1095	144	10.60	5.30	2.06	10.92	2.57	—	0.97	1.17	0.81	3,048
10-26-65	1097	147	10.56	5.28	2.05	10.81	2.58	180	0.97	1.16	0.82	4,152
12-1-65	1102	151	10.58	5.29	2.10	11.11	2.52	—	0.98	1.13	0.84	5,016
1-28-66	1094	149	10.56	5.28	2.14	11.30	2.47	180	0.98	1.11	0.86	6,408
3-28-66	1094	152	10.54	5.27	2.16	11.38	2.44	180	0.98	1.10	0.87	7,821
4-28-66	1074	151	10.20	5.10	2.19	11.17	2.33	176	0.97	1.07	0.87	8,565
6-21-66	1073	151	10.24	5.00	2.18	10.90	2.40	174	0.97	1.10	0.86	9,834
8-12-66	1078	161	10.15	5.07	2.20	11.15	2.30	178	0.97	1.04	0.89	11,081
9-14-66	1075	161	10.16	5.07	2.19	11.10	2.32	175	0.97	1.06	0.89	11,873
12-27-66	1077	153	10.22	5.11	2.19	11.19	2.33	184	0.97	1.07	0.87	14,369
1-31-67	1073	159	10.12	5.06	2.20	11.13	2.30	179	0.96	1.05	0.90	15,209
4-1-67	1074	148	10.20	5.10	2.24	11.42	2.28	175	0.97	1.05	0.89	16,649
5-24-67	1076	150	10.28	5.14	2.20	11.31	2.34	179	0.97	1.08	0.88	17,921
6-30-67	Power Failure, Emergency Power Came On at 8:28 PM to 10:30 PM											
7-1-67	1067	159	10.00	5.00	2.19	10.95	2.28	175	0.95	1.00	0.88	18,833
9-26-67	1068	160	10.04	5.02	2.17	10.89	2.31	172	0.96	1.05	0.88	20,921

*Begin test on 4-19-65. Turned off from 5-20-65 to 6-7-65.

[1] Based on average of two N-leg Seebeck voltages.

[2] Based on average of four cold electrode thermocouples.

Table 2-8. Typical Performance Data SNAP-21B Prototype P5* (Continued)

Date	T_h [1] (°F)	T_c [2] (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (ohms)	P_I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
11-6-67	1067	158	10.08	5.04	2.19	11.04	2.30	174	0.96	1.00	0.89	21,953
12-29-67	1066	150	10.20	5.10	2.22	11.32	2.30	175	0.97	1.06	0.90	23,225
1-15-68	Power Failure, Emergency Power Came On for One Hour											
1-30-68	1070	151	9.90	4.95	2.21	10.94	2.26	175	0.94	1.01	0.87	23,993
2-17-68	Power Failure, Emergency Power Came On for Five Hours											
2-19-68	1068	149	10.10	5.05	2.17	10.96	2.33	177	0.96	1.00	0.87	24,473
5-22-68	1077	154	10.02	5.02	2.22	11.14	2.25	176	0.95	1.04	0.87	26,705
6-17-68	1042	157	9.92	4.96	2.14	10.61	2.32	171	0.98	1.06	0.90	27,329
6-17-68	Reduced Input Power											
8-13-68	1044	166	9.80	4.90	2.09	10.24	2.34	169	0.98	1.14	0.87	26,697
11-6-68	1052	162	9.76	4.88	2.10	10.25	2.32	170	0.97	1.13	0.87	30,737
12-16-68	1052	152	9.86	4.93	2.15	10.60	2.29	170	0.97	1.13	0.86	31,697
1-16-69	1052	151	9.88	4.94	2.12	10.47	2.33	170	0.97	1.13	0.87	32,441
1-27-69	Regulator Failure, Power Increased for 12 Hours											
2-10-69	1052	149	9.88	4.94	2.21	10.92	2.24	171	0.97	1.10	0.88	33,041
4-24-69	1050	152	9.78	4.89	2.18	10.66	2.24	172	0.96	1.09	0.86	34,649
6-12-69	1052	160	9.80	4.89	2.16	10.56	2.27	172	0.97	1.10	0.88	35,825
6-17-69	1052	161	9.80	4.85	2.16	10.48	2.29	172	0.97	1.11	0.87	35,945
6-17-69	Reduced Input Power											
6-18-69	1032	159	9.57	4.77	2.14	10.21	2.24	168	0.97	1.11	0.88	35,969

*Begin test on 4-19-65. Turned off from 5-20-65 to 6-7-65.

[1] Based on average of two N-leg Seebeck voltages.

[2] Based on average of four cold electrode thermocouples.

Table 2-8. Typical Performance Data SNAP-21B Prototype P5* (Continued)

Date	T_h[1] (°F)	T_c[2] (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (ohms)	P_I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
7-15-69	1032	162	9.54	4.78	2.11	10.09	2.26	167	1.00	1.12	0.89	36,617
7-29-69	1032	164	9.53	4.78	2.10	10.04	2.26	167	1.00	1.12	0.88	36,953
8-14-69	1032	167	9.54	4.78	2.07	9.89	2.30	165	1.00	1.15	0.87	37,337
8-28-69	1032	166	9.53	4.78	2.09	9.99	2.27	165	1.00	1.14	0.88	37,673
9-4-69	1032	167	9.56	4.78	2.09	9.99	2.29	165	1.00	1.15	0.88	37,841
9-15-69	1032	166	9.54	4.76	2.09	9.95	2.29	165	1.00	1.15	0.88	38,105

*Begin test on 4-19-65. Turned off from 5-20-65 to 6-7-65.

[1]Based on average of two N-leg Seebeck voltages.

[2]Based on average of four cold electrode thermocouples.

Table 2-9. Typical Performance Data SNAP-21B Prototype P6*

Date	T_h [1] (°F)	T_c [3] (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (ohms)	P_I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
6-2-65	1095[1]	132	10.88	5.44	2.58	14.03	2.10	204	1.03	1.02	1.02	24
6-30-65	1095[2]	145	10.88	5.44	2.34	12.73	2.32	206	1.04	1.11	0.96	720
7-29-65	1095[2]	157	10.88	5.44	2.28	12.40	2.38	—	1.04	1.13	0.96	1,416
9-1-65	1095[2]	162	10.80	5.40	2.20	11.88	2.45	201	1.04	1.16	0.93	2,184
11-17-65	1095[2]	169	10.80	5.40	2.16	11.66	2.50	201	1.05	1.16	0.94	4,032
12-28-65	1095[2]	171	10.78	5.39	2.18	11.75	2.47	200	1.05	1.15	0.95	5,016
3-28-66	1095[2]	171	10.74	5.39	2.13	11.44	2.52	197	1.04	1.17	0.92	7,173
8-12-66	1075[2]	181	10.52	5.23	2.05	10.72	2.58	191	1.05	1.20	0.92	10,452
12-27-66	1075[2]	176	10.82	5.41	2.09	11.28	2.59	192	1.07	1.22	0.95	13,740
1-27-67	1075[2]	176	10.84	5.42	2.10	11.38	2.58	199	1.08	1.22	0.96	14,484
4-27-67	1075[4]	168	10.38	5.19	2.07	10.72	2.51	194	1.03	1.20	0.89	16,524
6-16-67	1075[4]	176	10.58	5.29	2.05	10.84	2.58	194	1.05	1.23	0.90	17,844
6-22-67	Power Input Reduced							186				17,988
6-30-67	1055[4]	Bldg. Power Failure, Emergency Power for Approx. 2 Hours										
7-1-67	1055[4]	172	10.10	5.05	2.04	10.28	2.48	184	1.03	1.20	0.88	18,204
9-26-67	1055[4]	175	10.08	5.04	2.02	10.18	2.50	186	1.03	1.21	0.88	20,292
11-6-67	1055[4]	172	10.08	5.04	2.02	10.18	2.50	185	1.03	1.21	0.87	21,324
11-30-67	1055[4]	166	10.00	5.00	2.04	10.20	2.45	190	1.02	1.20	0.86	21,900

*Begin test 6-1-65.

[1] Based on average of two hot electrode thermocouples.

[2] Based on hot frame thermocouple referenced to 6-2-65.

[3] Based on average of two cold electrode thermocouples.

[4] Based on average input power from 6-5-66 to 12-27-66.

Table 2-9. Typical Performance Data SNAP-21B Prototype P6* (Continued)

Date	T_h[1] (°F)	T_c[3] (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (ohms)	P_I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
1-15-68	Bldg.	Power Was Off – Emergency Power Came On for One Hour										
1-17-68	1055[2]	166	10.04	5.02	2.03	10.19	2.47	192	1.02	1.20	0.86	23,052
2-17-68	Bldg.	Power Was Off – Emergency Power Came On for 5 Hours										
3-14-68	1055[2]	171	10.02	5.01	2.04	10.22	2.46	192	1.02	1.19	0.88	24,420
5-9-68	1055[2]	169	10.00	5.00	2.04	10.20	2.45	192	1.01	1.19	0.87	25,764
7-10-68	1035[2]	173	9.76	4.88	1.97	9.61	2.48	188	1.03	1.23	0.87	27,252
9-16-68	1035[2]	175	9.76	4.88	1.98	9.66	2.46	188	1.03	1.22	0.87	28,884
5-9-68	1055	169	10.00	5.00	2.04	10.20	2.45	192	1.01	1.19	0.87	25,764
6-17-68	Reduced Input Power											
7-10-68	1035[2]	173	9.76	4.88	1.97	9.61	2.48	188	1.03	1.23	0.87	27,252
9-16-68	1035[2]	175	9.76	4.88	1.98	9.66	2.46	188	1.03	1.22	0.87	28,884
12-16-68	1035[2]	165	9.80	4.89	2.00	9.78	2.46	188	1.03	1.23	0.87	31,068
1-16-69	1035[2]	165	9.83	4.90	2.00	9.80	2.47	188	1.03	1.24	0.87	31,812
1-27-69	Regulator Failure,		Power Increased for 12 Hours									
2-10-69	1035[2]	164	9.83	4.91	2.05	10.07	2.40	188	1.03	1.20	0.89	32,412
4-24-69	1035[2]	168	9.80	4.90	2.04	10.00	2.40	190	1.03	1.19	0.89	34,020
5-9-69	1035[2]	171	9.81	4.90	2.04	10.00	2.41	190	1.03	1.20	0.89	34,380
6-17-69	1035[2]	178	9.82	4.92	2.01	9.89	2.44	190	1.04	1.20	0.87	35,316
6-17-69	Reduced Input Power											

*Begin test 6-1-65.

[1] Based on average of two hot electrode thermocouples.

[2] Based on average input power from 6-5-66 to 12-27-66.

[3] Based on average of two cold electrode thermocouples.

Table 2-9. Typical Performance Data SNAP-21B Prototype P6* (Continued)

Date	T_h[1] (°F)	T_c[3] (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (ohms)	P_I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
6-18-69	1015[2]	175	9.55	4.77	1.99	9.49	2.40	185	1.04	1.20	0.88	35,340
7-15-69	1015[2]	179	9.57	4.75	2.00	9.50	2.41	185	0.99	1.19	0.89	35,988
7-29-69	1015[2]	180	9.55	4.73	1.99	9.41	2.42	185	0.99	1.19	0.88	36,325
8-14-69	1015[2]	184	9.52	4.71	1.98	9.33	2.43	185	0.99	1.19	0.89	36,708
8-28-69	1015[2]	184	9.52	4.70	1.98	9.31	2.43	185	0.99	1.19	0.89	37,044
9-4-69	1015[2]	184	9.52	4.70	1.99	9.35	2.42	185	0.99	1.19	0.89	37,212
9-15-69	1015[2]	184	9.53	4.70	1.98	9.31	2.44	185	0.99	1.20	0.89	37,476

*Begin test 6-1-65.

[1] Based on average of two hot electrode thermocouples.
[2] Based on average input power from 6-5-66 to 12-27-66.
[3] Based on average of two cold electrode thermocouples.

Table 2-10. Typical Performance Data SNAP-21B Prototype P7*

Date	T_h[1] (°F)	T_c[2] (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (ohms)	P_I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
6-8-65	1099[1]	127	10.80	5.40	2.44	13.17	2.21	200	1.01	1.08	0.95	168
7-14-68	1098[1]	142	10.80	5.40	2.21	11.95	2.44	194	1.01	1.18	0.88	1,032
8-24-65	1100[3]	152	10.82	5.41	2.13	11.52	2.54	192	1.03	1.21	0.88	1,968
10-12-65	1100[3]	156	10.86	5.43	2.11	11.47	2.57	194	1.04	1.22	0.82	3,144
12-28-65	1095[3]	159	10.78	5.39	2.07	11.16	2.60	191	1.04	1.23	0.88	4,992
2-10-66	1095[3]	158	10.82	5.41	2.06	11.14	2.63	191	1.04	1.24	0.88	6,048
5-16-66	1095[3]	163	10.82	5.41	2.02	10.93	2.68	189	1.04	1.26	0.86	8,324
6-4-66	Reduced Input Power											
6-21-66	1075[3]	158	10.72	5.40	1.99	10.75	2.67	186	1.06	1.28	0.87	9,181
6-28-66	Moved Test from T.C.A. to Space Center											
8-12-66	1075[3]	173	10.56	5.26	1.96	10.31	2.55	188	1.05	1.26	0.86	10,428
10-3-66	1075[3]	178	10.62	5.31	1.95	10.35	2.72	185	1.05	1.27	0.89	11,676
12-28-66	1075[4]	165	10.70	5.35	1.94	10.37	2.76	186	1.05	1.31	0.84	13,760
3-13-67	1075[4]	173	10.60	5.30	1.94	10.26	2.74	186	1.06	1.29	0.86	15,560
5-13-67	1075[4]	175	10.61	5.30	1.91	10.11	2.78	186	1.06	1.31	0.85	17,024
6-22-67	Input Power was Reduced											
6-23-67	1055[4]	171	10.30	5.15	1.91	9.84	2.70	180	1.05	1.31	0.84	18,008
6-30-67	Bldg. Power Failure, Emergency Power was on for Approx. 2 Hours											
7-1-67	1055[4]	165	10.30	5.15	1.86	9.58	2.77	180	1.05	1.35	0.81	18,192
9-26-67	1055[4]	166	10.26	5.13	1.92	9.85	2.67	179	1.04	1.30	0.83	20,286

*Begin test 6-2-65.

[1] Based on average of two hot electrode thermocouples.
[2] Based on average of two cold electrode thermocouples.
[3] Based on hot frame thermocouple referenced to 6-30-65.
[4] Based on average input power from 7-13-66 to 11-12-66.

Table 2-10. Typical Performance Data SNAP-21B Prototype P7* (Continued)

Date	T_h[1] (°F)	T_c[2] (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (ohms)	P_I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
10-20-67	1055[4]	171	10.14	5.07	1.91	9.68	2.65	176	1.03	1.29	0.83	21,091
1-15-68	Bldg. Power was off-Emergency Power came on for One Hour											
1-17-68	1055[4]	169	10.40	5.20	1.92	9.98	2.71	177	1.06	1.32	0.85	23,203
2-17-68	Bldg. Power was off-Emergency Power came on for about 5 Hours											
2-19-68	1055[4]	164	10.20	5.10	1.92	9.79	2.66	180	1.04	1.30	0.83	23,997
4-18-68	1055[4]	177	10.20	5.10	1.93	9.84	2.64	189	1.04	1.28	0.85	25,384
6-17-68	1055[4]	182	9.94	4.97	1.90	9.44	2.62	176	1.02	1.26	0.83	26,853
6-17-68	Reduced Power Input											
8-13-68	1035[4]	177	9.78	4.89	1.91	9.34	2.56	174	1.04	1.27	0.85	28,221
9-16-68	1035[4]	173	9.75	4.88	1.90	9.27	2.56	174	1.03	1.27	0.84	29,037
12-16-68	1035[4]	159	9.83	4.93	1.88	9.27	2.61	174	1.03	1.30	0.82	31,221
1-16-69	1035[4]	159	9.88	4.94	1.92	9.48	2.57	174	1.04	1.30	0.84	31,965
1-27-69	Regulator Failure, Power Increased for 12 Hours											
2-10-69	1035[4]	158	9.90	4.94	1.96	9.68	2.53	175	1.04	1.28	0.85	32,565
3-10-69	1035[4]	162	9.91	4.94	1.97	9.73	2.52	175	1.04	1.27	0.86	33,237
5-19-69	1035[4]	164	9.83	4.92	1.93	9.54	2.54	175	1.03	1.27	0.84	34,773
6-17-69	1035[4]	171	9.84	4.92	1.91	9.40	2.58	175	1.04	1.28	0.84	35,469
6-17-69	Reduced Power Input											
6-18-69	1015[4]	168	9.62	4.81	1.91	9.19	2.52	172	1.04	1.28	0.84	35,493
7-15-69	1015[4]	173	9.57	4.80	1.88	9.02	2.54	171	0.99	1.26	0.84	36,141

*Begin test 6-2-65.

[1] Based on average of two hot electrode thermocouples.
[2] Based on average of two cold electrode thermocouples.
[3] Based on hot frame thermocouple referenced to 6-30-65.
[4] Based on average input power from 7-13-66 to 11-12-66.

Table 2-10. Typical Performance Data SNAP-21B Prototype P7* (Continued)

Date	T_h[1] (°F)	T_c[2] (°F)	E_o (volts)	E_L (volts)	I_L (amps)	P_o (watts)	R (ohms)	P_I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
7-29-69	1015[4]	173	9.54	4.80	1.88	9.02	2.52	171	0.98	1.25	0.84	36,477
8-14-69	1015[4]	181	9.49	4.76	1.86	8.85	2.54	170	0.98	1.25	0.83	36,861
8-28-69	1015[4]	181	9.51	4.76	1.87	8.90	2.54	171	0.99	1.25	0.84	37,197
9-4-69	1015[4]	178	9.57	4.78	1.87	8.94	2.56	170	0.99	1.25	0.84	37,365
9-15-69	1015[4]	176	9.54	4.77	1.87	8.92	2.55	170	0.98	1.26	0.84	37,629

*Begin test 6-2-65.

[1]Based on average of two hot electrode thermocouples.
[2]Based on average of two cold electrode thermocouples.
[3]Based on hot frame thermocouple referenced to 6-30-65.
[4]Based on average input power from 7-13-66 to 11-12-66.

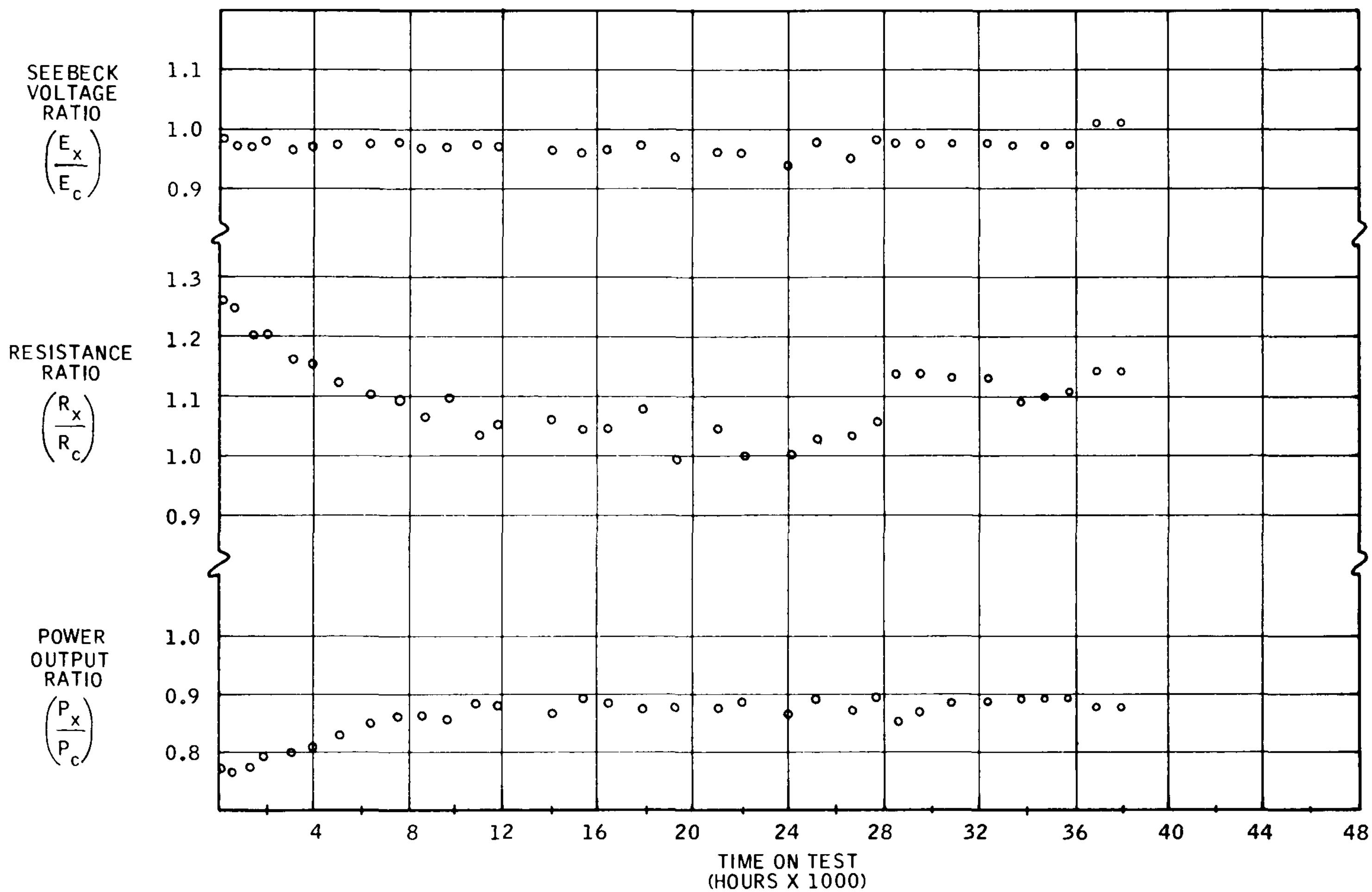


Figure 2-9. SNAP-21B 48-Couple Prototype Generator P5 Performance Ratios (Experimental/Calculated)

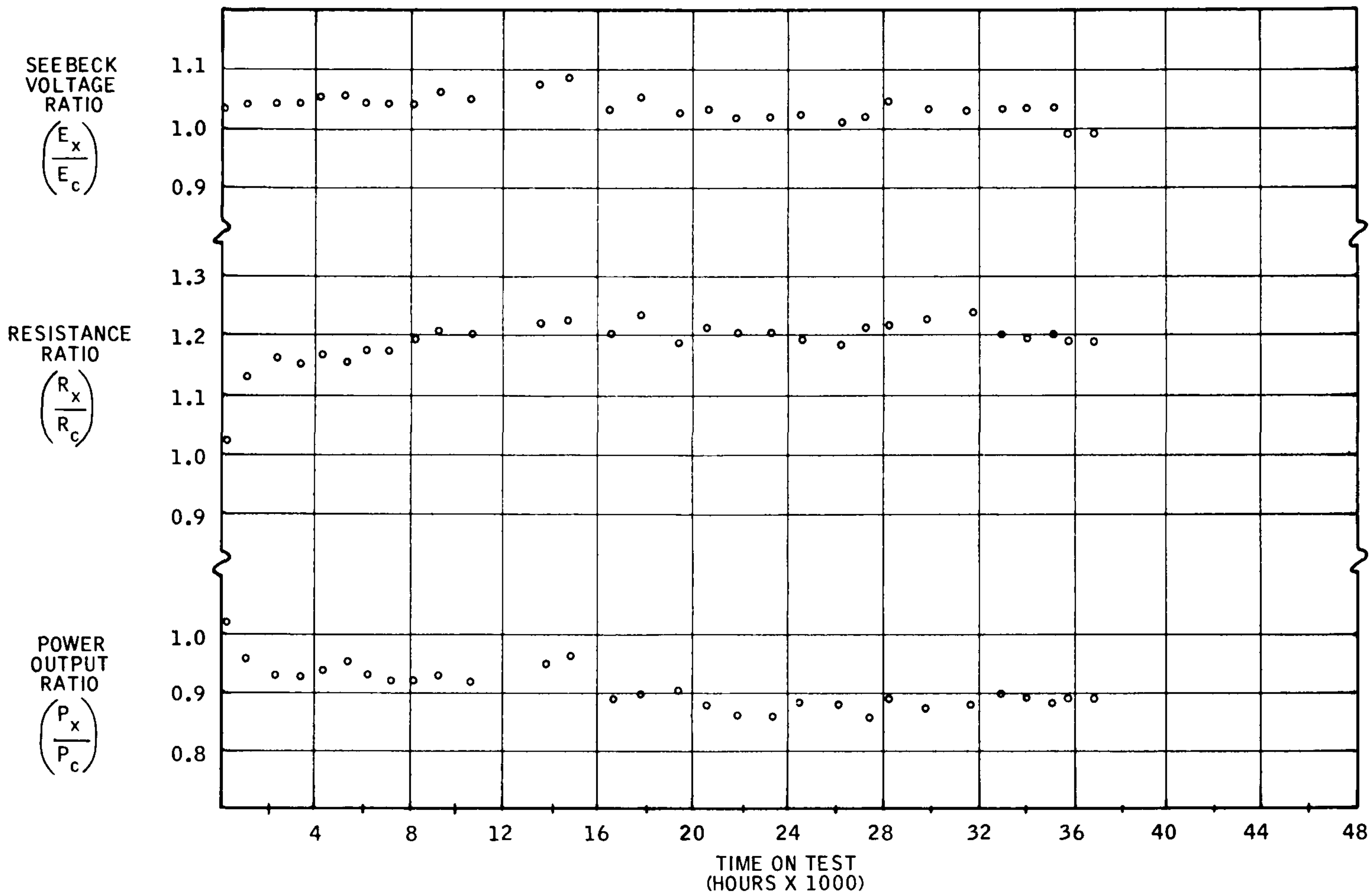


Figure 2-10. SNAP-21B 48-Couple Prototype Generator P6 Performance Ratios (Experimental/Calculated)

