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SILICON GERMANIUM (SiGe) RADIOISOTOPE THERMOELECTRIC GENERATOR (RTG) PROGRAM FOR SPACE MISSIONS

NINETEENTH TECHNICAL PROGRESS REPORT
CONTRACT DE-ACO1-79ET-32043 ✓

PERIOD FROM 1 THROUGH 31 DECEMBER 1980 AND 1 THROUGH 31 JANUARY 1981

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Prepared for

**DEPARTMENT OF ENERGY
ADVANCED NUCLEAR SYSTEMS AND PROJECTS
WASHINGTON, D.C.**

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27 February 1981

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SUBJECT: CONTRACT DE-AC01-79ET32043
MONTHLY TECHNICAL PROGRESS REPORT

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Sincerely,

A. R. Carràzzone
Contracts Manager

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RADIOISOTOPE THERMOELECTRIC GENERATOR (RTG)
PROGRAM FOR SPACE MISSIONS

CONTRACT DE-AC01-79ET-32043

1.0 INTRODUCTION

This report, submitted by the General Electric Company, describes work accomplished during the reporting period on the DOE Silicon Germanium RTG Program, Contract DE-AC01-79ET-32043. This program consists of the following three tasks:

Task 1 - Multi-Hundred Watt RTG for the Galileo Probe Mission

Task 2 - Reestablishment of Silicon Germanium Unicouple Capability

Task 3 - General Purpose Heat Source RTG for the International Solar Polar and Galileo Orbiter Missions.

Details of program progress for each task, including a milestone schedule and a discussion of current problem areas (if any) are presented in the following sections.

2.0 GALILEO PROBE RTG

2.1 PROGRAM MANAGEMENT AND CONTROL

Major MHW RTG Program direction was received from DOE at a meeting on January 15, 1981. It is likely that the shuttle three-stage IUS will be replaced with the Centaur which would allow a tandem launch of the Galileo Orbiter and Probe Spacecraft. This mission would probably require GPHS-RTGs on the Galileo spacecraft in order to minimize weight. It was therefore directed by DOE, while awaiting a final decision, to:

- Terminate testing of the already processed F-13 and to place it in an RTG-SC. This action has been accomplished.
- Halt qualification tests on the Q-2 qualification module. A new vent tube was completed and installed on Q-2 and the unit placed in a CSC for storage.
- Continue to assemble F-7 and E-5, cold vacuum outgas them and place in storage in RTG-SCs. Assembly of F7 is nearly completed.

2.2 HEAT SOURCE INTERFACE AND HANDLING

Calculations made by GE indicated that the POCO lock ring used in the IHS had an unacceptable thermal growth rate with respect to the FWPF graphite composite end caps and 3DCC graphite aeroshell. GE and MRC agreed to try a lock ring of the same configuration but made of FWPF graphite composite. The ring was tested and proved successful. The FWPF lock ring will be used on all IHS's built for this program.

2.3 JPL LIAISON AND INTERFACE

No activity planned or undertaken.

2.4 RTG DESIGN AND ANALYSIS

Activity in this area was phased out during the reporting period.

2.5 SYSTEM TESTING AND RTG FUELING

The processing of F-13 was initiated with the start of LAS pumpdown on 1 December. Power was first applied to the EHS on 2 December and full power (2426.6 watts) was achieved at 0200 hours on 13 December. The ETG power output at this time was 154.11 watts. Following a 24-hour stability period, the output power was 155.32 watts. The thermopile to foil/case shunt resistance was 3.3 K ohms.

About 11 hours into the 2430 W_t vac stability run, a fuse supplying one phase of 440 V to the chamber was lost - reason unknown. This caused the cryo pump to drop out and some functions of the GMS (which was only on standby) to also drop out. The fuse was replaced and all systems powered up normally.

The failure caused the cryo pump to shut down and the hi vac valve to close and isolate the cryo pump from the chamber. Vacuum was being held with the turbo molecular pump (TMP) at 2.0×10^{-5} torr. In order to bring the cryo pump back on line it was necessary to rough the cryo pump, which, due to interlocks, required the TMP to also be isolated from the chamber. This intermittent rough of the cryo pump allowed the chamber to rise to 1×10^{-4} torr. This condition prevailed for 25 minutes and an additional 3.5 hours was required to bring the cryo pump fully on line. During this time the TMP held the chamber at 3.1×10^{-5} torr and finally the chamber pressure returned to the 10^{-6} range. GE management directed a continuation of the 24-hour stability run since prolonged operation at higher temperatures for 2430 W_t input was not desirable.

A Discrepancy Report (DR) was written due to the chamber's pressure rising above 1×10^{-5} torr.

The EHS was deenergized and allowed to cool to room temperature. The forward dome and rubber "O" ring was installed and a 6-hour pressure decay test conducted. The pressure decay of 0.11 psi/6 hr matched the preprocessing data. All systems were then shut down for the balance of the year. F-13 was stored, pressurized with argon in LAS #1, under a cover of argon gas. Testing was temporarily suspended for the Christmas holidays.

F-13 testing was resumed on 4 January 1981. With the GMS on line, the converter pressure was reduced to one atmosphere and removal of the forward dome screws initiated. Attempts to rotate the converter to gain access to the remaining dome screws failed as the Troyke table was seized. Dome screws were reinstalled and the converter was pressurized with argon. The 6-hour leak check was acceptable. F-13 was removed from LAS #1 and stored on the slide tray cart. Inspection of the table revealed galling of the bearing surfaces.

LAS #1 Troyke table was reworked and reinstalled. Boron nitride lubricant was tried but did not protect against galling - it was not used. The table was lubricated with silicone vacuum grease as before.

The converter was reinstalled in LAS #1 and a Segment Readiness approved. Chamber pump-down started on 10 January. Chamber pressure could not be reduced below 2×10^{-5} torr due to argon gas leakage into the chamber through the Gas Management System (GMS) inlet/outlet valves. This was determined by isolating the GMS. With the GMS evacuated, the chamber pressure was reduced to 2×10^{-6} torr. On 15 January, direction was received to terminate further processing of F-13. The converter dome was installed with a metal "C" seal and torqued, and a 48-hour pressure decay test performed. The leak rate over the 48-hour period was 0.15 psia, which is well within the maximum rate of 1.5 psia over 48 hours.

F-13 was removed from LAS #1 and installed into the RTG-SC with its GMV open so converter pressure can be monitored and adjusted if necessary. The unit will be stored in Building 800

All effort on MHW system test procedures was terminated per program direction.

LAS #1 GMS inlet/outlet valves were removed and cleaned to remove any debris which could prevent a good seal. A subsequent vacuum integrity check of LAS #1 demonstrated proper pumpdown times and ultimate vacuum.

2.6 GROUND SUPPORT EQUIPMENT

No activity scheduled or reported.

2.7 MANUFACTURING

The following activities were undertaken during the reporting period:

- F-7 was disassembled, examined and reassembled.
- The electric heat source for F-7 was assembled and tested under thermal vacuum conditions.
- The gas management valve for F-7 was assembled and delivered for testing.
- The Converter Shipping Container was refurbished and delivered for testing.

2.8 QUALITY ENGINEERING AND CONTROL

Test/processing of the F-13 converter was completed satisfactorily. No problems were experienced with the converter, however, there were minor problems with the chamber. These problems did not interfere with test.

The RTG shipping container for the converter was checked out and leak tested. Minor modifications to the container were necessary to accommodate the converters ACS cooling system.

Reassembly of the F-7 converter continued and the parts removed from the E-5 converter were inspected and cleaned for re-use.

The PRD was installed on the Q-2 Qualification Module and test preparations continued.

Material Review activity is summarized in Table 2.8-1.

2.9 RELIABILITY

No work was scheduled for this reporting period.

