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INTRODUCTION

This is the ninety-sixth Monthly Top Summary Report prepared under Contract E(11-1)-2331 with the United States Energy Research and Development Administration. This report, covering the performance period which extends from February 1, 1976 to February 29, 1976, has been separated into the following sections:

- I. CRITICAL ACTION ITEMS
- II. MAJOR MILESTONE STATUS
- III. FUNDING
- IV. TECHNICAL OBJECTIVES
- V. PROBLEM AREAS
- VI. TECHNICAL HIGHLIGHTS

I. CRITICAL ACTION ITEMS

No critical action items required attention on the part of the Contractor or ERDA during this report period.

II. MAJOR MILESTONE STATUS

<u>MILESTONE</u> <u>NO.</u>	<u>DESCRIPTION</u>	<u>TARGET DATE</u>	<u>STATUS</u>
38	Submission of a detailed program plan (revise No. 2331-0253, Rev. 4, of September 1974).	Sept. 1975	Sept. 1975
39	Process and process control specifications of bonded partitioned P-elements.	Oct. 1975	Oct. 1975
40	Analysis of N-element contact-ing including the results of sputtering and bonding experiments.	Feb. 1976	Feb. 1976
41	Completion of 4000 hours test-ing of partitioned <u>P-TPM-217</u> leg with thermal conductivity measurement in vacuum of at least 10^{-6} torr.	Mar. 1976	

<u>MILESTONE</u> <u>NO.</u>	<u>DESCRIPTION</u>	<u>TARGET DATE</u>	<u>STATUS</u>
42	Preliminary process specification established for synthesis fabrication of N-material.	April 1976	
43	An improved 2-10 couple module which incorporates advanced in-couple hardware design will be placed on test in a configuration and physical and chemical environment appropriate to potential RTG operation in a vacuum bell jar in the temperature interval 800°/200°C.	May 1976	
44	An improved 2-10 couple module which incorporates the advances in material development will be placed on test in a configuration and physical and chemical environment appropriate to potential RTG operation in a vacuum bell jar in the temperature interval 800°/200°C.	June 1976	
45	A TPM-217 couple test capable of operating with a hot junction temperature of approximately 900°C will be placed on test in a bell jar.	June 1976	
46	An improved P-type TPM-217/ N-gadolinium-selenide couple placed on test in a vacuum bell jar in the temperature interval of 800°/200°C to obtain a direct efficiency measurement.	July 1976	
47	An advanced TPM-217 module capable of producing at least 20 watts(e) placed on test at 800°C or higher hot junction temperature.	Sept. 1976	

IV. TECHNICAL OBJECTIVES AND PROGRAM HIGHLIGHTS

- TASK 1.0: The objective of this task is to optimize an N-type thermoelectric material, gadolinium-selenide, to match the thermoelectric properties of and be compatible with P-type TPM-217 thermoelectric material.
- TASK 2.0: The objective of this task is to experimentally describe the chemical, electrical, and physical behavior and to measure long-term performance of P-type TPM-217 at temperatures to 1000°C.
- TASK 3.0: The objectives of this task are to design, obtain data, demonstrate performance, and predict long-term performance of thermoelectric couples using TPM-217 as the P-material.
- TASK 4.0: The objective of this task is to develop a preliminary design for a TPM-217 couple.
- TASK 5.0: The objective of this task is to provide liaison and limited amounts of TPM-217 thermoelectric material to the Jet Propulsion Laboratory of the California Institute of Technology.
- TASK 6.0: The objective of this task is to provide liaison and limited amounts of TPM-217 thermoelectric material to the Gulf Atomic Company.
- TASK 7.0: The objective of this task is to provide, at the request of the ERDA Project Director, technical evaluation of new thermoelectric materials or new thermoelectric module technology of potential use to ERDA/DANES.
- TASK 8.0: The objective of this task is to evaluate and develop advanced energy conversion and heat supply concepts which will take advantage of the unique properties of TPM-217 materials.

VI. PROBLEM AREAS

No potential problems from a technical viewpoint were encountered during this report period.

VI. TECHNICAL HIGHLIGHTS

TASK 1.0 - N-TYPE MATERIAL DEVELOPMENT

1.2 MATERIAL SYNTHESIS

Gadolinium-selenide compositions were synthesized and cast into geometries suitable for electrical (S and ρ) characterization. The synthesis samples are related to process experiments which are in progress and have the following objectives:

- Control Seebeck coefficient by precisely controlling the ratio of chalcogenide to rare earth.
- Control formation of second-phase material on grain boundary.

Periodic processing of large batches of N-type material continues in order to provide sufficient material for processing studies and module development. Batches BB-1 through BB-23 have been pressed and sintered to provide material for module testing, mechanical testing, and contacting studies. Batch BB-10 was used in pressing/sintering experiment No. 6 described in Top Summary Report No. 84. Batches BB-11 through BB-14 were pressed and sintered according to procedures described in Top Summary Report No. 86. Batches BB-14 through BB-23 were prepared for use in the 20-watt module; these batches were pressed and sintered by the same procedure (described in Top Summary Report No. 86 for BB-14). Batch BB-24 was used for RF induction casting experiments. Batch BB-25 was used in pressing/sintering experiments. Batch BB-26 was aborted when the furnace thermocouple malfunctioned during the 220°C soak. Batches BB-27, BB-28, BB-29, BB-30, BB-34, and BB-35 have completed the RQC cycle and have been used in pressing/sintering experiments. Batches BB-31, BB-33, and BB-36 have completed the RQC cycle and will be held in inventory in the RQC form until needed. Batches BB-37, BB-38, BB-40, BB-41, BB-42, and BB-43 have completed the LTR cycle and currently await the RQC casting cycle. Batches BB-32 and BB-39 were aborted during the LTR due to an improper seal of the quartz tube. Batches BB-30, BB-32, BB-34, BB-35, BB-38, BB-39, BB-40, BB-41, BB-42, and BB-43 have been synthesized with the nominal composition $GdSe_{1.480}$ whereas other batches have been synthesized with the standard $GdSe_{1.492}$ composition. It should be noted that batches BB-31, BB-34, and BB-35 appeared to have incomplete reaction in the LTR. There were two or three small hard pellets in each sample which are not usually found in the rather powdery normal LTR reaction. However, the samples were rapid quench cast with the small pellets so as not to alter the composition of the batch. In addition, batch BB-35 was rapid quench cast a second time at

a higher temperature and for an extended time in an attempt to improve the homogenization of the batch. The weight loss data of all BB batches processed to date are summarized in Table I.

High temperature processing of samples N-2515 through N-2518 has begun. This series, prepared from Ames 12773 MS1 gadolinium metal, was designed to evaluate the effects of the preparation of the pure gadolinium metal in tungsten crucibles. The compositional data for this series are shown in Table II.

TABLE II

Weight Loss Data - Samples N-2515 through N-2518

"N" No.	GdSe _x	
	LTR	RQC
2515	1.4922	1.4912
2516	1.4918	1.4908
2517	1.4918	
2518	1.4922	

High temperature processing of the erbium, neodymium, and samarium doping series (samples N-2466 through N-2471, and samples N-2487 through N-2492) is complete with the exception of the casting of N-2492. All available data on these samples was tabulated in Top Summary Report No. 92.