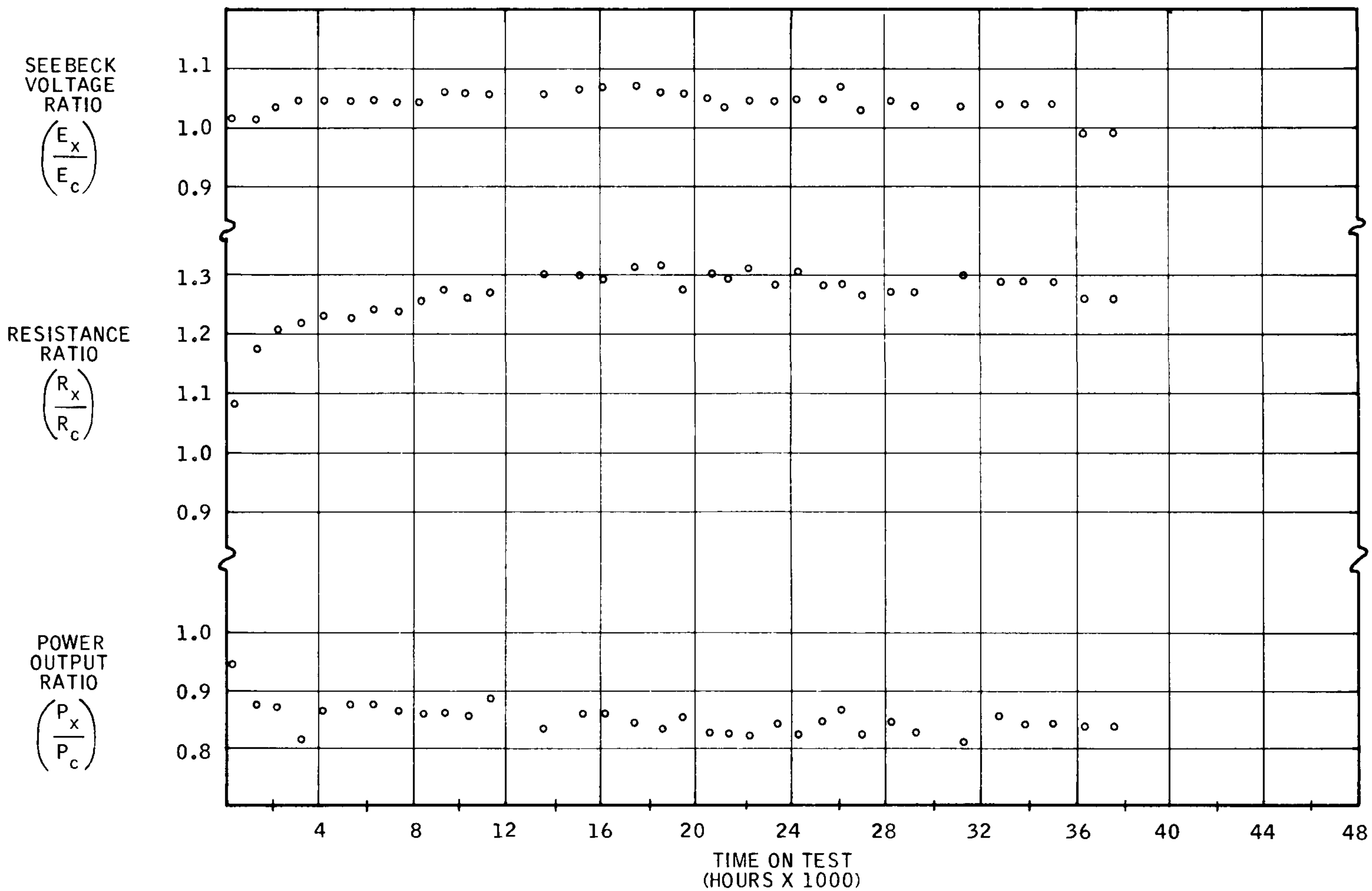


Figure 2-11. SNAP-21B 48-Couple Prototype Generator P7 Performance Ratios (Experimental/Calculated)

All Phase I modules and prototypes on test have performed without significant change in performance.

Six-couple module A1 reached five years of performance test time on July 28, 1969. This is a major milestone in thermoelectric testing and development.

Six-couple module A4 was taken off test on July 24, 1969, after reaching 41,655 hours (4.76 years) of test time. The unit was removed from test because of high internal resistance. Near the end of test, the internal resistance reached as high as 106 ohms. A post-test analysis on A4 was started this quarter and will be completed next quarter.

2.4.2 Phase II

All generators continued on test this past quarter except A10D7. Generator A10D7 developed a leak in its hermetic seal and was taken off test on August 23, 1969. Performance curves are shown in Figures 2-12a through 2-16. A history of each generator is shown in Tables 2-11 through 2-15. Performance for the generators this past quarter has been satisfactory.

On September 22, 1969, the building power was interrupted for about 30 minutes. At this time periodic maintenance was being conducted on the emergency generator which resulted in a lack of power for about 8 minutes. Analysis of the data shows that there was no apparent effect on the generators from this failure.

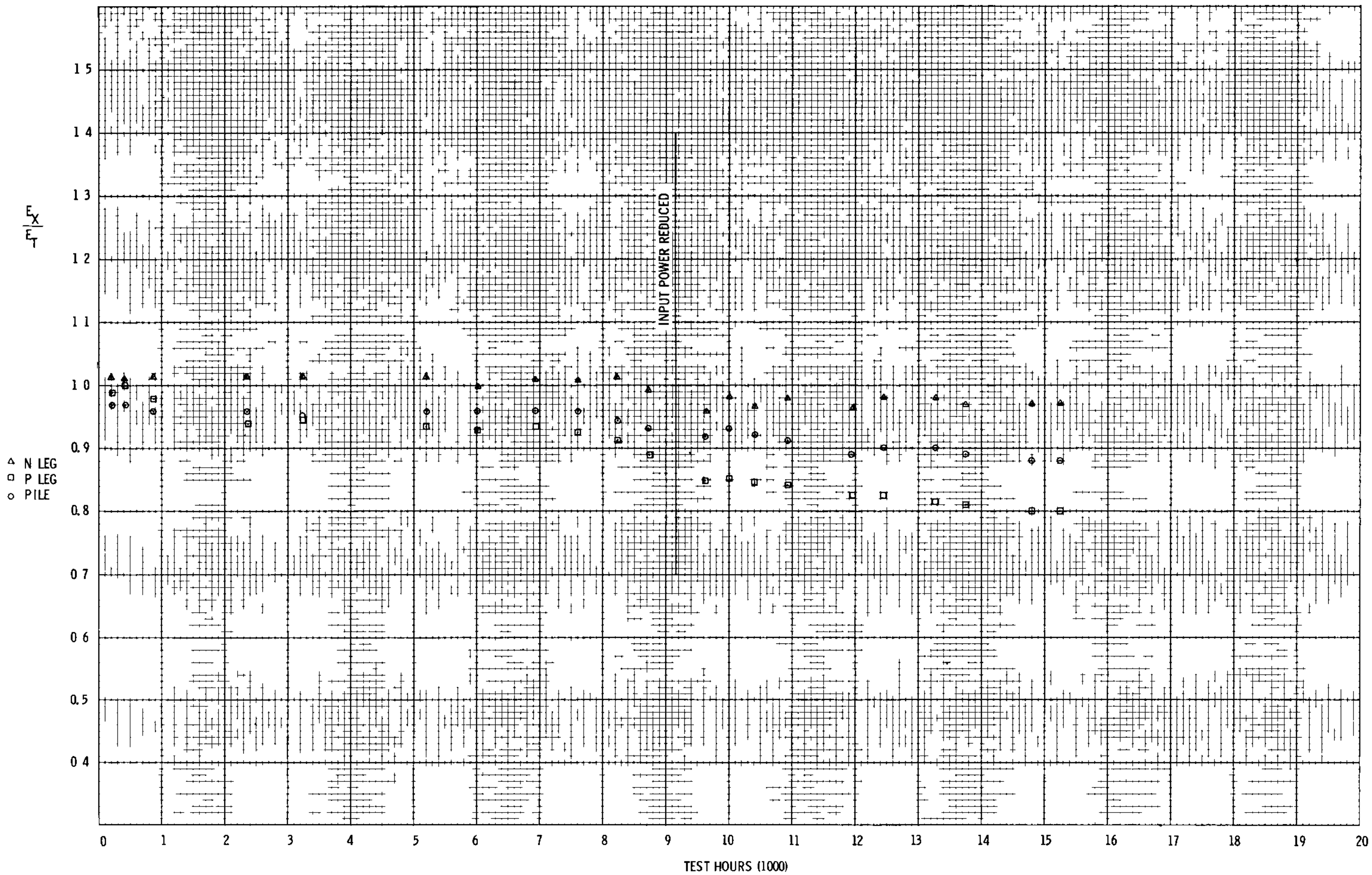


Figure 2-12a. SNAP-21 Thermoelectric Generator A10D1 Normalized Seebeck Voltage Ratio

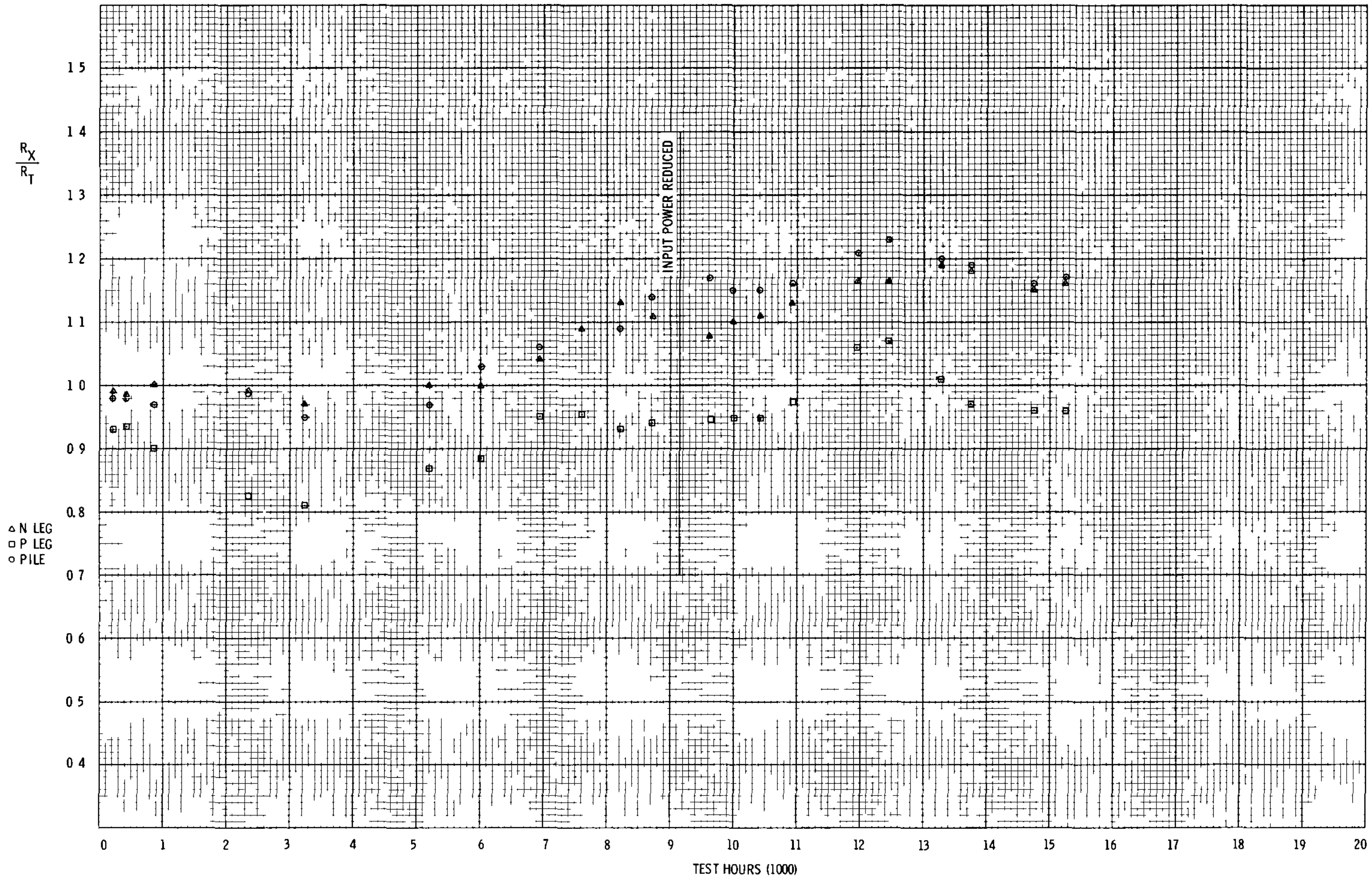


Figure 2-12b. SNAP-21 Thermoelectric Generator A10D1 Normalized Resistance Ratio

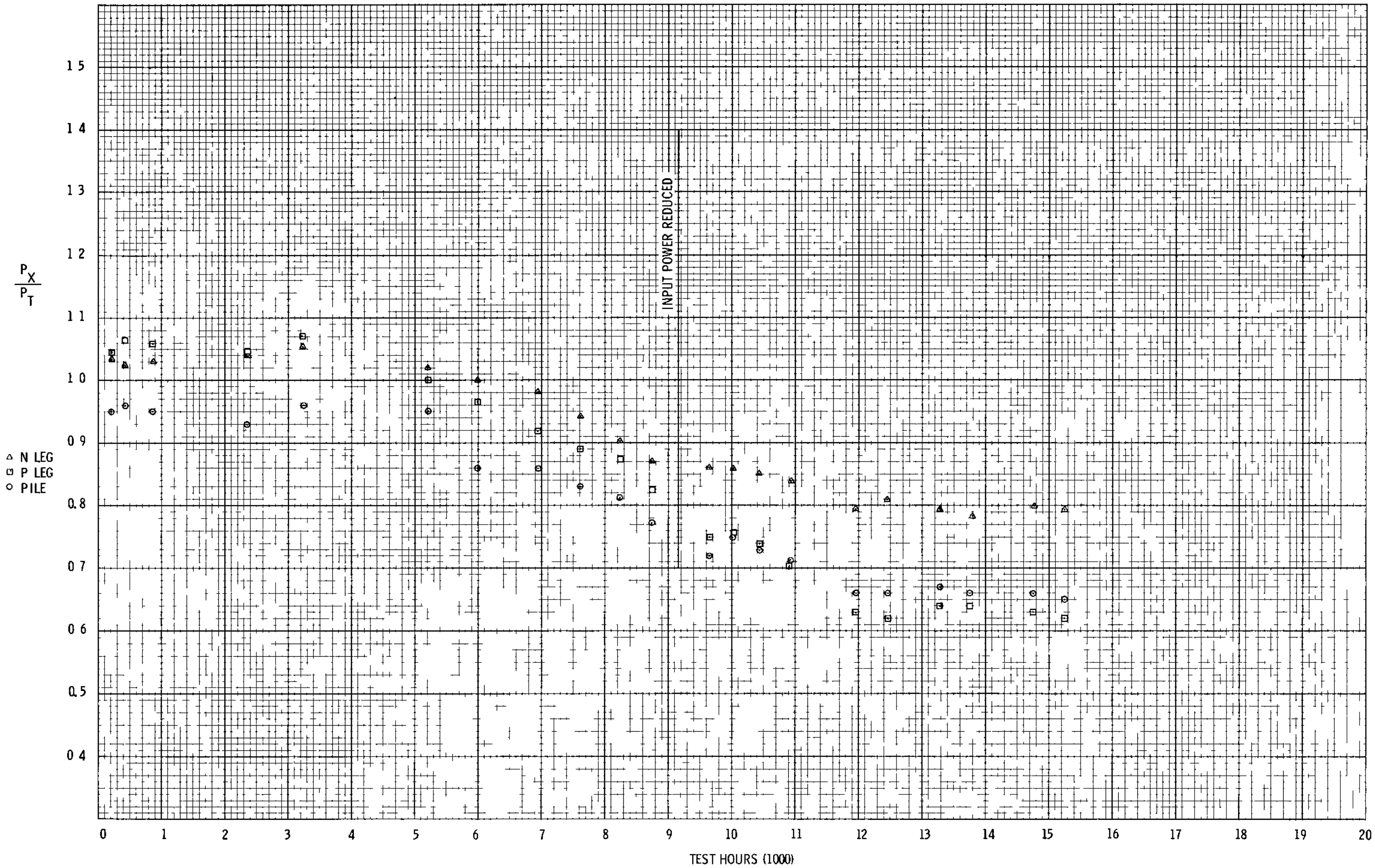


Figure 2-12c. SNAP-21 Thermoelectric Generator A10D1 Normalized Power Ratio

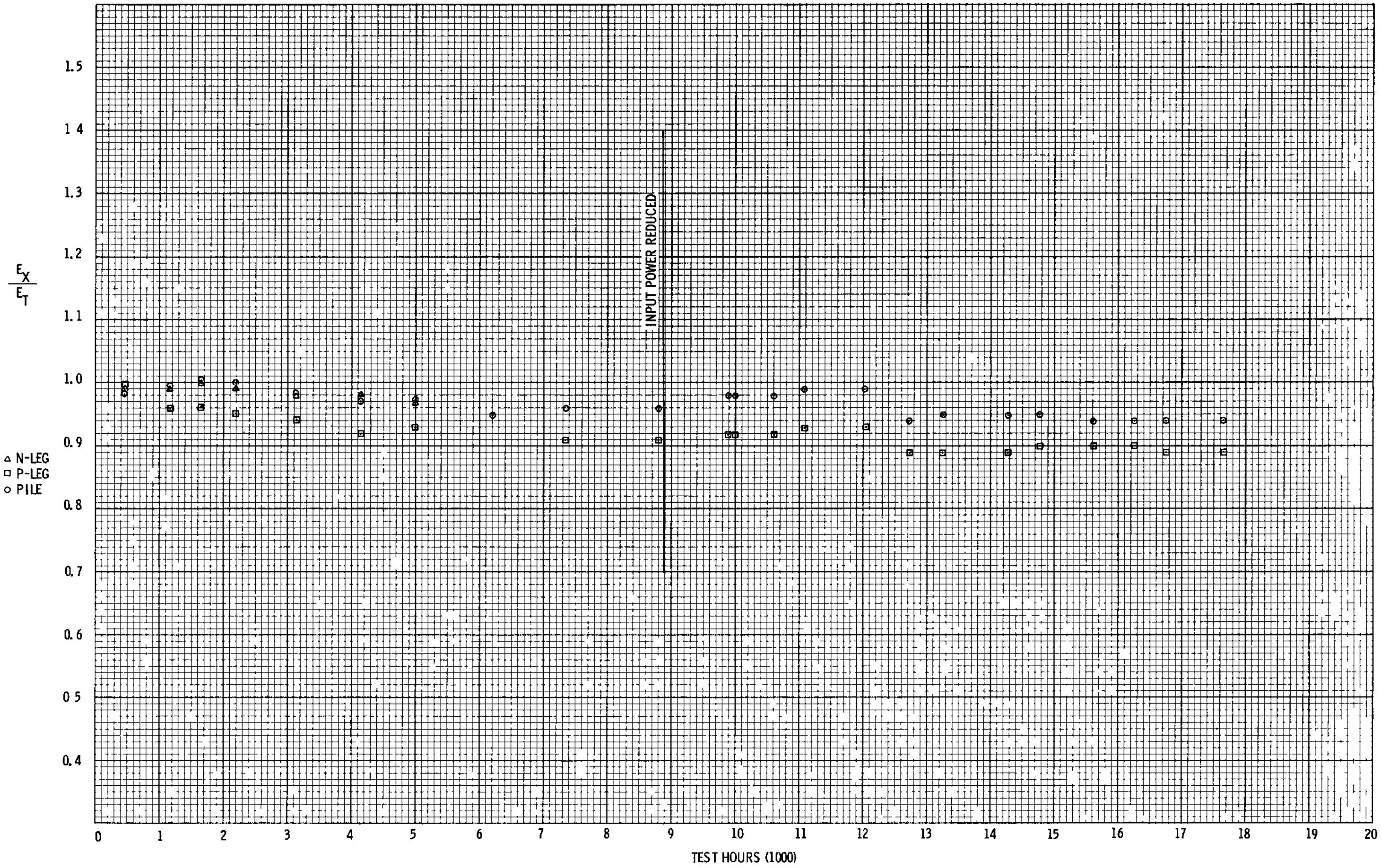


Figure 2-13a. SNAP-21 Thermoelectric Generator A10D2 Normalized Seebeck Voltage Ratio