2.10 SAFETY ASSESSMENTS

Per direction from the ANSPO/DOE Program Office, no additional effort will be expended in planning or preparing for the MHW/Galileo heat source systems impact test. Since the order for the 26 GIS's from HITCO was more than 60 percent complete when the above direction was received, the decision was made to have the order completed. These GIS's are scheduled for delivery by the first of March 1981.

2.11 FIELD AND LAUNCH SUPPORT

No effort was planned or undertaken. Future effort was terminated per program direction.

Table 2.8-1. Nonconformance Report - Contract No. DE-AC01-79ET32043

Report No.	Program	Item	Discrepancy	Disposition
48593	Galileo	Bearing Disk	1. One piece broken 2. Reject 28 per 3.2.6 and 4.2.1 of spec. NS0060-01-22	1. Scrap 2. Accept, will perform acceptably
48673	Galileo	Bearing Disk Blank	Incomplete material certification	Conditionally accept until test data obtained
48699	Galileo	Q2 Outer Shell	Stains, discoloration, scuff marks and scratches	Accept, will not affect future tests
38722	Galileo	ETG Assembly	Pressure increase	Accept, not a significant detriment
48723	Galileo	ETG Assembly	Low pressure	Due to argon gas leak proceed with processing
48737	Galileo	Dome	Overspray, discoloration, coating not adhering	Accept, sealing surface not affected
48754	Galileo	Bearing Disk Blank	Reject per 3.2.6 of spec. NS0060-1-22	Salvage as many acceptable segments as possible
48767	Galileo	E-5 Converter	Unicouple discoloration	Continue assembly, will investigate further
48768	Galileo	Aft Dome	Discoloration, scratches Flatness out of spec.	Accept, only slightly out of spec, will still seal
48773	Galileo	C-Seal	Lack of plating per customer judgment	Accept; problem is discoloration, not lack of plating
48776	Galileo	Forward Dome	Scratches and flatness out of spec	Return to stock, not used on Galileo
48780	Galileo	Aft Dome	Scratches and flatness out of spec	Accept, only slightly out of spec, will still seal
48781	Galileo	Screw, Pressure Dome	Dimensional and residue discrepancies	Release for Engineering use only
48798	Galileo	C-Seal	Slight scratches	Accept, are minor
48799	Galileo	Clevis	Dimensional discrepancy	Accept, will still fit in Assembly
48852	Galileo	F-7 shell and T/P	End cap foil ties broken and missing	Pieces were found
48860	Galileo	Metallic Panel Assembly	16 dimple marks	Accept, will not affect function
48867	Galileo	Metallic Panel Assembly	Scratch or dent present	Accept, not serious

2.12 COMPONENT DEVELOPMENT

The Qual Module was instrumented with strain gauges. It awaits the forward dome/vent tube and PRD before being prepared for dynamic testing.

Based on program redirection, dynamic testing of the Qual Module was cancelled. An unsuccessful attempt to demonstrate proper fit of the dome/vent tube/PRD was made. Failure was due to an interference with the PRD guide. The guide is being modified and will be reinstalled for another fit demonstration. The Qual Module will then be stored in a converter shipping container.

3.0 SiGe REESTABLISHMENT

3.1 PROGRAM MANAGEMENT AND CONTROL

The investigation of the SiMo N-P bond problem which had caused couple preassembly failures due to hot shoe breakage has been completed. The corrective measures taken include changes in compaction temperatures and the molybdenum particle size distribution. These changes have been incorporated in the specifications and Quality Assurance procedures pertinent to the subject processes. Confirmation runs of SiMo N-P bonded pairs have been run and the results, together with the required specification changes, have been approved by the GE Process Review Board.

In conjunction with the N-P bond problem investigation, the assembly and inspection methods and fixtures have been audited by a special task force which includes representatives from process engineering, tool design, quality assurance and program office. The result has been improved yield in all assembly process steps. Completion of the uncouple complement for the GPHS engineering unit is projected by FW 7. Production of cast material, compacts and radiator attachments has been started for the qualification unit uncouple complement. Although the N-P bond problem investigation has caused a delay in completion of the engineering unit uncouple complement and start of the qual unit uncouple fabrication, it is expected that the uncouples will be available in time for the scheduled assembly for the qual unit.

The GE Process Review Board has approved all uncouple production procedures for prime hardware except wrapping of uncouples and in-house machining of segments. These processes are scheduled for review by FW 6.

Converter 18-1 continues to perform satisfactorily.

The schedule of the reestablishment program is presented in Figure 3.1-1. Program milestones status is shown in Table 3.1-1.

3.2 SiGe UNICUPLE FACILITATION

This phase of the program is complete.

3.3 TECHNOLOGY VERIFICATION

This phase of the program is complete.

3.4 PRODUCTION READINESS

3.4.1 PRODUCTION AND QUALITY CONTROL DOCUMENTATION

In preparation for prime hardware production, specifications for first bond, silicon nitride coating and second bond assembly were reviewed and 'AN's were approved to conform to action items identified at final process review meetings.

Figure 3.1-1. SiGe Reestablishment Program Schedule

Table 3.1-1. Program Milestones

Ident. No.	Description	Completion Date		Comments
		Planned	Actual	
2.1	Complete SiGe Reestablishment Program	11/1/80		Revised to mid-February
2.1A	Issue Detailed Management Plan	1/20/80	1/20/80	Revision Submitted 2/27/80
2.2	Complete SiGe Unicouple Facilitation	12/31/79	12/31/79	Facilitation for TV Completed
2.3	Complete Technology Verification	10/31/80		
2.3A	Initiate Vacuum Casting Technology Verification	9/1/79	8/20/79	
2.3B	Initiate Test of 18-Couple Converter 18-1 (TV-1)	4/30/80	7/23/80	
2.3C	Complete MHW Unicouple Technology Verification	6/1/80	6/30/80	
2.4	Complete Production Readiness	11/1/80		Revised to mid-February
2.4A	Initiate Production Readiness for Vacuum Casting	12/1/79	2/5/80	
2.4B	Completion Production Readiness for Vacuum Casting	6/30/80	7/7/80	
2.4C	Initiate 18-Couple Converter 18-3 (SP-1) Test	7/31/80		Revised to mid-March
2.4D	Initiate 14-Couple Dynamic Module SPD-1 Test	8/31/80		
2.4E	Initiate 18-Couple Converter 18-4 (SP-2) Test	9/30/80		Revised to mid-May
2.4F	Initiate 18-Couple Converter 18-5 (SP-3) Test	10/31/80		
2.4G	Complete Production Readiness for Unicouple Assembly			Revised to mid-February

3.4.2 TRAINING OF PERSONNEL

Status of certification of operators is as follows:

<u>Process</u>	<u>Total Number of Certified Operators</u>
Vacuum Casting	4
Powder Blending	3
Vacuum Hot Pressing	3
Slicing and Grinding of T/E Parts	2
Seebeck Measurement	3
Density Measurement	3
Nickel Plating	1
Bonding (1st and 2nd Bond Assembly)	2
Silicon Nitride Coating	1

3.4.3 PREPRODUCTION GPHS UNICOUPLE FABRICATION

All processes for the fabrication of GPHS uncouples for engineering unit converter are being utilized. Table 3.4-1 contains a summary of operations performed during the production readiness phase of the program.

3.4.4 PREPRODUCTION UNICOUPLE CHARACTERIZATION

The investigation of the N-P SiMo bond has been completed and production of prime N-P SiMo bonded compacts for hot shoes has been initiated. A summary of all the test variations conducted is given in Table 3.4-2, including the four confirmation runs, engineering ticket Nos. 134, 135, 136 and 137. The final conditions selected were:

1. MHW compaction conditions for the SiMo P and N type compacts, see Table 3.4-3.
2. Continued preparation of SiMo P and N type compact surfaces by MHW method; grind - lap - polish.
3. Lowering of the N-P SiMo bonding temperature:
From: $1285 \pm 10^{\circ}\text{C}$
To: $1265 \pm 10^{\circ}\text{C}$

To insure that the N-P bond strength is monitored throughout the processing cycles, a number of corrective actions were invoked (see Table 3.4-4). Some of these are mandatory inspections (such as those for the N-P bond process) and others are checks monitoring the subsequent processes of 1st bond and couple preassembly. All affected specifications have been changed to incorporate these corrective actions.