1.3 MATERIAL ANALYSES

1.3.1 Chemical, Crystal Structure, and Metallurgical Analyses

Chemical analyses are being performed on raw materials, on atmosphere for control of the synthesis process, on element contact structure, on doping studies, and on isothermal chemical compatibility experiments as required.

1.3.2 Thermoelectric Properties

Sixteen samples of N- and P-materials were measured for Seebeck coefficient and electrical resistivity on a routine basis. The hardware and software for the new Seebeck measurement apparatus is being checked out and calibrated as time permits.

TABLE I
Compositional Data for 65-Gram N-Type Batches

"N" No.	BB No.	Ames Gd No.	Sample Weight (grams)	GdSe _x		
				LTR	RQC	HTR
2428	1	103173	65	1.4922	1.4912	1.4901
2429	2	112173	65	1.4919	1.4918	1.4906
2430	3	112173	65	1.4921	1.4921	1.4915
2431	4	112173	65	1.4920	1.4918	1.4913
2432	5	112173	65	1.4921	1.4919	1.4907
2439	6	112173	65	1.4920	1.4919	1.4916
2440	7	103173	65	1.4920	**	**
2441	8	61573	65	1.4920	1.4917	*
2442	9	61573 +				
		103173	65	1.4920****	1.4905	1.4894
2449	10	4374	65	1.4920	1.4915	
2450	11	4374	65	1.4920	1.4919	
2451	12	4374	65	1.4920	1.4919	1.4914***
2452	13	4374	65	1.4921	1.4917	
2453	14	4374	65	1.4919	1.4916	
2454	15	4374	65	1.4920	1.4912	
2460	16	4374	65	1.4921	1.4920	
2461	17	4374	65	1.4920	1.4903	
2462	18	4374	65	1.4920****	1.4913	
2463	19	4374	65	1.4920	1.4915	
2464	20	11674	65	1.4920	1.4917	
2465	21	11674	65	1.4920	1.4920	
2472	22	11674	65	1.4920	1.4904*****	
2473	23	11674	65	1.4920	1.4916	
2474	24	11674	65	1.4920	1.4914	
2493	25	11674	65	1.4920	1.4910	
2494	26	11674	65	1.4919	**	
2495	27	82074	65	1.4920	1.4916	
2502	28	82074	65	1.4924	1.4919	
2503	29	82074	65	1.4920	1.4917	
2504	30	82074	65	1.4800	1.4799	
2511	31	82074	65	1.4919	1.4916	1.4911***
2512	32	82074	65	1.4800	**	
2519	33	82074	65	1.4920	1.4918	1.4914***
2526	34	92774	65	1.4799	1.4793	
2527	35	92774	65	1.4798	(1)	(2)
2528	36	92774	65	1.4920	1.4917	
2529	37	92774	65	1.4920		
2530	38	92774	65	1.4799		
2531	39	92774	65	1.4798	**	
2538	40	101273	65	1.4796		
2539	41	101273	65	1.4800		
2540	42	101273	65	1.4800		
2541	43	101273	65	1.4800		

TABLE I (Continued)

*Casting crucible broke so accurate weight of cast ingot could not be obtained.

**Sample did not survive the LTR cycle.

***Composition of RQC No. 2.

****Vitreous carbon LTR crucible broke during LTR cycle.

*****Composition may be inaccurate due to a piece of material adhering to the casting crucible.

- (1) Sample apparently gained weight during RQC (may have been a weighing error). Therefore, RQC composition cannot be calculated.
- (2) RQC No. 2 - Sample again appeared to gain weight. Due to this weight gain and the fact that the RQC No. 1 composition could not be calculated, no RQC composition was calculated.

1.4 MATERIAL PROCESSING

1.4.1 Pressing and sintering Studies

Pressing and Sintering Experiments:

Cold pressing/sintering studies continue with the objective of forming high density, mechanically strong thermoelectric leg structures while at the same time reducing extraneous resistance to form elements with electrical properties on or near the 10% current standard material trend line. Elements have been formed with approximately a 30% extraneous resistance value.

The major variables studied in this pressing/sintering program include:

- Material used - HTR and RQC reacted ingot material
- Particle size - from 45μ to 5μ and mixtures thereof
- Element geometry - 0.188" - 0.500" diameter
- Pressing pressure - related to geometry - 2,000 to 68,000 psi
- Atmosphere control:
 1. LabVac box: "as is" to implementing the USERDA Ames gas purification system.
 2. Transporting green pressed legs from the LabVac to the Astro Furnace.
 3. Astro furnace atmosphere: "as is" to use of gas purifier.
- Sintering Cycle
 1. Heat-up rate
 2. Soak temperature
 3. Soak time
- Particle reduction techniques
- Homogeneity of starting materials
- Purified kerosene "wet"/air grinding
- Effects of lubricants
- Hot pressing

The objective of cold pressing/sintering experiment 45, BB-28 (65-gram RQC, composition $\text{GdSe}_{1.4919}$) was to investigate the effect of wet grinding, sieving and pressing on N-leg electrical properties and physical structure. The liquid used for wet grinding was benzene purified by passing through an alumina column and subsequently stored with molecular sieve to remove water. A total of almost forty milliliters of benzene was added to the 65-gram batch. The helium atmosphere in the glove box was passed through the molecular sieve section of the purifier because the getter furnace is still under repair. This atmosphere was of sufficient purity to allow a bare tungsten filament to burn for approximately three hours; with the getter furnace working properly, the tungsten filament would last over 1000 hours. The grinding sequence was the same as other recent experiments (e.g. P/S 42), but grinding times were reduced. The slurry did not stick to the walls or grinding balls and a very uniform, rapid particle reduction was observed. The slurry was placed on the No. 20 mesh sieve, dried out very rapidly, and the dry powder was completely worked through the sieves in much less time than normal material. Half the powder was prepressed and dry pressed with Octoil lubrication, while the other half was mixed with more benzene and "wet pressed" without the Octoil lubricant. All legs were simultaneously sintered at 1650°C . The grinding, pressing, and sintering cycle is summarized in Table III.

The metallographic results show some promise for "wet grinding." Grain size was smaller and more uniform than most dry grinding experiments. Legs pressed dry with Octoil ram lubrication after wet grinding showed varying grain growth regions and higher porosity than legs wet pressed with no Octoil. Pores were of $7\text{ }\mu\text{m}$ diameter and located on grain boundaries for the wet pressed structure; dry pressed pores were 13 to $20\text{ }\mu\text{m}$ and larger on and within grain boundaries.

Equipment:

Glove Box - Inert Gas Purification System:

The purifier remains under repair after it was found that a hole had been melted in the side of the furnace tube. Other parts had been repaired; the hole, however, was concealed by the furnace tube windings on a ceramic form, resulting in additional delays. Three months is the estimate to obtain a replacement Inconel tube; consequently, an Inconel patch was made and welded into the area cut out of the tube. The purifier is now ready for final re-assembly and leak checking.

The cost estimate of a new purifier system is being made as Bernie Beaudry, ERDA Ames Laboratory, has recently indicated the desire to recall the loaned Ames system about February 1977.