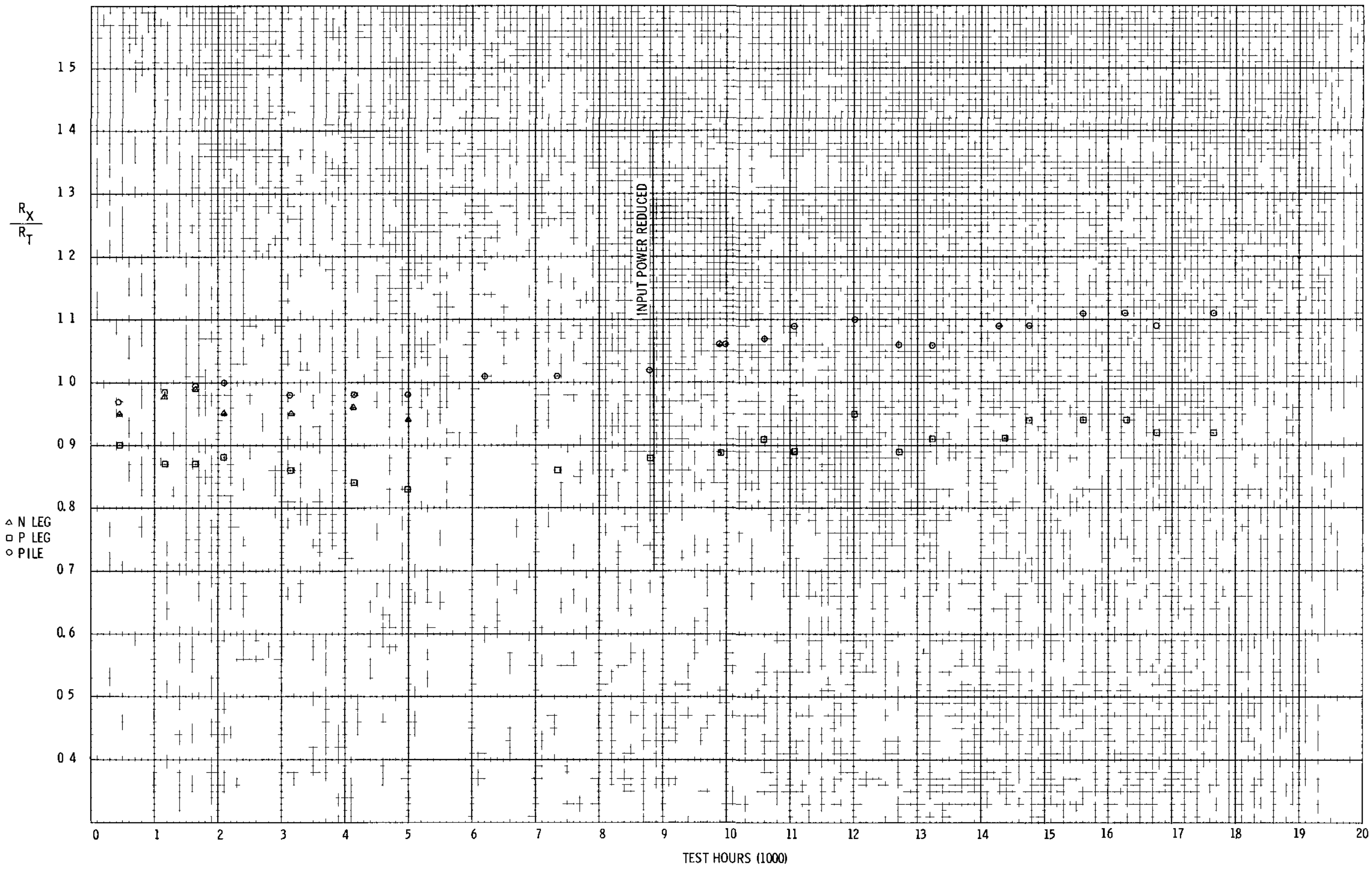


Figure 2-13b. SNAP-21 Thermoelectric Generator A10D2 Normalized Resistance Ratio

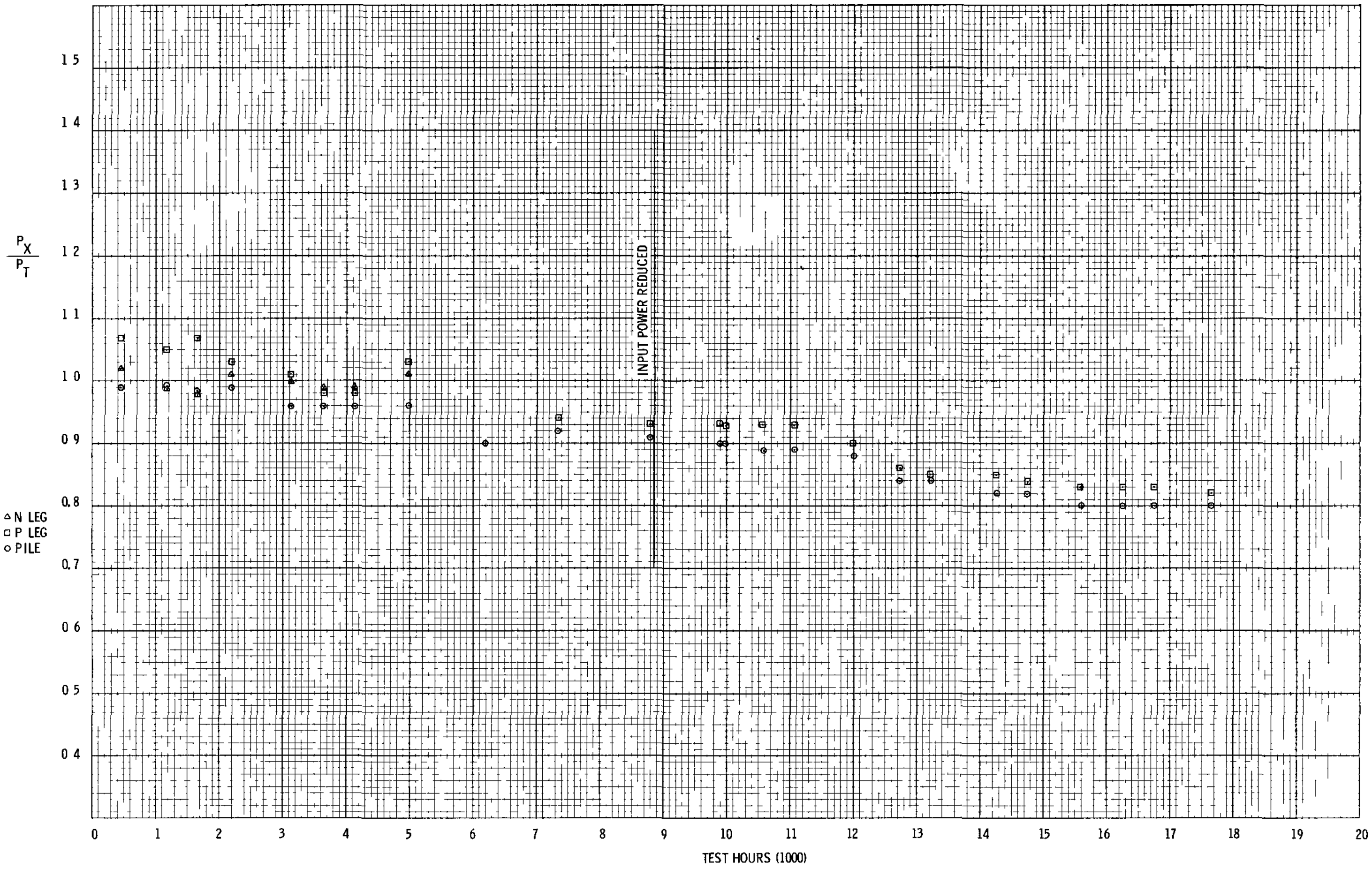


Figure 2-13c. SNAP-21 Thermoelectric Generator A10D2 Normalized Power Ratio

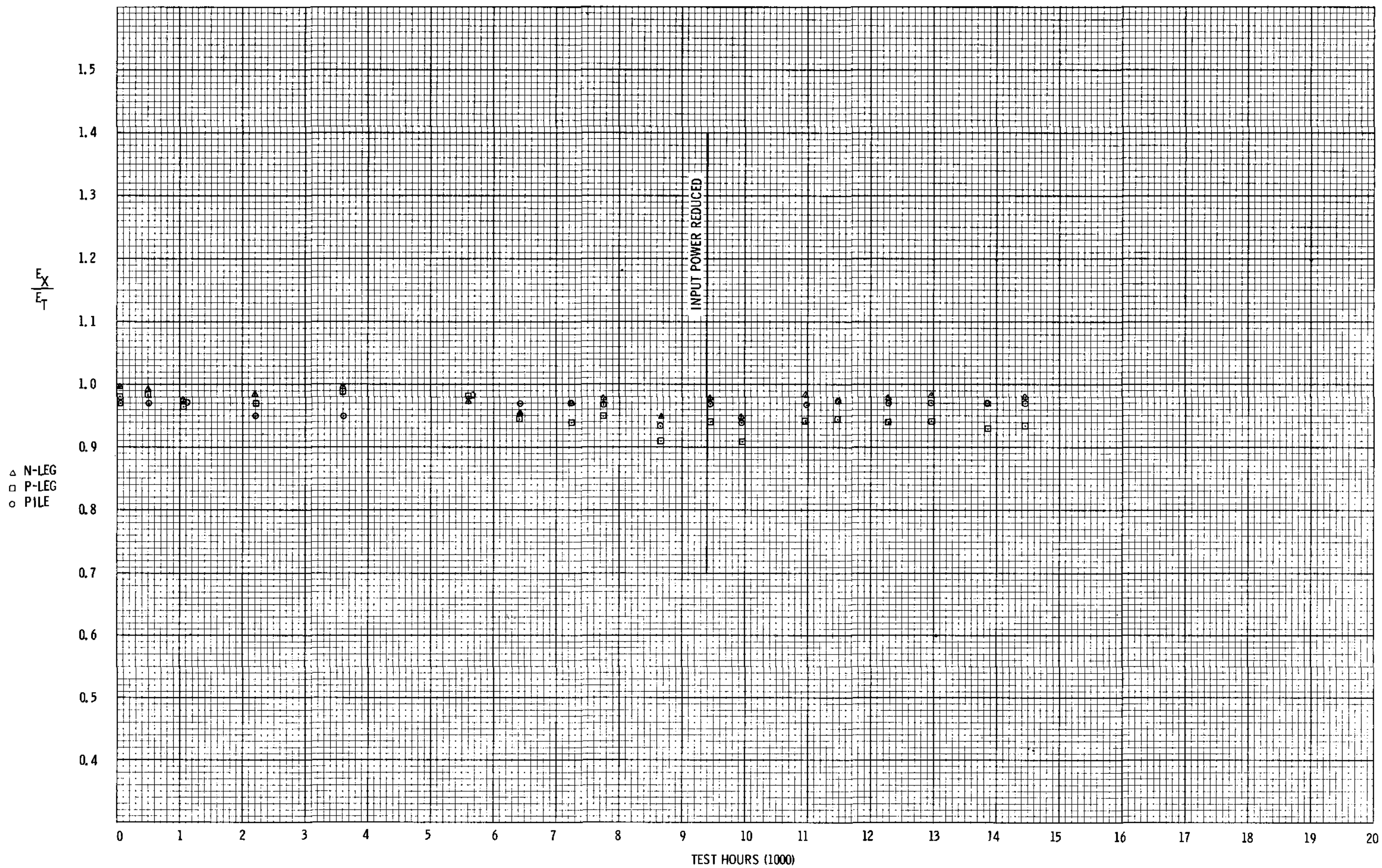


Figure 2-14a. SNAP-21 Thermoelectric Generator A10D6 Normalized Seebeck Voltage Ratio

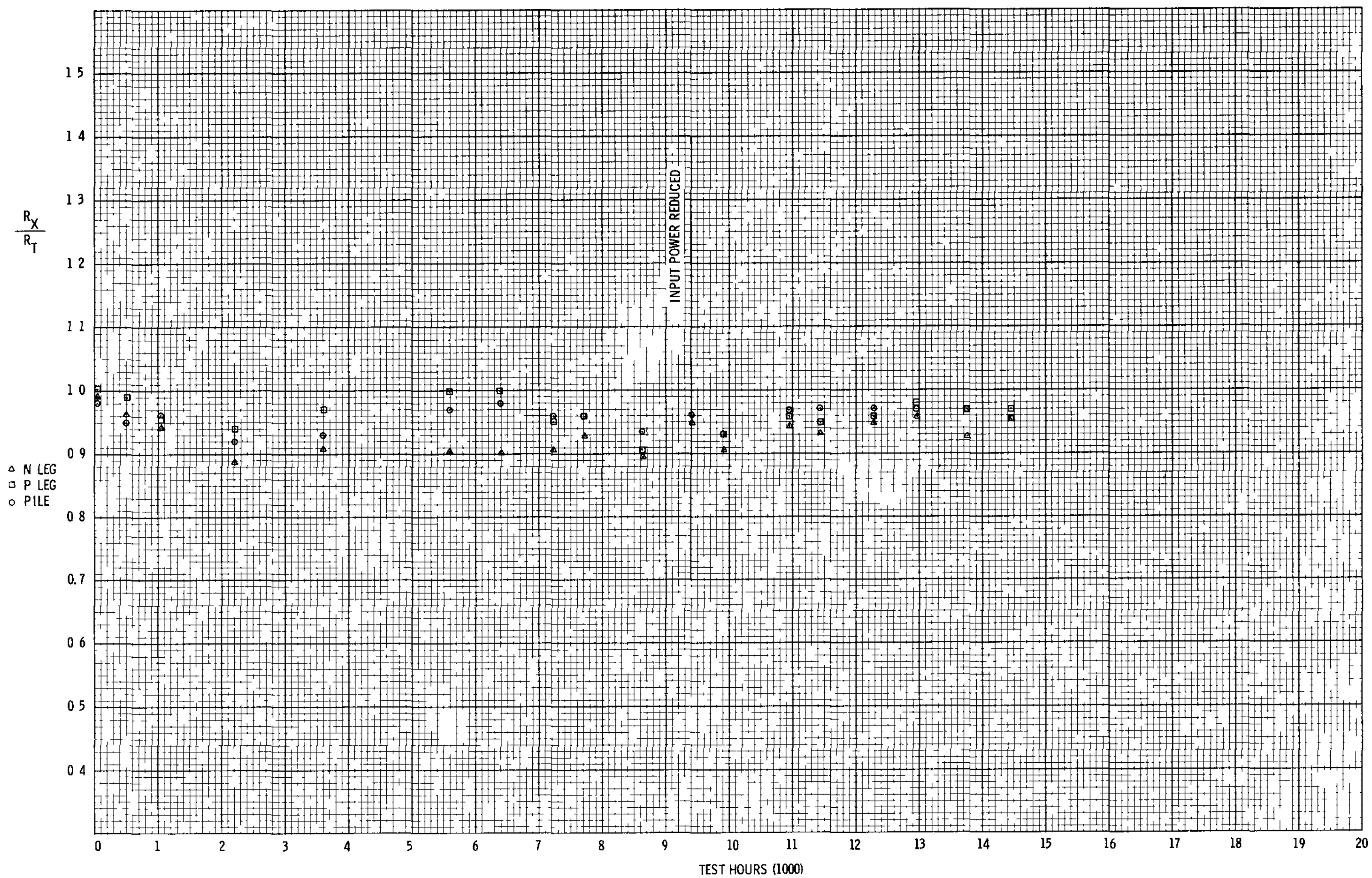


Figure 2-14b. SNAP-21 Thermoelectric Generator A10D6 Normalized Resistance Ratio

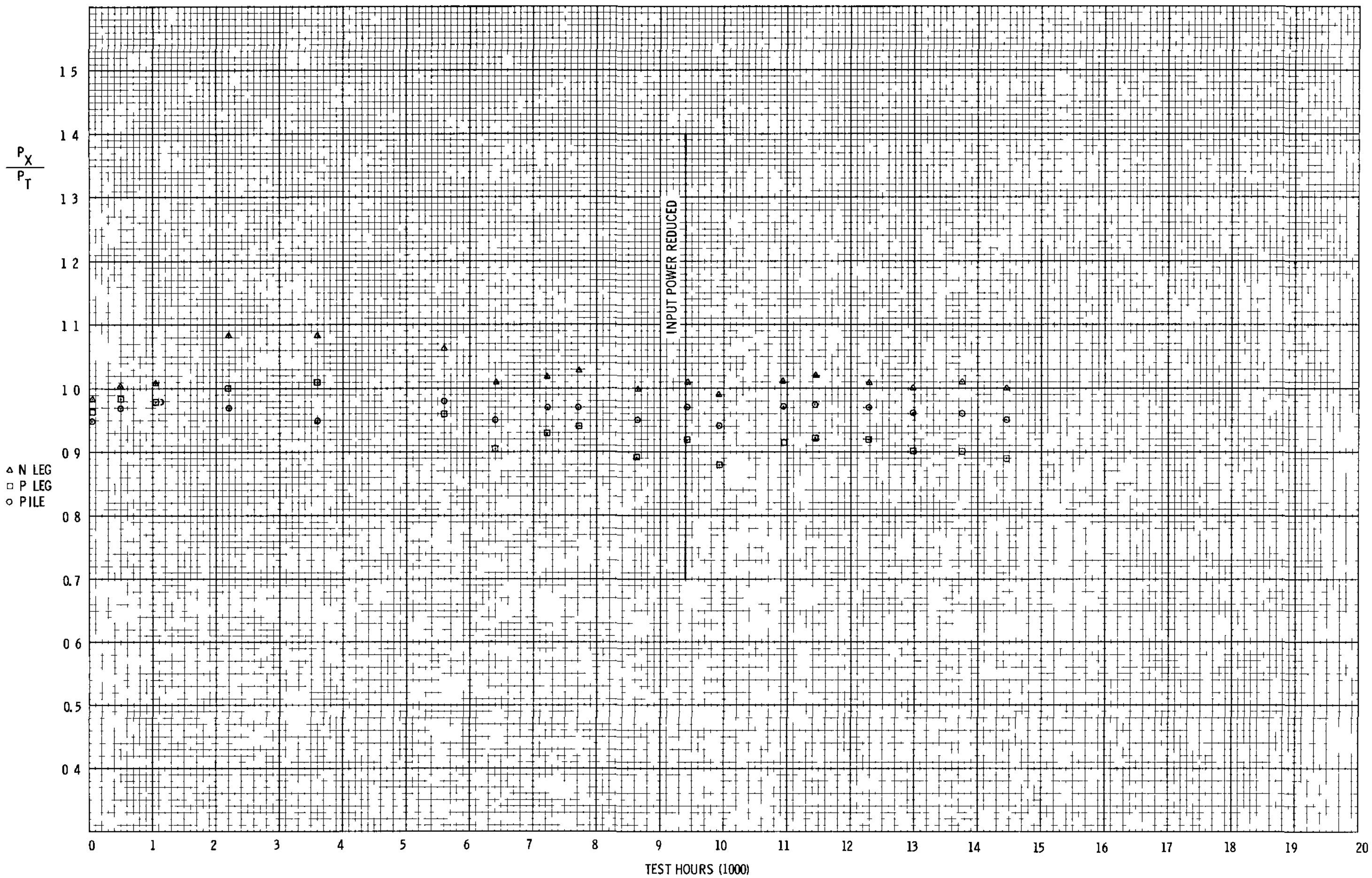


Figure 2-14c. SNAP-21 Thermoelectric Generator A10D6 Normalized Power Ratio

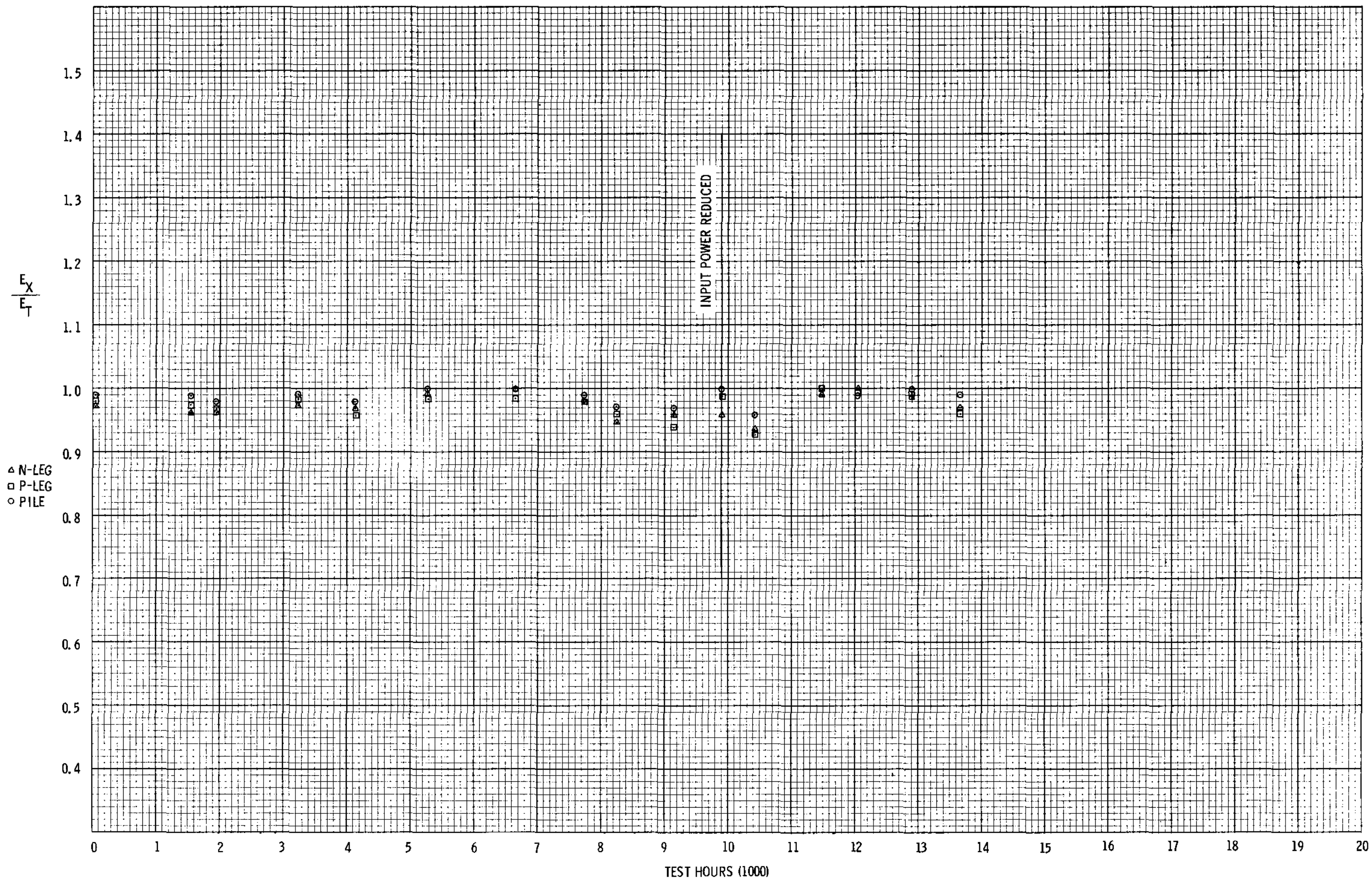


Figure 2-15a. SNAP-21 Thermoelectric Generator A10D7 Normalized Seebeck Voltage Ratio