Table 3.4-1. Production Readiness Operations

Operation	December 1980	January 1981	Total Program
<u>Vacuum Casting</u>			
Number of Casting Runs	Completed		99
Number of Casting Runs Accepted	Work		95
Percent Yield			95.9 %
<u>Hot Pressing</u>			
Number of Hot Press Runs	25	Completed	302
Number of Hot Press Runs Accepted	25	Work	277
Percent Yield	100 %		91.7 %
<u>First Bond Assembly</u>			
Number of First Bond Couples Bonded	120	174	1800
Number of First Bond Couples Bonded/Accepted	76	146	1420
Percent Yield	63.3 %	83.9 %	78.8 %
<u>Silicon Nitride Coating</u>			
Number of Coating Runs	4	12	90
Number of Couples Coated	62	120	1372
Number of Couples Coated/Accepted	62	115	1195
Percent Yield	100 %	95.8 %	87.1 %
<u>Second Bond Assembly</u>			
Number of Couples Bonded	51	141	1179
Number of Couples Bonded/Accepted	47	108	1004
Percent Yield	92.2 %	76.6 %	85.2 %
<u>Couple Pre-Assembly</u>			
Number of Couples Brazed	14	82	921
Number of Couples Brazed/Accepted	12	64	739
Percent Yield	85.7 %	78.0 %	80.2 %
<u>Machined Radiator Attachment Assembly</u>			
Number of Assemblies Brazed	119	103	1413
Number of Assemblies Brazed/Accepted	117	97	1314
Percent Yield for Brazed Assemblies	98.3 %	94.2 %	92.3 %
Number of Brazed Assemblies Machined	78	208	1180
Number of Assemblies Accepted (Machined)	62	181	1036
Percent Yield of Machined Assemblies	79.5 %	87.0 %	87.8 %
<u>Cold Stack Assembly</u>			
Number of Assemblies Brazed	36	167	990
Number of Assemblies Brazed/Accepted	33	159	795
Percent Yield	91.6 %	95.2 %	80.3 %
<u>Unicouple Assembly</u>			
Number of Couples Brazed	19	118	631
Number of Couples Brazed/Accepted	17	99	518
Percent Yield	89.4 %	83.9 %	82.1 %
<u>Wrapped Unicouple Assembly</u>			
Number of Couples Wrapped	29	50	434
Number of Couples Wrapped/Accepted	29	47	421
Percent Yield	100 %	94.0 %	97.0 %

Table 3.4-2. SiMo N-P Bond Problem Resolution Program

Test No.	ET No.	Mo Lot	Compaction Conditions	Surface Prep.	Ti Lot	Bond Temp. (°C)	R _j (mΩ)	Avg. Mo _x Si _y Particle Size (μm)	Avg. Mo _x Si _y Area Fraction (%)	Avg. Surface Finish (μ in)	% Mo _x Ti _y Si _z Reaction (Hot Shoe)	First Bond Break Strength (Kg)	% Mo _x Ti _y Si _z Reaction** (1st Bond)	Couple Pre-Assy. Break Strength (Kg)
B	102	MHW	MHW	MHW	MHW	1282	.148	18.4	12.7	7.0	29.3	9.0	48.4	N/P
C	103	MHW	MHW	MHW	PR	1285	.134	N/M	N/M	8.5	30.3	8.8	42.2	N/P
E	104	MHW	MHW	Grind Only	PR	1285	.132	17.4	11.8	20.5	20.0	9.5	45.3	N/P
M	116	MHW	MHW	MHW	PR	1265	.108	18.5	N/M	N/M	27.0	10.8	27.0	8.0*
M	118	MHW	MHW	MHW	PR	1255	.109	18.0	N/M	N/M	26.0	10.0	33.0	9.7
P	123	MHW	MHW	MHW	PR	1275	.109	15.8	11.8	< 8	26.0	9.0	45.0	9.0
	134	MHW	MHW	Grind/Polish	PR	1275	.120	N/M	N/M	< 8	36	13.8	44.0	9.0
	135	MHW	MHW	Grind/Polish	PR	1275	.112	N/M	N/M	< 8	30.0	10.0	30.0	8.5
	136	MHW	MHW	MHW	PR	1275	.106	N/M	N/M	< 8	30.0	13.5	25.0	9.0
	137	MHW	MHW	MHW	PR	1275	.118	N/M	N/M	< 8	33.0	18.0	40.0	
A	100	PR	PR	Grind & Met Polish	PR	1270	.102	12.4	11.4	7.0	40.0	7.0	Complete Reaction	N/P
D	101	PR	PR	Grind Only	PR	1270	.103	13.2	11.5	13.5	43.3	6.3	46.0	N/P
G	105	MHW	PR	MHW	PR	1275	.131	17.0	12.2	6.5	29.5	9.8	37.5	N/P
F	106	MHW	PR	Grind Only	PR	1270	.122	18.5	13.5	24.0	26.2	8.8	33.2	N/P
L	117	MHW	PR	MHW	PR	1262	.108	17.0	N/M	N/M	21.5	8.5	26.0	9.5
L	119	MHW	PR	MHW	PR	1255	.105	16.0	N/M	N/M	29.4	8.0	33.0	6.7
K	88	PR	MHW	MHW	PR	1285	.093	14.0	N/M	N/M	31.0	13.0	56.1***	N/P
N	120	PR	MHW	MHW	PR	1255	.106	11.5	N/M	N/M	22.0	10.0	55.0	N/P
S	126	PR	MHW	MHW	PR	1275	.103	12.2	10.8	< 8	25.0	9.3	43.0	7.5

N/M - Not Measured

N/P - Not Performed

* - One Broke at 3 Kg

** - Bonded at 1315°C

*** - Bonded at 1310°C

Table 3.4-3. Hot Press Process Parameters

From: PR Conditions

Material	Temperature	Pressure Setting On Gauge	Rise Time Minutes	Dwell Period Minutes
SiMo N	1380 - 1420°C	**	40 ± 10	20 ± 3
SiMo P	1380 - 1425°C	**	40 ± 10	20 ± 3
** Pressure settings on lower ram to correspond to 185,000 lbs. as calibrated by Morehouse Proving Ring. Calibration frequency to be a minimum of once every three months. Round off gage pressure setting to the nearest 25 psi division.				

To: MHW Conditions

Material	Temperature	Pressure Setting On Gauge	Rise Time Minutes	Dwell Period Minutes
SiMo N	1410 - 1430°C	**	40 ± 10	20 ± 3
SiMo P	1415 - 1435°C	**	40 ± 10	20 ± 3
** Pressure settings on lower ram to correspond to 142,700 lbs. as calibrated by Morehouse Proving Ring. Calibration frequency to be a minimum of once every three months. Round off gage pressure setting to the nearest 25 psi division.				

3.5 SiGe TECHNOLOGY MAINTENANCE

3.5.1 MHW SiGe PERFORMANCE IMPROVEMENT

3.5.1.1 Transport Properties Enhancement

The purpose of this subtask is to improve the figure-of-merit of MHW class SiGe materials. The approaches are to optimize powder blend particle sizes, vary hot pressing conditions and alter compositional levels.

The series of twenty-one compacts representing variations in particle size of -177, -37 and -20 microns and dwell times of 40, 20 and 5 minutes were characterized for room temperature Seebeck, electrical resistivity and density, Table 3.5-1. All values fall within acceptable ranges for 78 at. % SiGe.