TABLE III
Pressing/Sintering experiments Performed February 1976

P/S Exp. No.	Batch	Wt.	RQC GdSe _x X	Grinding Sequence				Sintering Temp (°C)	Grain Size (μm)	Prepress Pressure (psig)	Pressing Pressure (psig)	Density (g/cc)	°RT (mΩ-cm)
				1	2	3	4						
45	BB-28	65	1.4919	1/4 R	1/2 L	3/4 R	1/2 R	1650	10	-	8800	6.72	4.9**
				5 min	5 min	and L	and L*	1650	13-65	200	8800	7.19	5.5***
						10 min	5 min	1650	7	200	8800	6.15	9.4

*Wet grinding using benzene for entire sequence.

**This element "wet" pressed - no Octoil lubrication of pressing rams as was done for other two listed.

***Lateral crack running through center - found during metallographic examination.

1.5 ELEMENT CONTACTING

A report, "Analysis of N-Gadolinium-Selenide Element Contacting," is being prepared to satisfy the requirements of milestone No. 40.

1.7 INGRADIENT COMPATIBILITY AND LIFE TESTING

An updated summary of N-leg performance for the last eight months is contained in Table IV. Theoretical values for current standard elements are shown in the chart for reference. The duration of each of the tests at the end of February is also shown in this table.

The six-station N-leg tests (ATT 322, 324, 325, 365, 366, 367) have now been terminated. A post-test analysis of the N-legs will be performed and the results will be reported in subsequent monthly reports.

A new series of N-leg tests (ATT 407-412) has been initiated in the the six-station fixture which previously contained tests ATT 322 et al. The two objectives of these tests are:

1. to life test legs at 50% nominal extraneous resistance,
2. to determine the effect of hot end contacting means on performance.

Three different hot end contacting configurations were used with two tests of each type; the element test configuration is summarized in Table V. The tests are operating in a nominal temperature interval of 850°/200°C in a vacuum of 2.5×10^{-7} torr and the legs are uninsulated.

TABLE V

Element Configuration of Hot End Contacting N-Leg Series

<u>ATT No.</u>	<u>Hot End Foil</u>	<u>Sputter Contacting</u>
407	Gd	W
408	Gd	W
409	Pt	W
410	Pt	W
411	None	Cu
412	None	Cu

Additional N-legs which are currently on test are ATT 364, 378, and 385. ATT 364 was initiated in April 1975 to determine the status of the N-material and contacting procedures at that time. The test has been running continuously since that time with the exception of one cool-down due to a light bulb/heater failure.

Key to Parenthetical Numbers

TABLE IV. Eight-Month Life Test Performance Summary

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(1) Terminated (2) Temporarily Shut Down (3) Instrumentation Problems (4) New Tests Started in April-Replaced ATT 311+316, 321 323 & 326 in Six-Station			ATT No.	Nominal T_h/T_c ($^{\circ}\text{C}$)	Theoretical S ($\mu\text{v}/^{\circ}\text{C}$, rel. to Pt)	Theoretical R ($\text{m}\Omega$)	FEBRUARY, 1976				JANUARY 1976				DECEMBER 1975				NOVEMBER 1975			
							S (mean) ($\mu\text{v}/^{\circ}\text{C}$, rel. to Pt)	S (Std. Dev.)	R (mean) ($\text{m}\Omega$)	R (Std. Dev.)	S (mean) ($\mu\text{v}/^{\circ}\text{C}$, rel. to Pt)	S (Std. Dev.)	R (mean) ($\text{m}\Omega$)	R (Std. Dev.)	S (mean) ($\mu\text{v}/^{\circ}\text{C}$, rel. to Pt)	S (Std. Dev.)	R (mean) ($\text{m}\Omega$)	R (Std. Dev.)	S (mean) ($\mu\text{v}/^{\circ}\text{C}$, rel. to Pt)	S (Std. Dev.)	R (mean) ($\text{m}\Omega$)	R (Std. Dev.)
Hours	61,419	127	700/280	285	35.8	263	1.3	26.7	0.6	259	0.8	23.4	0.7	261.2	4.1	22.8	1.0	(3)				
P	61,419	128	700/280	285	35.8	280	0.3	30.1	0.5	280	0.5	29.6	0.3	280.3	0.4	29.2	0.5	281.9	0.5	28.1	1.0	
	61,419	129	700/280	285	35.8	254	0.4	11.7	0.3	255	0.7	11.7	0.3	254.4	1.0	11.8	0.3	(3)				
	61,419	132	600/260	270	31.4	247	0.3	17.6	0.1	248	0.7	17.6	0.1	248.1	0.6	17.9	0.2	(3)				
	61,419	133	600/260	270	31.4	245	0.4	15.2	0.1	245	0.5	15.3	0.5	246.0	0.5	15.6	0.3	(3)				
	61,419	136	500/210	244	24.4	209	0.8	14.0	0.1	209	0.7	14.0	0.03	210.1	0.9	14.0	0.02	(3)				
	61,419	137	500/210	244	24.4	198	0.8	11.6	0.2	198	0.3	11.6	0.03	198.1	0.3	11.7	0.5	(3)				
	45,659	178	700/280	284	35.5	170	5.7			157	6.3			166.8	18.1	570.0	120	(3)				
	41,561	192	700/260	276	32.8	276	0.4	27.8	0.8	277	0.4	28.1	0.2	277.0	0.4	28.4	0.2	277.8	0.2	28.2	0.5	
	41,558	195	700/260	276	32.8	266	0.3	23.2	0.1	267	0.4	23.6	0.2	269.0	0.9	24.5	0.4	(3)				
	41,535	196	800/300	297	40.1	297	0.2	37.0	0.2	297	0.2	36.6	0.2	297.0	0.1	37.4	0.2	296.6	0.1	35.8	0.2	
	25,425	287	565/200	250	13.2	234	0.4	21.3	0.2	234	0.3	21.2	0.1	234.6	0.3	21.6	0.2	234.5	0.1	20.6	0.2	
	25,430	288	565/200	250	13.2	246	0.4	16.2	0.1	246	0.3	16.1	0.1	244.3	0.3	15.8	0.5	(3)				
	25,430	289	565/200	250	13.2	238	0.5	17.1	0.1	239	0.6	17.0	0.1	244.2	1.6	17.9	0.6	245.0	0.2	16.8	0.2	
	22,500	292	565/200	250	13.2	265	0.6	19.0	0.2	266	0.2	19.3	0.1	266.4	0.3	19.5	0.5	265.2	0.4	19.5	0.3	
	Partitioned P	38,218	210	800/270	296	40.7	284	0.3	65.9	0.7	284	0.4	64.5	0.5	283.5	0.6	64.0	0.5	288.2	0.3	51.3	2.3
		32,873	241	800/270	314	53.4	281	2.6	52.7	0.7	289	6.6	52.3	2.7	285.3	4.2	55.2	2.5	284.8	1.1	52.8	1.7
6,740		371	800/200	277	18.3	248	2.9	12.6	0.3	253	2.4	12.7	0.2	(3)				(3)				
5,380		372	800/200	277	18.3	(2)				(2)				(3)				(3)				
5,890		373	800/200	277	18.3	(3)		11.8	0.4	(3)		12.6	0.5	(3)				(3)				
6,740		374	800/200	277	18.3	115	17.6	4.4	0.5	141	27.1	5.1	0.4	(3)				(3)				
6,740		375	800/200	277	18.3	186	12.7	11.9	1.0	251	32.3	13.7	1.3	(3)				(3)				
6,370		376	800/200	277	18.3	298	16.3			297	0.9	11.7	3.9	(3)				(3)				
P Bonding	33,735	237	800/250	285	35.3	280	0.4	36.8	1.4	280	0.6	37.5	0.7	280.5	0.6	37.2	0.7	(3)				
	30,001	272	775/240	278	35.6	276	1.8	34.8	0.2	280	0.2	34.3	0.4	280.0	0.3	35.1	0.2	(3)				
Couple	N	6,220	378	800/200	195	14.2	186	2.5	49.5	3.4	182	0.7		186.4	12.5	39.5	9.6	(3)				
	P	6,220	379	800/200	277	18.3	241	6.7	50.6	5.3	255	5.1	65.4	12.0	268.0	4.1	49.3	9.4	293.3	0.3	32.7	1.5
N	4,620	385	800/200	195	14.2	171	0.8	46.9	2.7	172	0.4	47.2	1.4	174.9	7.8	50.0	2.7	(3)				
	248	407	850/200	211	15.7	172	1.1	19.3	0.9					(1)				(1)				
	248	408	850/200	211	15.4	150	1.9	13.1	0.5					(1)				(1)				
	248	409	850/200	211	15.6	184	1.3	40.8	1.1					(1)				(1)				
	248	410	850/200	211	15.4	186	5.9	25.6	0.2					(1)				(1)				
	248	411	850/200	211	15.2	146	3.1	17.9	0.5					(1)				(1)				
	248	412	850/200	211	15.3	133	5.4	13.2	1.4					(1)				(1)				
	7,339	364	800/200	195	13.5	170	1.0	42.3	0.4	170	0.4	41.8	0.1	171.0	1.2	42.6	0.5	172.8	0.5	43.0	0.4	