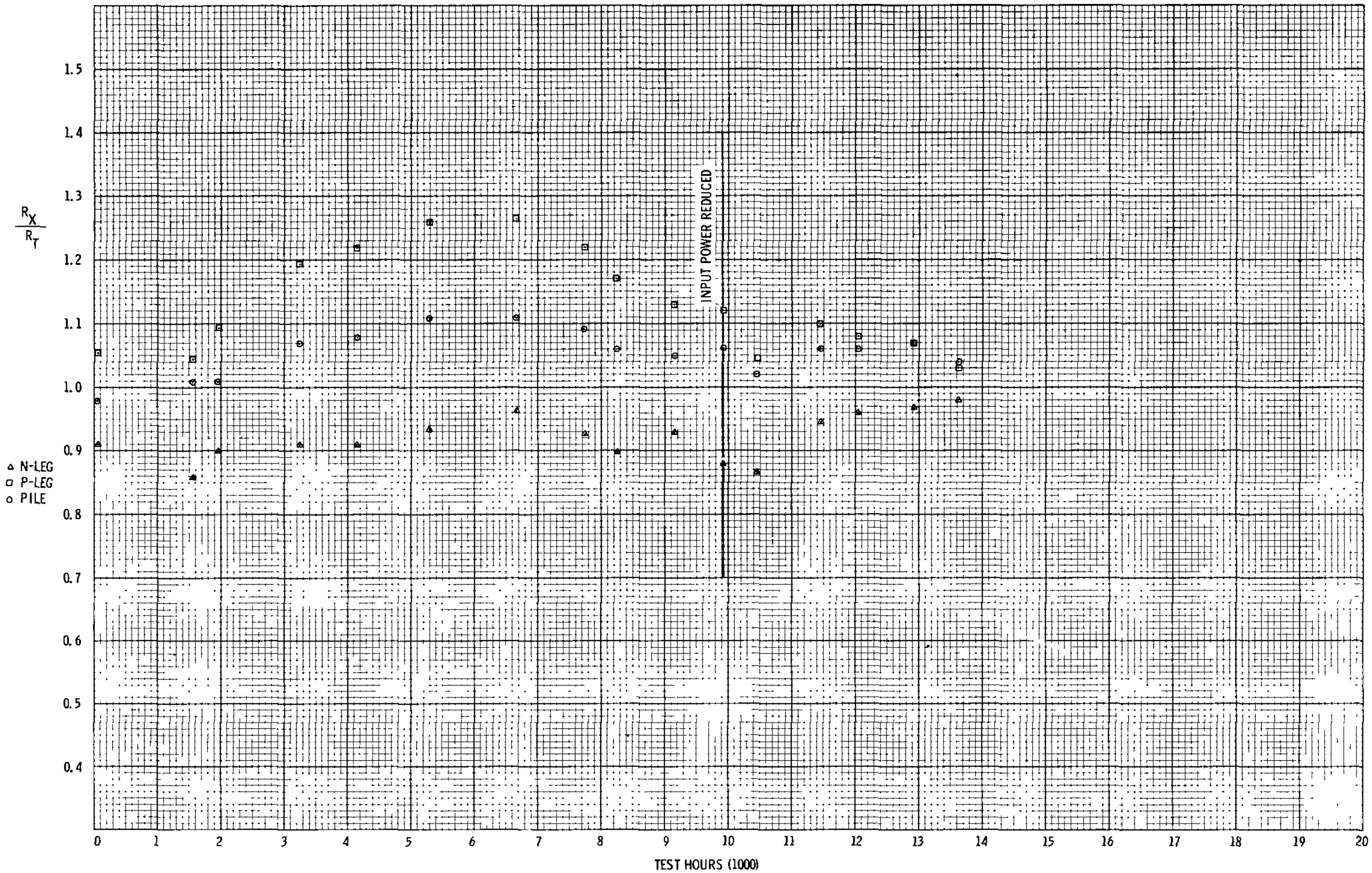


Figure 2-15b. SNAP-21 Thermoelectric Generator A10D7 Normalized Resistance Ratio

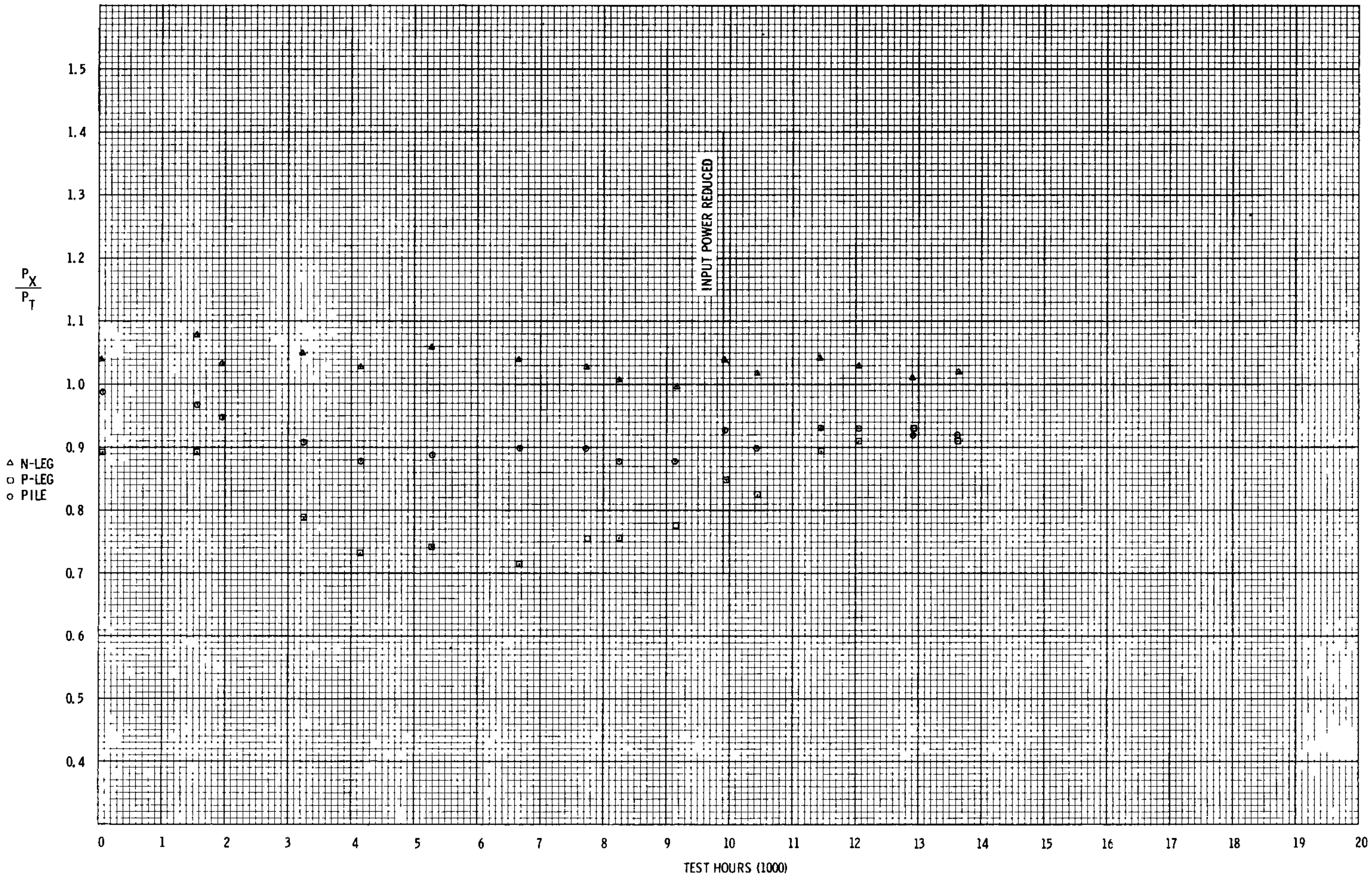


Figure 2-15c. SNAP-21 Thermoelectric Generator A10D7 Normalized Power Ratio

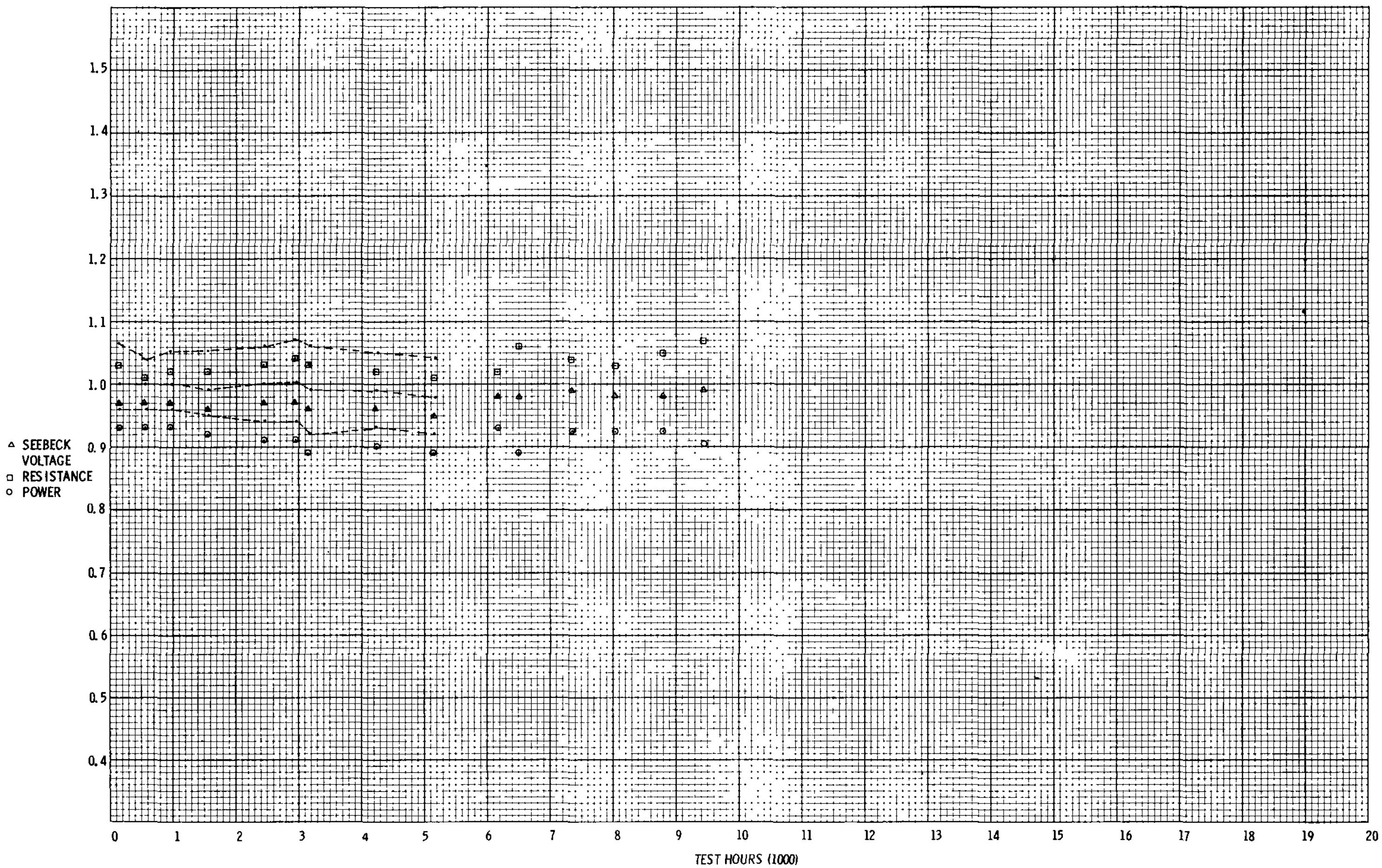


Figure 2-16. SNAP-21 Thermoelectric Generator A10P1 Normalized Data

Table 2-11. Generator A10D1 History

Date	Remarks
9/6/67	Power on BOL.
9/12/67	Generator leak, placed in dry box, headers tightened and backfilled.
9/22/67	TEG placed back on test.
10/2/67-10/4/67	TEG mapped. (Current voltage)
10/4/67	Power off.
10/5/67-10/6/67	Shock and vibration at Environ.
10/7/67	Power restored.
10/14/67	Special test.
10/24/67	Power off for integration into S10D1.
11/29/67	Power restored, TEG integrated into S10D1.
1/29/68	Generator leak, system taken off test.
2/27/68	Power on, component testing with additional outer long case.
3/2/68	Cold button temperature was above 240°F.
3/4/68	TEG backfilled.
4/1/68	TEG backfilled.
10/4/68	TEG backfilled and connected to Data Acquisition System.
10/17/68	Heater burned out, TEG taken off test and heaters replaced.
11/13/68	Power restored and TEG backfilled.
1/3/69	Power reduced for 20°F drop in hot end temperature.
1/19/69	On emergency power for 8.5 hours.
1/27/69	Sorenson regulator failure, TEG operated for approximately 12 hours about 200°F above normal on hot end.
8/12/69	Heater burned out, TEG taken off test and heaters replaced.
9/22/69	Building power failure for about 0.5 hour.

Table 2-12. Generator A10D2 History

Date	Remarks
8/4/67	Power on BOL.
8/5/67	Test was terminated for about 6 hours to repair test stand.
8/8/67-8/13/67	TEG mapping.
8/15/67	Power off.
8/17/67-8/18/67	Shock and vibration at Environ.
8/19/67	Power restored and TEG mapped.
9/12/67	Generator leak, placed in dry box for retorquing of conax fittings.
9/25/67	TEG placed back on test.
9/29/67-10/4/67	TEG backfilled daily.
10/18/67	Conax fittings were torqued.
1/15/68	Operated on emergency power for one hour.
1/23/68	Installed into efficiency fixture.
1/30/68	Changed from efficiency fixture to test stand.
2/17/68	Operated on emergency power for five hours.
5/20/68	TEG backfilled.
9/9/68	Power reduced for 20°F drop in hot end temperature.
9/10/68	TEG connected to Data Acquisition System.
10/21/68	Heater burned out, TEG taken off test and heaters replaced.
1/19/69	On emergency power for 8.5 hours.
1/27/69	Sorenson regulator failure, TEG operated for approximately 12 hours about 200°F above normal on hot end.
2/1/69	Heater burned out.
2/19/69	TEG taken off test and heaters replaced.
2/21/69	Power restored.
8/4/69	Load circuit opened, TEG operated at open circuit for approximately 3 hours.
9/22/69	Building power failure for about 0.5 hour.

Table 2-13. Generator A10D6 History

Date	Remarks
12/18/67	Power on BOL.
12/20/67-12/23/67	TEG mapping.
1/5/68	Power off.
1/9/68-1/10/68	Shock and vibration at Environ.
1/11/68	Power restored and TEG mapping.
1/15/68	Operated on emergency power for one hour.
1/17/68	TEG transferred to efficiency fixture.
1/23/68	Replaced back into test fixture.
2/17/68	Operated on emergency power for five hours.
6/9/68-6/20/68	Operated about 220°F above normal at the hot end.
8/14/68	Generator leak, the top of the cold frame was potted with Scotch Weld.
9/13/68	TEG connected to Data Acquisition System.
1/19/69	Operated on emergency power for 8.5 hours.
1/27/69	Sorenson regulator failure, TEG operated for approximately 12 hours about 200°F above normal on hot end.
2/14/69	Power reduced for 20°F drop in hot end temperature.
9/22/69	Building power failure for about 0.5 hour.

Table 2-14. Generator A10D7 History

Date	Remarks
1/17/68	Power on BOL.
1/18/68-1/23/68	TEG mapping.
1/23/68	Power off.
1/24/68-1/25/68	Shock and vibration at Environ.
1/29/68	Power restored and TEG mapping.
2/8/68	Installed into efficiency fixture.
2/17/68	Operated on emergency power for five hours.
3/25/68	Replaced back into test stand.
8/9/68	Heater failure, TEG remained on test.
9/13/68	TEG connected to Data Acquisition System.
1/19/69	Operated on emergency power for 8.5 hours.
1/27/69	Sorenson regulator failure, TEG operated for approximately 12 hours about 200°F above normal on hot end.
2/18/69	Power reduced for 20°F drop in hot end temperature.
8/10/69	Heater assembly replaced, off test for about one hour.
	Test terminated, leak at long case and cold frame interface.

Table 2-15. Generator A10P1 History

Date	Remarks
6/18/68	Power on BOL, efficiency fixture.
6/21/68	Power off, put in storage.
8/21/68	Power on, test fixture.
1/19/69	Operated on emergency power for 8.5 hours.
1/27/69	Sorenson regulator failure, TEG operated about 200°F above normal on hot end for approximately 12 hours.
3/4/69	TEG installed into HTVIS B10DL6 for long-term test.
8/21/69	Power reduced for 20°F drop in hot end temperature.
9/22/69	Building power failure for about 0.5 hour.

2.4.2.1 Performance Testing

During this past quarter a life performance analysis was conducted on the Phase II generators. Following are the results of this performance analysis:

A10D1

Most of the changes in the generator performance are due to the performance of the "P" leg. The "N" leg Seebeck voltage has remained stable but the resistance has increased. It appears that the generator degradation is about twice what should be expected for a generator that operates at desired temperatures (1100°F first year, 1080°F second year). This performance could be due to bad cover gas or air which leaked into the TEG. (Reference Table 2-11.)

A10D2

Because of the lack of hot end thermocouples, temperature determination has been a problem with this generator. The temperature at the hot end could be in error as much as 30°F. It appears that the "P" leg Seebeck voltage and resistance has decreased. Because of the loss of instrumentation, the "N" leg performance cannot be ascertained. Based on the total circuit performance, the degradation rate is equivalent to a generator that has operated at 1080°F hot button temperature. It is believed that this temperature is fairly close to the actual hot side temperature on A10D2.

A10D6

Performance for this TEG has been stable. It appears that the generator has been operating about 20°F lower than the desired hot button temperature of 1100°F for the first year. The xenon cover gas decreases the rate of performance degradation of the generator.

A10D7

This generator was taken off test on September 23, 1969. A gross leak was found at the interface of the long case and cold frame. The Seebeck voltage for the N- and P-legs had been stable. The N-leg resistance had been satisfactory. The major performance change had been due to the change in "P" leg resistance. The resistance increased about 25% at which point it appeared to have started to decrease. It is speculated that the resistance increased because of a Mn deposit build-up at the hot junction interface. The resistance has started to decrease because this build-up terminated and the Mn deposit was forced out, possibly by the spring pressure. Another factor which could be responsible of the resistance changes is the thermal insulation (Min-K 1999) used in this generator. A10D7 is off test and will be put in storage. No post-test analysis is scheduled.

A10P1

This generator is fairly stable and it is too early to establish a degradation trend. It is operating at a lower hot end temperature (a resultant design change) and the cover gas is xenon – both of which are conducive to low degradation rate.

In summary, it appears that only two generators' performance characteristics (A10D1 and A10D7) deviate significantly from the long-term performance trends expected. These expected trends are based on SNAP-21, -23, -23A and -27 modules and the resultant Degradation Model.

Generator A10D1 degradation is approximately twice as great as expected. This could be due to the leaks in its hermetic seal.

Generator A10D7 fluctuations are due to the performance of the P-leg. This, in turn, is probably related to both Min-K 1999 and a Mn deposit at the hot junction. Further development efforts are needed with Min-K 1999 before it can be used as the primary insulation.

2.5 POWER CONDITIONERS

2.5.1 Phase I Power Conditioners

Phase I electronic component testing continued this past quarter with the automatic selector switch, power conditioner MP-C, and regulators operating satisfactorily. Tables 2-16 through 2-19 represent performance data for these electronic units. The performance of these units remains stable.

2.5.2 Phase II Power Conditioners

Tables 2-20 and 2-21 are the performance data for power conditioners H10D3 and H10D6. As can be seen, the performance for these units has been stable this past report period.

2.6 NRDL SYSTEM TESTING

2.6.1 System Performance

It was planned that the data from the implanted systems would be available to 3M Company via a data phone which is connected into the Data Acquisition System. Because the data phone has been inoperable, the data has not been available via this route. The data shown in Tables 2-22, 2-23, and 2-24 were received by 3M Company from NRDL personnel. From the data it appears that the systems are performing satisfactorily.

Table 2-25 is a summary of the system performance of all SNAP-21 10-watt fueled systems.

2.6.2 System S10P2 Low Power Output

The power output for system S10P2 is 9.75W as compared to the expected power output of 10.3W. The low power output results from a system load resistance of 61.7Ω rather than the nominal 57.6Ω. It appears that there is a 4.1Ω extraneous resistance in the system load circuit (see Figure 2-17).

The load resistance and power output are calculated values. These values are based on the system load voltage and system current. The current is measured via a voltage drop across a calibrated resistor (component "C" in Figure 2-17). The design value of shunt "C" is 0.100Ω but with the actual placement of the leads, the resistance value which was read after assembly was 0.1045Ω.

Table 2-16. Phase I Regulator Test Fixture Performance Data

Operating Hours	A Output (vdc)	TRIO-LAB Regulators C Output (vdc)	D Output (vdc)	F Output (vdc)	High Power Regulator-A HPR-A Output (vdc)	Operating Hours
0	21.7	21.92	22.58	21.36	26.78	0
552	21.82	21.96	22.56	22.04	26.67	451
1,029	21.83	21.98	22.56	22.08	26.76	1,267
1,965	21.82	21.93	22.55	21.98	26.78	2,010
3,045	21.80	21.89	22.54	22.00	26.76	2,929
4,011	21.82	21.92	22.56	22.02	26.78	3,961
5,043	21.81	21.90	22.55	22.00	26.81	4,945
6,147	21.78	21.87	22.52	21.95	26.78	6,121
7,015	21.79	21.88	22.53	21.98	26.77	6,792
8,023	21.80	21.88	22.53	21.98	26.80	8,017
9,125	21.78	21.86	22.52	21.99	26.81	9,504
10,133	21.75	21.82	22.50	21.94	26.82	10,590
11,143	21.79	21.87	22.52	21.98	26.82	11,314
12,031	21.79	21.85	22.52	21.97	26.75	14,288
18,369	21.75	21.86	22.49	21.93	26.78	17,552
18,729	21.72	21.79	22.47	21.90	26.77	17,912
19,257	21.72	21.78	22.46	21.89	26.80	18,440
19,401	21.72	21.78	22.46	21.88	26.81	18,584
19,881	21.54	21.63	22.41	21.88	26.46	19,064
20,265	21.53	21.55	22.42	21.90	26.47	19,448
20,673	21.53	21.46	22.42	21.88	26.51	19,856
21,117	21.49	21.39	22.40	21.84	26.51	20,360
21,161	21.52	21.37	22.39	21.85	26.51	21,344
22,617	21.60	20.79	22.40	21.88	26.48	21,800
23,145	21.46	21.45	22.35	21.82	26.45	22,328
23,769	21.46	21.13	22.31	21.82	26.36	22,952
24,297	21.35	21.52	22.41	21.82	26.31	23,480
24,777	21.43	20.93	22.33	21.76	26.34	23,960
25,137	21.49	21.00	22.36	21.83	26.47	24,320

Table 2-16. Phase I Regulator Test Fixture Performance Data (Continued)

Operating Hours	TRIO-LAB Regulators				High Power Regulator-A HPR-A	
	A Output (vdc)	C Output (vdc)	D Output (vdc)	F Output (vdc)	Output (vdc)	Operating Hours
25,449	21.49	21.00	22.39	21.84	26.53	24,632
25,929	21.50	20.97	22.39	21.83	26.56	25,112
26,381	21.51	20.95	22.40	21.84	26.60	25,564
26,693	21.74	21.81	22.46	21.92	26.93	25,876
28,061	21.52	21.30	22.41	21.83	26.52	27,244
28,541	21.51	21.27	22.38	21.81	26.56	27,724
29,525	21.48	21.00	22.33	21.75	26.52	28,708
30,773	21.46	21.01	22.31	21.75	26.52	29,956
31,733	21.48	20.82	22.32	21.76	26.53	30,916
32,189	21.49	20.28	22.33	21.80	26.51	31,372
33,029	21.51	20.25	22.36	21.78	26.55	32,212
33,941	21.61	21.07	22.39	21.81	26.73	33,124
34,541	21.70	21.73	22.39	21.83	26.78	33,724
35,405	21.70	21.74	22.40	21.85	26.85	34,588
36,317	21.71	21.74	22.41	21.86	26.87	35,500
37,325	21.70	21.74	22.40	21.84	26.86	36,508
37,709	21.63	21.35	22.37	21.78	26.85	36,892
38,405	21.63	21.35	22.37	21.78	26.84	37,588
38,765	21.69	21.73	22.40	21.85	26.85	37,948
39,101	21.70	21.72	22.40	21.82	26.83	38,284
39,413	21.70	21.74	22.41	21.90	26.88	38,596
40,085	21.72	21.74	22.41	21.87	26.87	39,268
40,877	21.70	21.73	22.41	21.87	26.88	40,060
41,429	21.69	21.72	22.40	21.88	26.90	40,612

Table 2-17. Performance of Phase I Power Conditioner MP-C

Converter Performance Power Conditioner	E_I (volts)	I_I (amps)	P_I (watts)	E_o (volts)	I_o (amps)	P_o (watts)	Efficiency %	Hours on Test	Notes
	4.909	2.386	11.814	24.00	0.434	10.42	88.10	23	
	4.912	2.380	11.792	24.00	0.433	10.39	88.08	577	
	4.911	2.388	11.830	24.00	0.434	10.43	88.16	1,072	
	4.909	2.388	11.824	24.00	0.435	10.43	88.22	2,064	
	4.908	2.383	11.798	24.00	0.434	10.42	88.30	3,069	
	4.913	2.382	11.804	24.00	0.433	10.39	88.03	4,058	
	4.910	2.379	11.782	24.00	0.433	10.39	88.20	5,054	
	4.910	2.363	11.602	24.00	0.429	10.30	87.89	6,017	
	4.910	2.372	11.749	24.00	0.431	10.34	88.04	7,165	
	4.910	2.373	11.754	24.00	0.431	10.34	88.00	8,154	
	4.909	2.366	11.718	24.00	0.430	10.32	88.07	9,136	
MP-C	4.913	2.395	11.809	24.00	0.436	10.464	88.61	15,783	
	4.908	2.360	11.606	24.00	0.429	10.296	88.71	16,143	
	4.909	2.374	11.757	24.00	0.432	10.368	88.19	16,671	
	4.910	2.378	11.779	24.00	0.433	10.392	88.22	16,815	
	4.906	2.372	11.740	24.00	0.432	10.368	88.31	17,295	
	4.905	2.374	11.747	24.00	0.432	10.368	88.26	17,679	
	4.904	2.353	11.642	24.00	0.428	10.272	88.23	17,087	
	4.909	2.389	11.831	24.00	0.439	10.416	88.04	18,591	
	4.912	2.395	11.867	24.00	0.436	10.464	88.18	19,575	
	4 913	2.396	11.878	24.00	0.436	10.464	88.10	20,031	
	4.910	2.375	11.764	24.00	0.432	10.368	88.13	20,559	
	4.908	2.371	11.740	24.00	0.431	10.344	88.11	21,183	
	4.909	2.375	11.762	24.00	0.432	10.368	88.15	21,811	
	4.909	2.376	11.767	24.00	0.432	10.368	88.11	22,098	
	4.910	2.375	11 764	24.00	0.432	10.368	88.13	22,485	
	4.912	2.403	11.907	24.00	0.438	10.512	88.28	22,770	
	4.911	2.377	11.776	24.00	0.433	10.380	88.92	23,250	
	4.909	2.357	11.674	24.00	0.428	10.270	87.99	24,066	Note Unit accidentally shut down. Discovered on 12/22/67. Power restored 12/22/67
	4.908	2.368	11.725	24.00	0.431	10.344	88.22	25,434	
	4.908	2.368	11.725	24.00	0.430	10.320	88.02	25,914	
	4.908	2.374	11.755	24.00	0.432	10.368	88.21	26,898	
	4 908	2.376	11 764	24.00	0.432	10 368	88.13	28,146	
	4 910	2.378	11.779	24 00	0.433	10.384	88.16	29,106	
	4.910	2.395	11.862	24.00	0.435	10.440	88.01	29,562	
	4 909	2.395	11.860	24.00	0.435	10.440	88.03	30,402	
	4.907	2.375	11.757	24.00	0.432	10.368	88.18	31,314	
	4.905	2.373	11.743	24.00	0.434	10.416	88.70	31,914	
	4.904	2.371	11.730	24.00	0.431	10.344	88.18	32,778	
	4 907	2.381	11.780	24.00	0.433	10.392	88.21	34,698	
	4.907	2.381	11.780	24.00	0.433	10.392	88.21	36,618	
	4.910	2.375	11.760	24.00	0.433	10.392	88.37	37,002	
	4.909	2.375	11.760	24.00	0.433	10.392	88.37	37,698	
	4.911	2.384	11.810	24 00	0.434	10.416	88.20	38,058	
	4.910	2.378	11.780	24.00	0.433	10 392	88.22	38,394	
	4.910	2.391	11.840	24.00	0.433	10.392	87.77	38,706	
	4.910	2.387	11.820	24.00	0.433	10.392	87.92	39,378	
	4.910	2.407	11.930	24.00	0.438	10.512	88.19	40,170	
	4.910	2.409	11.930	24.00	0.438	10.512	88.11	40,722	

Table 2-18. Phase I Automatic Selector Switch Performance Data

Notes	Hours	Output Voltage: Conditioner MP-A (vdc)	Output Voltage: Conditioner MP-D (vdc)
	360	24.60	24.45
	646	24.47	24.58
	1,056	24.47	24.59
	1,968	24.46	24.49
	2,975	24.48	24.59
	4,103	24.45	24.57
	5,087	24.46	24.58
	6,071	24.47	24.58
	7,415	24.44	24.56
	13,583	24.54	24.59
	14,471	24.56	24.60
Note: System turned off from 4/24/67 to 6/6/67.	15,095	24.62	24.58
	15,887	24.50	24.59
	16,799	24.45	24.57
	17,951	24.50	24.55
	18,959	24.47	24.57
	19,631	24.48	24.58
	20,687	24.45	24.56
	20,999	24.48	24.56
	22,367	24.49	24.60
Note: At 22,367 hours system shut down to install into cabinet type mount (2/28/67).	22,895	24.49	24.56
	24,119	24.49	24.57
	24,719	24.50	24.57
Note: 8/27/68 unit put back on test.	25,583	24.51	24.58
	26,495	24.48	24.55
	27,503	24.48	24.56
	27,887	24.46	24.56
	28,583	24.46	24.55
	28,943	24.50	24.56
	29,279	24.46	24.55
	29,591	24.50	24.58

Table 2-18. Phase I Automatic Selector Switch Performance Data (Continued)

Notes	Hours	Output Voltage Conditioner MP-A (vdc)	Output Voltage Conditioner MP-D (vdc)
	30,263	24.50	24.57
	31,031	24.52	24.56
	31,559	24.47	24.57

Table 2-19. Phase I Regulator Performance Data
Conditioner: MP-C
Regulator: I

Operating Hours	No-Load Voltage (vdc)
23	24.55
577	24.55
1,072	24.53
2,064	24.53
3,069	24.53
4,059	24.53
5,054	24.53
6,017	24.53
7,165	24.53
8,154	24.54
9,136	24.54
10,088	24.54
15,783	24.54
16,815	24.53
18,087	24.53
20,031	24.52
22,098	24.51
22,770	24.50
23,250	24.51
24,066	24.51
25,434	24.49
26,898	24.52
28,146	24.52
29,106	24.52
30,402	24.51
31,314	24.52
32,778	24.52
34,698	24.52
36,618	24.52
37,002	24.51
37,698	24.51
38,058	24.53
38,394	24.51
38,706	24.51
39,378	24.53
40,146	24.51
40,674	24.52

Table 2-20. Power Conditioner H10D3 Performance Data

E_I Primary (volts)	I_I Primary (amps)	P_I Primary (watts)	E_I Bias (volts)	I_I Bias (amps)	P_I Bias (watts)	E_o (volts)	I_o (amps)	P_o (watts)	Efficiency (%)	Temp. (°F)	Test* Hours
5.06	2.17	11.02	0.646	0.132	0.085	23.77	0.424	10.08	90.77	82	1296
5.06	2.17	11.00	0.657	0.132	0.085	23.76	0.423	10.05	90.66	82	1413
5.08	2.18	11.07	0.658	0.134	0.087	23.80	0.422	10.04	89.99	82	1576
5.08	2.18	11.07	0.647	0.132	0.085	23.81	0.422	10.05	90.09	80	1894
5.08	2.18	11.07	0.648	0.132	0.086	23.83	0.422	10.06	90.18	81	2106
5.08	2.18	11.07	0.648	0.134	0.087	23.82	0.422	10.05	90.10	86	2904
5.08	2.18	11.07	0.647	0.134	0.087	23.81	0.422	10.05	90.07	86	3575
5.08	2.18	11.07	0.648	0.134	0.087	23.82	0.422	10.05	90.07	86	4244
5.08	2.18	11.07	0.648	0.134	0.087	23.83	0.422	10.06	90.17	86	5058
5.08	2.18	11.07	0.648	0.134	0.087	23.82	0.422	10.05	90.08	87	5928
5.08	2.18	11.07	0.648	0.134	0.087	23.83	0.422	10.06	90.17	87	6476
5.08	2.18	11.07	0.648	0.134	0.087	23.85	0.422	10.06	90.17	92	7468
5.08	2.18	11.07	0.648	0.134	0.087	23.84	0.422	10.06	90.17	90	7684
5.07	2.18	11.05	0.646	0.134	0.087	23.79	0.422	10.04	90.15	93	8081
5.07	2.18	11.05	0.646	0.134	0.087	23.79	0.422	10.04	90.15	92	8327
5.07	2.18	11.05	0.647	0.134	0.087	23.80	0.422	10.04	90.15	92	8640
5.07	2.18	11.05	0.646	0.134	0.087	23.79	0.422	10.04	90.15	93	9306
5.07	2.18	11.05	0.646	0.134	0.087	23.78	0.422	10.04	90.15	93	10102
5.07	2.18	11.05	0.646	0.134	0.087	23.78	0.422	10.04	90.15	92	10649

*Includes 1241 hours of short-term tests.