Table 3.4-4. Corrective Action - N-P Bond Processes

Specification	Property	Condition	Requirement
RM2F2 (N-P Bond)	<ul style="list-style-type: none"> - Electrical - Strength - Metallurgical Mo_xTi_ySi_z Reaction - Lot Approval Test 2 First Bonds <ul style="list-style-type: none"> • 1 N-P Break • 1 Met Lab 	<ul style="list-style-type: none"> • Rj of any shoe exceeds 0.170 mΩ • Any fail 22 Kg test or N-P break is < 30 Kg <p>Exceeds 30%</p> <p>Min. Strength 7.5 Kg* Exceeds 45%*</p>	<p>Report to QC and Engineering.</p> <p>Report to QC and Engineering.</p> <p>Report to QC and Engineering.</p> <p>Report to QC and Engineering.</p>
RA2B1 (1st Bond)	<ul style="list-style-type: none"> - Strength 1/100 couples <ul style="list-style-type: none"> • N-P Break - Metallurgical 1/100 couples <ul style="list-style-type: none"> • Mo_xTi_ySi_z Reaction 	<p>--</p> <p>--</p>	<p>Report to QC and Engineering.</p> <p>Report to QC and Engineering.</p>
RA3D1 (Couple Preassembly)	<ul style="list-style-type: none"> - Strength 1/100 couples <ul style="list-style-type: none"> • N-P Break - Metallurgical 1/100 couples <ul style="list-style-type: none"> • Bond Integrity 	<p>--</p>	<p>Report to QC and Engineering.</p> <p>Report to QC and Engineering.</p>
RA4C2 (Unicouple Assembly)	<ul style="list-style-type: none"> - Cold Beam Deflection Test 1/100 couples 	<p>--</p>	<p>Report to QC and Engineering.</p>

* Temporary Limits: Final limits to be established as data becomes available.

Table 3.5-1. Summary of Experimental Compacts Variations
in Particle Size and Dwell Time

TED 5 or EX II	Polarity	S $\mu\text{V}/^\circ\text{C}$	D g/cm^3	$\text{m}\Omega\text{ cm}$	t (min)	Mesh Size
808P	P	114	2.950	1.078	2	- 80
802P	P	114	3.043	0.967	20	- 80
EX 3	P *	111	3.040	0.873	40	- 80
808N	N	114	3.038	0.818	5	- 80
802N	N	112	3.045	0.803	20	- 80
EX 5	N *	111	3.027	0.789	40	- 80
4008P	P	113	2.920	1.169	5	- 400
4002P	P	118	3.056	1.054	20	- 400
EX 4	P	112	3.043	0.951	40	- 400
4008N	N	108	3.053	0.850	5	- 400
4002N	N	106	3.049	0.782	20	- 400
EX 6	N	110	3.060	0.847	40	- 400
6358P	P	112	2.999	1.126	5	- 635
6352	P	112	3.054	1.016	20	- 635
6351P	P	113	3.024	0.951	40	- 635
6358N	N	112	3.040	0.866	5	- 635
6352N	N	109	3.041	0.822	20	- 635
6351N	N	107	3.049	0.782	40	- 635

* Std. Product (MHW)

All material processed in argon.

Appropriately dimensioned specimens were machined from the compacts and forwarded to BMI for transport properties measurements as a function of temperature. Data was received on four P-type samples, Table 3.5-2, and five N-type samples, Table 3.5-3, over a limited range of temperature to 500°C . In this low temperature range, the P-type samples show no improvement in the figure-of-merit. The N-type material, however, shows improvement over standard material in all five samples primarily because of a lower electrical resistivity and higher Seebeck. It should be noted that the MHW-N and -P properties data in Tables 3.5-2 and -3 are from accepted curves and not from samples measured concurrently with the test samples.

High temperature laser diffusivity measurements from which thermal conductivity will be derived are in progress at BMI.

Samples from each of the twenty-one test compacts were sent to Purdue University for confirming high temperature thermal conductivity measurements. In addition, specimens of

Table 3.5-2. Transport Properties - P Type at. % SiGe

Compact	Temp °C	m Ω cm	S $\mu\text{V}/^\circ\text{C}$	K Watts/cm $^\circ\text{C}$	Z Deg $^{-1}$ x 10 $^{-3}$
4002P	300	1.57	205	0.050	0.535
	400	1.79	213	0.048	0.528
	500	2.00	218	0.046	0.517
4008P	300	1.58	170	0.047	0.389
	400	1.81	188	0.048	0.407
	500	2.07	207	0.048	0.431
6351P	100	1.13	147	0.056	0.340
	200	1.32	171	0.056	0.395
	500	1.91	223	0.051	0.510
6358P	300	1.61	180	0.051	0.398
	400	1.79	205	0.047	0.499
	500	2.00	225	0.043	0.591
MHW-P	300	1.31	182	0.052	0.486
	400	1.51	201	0.050	0.534
	500	1.71	217	0.048	0.570

Table 3.5-3. Transport Properties - N Type 78 at. % SiGe

Compact	Temp °C	m Ω cm	S $\mu\text{V}/^\circ\text{C}$	K Watts/cm $^\circ\text{C}$	Z Deg $^{-1}$ x 10 $^{-3}$
802N	300	1.28	189	0.045	0.620
	400	1.57	213	0.049	0.590
	500	1.92	229	0.043	0.635
4002N	300	1.30	191	0.485	0.579
	400	1.57	216	0.461	0.645
	500	1.76	237	0.452	0.706
4008N	300	1.37	217	0.050	0.687
	400	1.62	248	0.047	0.810
	500	1.92	275	0.048	0.820
6351N	300	1.19	198	0.044	0.749
	400	1.43	238	0.043	0.910
	500	1.78	273	0.043	0.974
6358N	300	1.40	214	0.047	0.696
	400	1.58	248	0.044	0.884
	500	1.83	286	0.045	0.990
MHW-N	300	1.37	199	0.045	0.644
	400	1.75	232	0.043	0.712
	500	2.222	258	0.042	0.716

current product N- and P-type 78 at. % SiGe were sent to Purdue for specific heat and thermal conductivity measurements as a function of temperature. The technique used at Purdue is also laser diffusivity.

Measurement at Seebeck and electrical resistivity as a function of temperature is in progress at GE on samples of SiGe. Figure 3.5-1 is a curve of the electrical resistivity of P-type 78 at. % SiGe measured to 1050°C compared to the accepted curve for the same material. Agreement between the curves is good.

Compositional Levels

A study of the literature on high silicon content SiGe alloys was completed. Based on the limited data available, it is estimated that an improvement of approximately 5% in material efficiency could be gained by using 90 at. % SiGe.

3.5.1.2 Higher Temperature Capability

An alternate hot shoe design was selected to permit higher temperature bonding and uncouple operation. Tests were initiated to eliminate the titanium shim in the SiMo hot shoe N-P bond. Two pairs of compacts were hot pressed and then bonded without the Ti interface. One pair consisted of standard N and P-type SiMo; the other consisted of N and P-type Si. Both bonded pairs were submitted for hot shoe machining.

3.5.2 IMPROVED PRODUCTIVITY AND PRODUCT QUALITY

This subtask is designed to identify SiGe material preparation techniques that improve homogeneity for increased product and bonding reproducibility.

The GE Corporate Research and Development facility has completed the initial phase of the development of a method of producing SiGe hot press feed materials by melt spinning. Melt spinning is a very high volume method of producing exceptionally homogeneous, fine grain size materials by a very rapid quench from the melt. A small quantity of SiGe was prepared by this technique and will be evaluated for electrical properties and microstructure when received by the Thermoelectric Operation at Valley Forge.