Key to Parenthetical Numbers

TABLE IV (continued)

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(1) Terminated (2) Temporarily Shut Down (3) Instrumentation Problems (4) New Tests Started in April-Replaced ATT 311+316, 321 323 & 326 in Six-Station															Page 14														
Hours		ATT No.	Nominal T_h/T_c ($^{\circ}\text{C}$)	Theoretical S ($\mu\text{V}/^{\circ}\text{C}$, rel. to Pt)	Theoretical R (m Ω)	OCTOBER 1975				SEPTEMBER 1975				AUGUST 1975				JULY 1975											
						S (mean) ($\mu\text{V}/^{\circ}\text{C}$, rel. to Pt)	S (Std. Dev.)	R (mean) (m Ω)	R (Std. Dev.)	S (mean) ($\mu\text{V}/^{\circ}\text{C}$, rel. to Pt)	S (Std. Dev.)	R (mean) (m Ω)	R (Std. Dev.)	S (mean) ($\mu\text{V}/^{\circ}\text{C}$, rel. to Pt)	S (Std. Dev.)	R (mean) (m Ω)	R (Std. Dev.)	S (mean) ($\mu\text{V}/^{\circ}\text{C}$, rel. to Pt)	S (Std. Dev.)	R (mean) (m Ω)	R (Std. Dev.)								
P			127 700/280	285	35.8	269.5	1.7	27.2	0.3	270.5	1.2	27.0	0.6	268.2	1.1	25.0	1.1	266.8	0.8	22.8	0.7								
			128 700/280	285	35.8	283.5	0.7	31.4	0.2	284.5	1.0	31.3	0.3	287.7	0.5	29.3	0.5	280.8	3.6	38.8	5.97								
			129 700/280	285	35.8	264.1	1.2	12.9	0.2	263.9	1.3	13.0	0.3	264.4	1.0	13.0	0.2	262.6	1.3	12.8	0.3								
			132 600/260	270	31.4	246.0	0.3	17.9	0.1	246.4	0.6	18.0	0.1	248.2	0.3	18.3	0.4	248.3	0.3	18.4	0.0								
			133 600/260	270	31.4	252.4	0.4	17.4	0.1	252.3	0.3	17.5	0.6	251.9	0.5	17.5	1.0	251.3	0.4	17.5	0.1								
			136 500/210	244	24.4	222.1	0.7	18.6	0.1	220.1	3.8	17.9	0.9	218.4	1.0	17.7	0.6	217.7	0.9	17.5	0.1								
			137 500/210	244	24.4	201.2	0.3	12.3	0.4	201.0	0.3	12.3	0.3	200.3	0.4	12.2	0.1	196.6	2.2	11.6	0.4								
			178 700/280	284	35.5	217.8	5.0	74.9	21.3	213.1	6.2	61.3	2.1	192.5	4.2	52.6	2.6	192.7	2.7	48.4	2.3								
			192 700/260	276	32.8	276.6	0.6	27.8	0.2	276.8	0.6	27.3	0.2	276.3	0.5	25.7	0.5	276.0	0.5	27.0	0.7								
			195 700/260	276	32.8	264.9	0.5	23.6	0.3	265.3	0.6	23.7	0.1	266.2	0.5	24.0	0.2	267.2	0.7	24.7	0.3								
			196 800/300	297	40.1	295.9	0.3	35.6	0.1	295.5	0.3	36.0	0.2	295.2	0.3	36.6	0.2	294.9	0.7	37.0	0.2								
			287 565/200	250	13.2	233.4	0.4	20.8	1.2	232.6	0.3	20.8	0.9	232.0	0.3	20.6	1.0	231.4	0.5	20.2	0.2								
Partitioned P			288 565/200	250	13.2	244.4	0.1	15.8	0.2	244.1	0.6	15.7	0.7	245.6	3.2	16.5	0.5	244.4	0.3	16.3	0.6								
			289 565/200	250	13.2	237.2	0.4	16.6	0.8	238.3	3.6	16.7	0.2	242.2	0.3	17.1	0.9	241.3	0.6	17.9	0.7								
			292 565/200	250	13.2	261.5	0.4	18.7	1.9	258.1	6.9	19.9	0.3	231.3	0.6	13.3	0.4	229.2	2.2	12.9	0.9								
			210 800/270	296	40.7	289.1	1.0	49.3	1.9	288.2	1.2	49.7	1.9	285.3	1.7	59.1	3.1	286.8	3.0	51.8	3.5								
			241 800/270	314	53.4	292.1	0.8	50.0	3.4	291.9	1.4	44.4	1.0	281.7	5.2	46.1	2.0	292.9	1.5	43.5	1.5								
			371 800/200	277	18.3	(2)				(2)				253.8	5.4	12.5	0.5	257.0	3.4	12.7	0.3								
			372 800/200	277	18.3	(2)				(2)				256.0	1.0	21.0	2.0	254.1	3.1	18.5	2.3								
			373 800/200	277	18.3	(2)				(2)				(3)		17.6	0.6	(3)		20.3	1.3								
			374 800/200	277	18.3	(2)				(2)				233.0	14.1	12.9	0.9	255.3	3.9	14.3	0.3								
			375 800/200	277	18.3	(2)				(2)				233.3	3.6	14.1	0.4	241.9	8.7	16.4	1.5								
			376 800/200	277	18.3	(2)				(2)				(2)		(2)		293.8	2.5	(3)									
	P Bonding		237 800/250	285	35.3	281.2	0.6	37.1	1.2	281.1	0.5	34.2	0.8	279.6	0.6	37.7	0.3	279.6	0.6	37.1	0.9								
		272 775/240	278	35.6	271.6	0.3	34.2	0.5	271.3	0.8	33.2	0.5	268.9	0.3	33.5	0.2	269.0	0.3	33.2	0.1									
Couple	N		378 800/200	195	14.2	180.1	1.5	35.2	1.0	183.0	3.2	36.2	1.4	187.2	1.4	32.8	0.7	190.9	1.3	35.7	1.0								
	P		379 800/200	277	18.3	293.9	2.4	34.4	1.1	294.6	3.1	33.8	1.4	295.3	9.2	33.3	2.6	293.5	1.6	33.4	2.2								
N			385 800/200	195	14.2	177.3	4.9	46.9	1.5	170.9	0.9	17.5	0.1	177.7	2.4	19.5	1.0	186.9	5.7	28.1	4.6								
			365 800/200	195	14.2	(2)				(2)				216.2	2.1	90.1	1.9	224.8	2.4	95.9	1.0								
			322 800/200	195	16.2	(2)				(2)				220.7	34.4	191.2	2.6	200.0	4.3	262.4	20.7								
			366 800/200	195	13.2	(2)				(2)				210.0	0.4	42.0	0.6	206.8	1.8	36.8	1.9								
			324 800/200	195	16.2	(2)				(2)				(3)		(3)		(3)		(3)									
			325 800/200	195	16.2	(2)				(2)				219.5	0.7	156.3	0.9	218.3	1.9	151.4	3.5								
			367 800/200	195	13.5	(2)				(2)				192.4	0.3	50.9	0.6	193.5	0.5	53.9	1.0								
			364 800/200	195	13.5	173.5	0.8	43.0	1.1	174.9	0.8	41.0	2.2	176.1	1.5	38.9	0.7	178.2	0.6	40.5	0.5								