Table 2-21. Power Conditioner H10D6 Performance Data

E_I Primary (volts)	I_I Primary (amps)	P_I Primary (watts)	E_I Bias (volts)	I_I Bias (amps)	P_I Bias (watts)	E_o (volts)	I_o (amps)	P_o (watts)	Efficiency (%)	Temp. (°F)	Test Hours
4.81	2.35	11.30	0.646	0.122	0.079	24.00	0.430	10.32	90.69	82	1296
4.81	2.35	11.30	0.646	0.122	0.079	24.00	0.430	10.32	90.69	82	1437
4.82	2.35	11.33	0.648	0.122	0.079	24.08	0.425	10.23	89.67	82	1600
4.83	2.35	11.35	0.648	0.122	0.079	24.20	0.430	10.41	91.08	80	1968
4.83	2.35	11.35	0.648	0.122	0.079	24.09	0.425	10.24	89.60	81	2278
4.82	2.35	11.33	0.648	0.122	0.079	24.07	0.425	10.23	89.67	87	2904
4.82	2.35	11.33	0.647	0.122	0.079	24.07	0.425	10.23	89.67	86	3575
4.82	2.35	11.33	0.648	0.122	0.079	24.07	0.425	10.24	89.75	87	4244
4.82	2.35	11.33	0.648	0.122	0.079	24.08	0.425	10.23	89.67	87	5058
4.82	2.35	11.33	0.647	0.122	0.079	24.07	0.430	10.35	90.72	88	5928
4.82	2.35	11.33	0.648	0.122	0.079	24.10	0.425	10.24	89.75	87	6476
4.82	2.35	11.33	0.648	0.122	0.079	24.10	0.430	10.36	90.80	93	7468
4.82	2.35	11.33	0.648	0.122	0.079	24.09	0.425	10.24	89.75	89	7684
4.82	2.35	11.33	0.648	0.122	0.079	24.06	0.425	10.23	89.67	94	8081
4.82	2.35	11.33	0.647	0.122	0.079	24.04	0.425	10.22	89.81	93	8327
4.81	2.35	11.30	0.647	0.122	0.079	24.04	0.425	10.22	89.81	89	8640
4.81	2.35	11.30	0.647	0.122	0.079	24.03	0.425	10.22	89.81	93	9306
4.82	2.35	11.30	0.647	0.122	0.079	24.04	0.425	10.22	89.81	93	10102
4.82	2.35	11.30	0.647	0.122	0.079	24.07	0.425	10.23	89.90	92	10649

Includes 1271 hours of short-term tests.

Table 2-22. System S10P1 Environmental Performance

Parameter Date	Data 8/5/69	 8/20/69
Environmental Temp	71	72
Pressure Vessel	73	71
Segmented Ring	83	80
Cold Frame	91	88
Hot Frame Center	1048	1047
Hot Frame Edge	1060	1060
Emitter Plate	1259	1260
V_{gbr} (volts)	0.00671	0.00673
V_{gpr} (volts)	0.01139	0.0113
V_{gb} (volts)	0.703	0.704
V_{gp} (volts)	4.973	4.974
V_{sr} (volts)	0.04205	0.04206
V_{sl} (volts)	24.51	24.54
V_{go} (volts)	9.495	9.478
V_{bo} (volts)	1.393	1.392
V_{so} (volts)	9.504	9.474
I_b (amps)	0.1355	0.1359
I_p (amps)	2.847	2.8466
I_{so} (amps)	0.4123	0.4123
P_g (watts)	14.253	14.256
P_{so} (watts)	10.105	10.12
R_1 (ohms)	59.45	59.45
P_{so} (w/57.6 Ω resistance)	10.42	10.45
Implantment date: 6/25/69		

Table 2-23. System S10P2 Environmental Performance

Parameter Date	Data	
	8/13/69	8/20/69
Environmental Temp	53	55
Pressure Vessel	55	57
Segmented Ring	64	67
Cold Frame	73	75
Hot Frame Center	Out	Out
Hot Frame Edge	1025	1025
Emitter Plate	1227	1227
V_{gbr} (volts)	0.00604	0.00606
V_{gpr} (volts)	0.01115	0.01116
V_{gb} (volts)	0.695	0.695
V_{gp} (volts)	4.96	4.965
V_{sr} (volts)	0.04152	0.04153
V_{sl} (volts)	24.53	24.54
V_{go} (volts)	9.26	9.297
V_{bo} (volts)	1.36	1.372
V_{so} (volts)	9.23	9.280
I_b (amps)	0.1208	0.1212
I_p (amps)	2.79	2.791
I_{so} (amps)	0.397	0.397
P_g (watts)	13.92	13.942
P_{so} (watts)	9.74	9.75
R_1 (ohms)	61.79	61.68
P_{so} (w/57.6Ω resistance)	10.44	10.45
Implantment date: 6/26/69		

Table 2-24. System S10P3 Environmental Performance

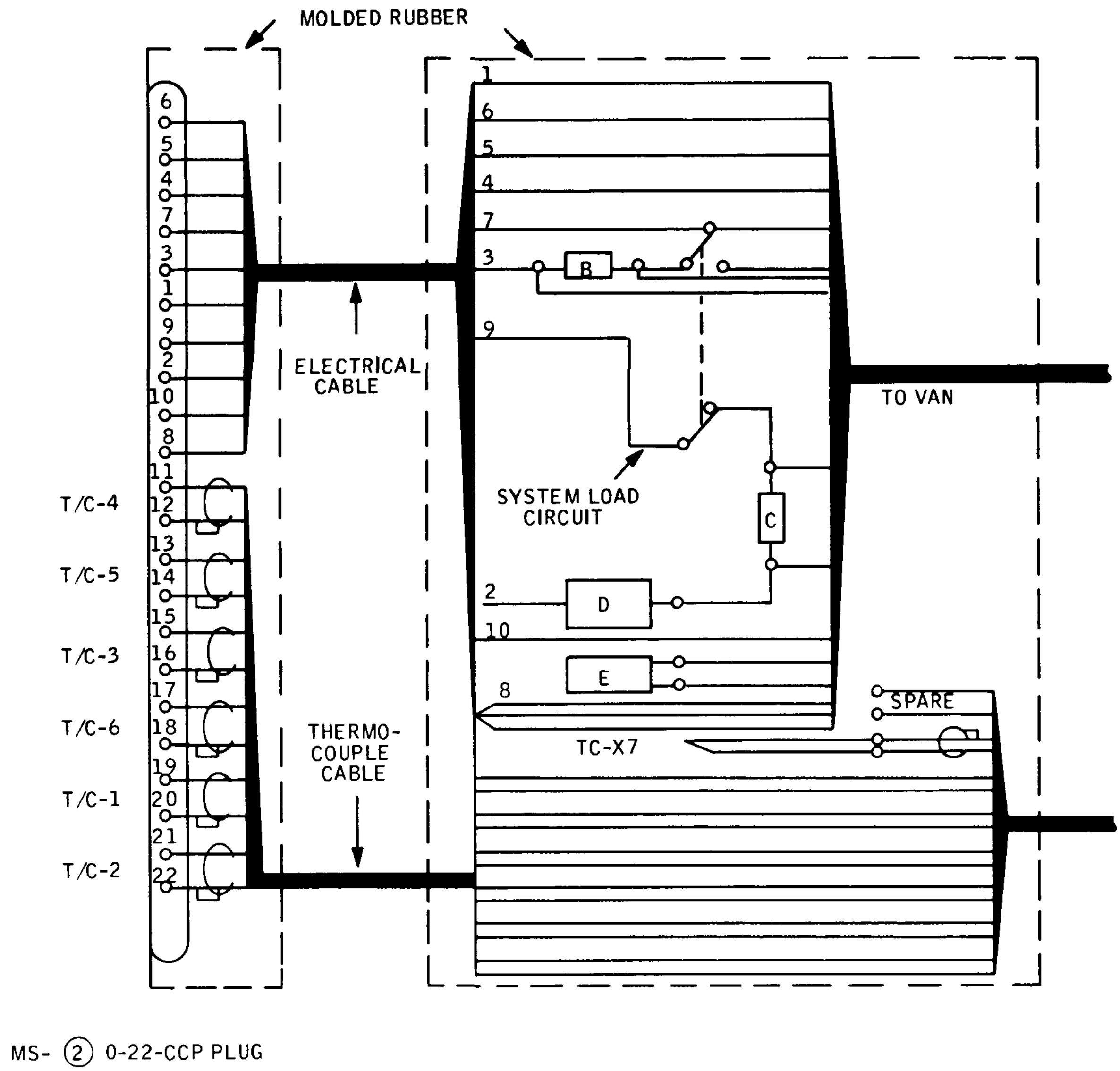
Parameter Date	Data 8/20/69
Environmental Temp (°F)	76
Pressure Vessel (°F)	106
Segmented Ring (°F)	120
Cold Frame (°F)	127
Hot Frame Center (°F)	1091
Hot Frame Edge (°F)	1108
Emitter Plate (°F)	1297
V_{gbr} (volts)	0.00713
V_{gpr} (volts)	0.01130
V_{gb} (volts)	0.7016
V_{gp} (volts)	4.973
V_{sr} (volts)	0.04307
V_{s1} (volts)	24.54
V_{go} (volts)	9.938
V_{bo} (volts)	1.460
V_{so} (volts)	10.019
I_b (amps)	0.1440
I_p (amps)	2.8252
I_{so} (amps)	0.4182
P_g (watts)	14.152
P_{so} (watts)	10.26
R_1 (ohms)	58.60
P_{so} (w/57.6Ω resistance)	10.45
Implantment date: 8/12/69	

Table 2-25. SNAP-21 10-Watt System Summary of Fueled System Performance (All data based on operation in 40°F water and fixed load resistance of 57.6Ω)

System Designation / System Characteristics	System S10P1		System S10P2		System S10P3		System S10P4	
	BOL	EOL	BOL	EOL	BOL	EOL	BOL	EOL
Thermal								
• Fuel Loading, watts (t)	210.4	185.5	207.7	183.1	213.5	188.3	210.4	186.0
• Insulation System Heat [1] Loss, watts (t)	52.3	48.4	56.7	52.0	55.4	50.9	57.3	52.5
• Insulation System Thermal Efficiency, %	74.9	73.9	72.8	71.6	74.1	73.0	72.8	71.7
• Temperature Profile								
– Pressure Vessel, °F	45	44	43	42	44	43	42	42
– Cold Frame, °F	63	56	60	56	64	58	63	61
– Cold Junction (avg.), °F	92	83	88	79	92	81	91	86
– Hot Junction (avg.), °F	985	893	958	867	992	894	984	999
– Hot Frame (avg.), °F	1040	940	1040	917	1054	947	1052	945
– Emitter Plate, °F	1255	1155	1227	1130	1267	1170	1255	1158
Electrical								
• Total Thermoelectric Generator Power Output, watts (e) (before conditioning)	14.64	11.79	14.24	11.33	14.75	12.13	14.58	11.90
• System Power Output, watts (e) [2] (conditioned to maintain 24 ± 1 vdc)	10.40	10.31	10.38	10.15	10.45	10.33	10.35	10.35
• Conditioned Output Voltage Ripple, mv	68	68	65	65	60	60	60	60
• System Efficiency, % (before power conditioning)	6.96	6.35	6.86	6.19	6.91	6.44	6.93	6.39

(1) Insulation system heat loss corrected for actual system temperature profile

(2) Power conditioner limits system power output to 10.4 watts (e) at fixed system load resistance of 57.6Ω. Excess power is dissipated in power conditioner.



B TEG BIAS SHUNT 0.005Ω

C SYSTEM SHUNT 0.1Ω

D SYSTEM LOAD 57.6Ω

E OPEN CIRCUIT RELAY DPDT

TC-X7 BULK WATER TEMP THERMOCOUPLE

Figure 2-17. System Circuit

Investigation of the data shows that this extraneous resistance (4.1Ω) has existed since the system checkout at NRDL. During the checkout at NRDL, it was assumed that the system load circuit was at approximately the design value of 57.6Ω. It was expected that a small negligible extraneous resistance would exist. Also, it was expected that the shunt resistance values would be the same as shown in Figure 2-17. When the data was taken via NRDL's Data Acquisition System it was assumed that the system load circuit resistance was at 57.6Ω. After the shunt resistors were measured, the load resistance and power out were not recalculated using these new values.

This high system load resistance does not affect the system performance. Based on the system load and environmental characteristics predictions for a system load of 61.7Ω the power output should be approximately 9.7W. The system is performing as expected with the off-design load and both absolute performance and relative long-term performance of the system will be monitored.

3.0 TASK II – 20-WATT SYSTEM

3.1 CONCEPTUAL DESIGN

Conceptual design of the 20-watt system was completed during this report period. Complete details of the design and analysis effort are included in the Conceptual Design Descriptiom MMM-3691-55, which was submitted during September.

This conceptual design and analysis effort was conducted to determine the best overall configuration for the 20-watt SNAP-21 radioisotope fueled thermoelectric generator system. The design and analysis effort borrowed heavily from the technology base established during the 10-watt system design and development program.

Two basic system concepts were explored Concept I which utilized two 10-watt thermoelectric generators mounted at opposite ends of a directly shielded fuel source and Concept II which utilized a single 20-watt thermoelectric generator in a configuration similar to the existing 10-watt system.

Both system concepts were evaluated from the standpoint of conformance to specification requirements including efficiency, size and weight, manufacturing ease and development risk.

As a result of the study, system Concept II (single TEG) was selected as the configuration that best suited the overall program requirements.

A number of significant design improvements over the existing 10-watt system have been incorporated in the 20-watt design concept including.

- The use of adjustable tension tie rods in the vacuum insulation system to simplify component fabrication;

- Using a machine wrapping method to apply the insulation foils in the vacuum insulation system to reduce cost;
- Simplified pressure vessel and generator mounting plate designs; and
- Improved power conditioner circuit design to eliminate the bias tap.

The feasibility of increasing the system dynamic capability and changing the fuel form from strontium titanate to strontium oxide was also evaluated. This evaluation revealed that the strontium oxide fuel form offered advantages in the areas of increased efficiency and reduced system size and weight. It was therefore decided that the strontium oxide fuel form will be used.

The selected SNAP-21 20-watt system configuration is therefore a strontium oxide fueled single generator system that is basically a scaled-up 10-watt system. The selected concept meets all of the technical specification requirements except maximum weight which it exceeds by 42 pounds (5.4%) and 51 pounds (5.7%) for the short and long cover models, respectively.

A drawing of the selected 20-watt system concept identifying and showing the location of major components is shown in Figure 3-1. Table 3-1 is a comparison of the predicted 20-watt system characteristics compared with the specification requirements.

3.2 INSULATION SYSTEM

During this report period effort on the high temperature vacuum insulation system (HTVIS) included machine applied insulation development, adjustable tension rod development and the 20-watt system design.

3.2.1 Machine Wrapped Demonstration Unit

System B10D3 components were refurbished for use as a demonstration machine wrapped insulation system.

The neck tube section of the failed inner liner was machined back to the flange area and a hydroformed neck tube section machined and then electron beam welded to the flange area. The inner liner was then solution annealed at 2000°F to maintain

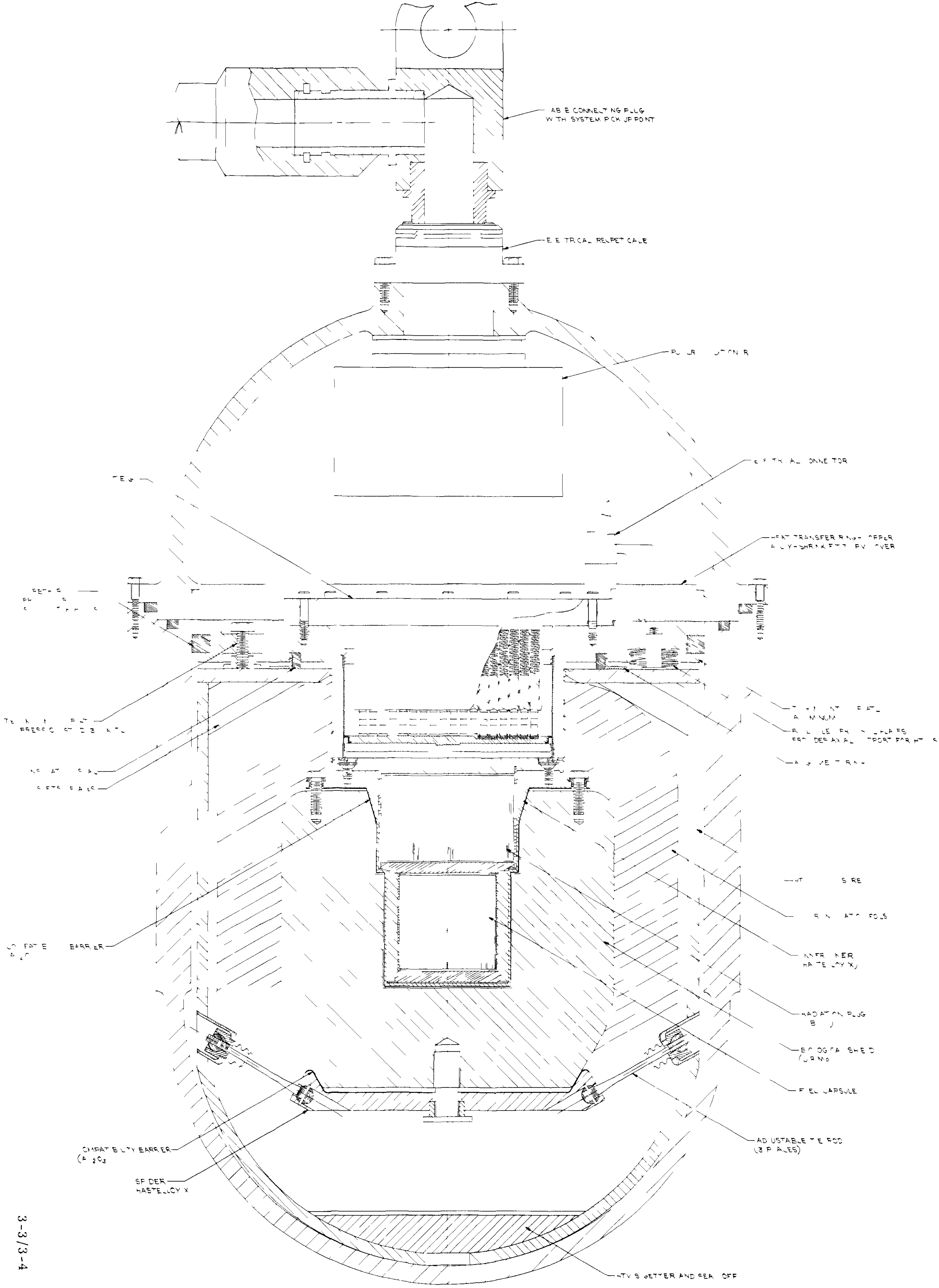


Figure 3-1. SNAP-21 20-Watt System, Concept II

Table 3-1. Comparison of Predicted 20-Watt System Characteristics with Specification Requirements

Data Source	Weight (Pounds)		Maximum Diameter (inches)	Length (Inches)		Design Fuel Loading BOL (watts)	System Efficiency % - EOL
	Long Cover	Short Cover		Long Cover	Short Cover		
Specification Requirement	890	775	18	44	32	372	6.11
Predicted Characteristics (SrO_2 Fuel Form)	941	817	17.8	39.3	31	368	6.16

the fine grain (7 ASTM No. 4) in the neck tube section. After annealing, the weld joint was radiographed for weld defects. All weld joints were 100% penetrated with no obvious porosity at an inspection level of 2-2T. After machining the neck tube section to final dimensions, the previous Al_2O_3 coating was removed by grit blasting and a new coating applied by plasma spraying Al_2O_3. The final coating was ground to fit the existing dimensions on the biological shield.

The biological shield was pickled to remove the old copper coating and replated with copper. This was done for handling purposes only.

The spider was stripped of its old Al_2O_3 and resprayed with Al_2O_3 by plasma spraying techniques. After spraying, the coating was ground to fit the existing dimensions of the recoated biological shield.

All refurbished parts were shipped to Linde for machine application of the insulation system.

3.2.2 Machine Applied Insulation Development

The purpose of the machine applied insulation development work is to develop a procedure and materials so that the HTVIS can be insulated by machine in a manner which is currently being employed at Linde Division for insulating cryogenic containers. The use of machine applied insulation will significantly reduce the amount of time and labor cost required to fabricate a HTVIS.

The development of techniques required for machine applied insulation of the SNAP-21 units is being accomplished in three steps:

- Step 1 – Machine wrapping of a 10-watt dummy shield with aluminum foil and glass paper.
- Step 2 – a. Machine wrapping of a 10-watt dummy shield with the actual insulation materials required for an operating unit. b. Perform a cylindrical thermal conductivity test on the materials to be used in an operating unit.
- Step 3 – Machine wrapping of a 10-watt system followed by a thermal performance demonstration test.

Step 1

During this reporting period the wood dummy of a 10-watt biological shield was fitted with the required fixturing for the insulation machine and insulation was machine-applied to the unit. Figure 3-2 shows the completed machine insulated unit. Aluminum foil and glass paper were used for the insulation materials because of their ready availability. The same materials would be used on a unit in the temperature range of ambient to 900°F. For the temperature range of 900°F to 1300°F the insulation materials will be copper foils with quartz paper separators. A combination wrap technique was used which employs both orbital and spiral applied layers. With this wrap, 100 orbital layers and 50 spiral layers were applied to the cylindrical portion of the unit. The heads of the unit are insulated with 100 thermally effective orbital layers.

It appears from this preliminary work with the machine insulation concept that it is entirely feasible to apply insulation by machine on the HTVIS unit geometry.

With the machine applied insulation it is desirable to install the tension rods after applying the insulation to prevent interference with the process. Thus, it is necessary to protrude the insulation after it has been applied for installation of the tension rods. To anticipate possible problems in the hole drilling required in the actual system, the dummy unit was installed in the tension rod installation fixture and several 3/8-inch diameter holes were drilled through the aluminum foil – glass paper insulation system at the proper angle. The holes are very uniform and there appears to be very little reason to expect any significant degrading of the thermal performance of the insulation due to these protrusions. Although part of the insulation in an actual system will be composed of two other materials the same hole drilling results are expected.

The hole drilling operation completed Step 1 of the machine applied insulation development program. The results were very encouraging and indicate that chances for success are high.

Step 2

During this reporting period most of the efforts in this area were expended selecting the materials to be utilized for the demonstration unit. These materials

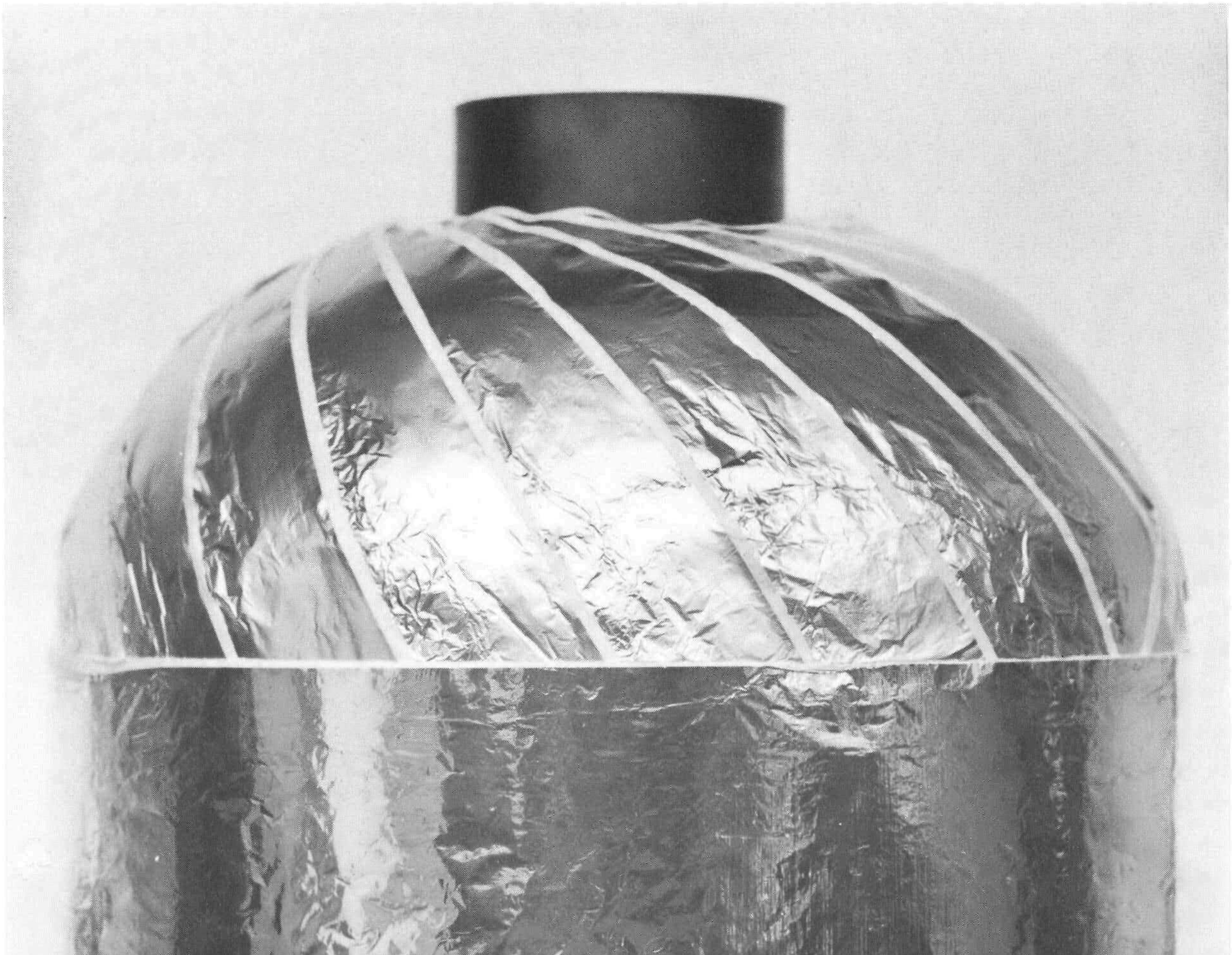


Figure 3-2. Wood Dummy of 10-Watt Configuration with Machine Applied Insulation (Neck Tube at Bottom of Photograph)

must be compatible with thermal performance, vacuum outgassing and machine application requirements. An attempt is being made to purchase the materials in a condition so they can be used without any additional processing.