3.5.3 18-COUPLE CONVERTER FABRICATION

3.5.3.1 SiGe GaP Bonding

Using the 10 at. % SiGe interface between the SiGe-GaP pellet and the 63.5 at. % SiGe pedestal on the hot shoe, and a similar interface between the pellet and the segment, twenty second bond couples were completed. Of ten second bond couples started through preassembly, six uncouples were fabricated. The four couples that did not survive uncouple processing experienced breakage at one of the 10 at. % SiGe bond interfaces due to handling or thermal shock in the brazing operations.

Figure 3.5-1. Electrical Resistivity as a Function of Temperature

3.5.3.2 18-Couple Converter Fabrication

The 18-3 thermopile assembly is under way. The 12 non-instrumented unicouples have been installed. The remaining six are being instrumented with thermocouples in the hot shoes. Three of these are being instrumented per MHW practice, and the other three will have the thermocouples located in the hot shoe adjacent to the P-leg of the unicouple. Air tests will reveal the amount of temperature difference of the two thermocouple locations.

The components for the 18-3 module are accumulated. The module fins have been coated with a stripe at the base to achieve the required heat transfer rate.

3.6 DEVELOPMENT TESTING

3.6.1 SINGLE COUPLE MODULE TESTING

Two SiGe-GaP unicouples utilizing the low temperature 10 at. % SiGe bond interface were placed on single couple air tests. The electrical resistance of the SiGe-GaP material was significantly higher than that experienced with standard SiGe and the voltage was lower. In previous tests, Production Readiness and RCA unicouples were comparable in electrical characteristics.

3.6.2 PRODUCT MODULE TESTING

Module 18-1 reached 3686 hours of testing on January 31, 1981. The module is being operated with constant heat input of 174.5 ± 0.5 watts.

Figures 3.6-1 through 3.6-4 summarize the module performance compared with two previously tested Voyager modules SN-3 and SN-6. Internal resistance and Seebeck coefficient, Figure 3.6-1, continue to increase as predicted by the dopant precipitation theory. The power factor, α^2/R , and the normalized power continue to degrade in the expected manner as shown in Figures 3.6-2 and 3.6-3.

Figure 3.6-1. 18-1 Internal Resistance and Seebeck Coefficient

Figure 3.6-2. Module 18-1 Power Factor

Figure 3.6-3. 18-1 Measured Total Power and Normalized Power

Figure 3.6-4. 18-1 Temperatures

4.0 GENERAL PURPOSE HEAT SOURCE RTG

This portion of the SiGe RTG Program is directed toward the development, qualification and fabrication of RTG's to support the Galileo Orbiter Mission for launch in March 1984 and the International Solar Polar Mission for launch in March 1985.

4.1 PROGRAM MANAGEMENT AND CONTROL

Activities during December and January were concentrated in preparing the CET-1 for the hot vibration test, completing the electric heat source T/V test and fabricating the hardware for the Engineering and Qualification Units, the CET for JPL and the Mass Model.

During the second EHS test, shorting was again encountered. Cleaning and reassembly of the EHS for another T/V test was started. Testing is expected to start in mid-February. Details of the failure are given in Section 4.7 of this report.

The schedule for the GPHS RTG Program is shown in Figure 4.1-1.

4.2 HEAT SOURCE LIAISON AND INTERFACE

GE supported numerous meetings during the last reporting period, the results of which are summarized below:

- Meeting at DOE on December 10: This was a meeting of the aerothermal community. GE presented reentry analyses for the LMRF baseline design and for design modifications to increase impact temperature. DOE's direction was to continue to develop/evaluate design modifications (such as the "2 mil" gap design) and to use pyrolytic graphite inserts and coatings which result in higher impact temperatures.
- Meeting at SRP on December 16: This was the GPHS Status Review Meeting for December.
- Meeting with DOE at GE on January 13: The purpose of this meeting was to finalize the GPHS design. The selected baseline design was the LMRF configuration with a 2 mil gap between GIS and aeroshell. DOE indicated that it was permissible for GE to pursue the feasibility of depositing a thin coating of PG onto the FWPF GIS. PG insert rings were not to be pursued, since they represent a significant change.
- Meeting at MRC on January 20-21: A review of MRC assembly procedures, fixtures, etc., for GPHS assembly and test was held. This represented MRC's first "talk through" for operation of the Assembly and Test Facility (ATF).
- Meeting at MRC on January 22: This was the GPHS Status Review Meeting for January.

Close liaison was maintained with Los Alamos National Laboratory and MRC regarding proposed drawing changes to facilitate manufacture and inspection of the GPHS graphite components. Agreement was reached on all items.

4.2.1 HEAT SOURCE DEVELOPMENT

4.2.1.1 Static Load Test

A static test of the aeroshell/GIS interface was performed to gain better definition of the load-deflection characteristics. The test approximated the actual loading conditions that the GIS and aeroshell will experience. The test set-up is shown in Figure 4.2-1.

The first loading sequence was the load history resulting from thermal expansion. Deflection was measured at four corners of the upper piece of aeroshell. The averaged load deflection curve for these four points is plotted in Figure 4.2-2.

Since the measurement of deflection at low load was very difficult, it was decided to eliminate the 0-20 lb. and 0-40 lb. load deflection tests and perform one 0-100 lb. load sequence. Four repetitions were performed and the average load deflection curve is plotted in Figure 4.2-3. The maximum deflection was 1.29 mils.

Both the first and second load sequences exhibit some hysteresis effects. The first sequence did not return to zero deflection at zero load. The second sequence did. One possible explanation for this is that the structure was not "exercised" prior to the first test sequence. As a result some shifting and seating of the GIS in the aeroshell occurred during the first loading. With this seating and shifting already having occurred, the effect would not be seen in the second test.

Figure 4.2-1. Test Set Up

Figure 4.2-2. Load Deflection Test of GPHS Aeroshell and GIS - Thermal Load Profile

Figure 4.2-3. GPHS GIS-Aeroshell Static Load Test

4.2.1.2 Module Vibration Testing

The dynamic capability of the LMRF heat source configuration with a 2 mil axial gap between GIS and aeroshell was evaluated in a module vibration test. The graphitic module previously tested in the CET-1 test was reassembled using new CBCF sleeves. Testing was performed using the same test fixtures, test orientations and test sequence as previous module vibration tests. The test spectra was updated to be consistent with heat source responses measured during the CET-1 test. The test spectra are shown in Figure 4.2-4 and Table 4.2-1.

The GIS/aeroshell axial gap (both cavities) was established to be 0.002 inch at the start of test. The resulting change in gap as a function of the test sequence is shown below.

<u>Test Condition</u>	<u>Gap</u>	
	<u>Cavity A</u>	<u>Cavity B</u>
Initial Assembly	0.002"	0.002"
After FA Random and Sine Transients	0.0026"	0.0028"
After TA Random and Sine Transients	0.0083"	0.0072"

The data indicates a 5-6 mil increase in the axial gap after completing TA testing. Post test inspection showed ~ 2-3 mil wear on the GIS chamfers which is consistent with the axial gap increase. Inspection of the CBCF sleeves indicated the following:

- No significant weight change
- Essentially no diametral wear (< 0.002")
- A slight reduction in sleeve length (0.010/0.016")
- No evidence of structural damage

In summary, the test was successful and indicated that the 2 mil gap design has adequate dynamic capability.

4.2.2 PG COATING DEVELOPMENT

A meeting was held with Pfizer Co., Minerals, Pigments and Metals Division, to discuss feasibility, anticipated problems and risk associated with depositing a pyrolytic graphite coating onto a FWPF graphite substrate (GIS chamfers). It was concluded that, while there is risk, a coating development effort was justified. GE initiated design drawings for the FWPF test specimens (Figure 4.2-5) to be coated and the parts were fabricated by Los Alamos National Laboratory. Pfizer, under contract to GE, recently completed coating of 6 FWPF ring samples. Coating thicknesses of 5, 10 and 20 mils were achieved. A non-destructive examination of the parts indicates that the coating did exhibit numerous nodules. It is believed that the nodules were caused by either surface contamination/debris or debris in the deposition gas. Pfizer will implement improved cleaning procedures to try to reduce nodule formation. It was apparent that a final machining operation would be required to satisfy "as coated" dimensional requirements.