It has accumulated 7300 hours test time and the performance has been quite stable in recent months. The light bulb/heater failure occurred in June. The resistance increased from approximately 28 to 42 mohms at that time, indicating some cracking. The best performance of this element was achieved in May 1975; this performance was characteristic of 110% extraneous resistance on the N-leg. Thus, this element is not representative of the type of elements which are currently being produced.

Tests ATT 378 and 385 both experienced thermal cycles due to light bulb/heater replacement this month. The resistances did not significantly increase as a result of these cycles. Both of these tests have experienced numerous thermal cycles; thus, the possibility of terminating these tests in the near future will be evaluated.

TASK 2.0 - TPM-217 P-TYPE CHARACTERIZATION

2.2 and 2.3 MATERIAL PREPARATION AND ANALYSIS

The casting of P-type TPM-217 batch R-28 has been completed and the characterization data of the batch is reported in Table VI.

2.5 ELEMENT CONTACTING

Quality Control Apparatus:

The second quality control test fixture (Top Summary Report No. 95, page 19) is now in routine operation. This additional fixture increases the present electrical QC measurement capability to approximately twenty elements per week.

2.6 THERMODYNAMIC STABILITY

The series of sealed tube free-evaporation experiments, described in Top Summary Report No. 85, continues. This work was initiated to supplement the mass spectrometer vapor pressure determinations. The importance of this type of experiment lies in the fact that the rate of material loss in an operating generator approximates a Langmuir free evaporation process rather than a Knudsen cell equilibrium process. The principal results obtained in recent months were summarized in Top Summary Report No. 90, page 23, and the experimental arrangement was described in Top Summary Report No. 85. As reported in Top Summary Report Nos. 93 and 94, a test facility consisting of an ion pumped quartz sample tube connected to a partial pressure analyzer has been constructed. The partial pressure analyzer has shown extensive desorption of gasses from the quartz tube and sample; the principle gaseous species identified in the sample tube are H_2O , H_2 , CO , CO_2 , N_2 , and hydrocarbon fragments. After repair of leaks which occurred in the initial configurations, the system has proven capable of operation at 3×10^{-8} torr after initial outgassing.

Experiments were performed this month using this system with the addition of copper, molybdenum, or titanium getter tubes around the samples to reduce the selenium diffusion length. The sample weight loss rates, R_m , measured with these getter tubes were 6×10^{-7} , 2.3×10^{-7} , and 3.0×10^{-7} for the copper, molybdenum, and titanium getters, respectively. A selenium deposit formed on the quartz tube when the copper and molybdenum getters were used, but did not form when the titanium getter was used. In addition, the weight gain of the titanium was greater than for the copper or molybdenum tubes. This indicates that titanium is effective in gettering the selenium and reducing its diffusion length.

TABLE VI
Characterization Data - R-28

<u>Sample</u>	<u>Atomic Absorption Analysis - %wt Ag</u>	<u>Emission Spectrographic*</u> <u>Analysis (ppm by weight)</u>		<u>S₅₀₀</u> <u>(μv/°C rel. to Pt)</u>	<u>ρ₅₀₀</u> <u>(mΩ-cm)</u>
		<u>Fe</u>	<u>Mg</u>		
Synthesis Top		1	<1		
Synthesis Bottom		<1	<1		
Tier 1 No. 2	1.53)	1	<1		
Tier 3 No. 1	1.55) mean	1	<1		
Tier 4/5 No. 2	1.56) 1.54	1	<1		
Tier 8 No. 1	1.54)	<1	<1		
Tier 10 No. 2	1.54)	1	<1		
Tier 1 No. 1				+258) mean	9.1
Tier 4/5 No. 1				+259) +260.0	8.1
Tier 10 No. 1				+263)	8.6

*These were the only elements detected.

As reported in Top Summary Report No. 95, a series of weight loss experiments in sealed tubes with known pressures of argon has been conducted. The measured weight loss data (R_m), is given in Figure 1 and Table VII. The objective of this experiment was to determine the correlation of weight loss rate with inert gas pressure, so no attempt was made to correct this measured data for tube geometry or convection effects. The line in Figure 1, corresponding to a simple inverse relation between weight loss rate and inert gas pressure, is seen to be a good representation of the experimental data in the region 0.1 torr to 2.5 torr. It is concluded that the sublimation rate of selenium from TPM-217 can be significantly reduced by inert gas pressure. Further experiments are being performed to obtain additional data on the effects of pressure on weight loss rate in different geometries but, due to the low loss rates, no further data was obtained this month.

TABLE VII
Summary of Vapor Pressure Data

Sample	Material	Temp. (°C)	Tube Dia. (mm)	Pressure (torr)	Weight Loss Rate (R_m) (gm/cm ² /min)
VP-62E	SAC-60	800	10	0.1(A)	6.8×10^{-8}
VP-39E	SAC-61	800	10	0.5(A)	1.9×10^{-8}
VP-60E	SAC-60	800	10	1 (A)	7.3×10^{-9}
VP-40E	SAC-61	800	10	2.5(A)	4.5×10^{-9}

2.8 ISOTHERMAL CHEMICAL COMPATIBILITY

The 700°-800°C isothermal test series continues. The test conditions are summarized in Table VIII.

2.9 INGRADIENT COMPATIBILITY AND INGRADIENT LIFE TESTING

The performance of partitioned and non-partitioned P-legs which are on life test are summarized in Table IV.

2.9.1 Non-Partitioned P-Legs

The first seven tests in Table IV have been on test for approximately 61,400 hours. The performance has been quite stable during this period except for events such as power failures, instrumentation problems, etc. The data acquisition malfunction of November 1975 has been corrected and stable data are again being observed

Figure 1.