The insulation materials required will include:

	Material	Nominal Thickness
a.	Aluminum Foil	1/4 mil
b.	Copper Foil	1/2 mil
c.	Glass Paper	3 mil
d.	Quartz Paper	5-8 mil

a. Aluminum Foil

Previous testing has indicated that the aluminum foil can be used in the as received condition. The required widths and thickness of this foil are available in Linde stock.

b. Copper Foil

The copper foil used in previous HTVIS units was 1/2-mil electrodeposited foil. However, this foil requires Linde processing in a reducing atmosphere to remove the large amounts of oxide on the surface in order to improve the reflectivity. However, in the quantities and widths required for machine application this would be a very cumbersome process. A sample of annealed rolled copper foil was obtained with the anticipation that this foil could be used in the as received condition. An integrating sphere reflectance test provided the basis for comparison of the rolled annealed foil with the Linde processed foil and as received electrodeposited foil. The optical density was measured at 1.2μ and converted to percent reflectance. This wavelength is the longest at which the reflectance could be measured with the available equipment. This corresponds to the near infra-red region, a temperature much above the 900°F to 1350°F operating range of the copper foil. The reflectance values presented below are average values for both sides of the foil. These values should be used only as a comparison and not as absolute values.

Copper Foil	Average Reflectance
Electrodeposited (as received)	81%
Electrodeposited (Linde processed)	93%
Rolled annealed (as received)	87%

The results indicate that although reflectance of the as received rolled foil is not as good as the Linde processed electrodeposited foil, it is significantly better than the as received electrodeposited foil. Thus, the use of the rolled foil may create some increase in the overall system thermal conductivity, but it is anticipated that the compromise in total performance would be reasonably small. It may be possible to improve reflectivity of the foils after the insulation has been applied with alternate evacuation and reducing gas back fills with the insulation system hot. It was decided to proceed on the basis of using the rolled annealed foil. Although the as received rolled foil will be more expensive, it is a much better approach than having to process the nearly 1/2 mile of electrodeposited foil strip required for the machine application. An attempt is being made to substitute the vendor's annealing process for the Linde processing procedure since the vendor has automated facilities to anneal very large quantities. However, storage of the annealed foil to avoid surface contamination would then become an important consideration.

c. Glass Paper

Linde has adequate quantities of the glass paper in stock which can be cut to the required width for this application.

d. Quartz Paper

The high temperature paper utilized in previous applications was composed of Refrasil fiber with an organic binder. This paper required Linde processing to remove the organic binder before it could be applied. The strength of this paper after processing is much too weak to apply with present machine insulation techniques. After some discussion with the Dexter Corporation, a different fiber has been selected for this application. Some samples of this paper have been obtained which offer several advantages.

1. The cost of the fiber is much less than Refrasil yielding a paper cost about one-fourth that of Refrasil paper.

2. The strength as measured from processed hand sheets is 0.3 pound/inch versus only 0.06 pound/inch for processed Refrasil paper in the wrap direction.

3. Dexter will fabricate some hand sheets to determine if the paper can be manufactured without the organic binder. If not, the paper will be produced with a binder and processed at Linde to remove the organic material.

Once all the materials have been procured, the dummy unit will be insulated as required for an actual unit. In addition to insulating the dummy unit, a cylindrical thermal conductivity tester will be insulated. The purpose of this test is three-fold:

1. To preview thermal performance of the materials which are going to be utilized for the machine applied insulation.

2. To preview the total insulation system outgassing rate and composition.

3. If required, develop a procedure for rectifying unsatisfactory thermal performance or outgassing rate of the applied insulation.

Step 3

The techniques utilized in Step 3, the machine application of insulation on the actual unit, will be founded on the results of Step 2.

Enclosure heads (from Task I units) have been reworked to provide the required girth and neck tube weld joints so that these heads can be used to fabricate the machine applied insulation demonstration unit. Other components required for this unit which were not in inventory have been ordered.

3.2.3 Adjustable Tension Rod Development

An adjustable tie rod design has been developed for the 20-watt insulation system. This design allows for adjustment of the tie rods to compensate for slight variations in the axial length of the shield assembly and also allows the system to be processed at a higher temperature.

Fabrication was started on the tension rod test apparatus and associated components. Development of welding parameters for the weld between the bellows and tension rods was also started.

A schematic of the adjustable tension rod device test apparatus is shown on Figure 3-3. The device is composed of a small vacuum enclosure into which the tension rod with bellows assembly is assembled. It is planned to make the seals between the bellows and the tension rod and spherical washer by welding. The seal between the spherical washer and the receptacle will be made with epoxy. The apparatus is designed to mount on a vibration machine so that the tension rod assembly can be subjected to the unit dynamic test conditions while exposed to vacuum. The anti-rotation of the hot end spherical ball is provided for by a pin which fits into a slot milled into the ball while the pin ends spring into pilot holes in the simulated spider. The anti-rotation of the cold end spherical ball (adjustment of rod tension) is provided for by a slotted tension rod end with an internal thread which will receive a Nylok set screw. An anti-rotation pin is set in the tension rod slot to contact the face of the ball after the ball has been tightened. The Nylok set screw is then tightened on the pin, thus preventing the ball from any upward movement (loosening) on the tension rod.

Shown on Figure 3-4 is an exploded view of the actual hardware to be used for the development testing of the adjustable tension rod. When weld parameters are developed for the bellows vacuum seals, the tension rod assembly can be made and the function of the apparatus tested in a dynamic environment.

The bellows to be used for this adjustable tension rod development has been purchased from the Mini-Flex Corporation, Van Nuys, California, as a stock item (SS-320-50-164). The bellows is made from Type 321 stainless steel and

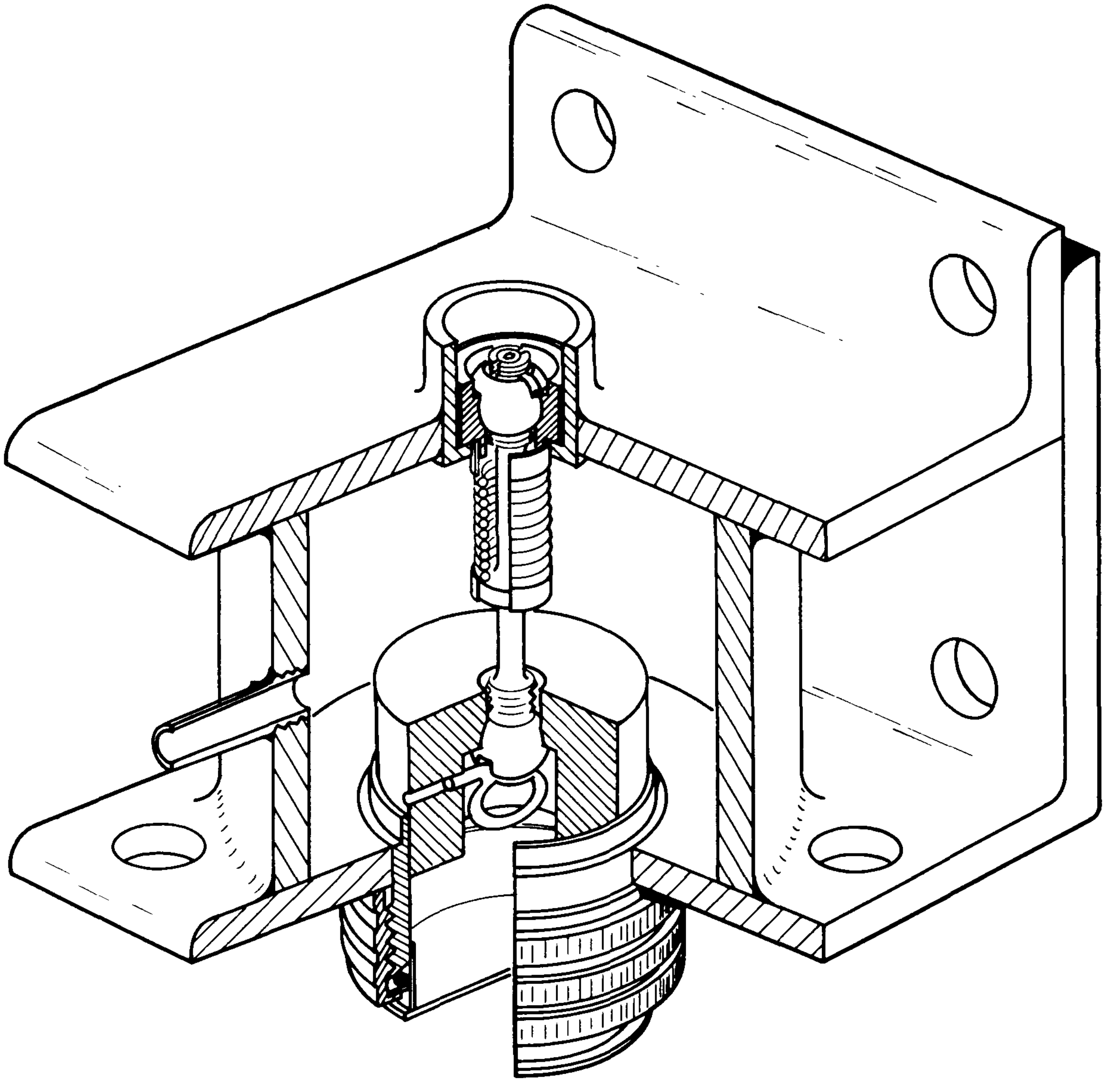


Figure 3-3. Schematic of Adjustable Tension Rod Device Test Apparatus

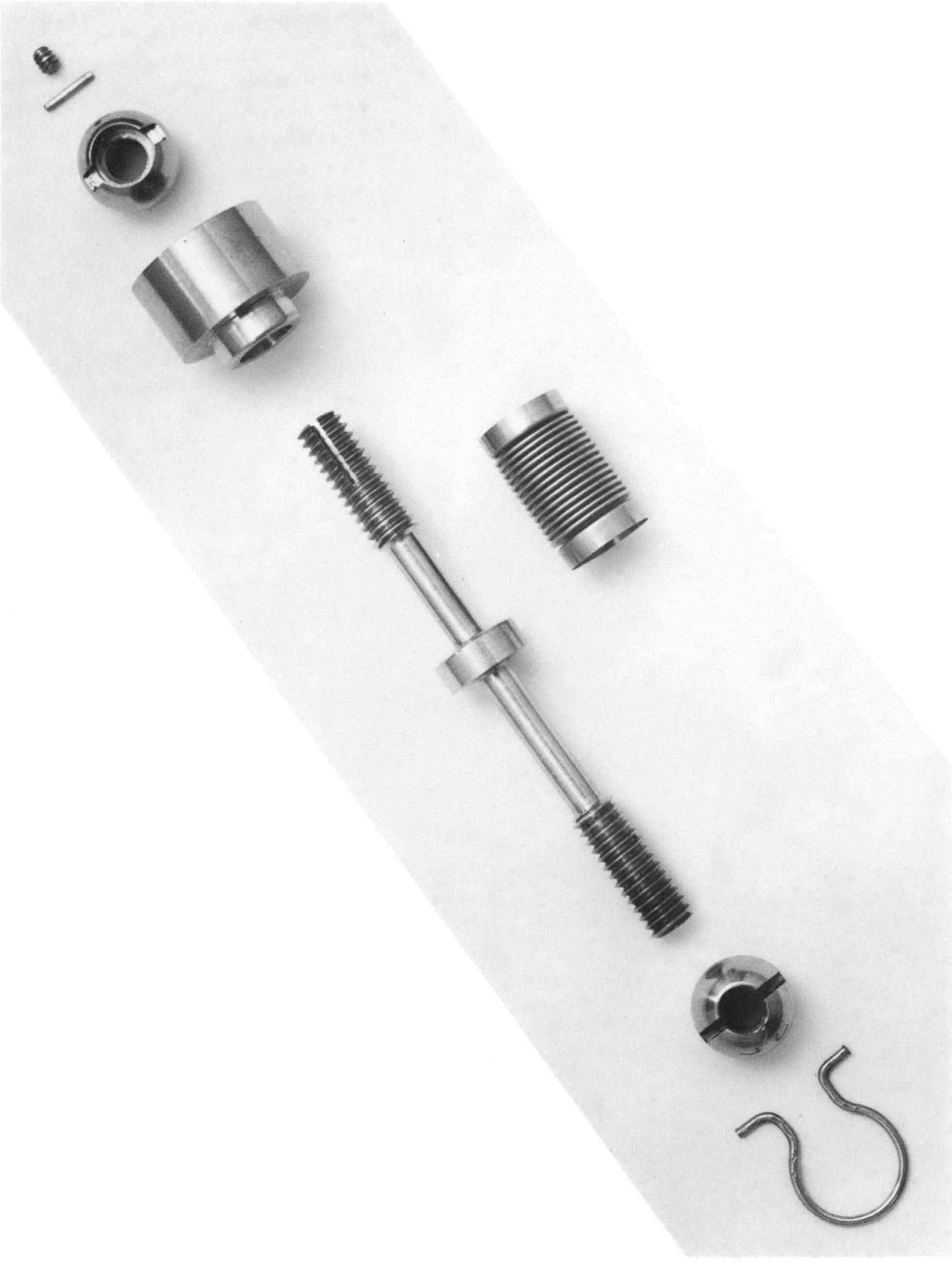


Figure 3-4. Components Fabricated for Adjustable Tension Rod Development

has a wall thickness of 0.005 inch. The inside diameter is 0.306 inch, and the outside diameter is 0.474 inch while the 14 convolutions provide a free length of 0.52 inch with a maximum allowable deflection of 0.10 inch.

To determine the weld parameters for sealing the bellows to the tension rod and the spherical washer the following procedure was followed. The bellows ends, where the welding will be performed, were simulated with a 3/8-inch diameter x 0.006 inch thick stainless steel tube. The tension rod was simulated by a stainless steel rod which was machined to tightly fit inside the tube. Three types of welds were performed during this period which included Heliarc without filler, Heliarc with filler, and capacitor discharge overlapping spot welds.

The Heliarc weld without filler was performed by positioning the tube on the rod so that the edge of the tube butted against a machined edge on the rod which had an outside diameter the same as the tube. A copper chill band 3/8-inch wide was wrapped around the tube approximately 1/32-inch from the weld edge. The welding was performed with the test piece being rotated at 1 inch/minute while hand holding the torch. The initial current was 60 amps and this was decreased to 30 amps as the part warmed up. The joint was leak tested with a helium leak detector and found to be tight. The joint was sectioned for further examination and it was found that there was good fusion between the parts; however, the penetration was quite deep into the rod material.

The Heliarc weld with filler wire was performed in a similar manner to the weld without filler except that the tube was fitted on the rod without the end of the tube contacting a shoulder. Welding was performed while rotating the work 1 inch per minute weld speed while hand feeding in the 0.020-inch diameter Type 308 weld filler wire. The current varied from 60 amps to 20 amps to adjust the weld puddle and prevent burning the thin wall tube. After welding, the specimen was leak checked with a helium leak detector and found to be leak tight. The sectioned joint showed good fusion between the tube and the rod. As with the sample without filler wire the weld penetration into the rod is quite deep.

To prevent the possibility of a burnout while welding the thin wall tube to the rod with a Heliarc torch and the accompanying deep penetration which could cause distortion, welds were made for evaluation, using a Unitek capacitor discharge welder employing an overlapping spot weld technique. Figure 3-5 shows a

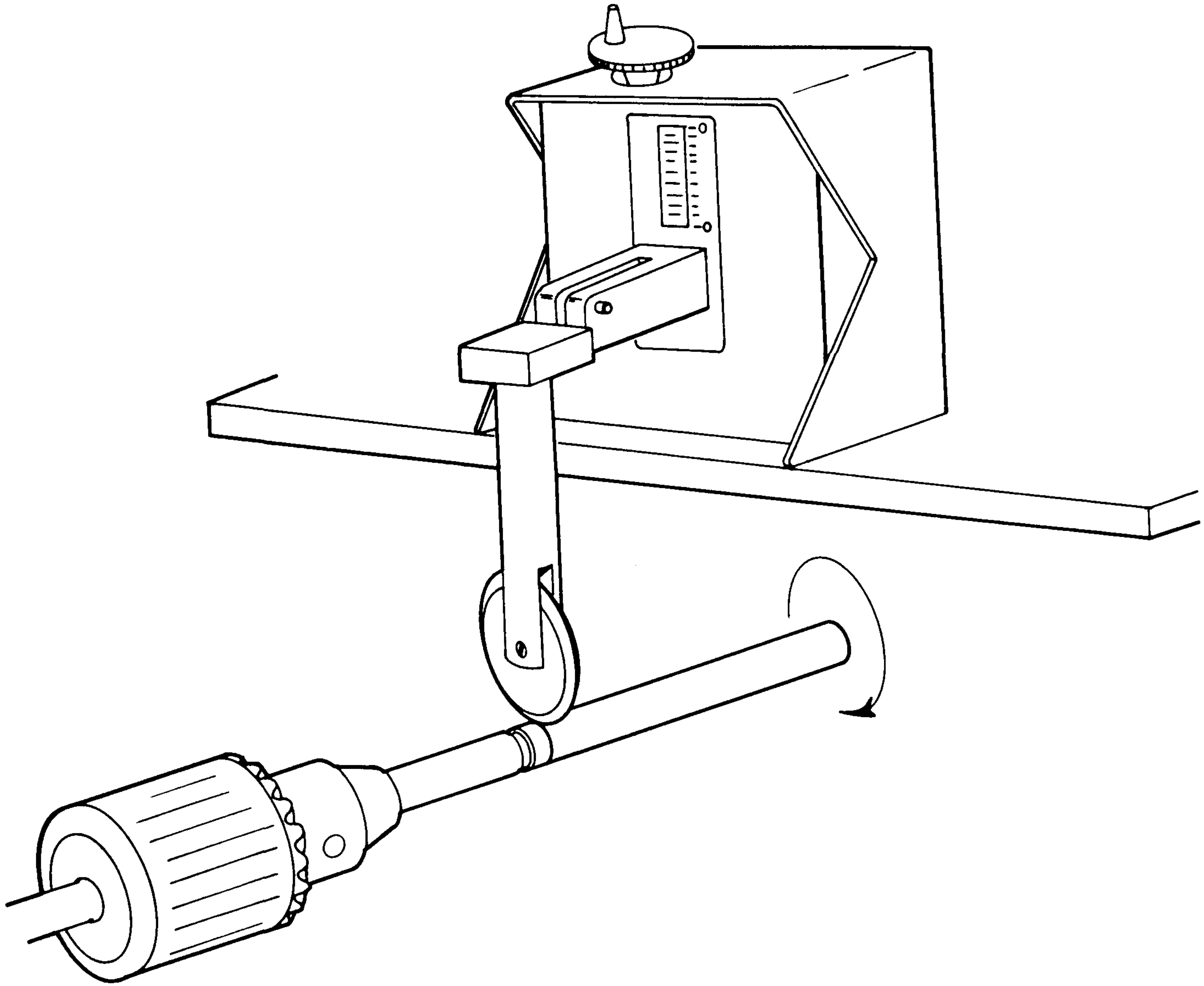


Figure 3-5. Schematic of Overlapping Spot Weld Apparatus

schematic of the welding setup. The weld sample is rotated in a positioner while a copper wheel under a spring force tracks on the outside of the tube. The individual spot welds are made so that they are overlapping and in effect make a continuous weld.

Seven weld joints were produced on one sample to evaluate various weld parameters. Table 3-2 presents the parameters recorded during the welding.

Table 3-2. Weld Parameters for Overlapping Spot Weld (3/8-Inch O.D. S.S. Tube x 0.006 Inch Thick)

Unitek Welder

Weld No.	Power Setting Watt/Seconds	Weld Travel Inch/Minute	Welds Per Minute	Pressure Setting Mark
1	25	0.34	98	7
2	25	0.32	98	9
3	20-24	0.33	98	8
4	20	0.32	58	7
5	15	0.33	58	7
6	10	0.34	58	7
7	5	0.34	58	7

To determine the structural integrity, the welds were sectioned and it was found that for all seven welds there was incomplete fusion between the tube and the rod indicating that further weld development work would be required.

To improve the quality of this type of seal weld a new capacitor discharge unit was purchased from Unitek Corporation. This unit is a Model 1-132-02 Multi-pulse dual range. The available weld pulse shapes include 0.006 second, 0.007 second, and 0.010 second. Longer discharge pulses result in more penetration of the welds. The unit has a capacity of 250 watt/second.

At the end of the reporting period, sample welds were made for both stainless steel to stainless steel and Inconel 718 to stainless steel. Preliminary investigation of the welds showed that good weld penetration was achieved. These sample welds will be discussed more fully in the next report.

3.2.4 Insulation System Design

A 3M-Linde meeting was held in St. Paul on August 28, 1969, for the purpose of establishing the required interface parameters of the insulation system so that Linde can proceed on the HTVIS design work. The unit design is based on the depleted uranium biological shield being supported by a neck tube at one end and three adjustable tension rods at the other end. The design input parameters are summarized below:

a. The neck tube will be 6.545 inches outside diameter at the upper enclosure head.

b. The outside diameter of the enclosure shell will be 14.000 ± 0.030 inch with the upper head being flat and the lower head having a 7.000 inch outside spherical radius.

c. The distance from the top of the neck tube along the unit axis to the center of the tension rod hot ball is 11.86 inches. This distance is divided as follows:

2.66 inches:	Top of neck tube to emitter plate.
1.00 inch:	Emitter plate to center of inner taper in shield.
7.70 inches:	Center of liner taper to center of spider taper on the shield.
0.50 inch:	Center of spider taper to center of hot ball.

The distance from the unit centerline axis to the center of the hot ball is 4.000 inches.

d. The outside radius of the biological shield is 4.63 inches.

e. The following operating temperatures were defined for use in the unit analysis:

Top of neck tube (70°F)

Emitter plate – bottom of neck tube (1380°F)

Average temperature of liner on taper (1400°F)

Shield at top taper (1400°F)

Shield at bottom taper (1455°F)

Average spider temperature (1430°F)

Hot end tension rod ball (1430°F)

Cold end tension rod ball (50°F)

Outer enclosure shell (50°F)

Other operating temperatures resulting from conditions such as minimum fuel loading, end of life, and shipping will be defined at a later date so that the effect on rod loads can be determined.

f. The weight of the shield and shield attachments is 335 pounds and the center of mass is located 7.40 inches from the top of the neck tube on unit centerline axis. The unit will be designed for the same dynamic loading as for Task I, namely maximum 6 "g" shock and maximum 3 "g" vibration at 50 Hertz.

g. The construction materials for the HTVIS are as follows biological shield – depleted uranium with 8 percent molybdenum, neck tube – Hastelloy-X, spider – Hastelloy-X, attachment bolts – depleted uranium with 8 percent molybdenum, bolt washers – molybdenum, outer enclosure – stainless steel, receptacle – stainless steel, spherical washer – stainless steel, adjustable rod bellows – stainless steel, cold end tension rod ball – stainless steel, tension rod – Inconel 718 (use for entire length if creep properties are equal to Inconel 625 and heat loss is not greater than a two material rod), and hot end tension rod ball – Hastelloy C.

4.0 PLANNED EFFORT FOR NEXT QUARTER

- Complete Final System Design Description.
- Complete Task II Conceptual Design Description.
- Complete 16 mm SNAP-21 Documentary Film.
- Begin Detail Design of Task II Development Hardware.
- Start Procurement of Biological Shields for 20-Watt Systems.
- Complete Evaluation of Machine Wrapped 10-Watt Insulation System.
- Complete Weld Development Work for Adjustable Tie Rods.
- Start Procurement of 20-Watt Pressure Vessels, Mounting Plate and Retainer, and Thermoelectric Generator Material.
- Continue Long-Term Testing of Phase I and Phase II Thermoelectric Generators.
- Continue Long-Term Testing of Phase II Systems, Power Conditioners and Insulation Systems.