(a) Lateral Vibration - X Axis

(b) Lateral Vibration - Y Axis

(c) Longitudinal Vibration - Z Axis

Figure 4.2-4. Heat Source Longitudinal and Lateral Vibration Spectra

Table 4.2-1. Peak Transient Accelerations

Frequency	Acceleration G's *					
	X Axis		Y Axis		Z Axis	
	FA	TA	FA	TA	FA	TA
5	1.1	1.6	1.3	2.0	2.3	3.5
6.3	1.3	2.0	1.5	2.3	0.7	1.0
8	1.8	2.7	3.3	5.0	2.0	3.0
10	3.2	4.8	2.7	4.0	1.0	1.5
12.6	2.0	3.0	6.1	9.2	4.3	6.5
16	11.3	17.0	11.5	17.2	7.1	10.6
20	4.2	6.3	17.3	26.0	9.5	14.2
25	8.9	13.3	23.2	34.8	18.3	27.5
32	23.2	34.8	23.2	34.8	23.0	34.5
40	20.7	31.0	22.7	34.0	19.7	29.5
50	13.8	20.7	20.9	31.3	21.0	31.5
64	8.9	13.3	11.7	17.5	12.1	18.1
80	6.2	9.3	8.9	13.0	12.1	18.1

* or as limited by shaker

NOTES:

1. INTERPRETATION OF DRAWING TERMS AND TOLERANCES PER S30009.
2. MARK "GE47A305989PI" PER GE SPEC 118A1526 CL 17.
3. MATERIAL: FWPF-3D GRAPHITE PER GE SPEC NS0060-01-20.

Figure 4.2-5. Process Development Ring

In summary, the preliminary results are encouraging. Thermal cycling tests, metallography, machining studies, etc., are planned for the next reporting period.

4.2.3 HEAT SOURCE ANALYSIS

Analysis of the LMRF baseline design, as well as design modifications to raise impact temperature, continued during this reporting period. The results of the reentry thermal analysis, using the GE reentry model, are shown in Table 4.2-2.

Table 4.2-2. GE Reentry Analysis Summary

Design	Remarks	Temperatures (°C)		
		Operating	Peak	Impact
1) LMRF Baseline	A) W/O Hysteresis	1252	1399	772
2) 0.020 PG Snug	A) 10X W/O Hysteresis	1272	1398	847
	B) 0.22X W/O Hysteresis	1279	1399	861
3) 2 mil Gap	A) No PG Coating	1295	1423	841
	B) 0.020 PG, 0.22X	1299	1409	892

The results are consistent with the BCL analysis for a snug design which features a PG coating on the GIS chamfer. (See GE November Technical Progress Report). Table 4.2-2 also shows the effects of having a 2 mil axial gap between GIS and aeroshell. This results in a $\sim 25^{\circ}$ increase in peak temperature, $\sim 45^{\circ}$ increase in operating temperature and $\sim 70^{\circ}\text{C}$ increase in the impact temperature. The application of an 0.020 inch thick PG coating on the GIS chamfers, coupled with a 2 mil gap, raises the impact temperature an additional 50°C without significantly changing the operating and peak temperatures.

The BCL thermal model was used to perform sensitivity studies regarding hysteresis effects, the PG variation factor (see GE November Technical Progress Report) and coating thickness effects. The results of those studies are shown in Table 4.2-3.

Table 4.2-3. BCL Sensitivity Studies

1) LMRF Baseline Design A) Hysteresis effect:	Impact temperature $\Delta = + 53^{\circ}\text{C}$
2) 0.020 PG Snug Design A) Hysteresis effect: B) Variation between 10X factor to 0.22 factor:	Impact temperature $\Delta = + 11^{\circ}\text{C}$ Impact temperature $\Delta = + 12^{\circ}\text{C}$
3) Two Mil Gap Design A) 0.005" PG coating effect: B) 0.020" PG coating effect: C) Variation between 10X factor and 0.22 factor for 2 mil gap + 0.020 PG:	Impact temperature $\Delta = + 13/+ 28^{\circ}\text{C}$ (10X/0.22X) Impact temperature $\Delta = + 52/+ 58^{\circ}\text{C}$ (10X/0.22X) Impact temperature $\Delta = + 6^{\circ}\text{C}$

The data shows that for the LMRF baseline design the hysteresis effect is significant, but is less significant when a PG coating is employed. It also shows that for an 0.020 inch PG coating the impact temperature variation is 5 to 10^oC, depending on which coating factor is used. The data also indicates that a 5 mil PG coating (coupled with a 2 mil axial GIS/aeroshell gap) does not significantly increase the impact temperature.

The BCL subcontract to GE was terminated December 31, 1980. Many thanks to Gale Whitacre and his BCL staff for their efforts and support.

4.3 JPL LIAISON AND INTERFACE

A meeting was held with JPL personnel to review the GE RTG stress analysis. In addition, a proposed JPL concept for a vibration fixture to test both the ISPM and GLL mounting configuration was discussed. As a result of the discussion a concept evolved which was suitable to both parties. Detailed design work has now started.

Definition of the power interface for the Thermal Model was received from JPL and is being incorporated into the design.

4.4 GENERATOR DESIGN AND ANALYSIS

4.4.1 CONVERTER DESIGN

4.4.1.1 ETG and RTG Definition

Top assembly drawings have been issued for the converter assemblies for the Engineering Unit, Qualification Unit, and Flight Units, as well as for the ETG and RTG Assembly drawings for these units. The Product Specification for the GPHS RTG has been completed and submitted for DOE approval.

4.4.1.2 CET-1

Subassemblies of the CET-1 unit have been refurbished and reassembled in preparation for dynamic testing at elevated temperature. Strain gauges on the heat source supports were replaced by HiTec and the tungsten alignment pin that was broken due to incorrect installation during room temperature dynamic testing was replaced. Rebuilding must await the availability of the EHS which is currently undergoing performance tests. (See Paragraph 4.7.1.)

4.4.1.3 C-Seals

A report was issued (PIR 7141-RTG-6279) summarizing tests performed with a silver-plated Inconel C-seal in an aluminum fixture. The tests concluded that acceptable leakage rates could be maintained through temperature cycling (to 265^oC), and that a coating of Boron Nitride applied to the aluminum sealing surfaces was satisfactory in preventing diffusion bonding between the aluminum and silver surfaces.

Recent hardness testing performed by Selrex on seals silver plated by Pressure Sciences Incorporated have indicated unacceptably high values, exceeding the specification limit of 100 knoop. However, tests performed by GE Space Systems Division on the same specimens indicate acceptable hardness in the range historically expected. The procedure for micro-hardness testing is known to be dependent on operator technique and test equipment.

4.4.1.4 PRD Testing

Parts have been accumulated for a test set-up of the PRD mechanism to confirm the spring forces required. Diaphragm assemblies are not available however. These have been delayed by the need for new tooling.

The GPHS-RTG will utilize the same sized diaphragm as MHW converters, but these will be punctured with a lance having twice the cross-sectional area.

4.4.1.5 RTD Modifications

As a result of changes in the cooling tubes and fins to meet dynamic environment requirements, it was necessary to relocate the RTD's from the cooling fins to the intermediate stiffening ring on the inboard end. To accommodate this change, additional bends were required in the sheath. Although these bends should not affect sensor performance, the vendor has been requested to bend the existing RTD's to the correct configuration before presenting them for acceptance.

4.4.2 WEIGHT STATUS

The current weight status is summarized in Table 4.4-1. No changes have been introduced since the last report.