DEPENDENCE OF MEASURED WEIGHT LOSS
RATE ON INERT GAS PRESSURE
 $T = 800^{\circ}\text{C}$

TABLE VIII

P-Type TPM-217 Isothermal Chemical Compatibility

<u>Test Description</u>	<u>Temp. °C</u>	<u>Test Duration (Hrs)</u>
I. <u>Non-Magnetic Electrodes</u>		
A. W and W-25Re	700-800	33,370 and 30,570 respectively
B. Mo	700-800	33,370 and 30,570 respectively
II. <u>Thermal Insulations</u>		
A. Fiberfrax ($\text{Al}_2\text{O}_3/\text{SiO}_2$)	800	30,570
B. Fiberfrax H Blanket	800	2,370
C. Fiberfrax 660H HF Paper Insulation	800	2,370
D. 3M A CO_2 Fiberfrax Insulation	800	2,370
E. Asbestos Fiber (component of Microtherm)	800	2,370
F. Min-K 2020 ($\text{SiO}_2/16\text{TiO}_2$)	800	30,570
III. <u>System (Non-Magnetic Electrodes/Thermal Insulation)</u>		
A. W/Min-K 2020	700	23,770
B. W-25Re/Min-K 2020	700	23,770
C. W/Fiberfrax	700	23,770
IV. <u>Miscellaneous</u>		
A. Cb-103 Rod	800	2,370
B. TZM Rod	800	2,370
V. <u>Control TPM-217</u>	700	33,370

for most tests. As reported last month, ATT 178 (an ingradient compatibility test with a molybdenum hot junction electrode in direct contact with TPM-217 at 700°C hot junction temperature) is continuing to exhibit erratic behavior. It is felt that this test should be examined in the near future. In general, the performance of the non-partitioned P-legs on life test continues to exhibit good stability.

2.9.2 Partitioned P-Legs

The partitioned P-leg tests are being monitored again this month after a data acquisition problem two months ago. Tests ATT 210, 241, and four tests in the six-station (ATT 371, 372, 373, 376) are performing well. Tests ATT 374 and 375 are producing spurious data which may be related to instrumentation problems.

Test PM-024:

Test PM-024 initiated in October, is being conducted in a test fixture equipped with a heat flux meter to provide information on the behavior of thermal conductivity with respect to time. The test element is a partition bonded P-TPM-217 element with the standard 0.3-inch diameter by 0.3-inch length geometry with a single partitioning foil 0.06 inch from the top. The operating conditions are 800°/200°C junction temperatures with 4.8 amp current.

This element is on test in the new 12-station fixture with radiantly heated hot end. The fixture is valved off from the main manifold turbo pump and is maintaining a pressure of 2×10^{-7} torr at the ion pump. The principle objective of this test is to determine whether there exists any systematic change in thermal conductivity with time. Up to the present time, 3300 hours, no systematic change in $\bar{S}$, $\bar{\rho}$, or $\bar{K}$ has been observed; Figure 2 shows the deviations in $\bar{S}$, $\bar{\rho}$, and $\bar{K}$ from their initial values. This test will be continued.

2.9.4 The 12-Station Test Fixture

A problem was detected last month in the current control and measuring circuit of the 12-station test fixtures. The problem was caused by wiring the current control and measuring circuit to the ground side of the load current circuit which produced two sources of error--a ground loop error, and parallel paths error. This was corrected by rewiring the circuit. A description of the faulty circuit and its effects are given below to aid in preventing this and similar problems in the future.

Figure 2

Deviation of Effective Seebeck Coefficient ($\bar{S}$), Resistivity ($\bar{\rho}$),
and Thermal Conductivity ($\bar{K}$) from Their Initial Values
as a Function of Test Time

The DC power supply had a finite resistance to ground which caused the ground loop. Since the cold end of all of the fixtures are connected to ground, a partially grounded power supply can cause currents to flow through the circuit which are not read by the series current shunt (Figure 3). The result of this extraneous current flow is that Seebeck coefficient and resistivity readings are approximately 4% low.

The errors due to a parallel current path caused erroneous current readings both above and below the true readings. Figures 4 and 5 show the correct and problem circuits. The current control rheostats and the shunts were wired on the common ground side of the fixtures. The errors involved can be as much as 100% in the measured current.

The rewiring to correct these problems has been completed in eleven of the twelve fixtures. The twelveth fixture has milestone test PM-024. This fixture has the ground loop problem only because it is connected to a separated power supply. The problem will be corrected at the end of the test and appropriate corrections will be applied to the data.

Figure 3. Ground Loop in Current Control and Measuring Circuit

Normal Current path →

Ground Loop Current path ⇨

Figure 4. Corrent Current Control and Measuring Circuit
when Test Fixtures are in Parallel

Current path for fixture #1 in operation →

Current path for fixture #3 not in operation ⇒

Figure 5. Problem Current Control and Measuring Circuit when Test Fixtures are in Parallel

Current path for fixture #1

Current path for fixture #2

TASK 3.0 - COUPLE DEVELOPMENT

3.3 DESIGN AND DEVELOPMENT OF TPM-217/GADOLINIUM-SELENIDE RARE EARTH CHALCOGENIDE COUPLE

The effort continues to utilize chemical, physical, and thermo-electric data which have been obtained on TPM-217 and gadolinium-selenide to develop effective couples appropriate to RTG operation.

Couple Test ATT 378/379:

A couple test (ATT 378/379) with hardware similar to that designed for the 20-watt module was placed on test to give an indication of the 20-watt module performance. This test has operated for 6200 hours in the temperature interval 800°/240°C in a vacuum of 4×10^{-6} torr in the four-station facility.

This test has been cycled to room temperature four times. The first thermal cycle occurred at 30 hours when one of the chambers in the four-station facility developed a leak; the automatic shut-off circuit turned the station off. The test was exposed to a high pressure during cool down. Although the seat-in process was interrupted, the N-leg apparently did not crack because the resistance of the leg returned to the pre-thermal cycle values. The second thermal cycle at 350 hours was caused by a power failure in the building. The N-leg apparently cracked because the resistance increased and was operating constantly at a higher value. The third temperature cycle apparently resulted in no further degradation because the properties returned to approximately the pre-thermal cycle values. The fourth thermal cycle apparently caused another degradation. Because of the numerous thermal cycles, the termination of this test is under consideration.

3.4 DESIGN AND DEVELOPMENT OF TPM-217/3N-PbTe COUPLES

Couple test ATT 273 has now operated for 29,160 hours in the temperature interval 540°/140°C (1000°/285°F). The performance has remained the same as that previously reported.

Couple test ATT 275 was shut down at the time of the changeover to emergency power. This test has now been restarted and is at temperature. The power output is at approximately the same value as it was before the shutdown (Top Summary Report No. 81). The total operating time for this test is now 19,550 hours.

3.6 ADVANCED GENERATOR CONCEPTS

HARDWARE DEVELOPMENT

Follower Friction Testing:

The frictional force has been measured for a number of follower/rail combinations. These measurements were obtained using the apparatus described in Top Summary Report No. 90 (pp. 27-28). A summary of the data is contained in Table IX. The designation, "rough or smooth" in the follower column indicates whether the part has been tested in the as-machined condition or whether a smoothing operation involving polishing stones has been employed. The designation "Cr-Cu/Rh(.0001)" refers to a chromium copper follower with a 0.0001 inch thick rhodium plate. The electroless nickel plate process is much harder but less pure than the sulfamate nickel plating process. The MoS_2 is a molybdenum disulfide dry lubricant. This material was checked independently for outgassing and did not demonstrate any undesirable characteristics.