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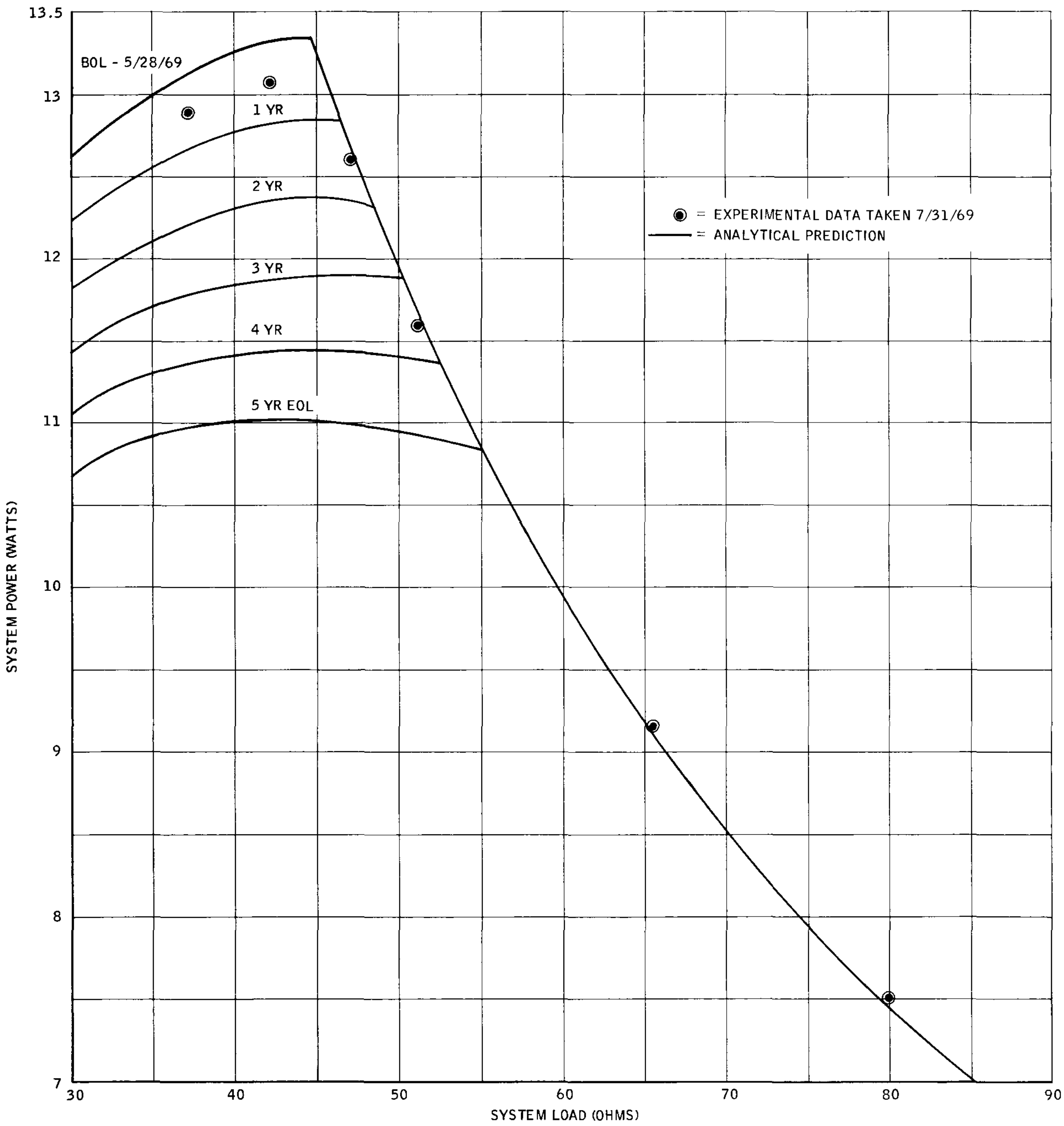