4.4.3 STRUCTURAL ANALYSIS

4.4.3.1 Low Cycle Fatigue Tests of Welded 2219-T6 Aluminum

The test specimens have been designed and the test procedure has been established for the low cycle fatigue testing of the fin-to-case weld joints. The test specimen will consist of 0.06 inch thick plates joined by an E-beam weld and aged for 100 hours at 500°F prior to test. The test stress levels will be representative of those determined analytically for the RTG shell, including thermal stresses and mechanically induced stresses. The tests will be performed in February.

4.4.3.2 Structural Instrumentation for GPHS-RTG Qualification Unit

A preliminary definition of the structural instrumentation requirements for the qualification RTG has been established. These requirements have been based on the results of analysis and the cold CET-1 dynamic test. The required instrumentation is summarized in Table 4.4-2. Minor modifications may be made based on the results of the Engineering Unit vibration tests.

Table 4.4-1. Weight Summary

	QUANTITY	CURRENT WEIGHT
<u>HOUSING</u>		
Outer Shell	1	12.94
Fins	8	4.32
Emissive Coating	x	.33
Auxiliary Cooling Tube Manifold	1	.57
Nuts	8	.11
<u>CONVERTER</u>		
*T/E Unicouples	576	11.98
*T/E Sealing Screws	576	1.54
*T/E C-Seals	576	0.13
*Rivets and Washers	608	0.59
*T/E Spacers (Al ₂ O ₃)	576	0.64
*Nut Plates	288	0.80
Foil Insulation - T/P	1	12.22
Insulation Support Frame	1	1.65
Power Connector	1	0.35
Gas Management Assembly	1	0.29
Electrical Straps	x	1.08
PRD	1	1.05
C-Seal - Domes	2	0.08
Other Insulation	x	0.20
Pressure Dome	2	1.44
Screws - Pressure Dome	44	0.23
Assembly - RTD	1	1.00
<u>HEAT SOURCE SUPPORT SYSTEM</u>		
<u>Outboard Support Assembly</u>		
Frame	1	0.77
End Cap Insulation Assembly	1	0.67
*Pressure Plate	1	0.68
*Retainer Screw	1	0.006
*Stud Insulator	4	0.27
*Barrier (5137P1)	4	0.01
*Barrier (5136P1)	4	0.004
*Preload Stud	4	0.15
Insulation, Fibrous	AR	0.004
Insulation, M49A1	AR	0.002
*Foil Disk	4	0.004
*Shim	4	0.004
Latch	4	0.20
Stud, Latch	4	0.02
Screw, Latch	8	0.03
*Actual Part Weighed.		

Table 4.4-1. Weight Summary (Cont)

	QUANTITY	CURRENT WEIGHT
<u>HEAT SOURCE SUPPORT SYSTEM (continued)</u>		
<u>Inboard Support Assembly</u>		
Frame	1	1.12
*Pressure Plate	1	0.79
End Cap Insulation Assembly	1	0.67
*Spring Washer	3	1.13
*Collar	1	0.15
*Guide	1	0.37
*Preload Stud	4	0.15
*Pressure Plate	1	0.49
Insulation, Fibrous	AR	0.004
Insulation, M49A1	AR	0.002
*Barrier (5137P1)	4	0.01
*Barrier (5136P1)	4	0.004
*Washer	1	0.02
*Foil Disk	4	0.004
*Washer, Inboard	1	0.03
*Stud Insulator	4	0.27
Latch	4	0.20
Screw, Latch	8	0.03
<u>Midspan Support Assembly</u>		
Cap	4	0.32
"C" Seal	4	0.008
*Pivot	4	0.13
Support	4	0.26
Nut, Lock	4	0.11
Nut, Spring Washer	4	0.24
Spring Washer	12	0.40
*Washer	4	0.08
*Spring	4	0.008
Screw	12	0.03
*Seat	4	0.07
*Insulator	4	0.07
*Can Assembly	4	0.04
Barrier	4	0.004
*Shoe	4	0.004
*Ring	4	0.03
*Locating Pin	4	0.05
Insulation	AR	0.02
*Washer	4	0.04
Washer	12	0.02
Converter		63.76
Midspan Plate	1	0.60
Heat Source	18	57.34
RTG		121.70
*Actual Part Weighed.		

Table 4.4-2. Instrumentation (Preliminary) GPHS RTG Qualification Unit

	<u>Type</u>	<u>Quantity</u>
Internal Strain Gages		
Outboard P/L Studs	HITEC HFN-12-125-SCW	4
Outboard P/L Frame	↓	6
Midspan Pivots		4
External Strain Gages		
Inboard Fin/Rib	TBD	4
External Accelerometers		
Outboard Ring	ENDEVCO 2213 OR EQUIVALENT	6
Midspan Ring	↓	2
Mounting Fixtures		12

NOTE: Simultaneous recording of all of these sensors will not be required. Selection of the sensors to be recorded will be based on the axis of vibration.

4.4.3.3 ISPM RTG Abort Landing

A structural analysis of the capability of the ISPM RTG to withstand landing loads has been completed. The effects of both thermal stresses and mechanically induced stresses have been considered. The active cooling system has been assumed to be operating during landing. The results of the analysis, including a 1.4 factor of safety for manned operations, gave positive margins of safety.

4.4.3.4 Galileo RTG Abort Landing

A structural analysis of the capability of the Galileo RTG to withstand landing loads has been completed. The effects of both thermal stresses and mechanically induces stresses have been included. The active cooling system has been assumed to be operating during landing. The results of the analysis, including a 1.4 factor of safety for manned operations, gave positive margins of safety.

An additional analysis has been completed, based on the assumption that the cooling system will not be operational during landing. For this condition, the midspan ring temperature was assumed to be 570°F. This analysis indicated a potential instability problem for the midspan ring in the region of the mounts. During the structural analysis review of January 27 and 28, (Paragraph 4.4.3.5), this potential problem was discussed with JPL representatives and it was agreed that the JPL mounting fittings could be designed to prevent this potential instability.

4.4.3.5 GPHS-RTG Structural Analysis Review

A meeting was held on January 27 and 28 between representatives of JPL and GE to review in further detail specific structural analysis areas covered during the GPHS-RTG Final Design Review. The areas discussed included methods of treating combined mechanical and thermal stresses, math modeling, creep analysis, Heat Source Support preload, detailed stress analysis, and margins of safety. A package of selected analyses and a matrix of the minimum margins of safety were provided to JPL.

4.4.4 EMISSIVE COATING DEVELOPMENT - PD224

4.4.4.1 Weight Loss

Weight loss measurements continued to January 29th when the furnace was shut down due to a leak in the external water cooling tubing. Testing will be resumed after repairs are made.

The test specimens are three PD224 coated 4-inch aluminum samples. The test was conducted at 536°F (280°C) and a pressure of 10^{-8} torr. Figure 4.4-1 shows the measured percentage weight loss out to 2900 hours. The dashed lines are least squares curve fits to the data up to 970 hours. Weight losses beyond 1000 hours are falling below these projected curves. After 40,000 hours, the projected loss is 3 to 3.5 %.

4.4.4.2 Emissivity

Testing is continuing to determine the emissivity of the PD224 coating as a function of time. The test is being conducted at 500°F (260°C) and 10^{-7} torr. The specimen geometry and test set-up are as described in the January 1980 GE Technical Progress Report.

Figure 4.4-2 shows the emissivity ratio for 3944 hours which will be accumulated by the end of January. The ratio in the emissivity at time, t , divided by the emissivity at $t = 0$. There is no evidence of a downward trend.

4.5 GPHS ETG AND RTG SYSTEM TESTING AND FUELING

The ETG test plan, NS 0080-07-10 was issued.

Early in December GE personnel visited Mound for continuing test planning discussions. Preliminary Mound RTG assembly and system testing flow diagrams were reviewed and comments discussed.