The force measurements provide a useful measure of the potential for a reduction of load pressure due to increased follower friction. These are short-term measurements, however, and long-term effects could exist and will be checked out. In addition, a visual inspection of the interfaces after testing provides another means of determining relative merit. In particular, it was observed that the rhodium plate had a tendency to scrape off the copper surface. To select a follower/rail combination, the heat transfer characteristics must also be evaluated. This has also been done for several candidate combinations and will be described later in this section.

The procedure in the friction force tests was to measure the net force on a follower while it was being moved inward and outward on a rail. The average of the maximum inward and outward values is reported in Table IX. These tests were performed in a vacuum of approximately 3×10^{-6} torr and at a temperature of 200°C .

A number of general conclusions drawn as a result of the friction force testing are:

1. The roughness of the mating surface has an influence on the observed frictional force (compare smooth ETP with rough ETP on a smooth 2024 aluminum rail).
2. With an electroless nickel rail, a rhodium plate on the followers reduced friction (this may not have been true on a long-term test because of the tendency of the rhodium plate to scrape off).

TABLE IX

FRICTIONAL FORCE MEASUREMENTS FOR VARIOUS RAIL/FOLLOWER COMBINATIONS

Test No.	Rail	Follower	Interface Material	Average Frictional Force for Motion Inward and Outward (lb)				
				Cycle No. 1	Cycle No. 2	Cycle No. 3	Cycle No. 4	Cycle No. 5
1	Smooth 2024 Al	Smooth ETP	None	5.1	5.0	6.0	6.1	6.0
2	"	Rough ETP	None	6.9	6.6	8.1	8.8	
3	"	Smooth ETP	None	4.3	5.0	5.5	5.4	
4	Electroless Nickel	Cr-Cu /Rh (.00002)	None	1.6	2.2	2.4		
5	"	Cr-Cu Smooth	None	5.6	6.1	5.3		
6	"	Smooth ETP	None	9.5	8.9	8.6		
7	"	Cr-Cu /Rh (.0001)	None	1.2	1.3	1.4		
8	"	ETP /Rh (.0001)	None	2.9	3.6	4.1		
9	"	ETP /Rh (.00002)	None	4.2	5.7	5.3		
10	Sulfamate Nickel	Cr-Cu /Rh (.0001)	None	2.8	1.7	1.8		
11	"	ETP /Rh (.0001)	None	4.3				
12	Electroless Nickel	Cr-Cu Smooth	MoS ₂					
13	"	"	"	1.1	1.4	0.8		

3. With an electroless nickel rail, chromium copper followers exhibit less friction than ETP followers (compare test Nos. 5 and 6).
4. With a rhodium plated follower, electroless nickel had superior friction characteristics as compared to a sulfamate nickel plate.
5. The presence of the MoS_2 interfacial material significantly reduces friction (compare tests 5 and 13).

Hardness Testing:

The hardness of follower and rail surfaces has been shown to have an influence on the frictional characteristics of rail/follower interfaces. The hardness of various test materials has been measured and the results are summarized in Table X.

Some of the measurements were made using the Rockwell G test and others using the Rockwell K test. They were all converted to Brinnell hardness number. This conversion process is usually quite unreliable, so comparisons between R_G values and R_K values should be made only with great caution. Some general observations may, however, be made:

1. Operation at 200°C softens 2024 Al and ETP copper.
2. Rh plating on copper decreases the hardness of the part.
3. Cr-Cu is harder than ETP copper.

Additional measurements will be performed on similar parts in the future. An attempt will be made to perform all tests with the same Rockwell test to eliminate hardness number conversion problems.

Follower/Rail Thermal Resistance Testing:

There is a trade-off between low friction and low thermal resistance for the sliding follower/rail surfaces. That is, the physical properties which produce low friction tend to produce high thermal resistance and vice versa. Hardness is a typical example. Thus, it is necessary to compare both friction and thermal resistance for candidate interfaces to obtain the optimum pair. A three-couple module was assembled in the hardware motion fixture and the thermal resistance of the follower/rail interface was measured for various types of interfacial materials. These results are summarized in Table XI. An electroless nickel rail and three Cr-Cu followers were used. The interfacial material varied.

TABLE X
Hardness of Various Module Materials

<u>Material</u>	<u>Measured Hardness</u>	<u>Hardness (BHN)</u>
2024 Al Rail (before testing at 200°C)	47 R _G	148
2024 Al Rail (after testing)	41 R _G	138
ETP Follower (before testing)	62 R _G	178
ETP Follower (after testing)	58 R _G	168
Electroless Nickel Plated Rail	46 R _G	145
Sulfamate Plated Rail	46 R _G	145
ETP Follower (.0000" Rh Plate)	63 R _K	82
ETP Follower (.0001" Rh Plate)	45 R _K	66
Cr-Cu Follower (.00002" Rh Plate)	91 R _K	153
Cr-Cu Follower (.0001" Rh Plate)	93 R _K	160

TABLE XI
Follower/Rail Thermal Resistance

<u>Follower</u>	<u>Interface Material</u>	<u>Thermal Resistance (°C/w)</u>
N-Leg	None	1.8
P-Leg	None	8.1
N-Leg	MoS ₂	10.5
P-Leg	MoS ₂	35.0
N-Leg	MoSe ₂	13.5
P-Leg	MoSe ₂	10.4

The MoS₂ material is a commercial produced called Molykote Z powder. The MoSe₂ material was synthesized in our laboratory. The general conclusions are that the interfacial coating appears to severely degrade the heat transfer characteristics of the interface, especially in the case of the MoS₂. There is scatter in the data, so additional testing will ultimately be performed to verify these conclusions.

Cold End Current Strap Attachment:

The attachment of the cold junction current strap is the final assembly step for the bonded and partitioned P-elements. In the past, there has been a failure rate of about 10% in this assembly operation, the mode of failure being a separation of the leg below the partition. Previously, legs that went through this process were not tested ingradient because the test seemed to weaken the partition bonds.

A series of elements were tested to determine if legs that were tested by the standard QC procedure would have a different failure rate. The legs used passed all QC inspection. The only property that could affect the ability to complete a good staking assembly would be the electrical resistivity; a high value could indicate a poor bond. Therefore, the test series should identify a worst case failure rate.

Twenty-one elements had the current strap staked in place; the failure rate and mode of failure was the same as before, 10% rate, and separation of the leg below the partition. Some possible causes of the separation are poor bond strength and/or the staking methods.

The staking tool was examined to determine its ability to accommodate all partitioned and bonded P-elements which pass the quality control acceptance limits. The acceptable limits of various dimensions which play a part in this examination are listed below:

1. The bonding surface of the copper electrode - 0.339 to 0.346 inch diameter.
2. The element must be centered a minimum of 0.008 inch from the edge of the copper electrode.
3. The diameter of the element - 0.290 to 0.295 inch.
4. The diameter of the W/Re partitioning foil is 0.320 inch - it must extend a minimum of 0.005 inch out from the element.
5. The diameter of the staking tool is 0.330 inch at the staking point, and 0.375 inch diameter in the body.