Figure 1. System S10P4 Performance
Power vs. Load Resistance in 40°F Water

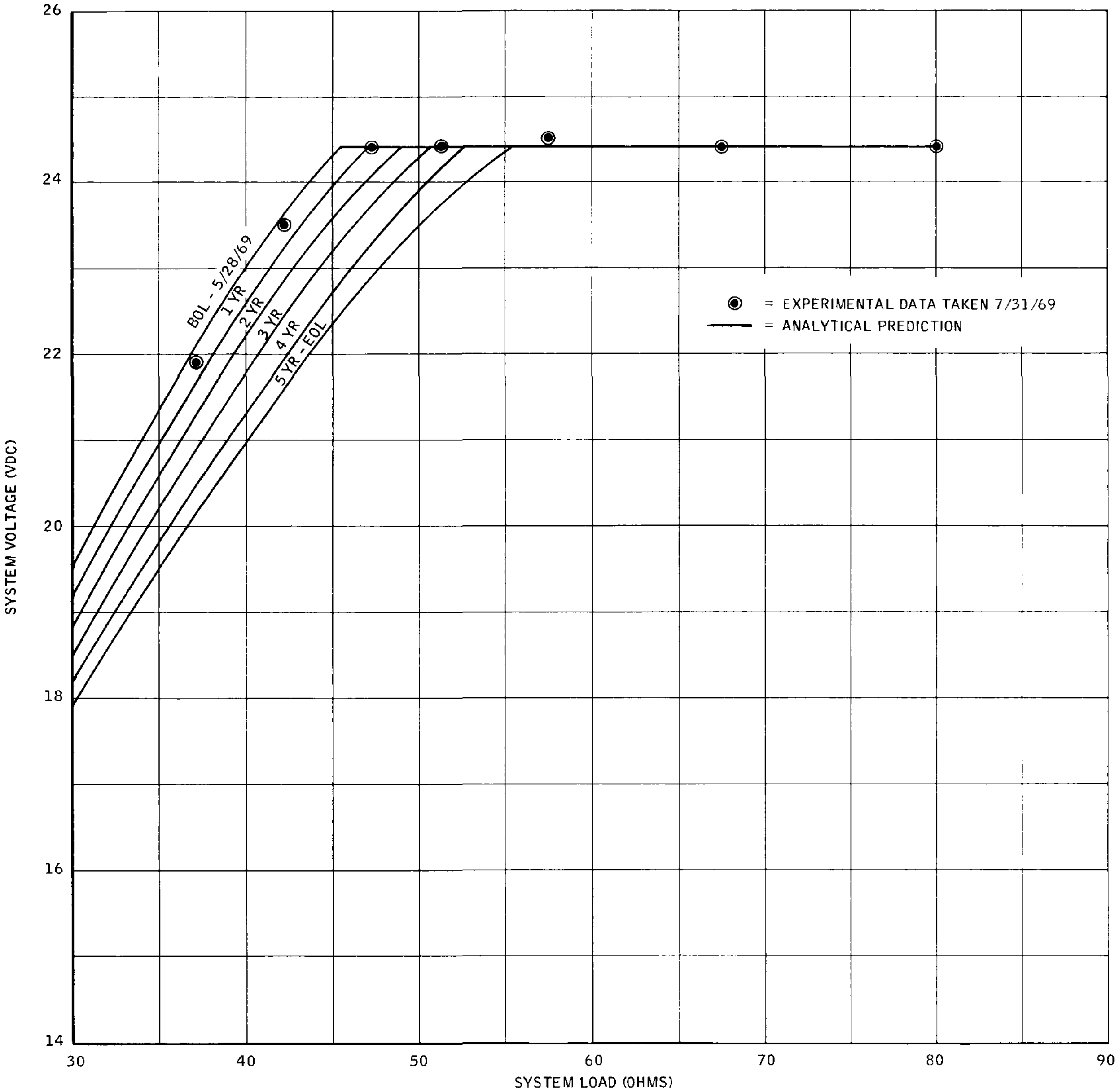

Figure 2. System S10P4 Performance
Voltage vs. Load Resistance in 40°F Water

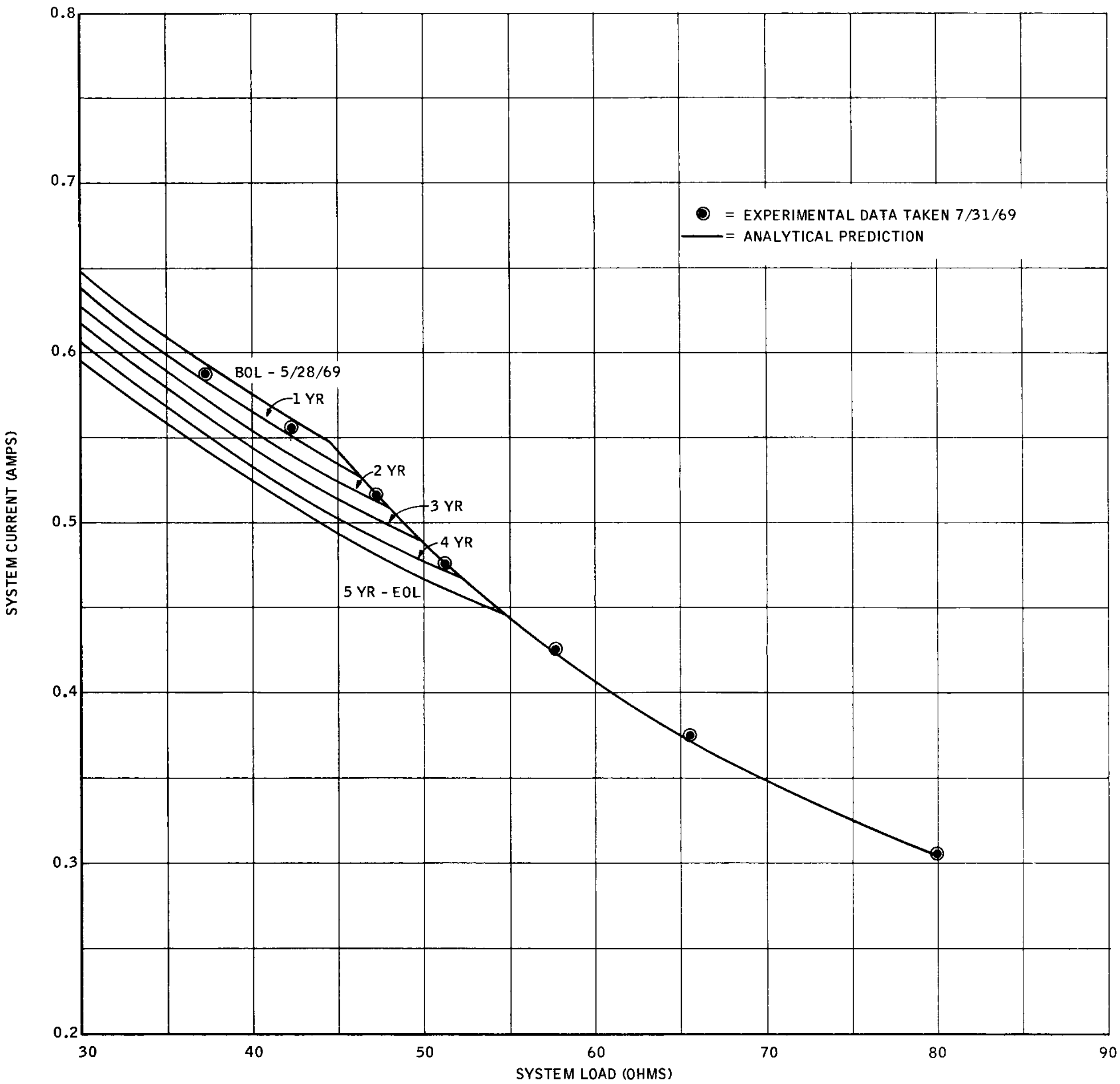

Figure 3. System S10P4 Performance
Current vs. Load Resistance in 40°F Water

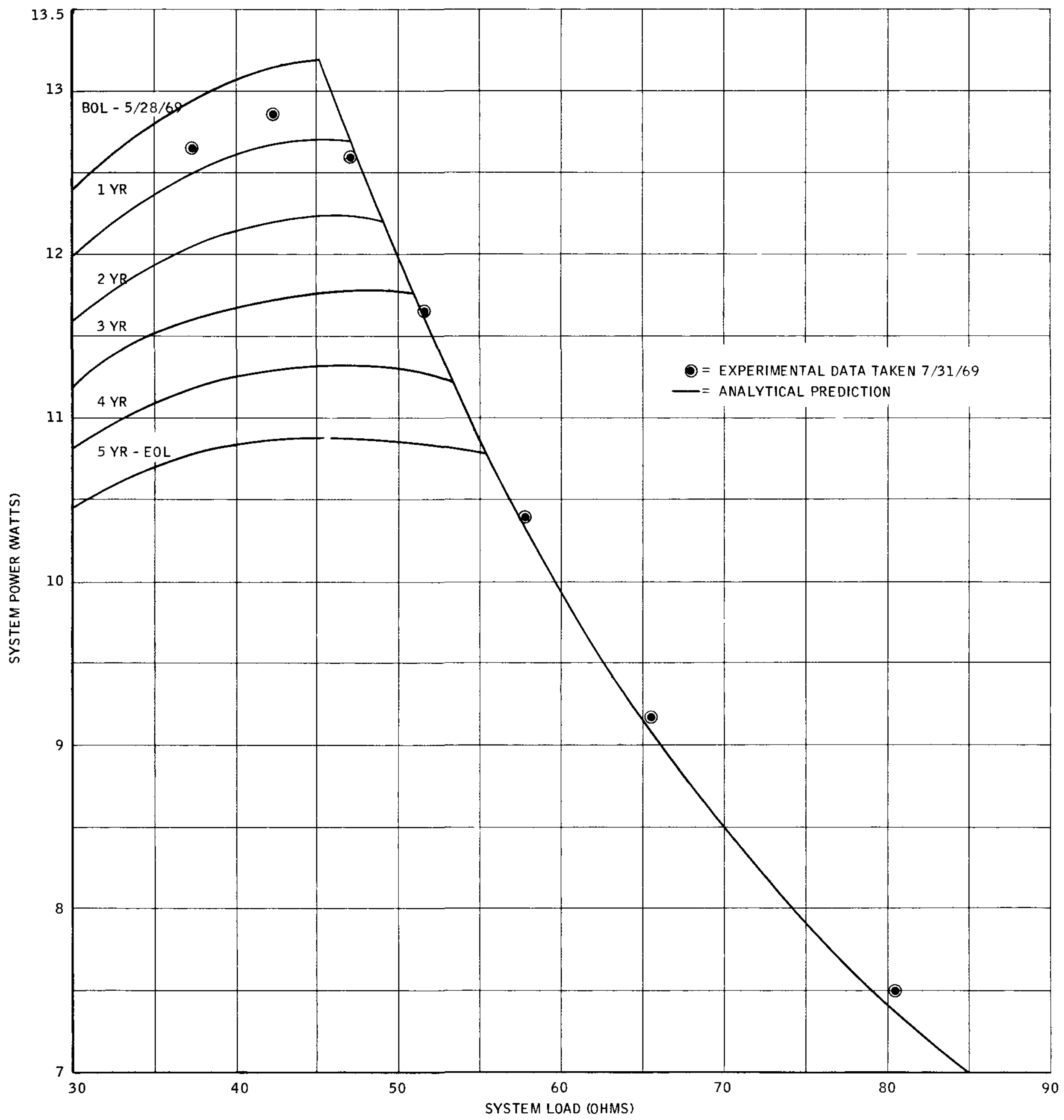

Figure 4. System S10P4 Performance
Power vs. Load Resistance in 60°F Water

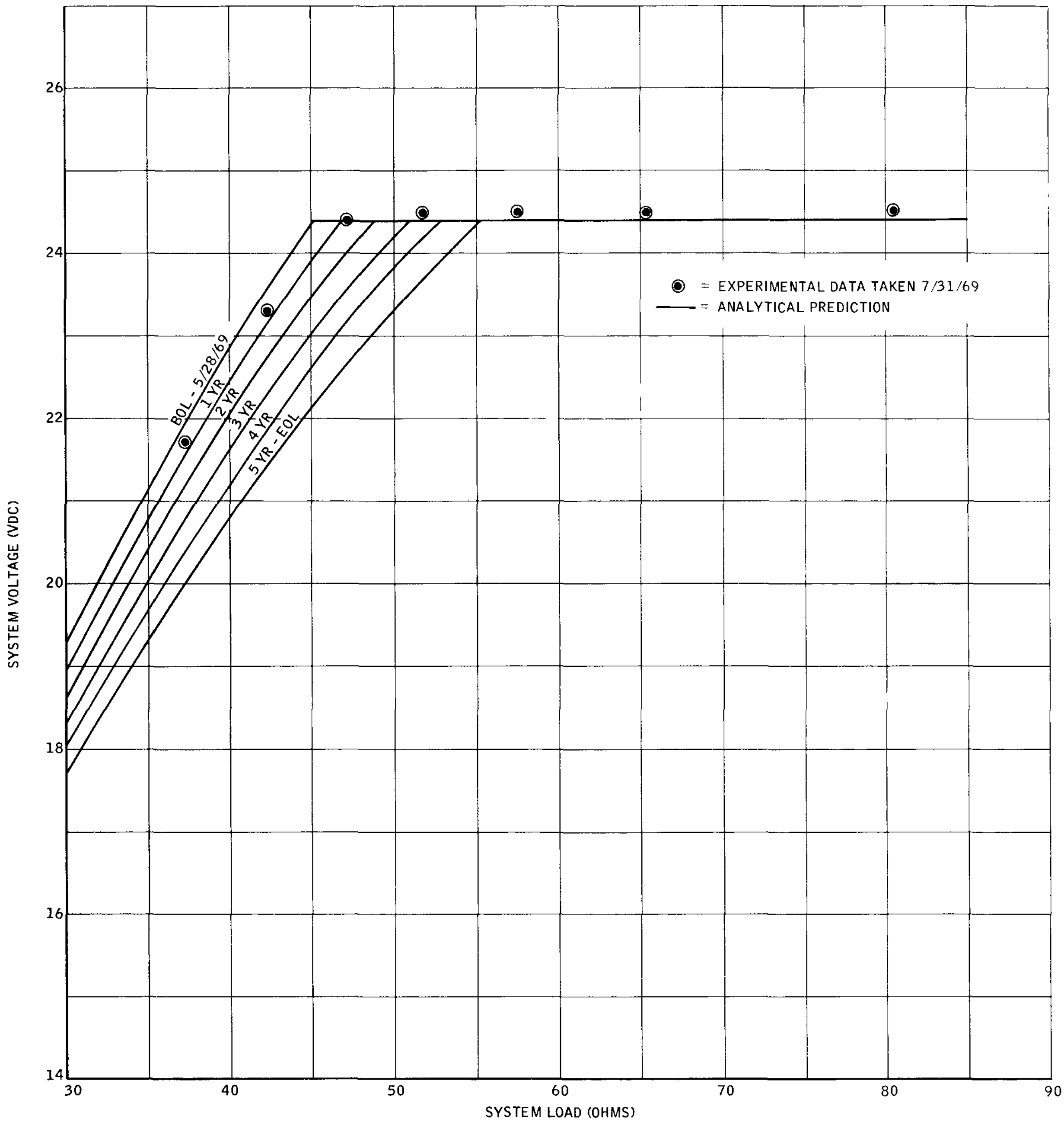

Figure 5. System S10P4 Performance
Voltage vs. Load Resistance in 60°F Water

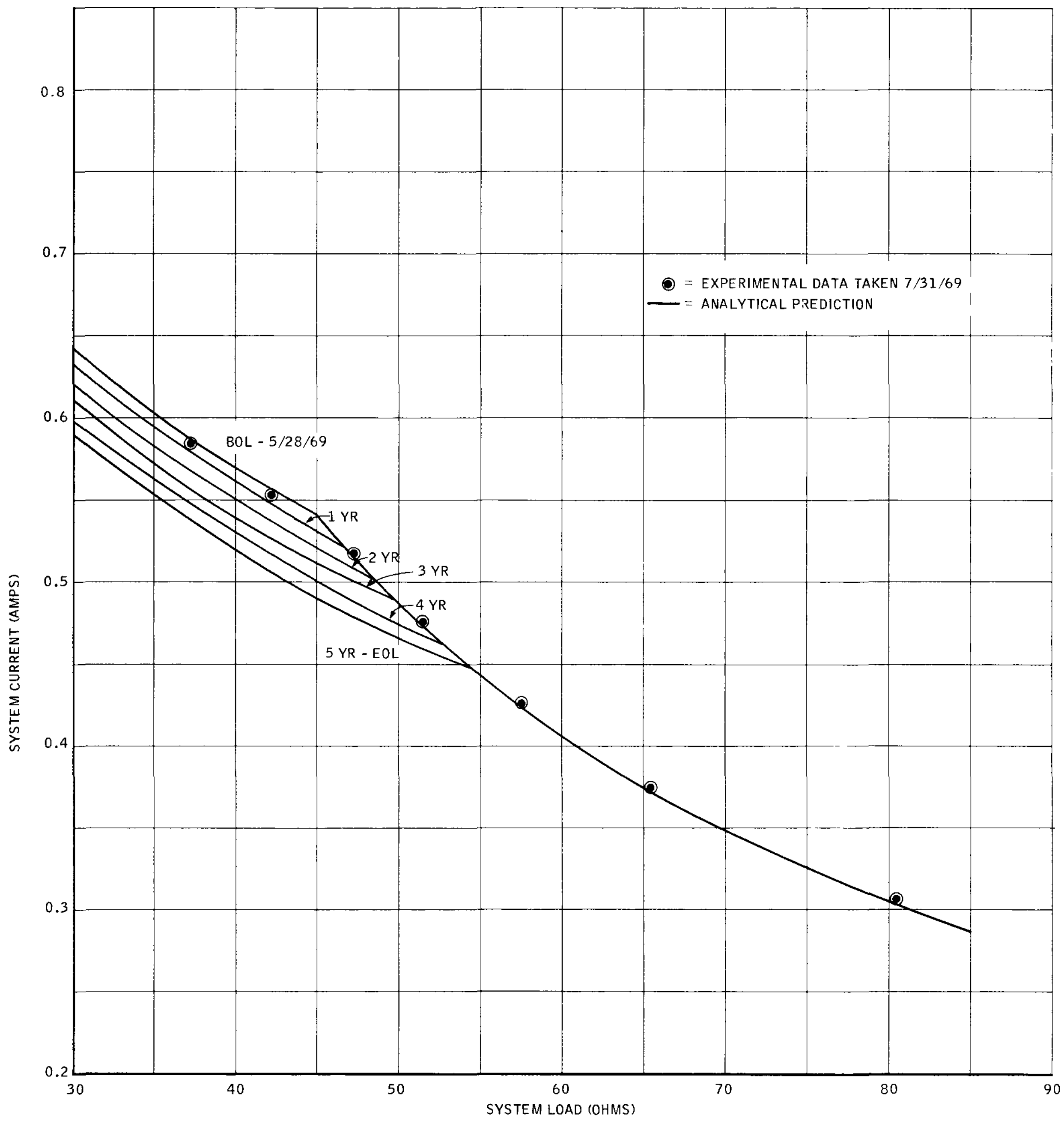

Figure 6. System S10P4 Performance
Current vs. Load Resistance in 60°F Water

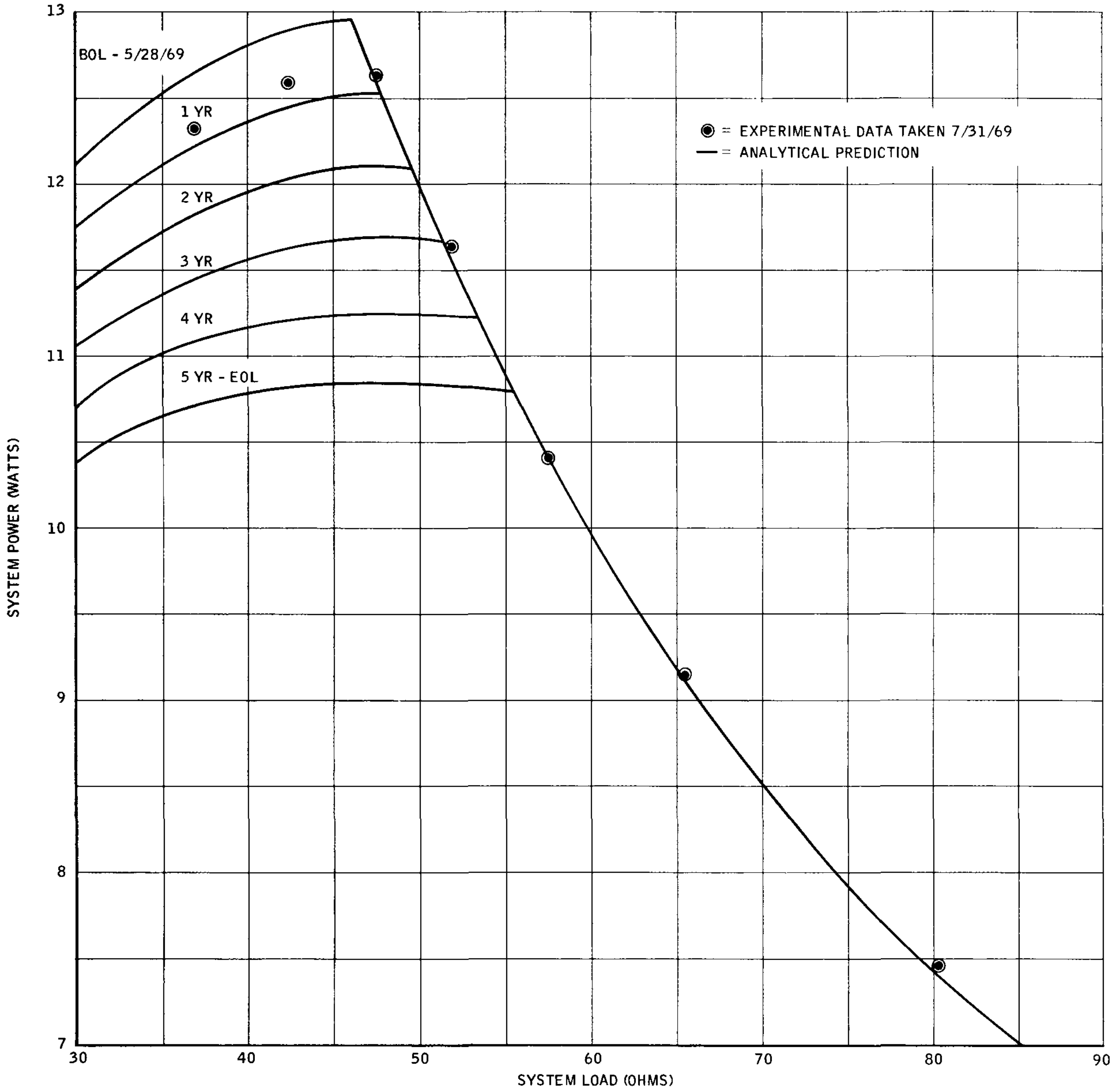

Figure 7. System S10P4 Performance
Power vs. Load Resistance in 80°F Water

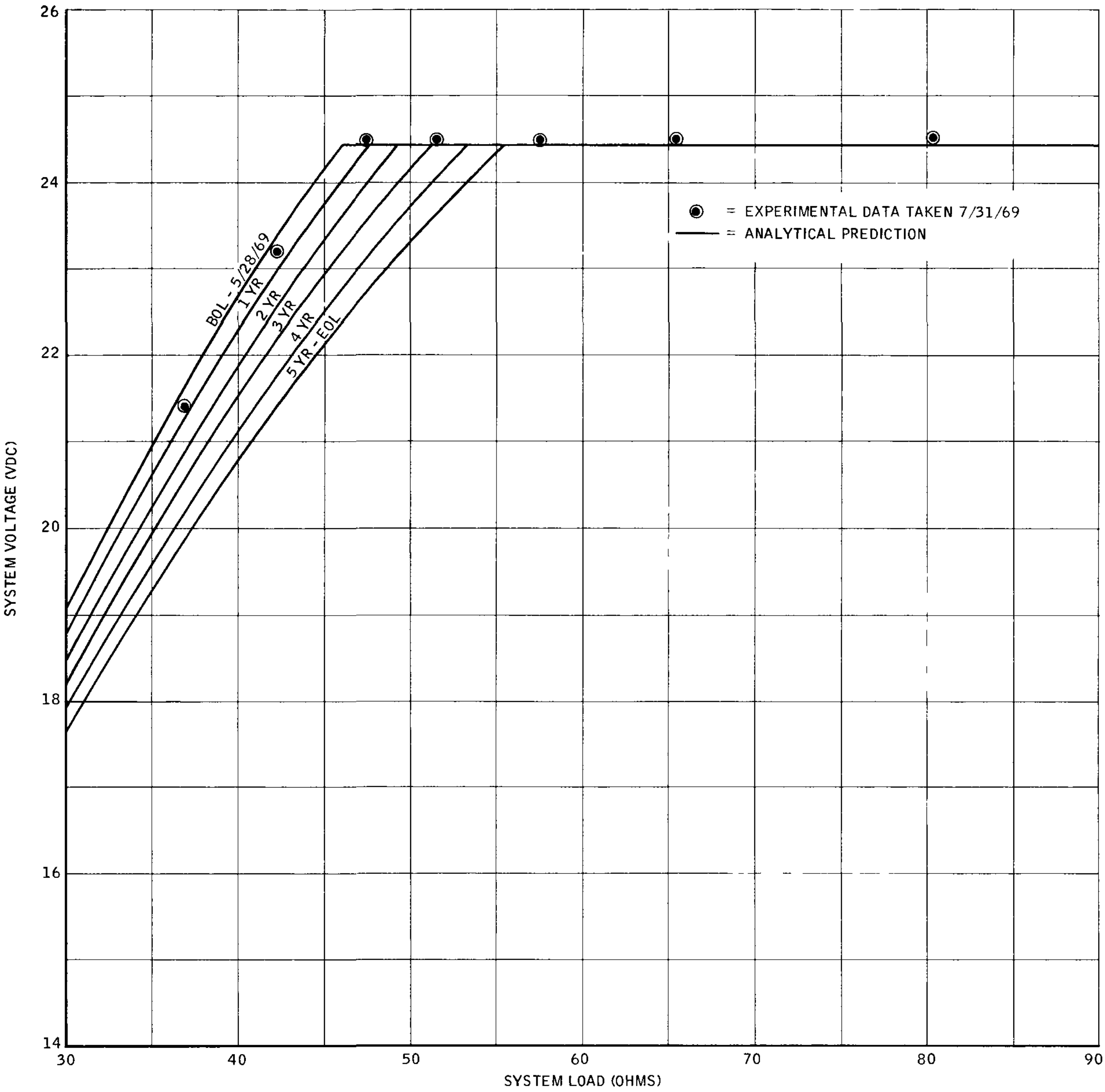

Figure 8. System S10P4 Performance
Voltage vs. Load Resistance in 80°F Water

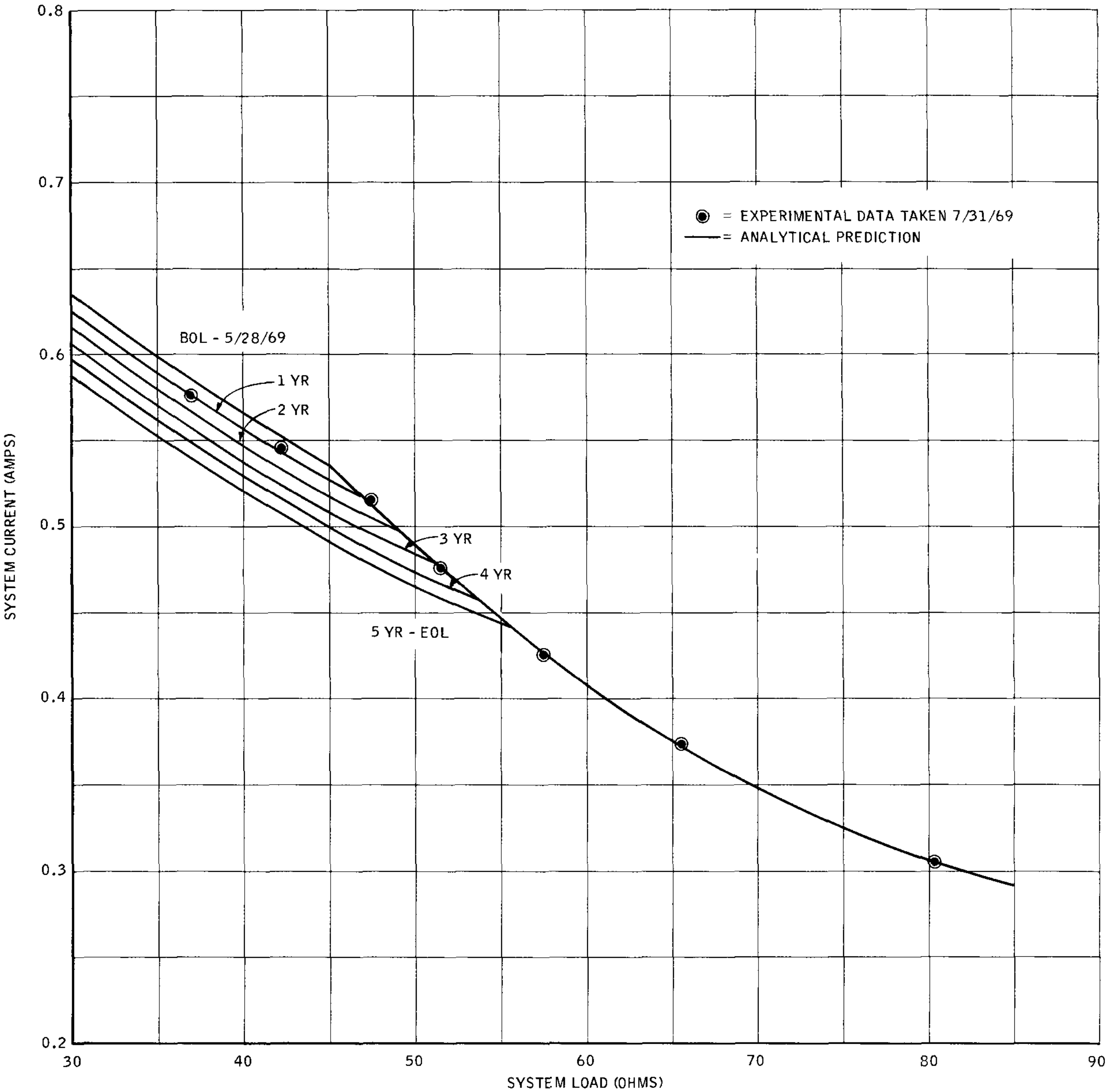

Figure 9. System S10P4 Performance
Current vs. Load Resistance in 80°F Water

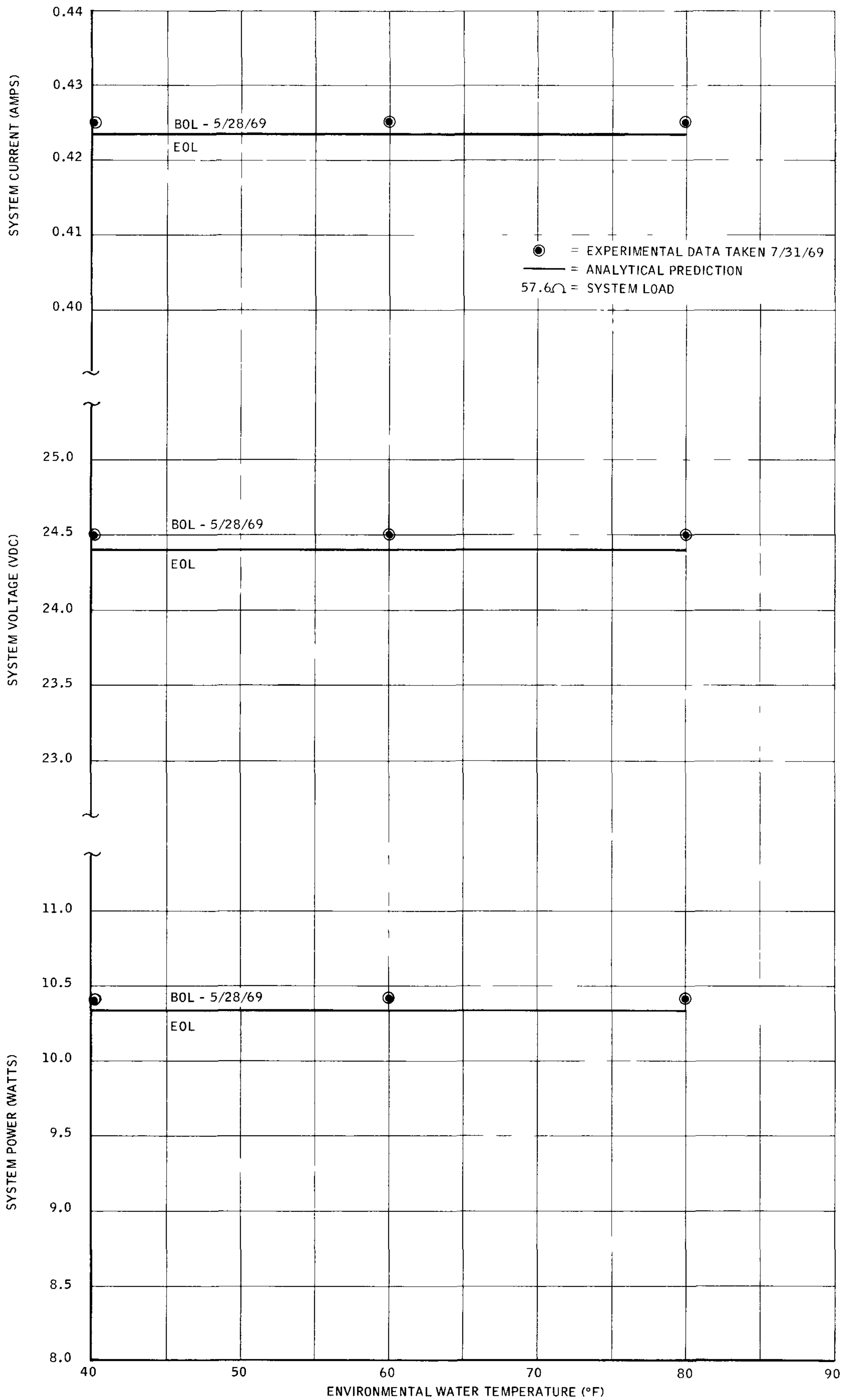

Figure 10. System S10P4 Performance
System Power, Voltage and Current vs. Water Temperature

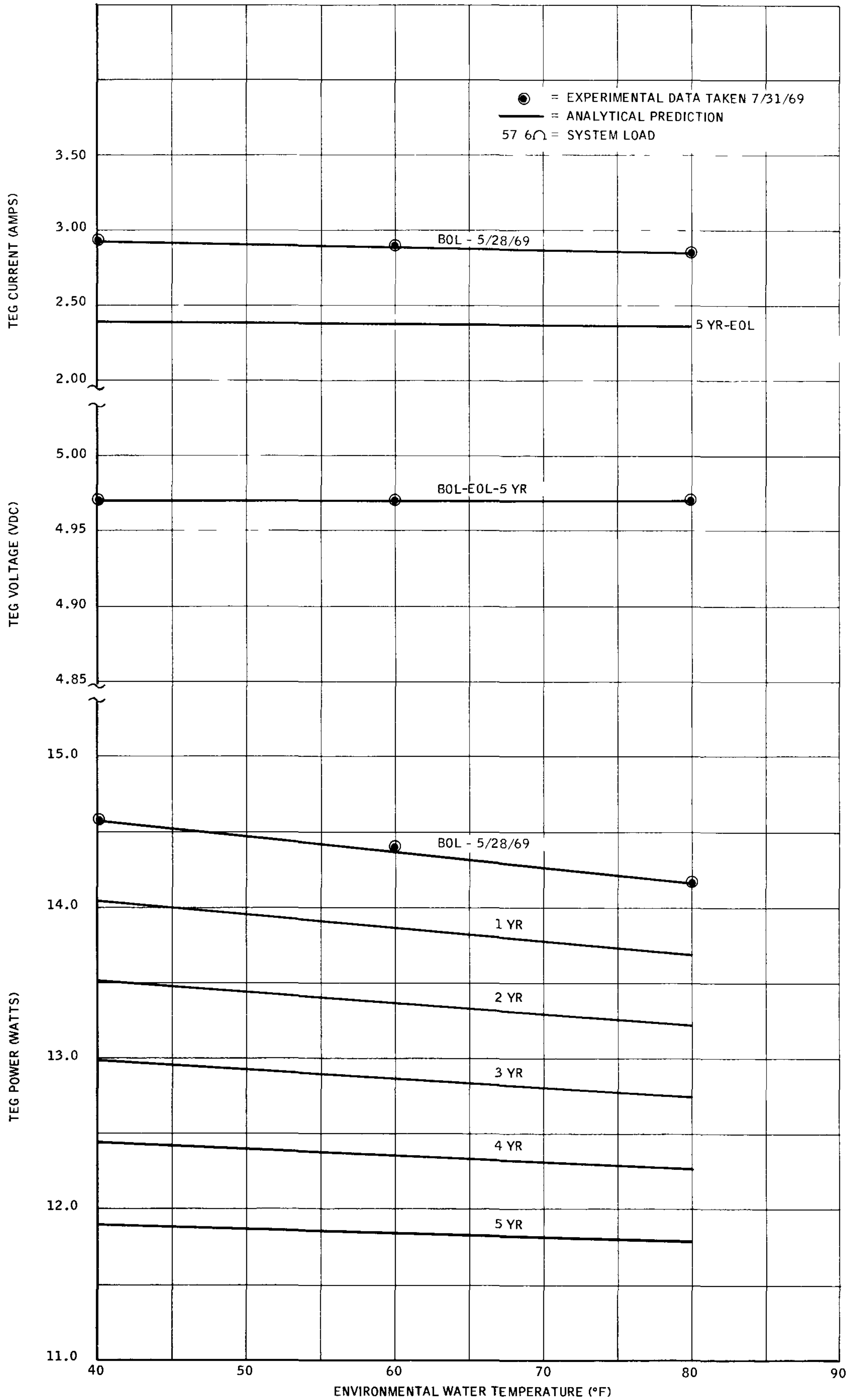

Figure 11. System S10P4 Performance
TEG Power, Voltage and Current vs. Water Temperature

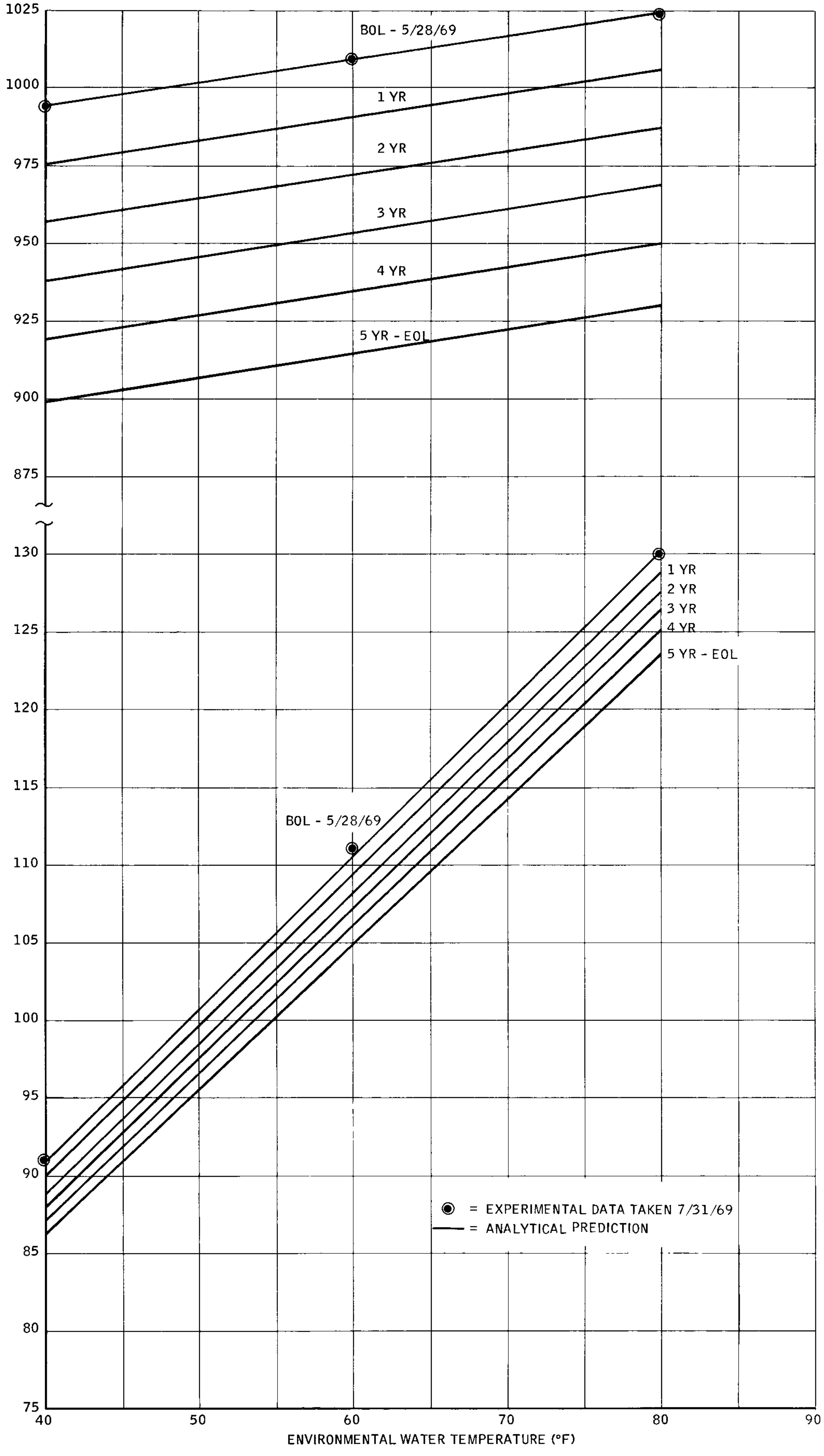

Figure 12. System S10P4 Performance
System Temperatures vs. Water Temperatures

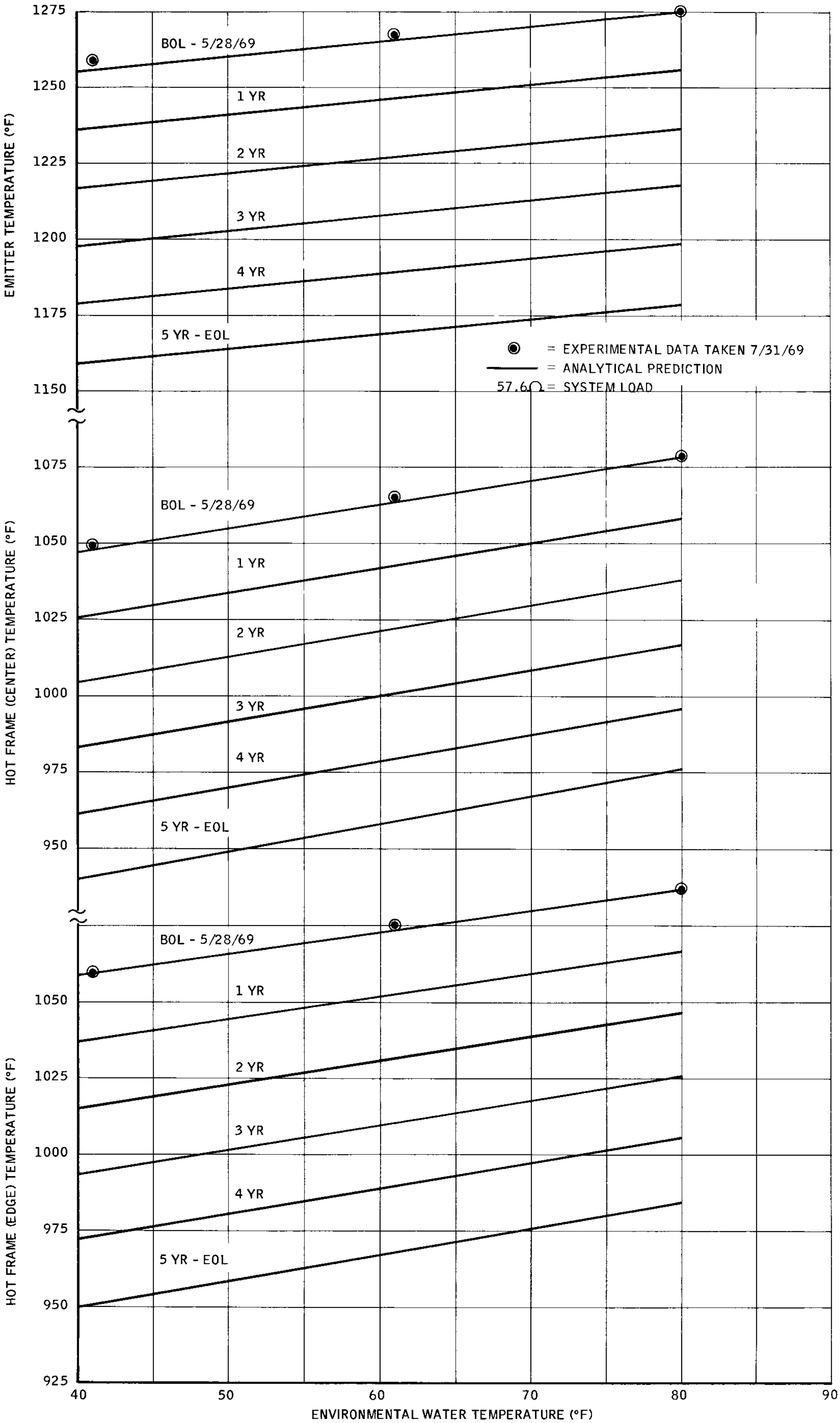

Figure 13. System S10P4 Performance
System Temperatures vs. Water Temperatures

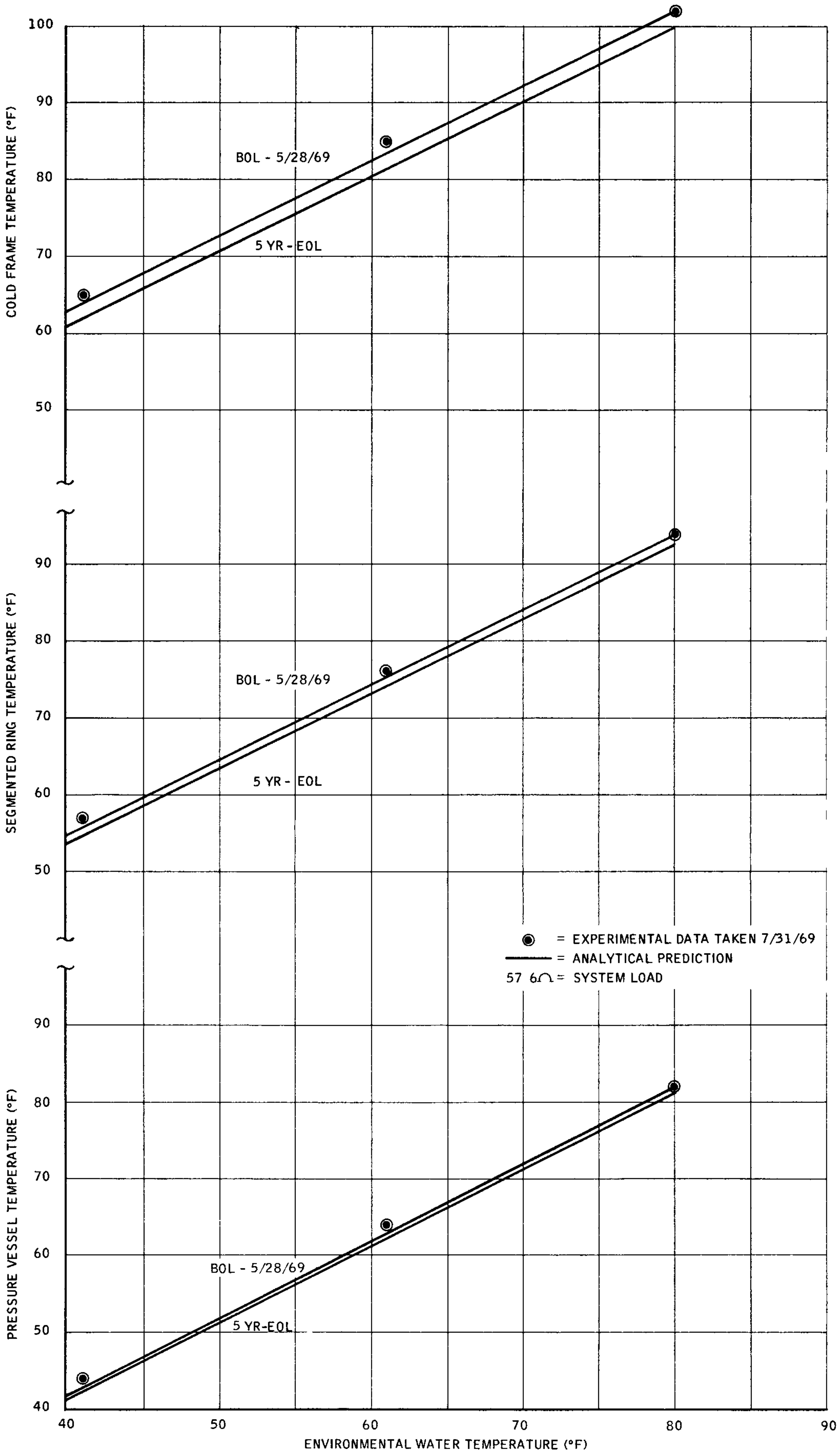

Figure 14. System S10P4 Performance
System Temperatures vs. Water Temperatures