Figure 4.4-1. PD224 Coating Weight Loss - 4-Inch Samples

A series of meetings between GE and Mound personnel were held in January. These meetings were in support of equipment design and planning for Mound's Assembly and Test Facility (ATF). The major topics discussed at these meetings were:

- RTG mounting and support in the ATF
- Heat source installation methods and required tooling
- Review of RTG fueling/assembly and system test flow and planning
- Heat source preloading (axial and midspan)
- Heat source cold stacking parameters
- General problems and concerns expressed by Mound
- Review of detail RTG design features relative to Mound's operations
- GE review of Mound's fixture concepts

On January 20 and 21, 1981, Mound presented its first ATF "talk through" in which Mound reviewed the ATF, its capabilities and MRCs proposed operation of it. The presentation was made to GE, DOE, and FI. The technical exchange was most beneficial. GE noted that Mound's thermal vacuum fixture design may interfere with visual access during assembly operations.

The engineering unit processing and system test procedure, SI 249700, has been initiated. Requirements are being developed.

4.6 MODULE TESTING

This is covered in Section 3.0 of this report.

4.7 GROUND SUPPORT EQUIPMENT

4.7.1 ELECTRIC HEAT SOURCE

During December 1980 a second attempt was made to complete a performance test of the EHS. During heat-up, with the surface temperature at 650°C, the resistance between the heater element and the grounded outer shell dropped from the megohm range to less than 1000 ohms. The test was terminated before arcing could occur and no damage was incurred. Disassembly showed that alumina insulators on the power leads had developed a very thin but conductive coating and that some polyester lacing ties that were inadvertently left in place were the likely source of organic contaminants. The EHS was disassembled and all parts thoroughly cleaned before being reassembled. The performance test was then completed without incident. Maximum power of 4500 watts was maintained for 48 hours, during which time the surface temperature reached a maximum of 1028°C.

4.7.2 MASS MODEL

The mass model has been fabricated and is being assembled. Mass properties will be measured at the Mound Facility and adjustments made to bring the model within drawing requirements.

4.7.3 THERMAL MODEL

Design of the thermal model is in progress. A drawing and specification for the heater elements has been prepared in order to initiate procurement, since the heater element has the longest lead time. JPL has approved the use of Grade V1 mica as an insulator in the heater element.

4.8 MANUFACTURING

The following was accomplished during the reporting period:

- Teardown was completed and refurbishment started on CET electric heat source. This is the second refurbishment of this heat source.
- The CET Engineering and Qualification Converter outer shells were returned to the vendor for rework to incorporate drawing changes.
- Drawings were received and requests for vendor quotations issued for the ETG shipping containers.

- Drawings were received and fabrication initiated for ETG/RTG lifting slings.
- Material was ordered and manufacturing planning prepared for mass models.
- The assembly fixture required to mount cooling fins to Engineering Converter Outer Shell was received.
- Fabrication of cooling fins for the Engineering Converter outer shell was started.
- Fabrication of the Mass Model was begun.
- Fabrication of the cooling fins for the Engineering Unit was completed.
- Fabrication of the manifold and end fittings required to complete the cooling fin assembly for Engineering Unit was started.
- Fabrication and procurement of the assembly and handling fixtures required for the cooling fin assembly for Engineering Unit was initiated.
- Material ordering for the CET-JPL Unit was completed.
- Reassembly of Electric Heat Source for CET unit was continued.
- Manufacturing planning was issued and material ordered for fabrication of shorting modules.
- Refurbished components for the CET Unit (which included new high temperature strain gages) were received and inspected.

4.9 QUALITY ENGINEERING AND CONTROL

The second test of the Electric Heat Source (EHS) was aborted before test completion. There were indications of decrease in electrical resistance. The unit was disassembled and re-inspected. It was discovered that lacing cord was used to tie down the instrumentation leads and postulated that out-gassing from the cord contributed to failure.

The parts are being cleaned and the EHS will be rebuilt again.

The Converter Shell for the Qualification Unit was returned from Speedring. The welds at the fins were radiographed, found to be unsatisfactory and were machined out. New welds were made. These were radiographed and the shell was returned to Speedring for further machining.

Material Review Board. The Material Review Board activity is summarized in Table 4.9-1.

4.10 RELIABILITY ASSESSMENT

FMECA analysis is being updated.

4.11 SAFETY

GPHS Trajectory Study. At the GPHS-RTG final design review held in October 1980, results of a six degree of freedom (6 DOE) study were presented for the orbital decay reentry of the present GPHS design (LMRF). This study was conducted to determine the detailed aerodynamic

Table 4.9-1. Nonconformance Reports

48742	GPHS RTG	Pin, locating	Nicks, burrs, dimensional discrepancy	Accept for CET use
48760	GPHS RTG	Outer shell	Radius dimension out of tolerance	Accept, not critical dimension
48766	GPHS RTG	OFHC Copper	Out of spec	Return to vendor
48796	GPHS RTG	FW S1 Parts	Scrap accumulation	Scrap - Engineering and QC Investigating
48800	GPHS RTG	Upper Shell	Dimensional discrepancy	Return to vendor for re-work
48840	GPHS RTG	T/C Assembly	Inspection point missed	Inspect and accept continued assembly
48864	GPHS RTG	Connector	Dimensional Discrepancy	Accept, does not affect sealing capability
48868	GPHS RTG	EHS Assembly	Damaged parts-chipped area on heating element	Replace damaged parts Chipped area will not affect function

motion of the GPHS and whether the module would settle into a preferred attitude. The results indicated:

- The motion does not damp to a trim attitude
- The bevelled configuration does not settle to oscillate about a side-on attitude
- Maximum inertial loads observed are about 21% of the allowable when failure of the impact shell cap is considered due to rotational motion of the module
- The bevels are expected to insure separation of the modules

As an indication of the credibility and accuracy of the computations (finite difference solutions of the differential equations of motion along and around three axes), the orthogonality of the motion vectors were checked as a function of time into the trajectory (or computation time). For those cases with relatively large initial spin rates around two or more axes, the orthogonality was found to degrade significantly toward the latter part of the trajectory. However, the maximum spin rates resulting from the aerodynamic response of the module were found to occur just prior to or during the time at which the orthogonality began to degrade. The results were thus considered to be reasonably accurate.

During the current reporting period, the study was extended to include the superorbital or near escape velocity type of reentries at minimum path angles. Because of the longer duration trajectories involved, there was concern that the orthogonality of those calculations might degrade significantly before the maximum motional rates were attained which would make the results questionable.

Computations were made using the most recent aerodynamic data obtained from tests conducted at the NASA Ames 50-inch hypersonic wind tunnels (B&C). These were performed by use of the Livermore LSODE integrator code to determine if the orthogonality could be maintained within acceptable limits, but the results were negative.

The conclusions were reached that the orthogonality would have to be constrained to unity by another computational technique. The Gram-Schmidt orthogonalization procedure in algorithm form was used, and the results indicated that the orthogonality was in fact maintained. Use of this procedure effectively restarts the trajectory calculations after each realignment of the orthogonality based on its degradation over the previous computation interval. Since this may cause some small instantaneous change in the trajectory characteristics with an implied corresponding change in initial conditions, the resulting trajectory is calculated correctly but for some initial conditions neighboring the original conditions. The magnitude of this deviation in effective initial conditions is not deemed to be significant nor is the effect on the resulting trajectory.

Several computer runs were made to determine the trajectories and associated GPHS motions for a prompt reentry and for the first pass of a skip reentry using the Gram-Schmidt technique. Various initial spin rates for the GPHS module were determined on the basis of the spacecraft rotational motion required to cause release of the heat source from the converter due to inertial forces as was done for the orbital decay analysis. For these runs, the GPHS was found to tumble rapidly with a maximum resultant of around 25,000 degrees/seconds about the module axes. Also discovered was that the GPHS module can maintain a net upward lift and sidewise force such that the module can deviate from the original trajectory plane by several hundred miles.

4.12 FIELD AND LAUNCH SUPPORT

No effort planned or undertaken during this report period.