A worst case condition was assumed; that is, all the dimensions at the limit that could cause a problem. This condition is shown in Figure 6. There are two points of concern--where the staking tool contacts the copper electrode, and where the staking tool body may contact the partition foil (Figure 6, A and B). With the present dimensional limits, there is a possibility that there would be zero clearance between the staking tool and the element on the copper electrode (point A). The dimensions of the two elements that failed were checked, and this was not the case. To prevent this from ever occurring, the specifications for the maximum diameter of the copper electrode should be changed from 0.346 inch to 0.345 inch, and the minimum centering of the element on the copper electrode should be changed from 0.008 to 0.010 inch. Neither of these changes in specifications would have rejected a leg or copper electrode to date.

The second point of concern, the staking tool body and partition foil (Figure 6, point B), potentially could have overlapped by 0.002 inch. Again, this was not the case with the two legs that failed. To prevent this from ever occurring, the body of the staking tool will be enlarged to 0.400 inch diameter. This, and the change in dimensional specifications recommended above, will yield a minimum gap of 15 mils at point B.

The dimensional aspects of the staking method are probably not the cause of the present failure rate but, by making the changes noted, it should prevent any future problems.

Figure 6. Worst Case Conditions for a P-Element
in the Staking Process

A and B are potential
problem points

TASK 4.0 - MODULE DEVELOPMENT

MODULE M-1 - TWO-COUPLE MODULE:

The two-couple module, M-1, has completed 14,200 hours of operation in a temperature interval $800^{\circ}/200^{\circ}\text{C}$ and a vacuum of about 10^{-4} torr. A power interruption at 3500 hours produced a temperature cycle which caused an irreversible change of performance. This temperature cycle undoubtedly resulted in cracked N-legs which was indicated by an increased resistance at that time. The cold junction of the module cycled to about 120°C at 4850 hours. This cycle had little effect on the average Seebeck coefficient of the N- and P-legs or on the resistance of the N-legs. The average resistance of the two P-legs increased by about 4% and has remained stable until this month. During the last month, the resistance of the P-leg increased by about a factor of three, indicating a contacting problem. Thus, high resistance produces a decrease in power output (Figure 7). This behavior is indicative of reduced load pressure and is somewhat similar to the problems observed on M-5. The followers used on M-1 have long since been replaced so that the solution to this problem is being obtained by the current follower friction studies.

MODULE M-5 - 10-COUPLE MODULE:

Module M-5 has been operating in a vacuum of 7×10^{-8} torr and a temperature interval of $800^{\circ}/200^{\circ}\text{C}$ for 5100 hours. The thermoelectric performance from the time that the $800^{\circ}/200^{\circ}\text{C}$ temperature was attained is displayed in Figures 8 through 16. The performance increased initially as seat-in occurred, but remained relatively stable from approximately 150 hours to 750 hours. At 750 hours the temperatures were adjusted to bring them more in line with the nominal values of $800^{\circ}/200^{\circ}\text{C}$. The power output subsequently increased from 4.2 to 4.4 watts. At approximately 1000 hours the resistance of one of the N-legs discontinuously increased from 22 to 60 milliohms (Figure 15). This did not occur at the same time as the temperature adjustment. Any temperature change which would have occurred at this time would have been minor.

This N-leg resistance has been gradually decreasing since the time of the discontinuous change and was approximately 24 milliohms at the end of the month. Thus, it appears that this N-leg is undergoing the same type of behavior exhibited by the two N-legs during the first 1000 hours of operation (Top Summary Report No. 90). That is, the change may have been caused by a slight end cracking which ultimately improves with seat-in, or a slight hang-up on the follower which finally freed itself. Two other N-legs have also exhibited some increase in resistance this month. Due to the erratic nature of the resistance variation, it appears that these changes may be due to contacting and follower hang-up.

Figure 7. Power Output of the Two-Couple Module (M-1)
Operating in the Temperature Interval 800°/200°C
and in a Vacuum (data not normalized)

Figure 8. Power Output of Ten-Couple Module (M-5)
Operating Between 800°/200°C in a Vacuum

Figure 9. Total Resistance of Ten-Couple Module (M-5)
Operating in the Temperature Interval 800°/
200°C in a Vacuum

Figure 10. Open-Circuit Voltage of Ten-Couple Module (M-5)
Operating Between 800°/200°C in Vacuum

Figure 11. Average Hot End Temperature of Ten-Couple Module (M-5) with Nominal Temperature Interval of 800°/200°C in a Vacuum

Figure 12. Average Cold End Temperature of Ten-Couple Module (M-5) with Nominal Temperature Interval of 800°/200°C in a Vacuum

Figure 13. Ingradient Seebeck Coefficient of TPM-217 N-Legs
in Ten-Couple Module (M-5) Operating in the Temperature Interval 800°/200°C in a Vacuum

Figure 14. Ingradient Seebeck Coefficient of P-Legs in Ten-Couple Module (M#5) Operating in the Temperature Interval 800°/200°C in a Vacuum

Figure 15. Resistance of N-Legs in Ten-Couple Module (M-5)
Operating in the Temperature Interval 800°/200°C
in a Vacuum

Figure 16. Resistance of P-Legs in Ten-Couple Module (M-5)
Operating in the Temperature Interval 800°/200°C
in a Vacuum

The resistances and Seebeck coefficients of the remainder of the N-legs are uniform (Figures 13-15). In addition to plots of the power, Seebeck coefficient, and resistance, the open circuit voltage and temperature history of M-5 are plotted in Figures 10, 11, and 12.

The power output of the M-5 which had degraded during December 1975 (Figure 8), primarily as a result of the increase in resistance of two P-legs, (Figures 9 and 16) has now stabilized. The value of resistances greater than 50 milliohms is shown in parentheses. The P-leg resistance of these legs is erratic, which is indicative of an electrical contacting problem. This behavior is probably caused by a reduction in load pressure on the P-legs. Resistance values have varied between 20 and 250 mohms for one leg. These variations have been random. The P-leg followers have weaker springs than the N-leg followers; thus, they have less ability to counteract friction between the follower and the rail. Current investigations in the follower/rail friction apparatus will define this problem more completely, and a solution to this problem will be identified as a result of these studies. A variety of materials, coatings, and surface preparations are being evaluated to determine the optimum rail/follower combination.

MODULE M-6 - TEN-COUPLE MODULE:

Module M-6 will be a ten-couple module similar in configuration to M-5. The changes in M-6 are summarized below:

<u>Module</u>	<u>M-5</u>	<u>M-6</u>
Rail	2024 Al	2024 Al with Electroless Nickel Plate
Follower	ETP Copper	Chromium-Copper
Rail/Follower Interface Material	None	None
Hot End Gimbal	Standard	Improved
N-Legs	100% Extraneous Resistance	50% Extraneous Resistance

The selection of the rail/follower configuration is somewhat tentative based on the results of a longer-term friction test which has just been started. If the frictional characteristics remain good with time, the configuration described above will be used.

TASK 9.0 - PROGRAM MANAGEMENT

Work under this task included technical direction and overall coordination of activities associated with the program and liaison with ERDA. The following report was published during this period:

Top Summary Report No. 95, dated February 9, 1976

Messrs. W. Barnett, A. Lieberman, and W. Osmeyer of Teledyne Isotopes, and Mr. A. Schafffauser of ORNL visited 3M on February 5, 1976, to discuss chemical compatibility related to the LCHPG program. A program review was held at ERDA/DANES on February 12, 1976, with Messrs. E. Hampl and R. Reylek in attendance.