Cassini RTG Program CDRL Transmittal

TO: U.S. Department of Energy Lawrence Livermore Nat'l Lab 7000 East Ave., Bldg. 311 L-293 Attention: Ken Quitoriano	Cassini RTG Program Contract No: DE-AC03-91SF18852	In Reply Refer to: **CON #1607** Date: **24 June 1996**
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INTRODUCTION

The technical progress achieved during the period 29 April through 26 May 1996 on Contract DE-AC03-91SF18852 Radioisotope Thermoelectric Generators and Ancillary Activities is described herein.

This report is organized by program task structure.

- 1.X Spacecraft Integration and Liaison
- 2.X Engineering Support
- 3.X Safety
- 4.X Qualified Unicouple Production
- 5.X ETG Fabrication, Assembly, and Test
- 6.X Ground Support Equipment (GSE)
- 7.X RTG Shipping and Launch Support
- 8.X Designs, Reviews, and Mission Applications
- 9.X Project Management, Quality Assurance, Reliability, Contract Changes, CAGO Acquisition (Operating Funds), and CAGO Maintenance and Repair
- H.X CAGO Acquisition (Capital Funds)

Note: Task H.X scope is included in SOW ¶ Task 9.5.
Task H. was created to manage CAGO acquired with capital equipment funding.

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Monthly Technical Report
Progress by Major Task

TASK 1 SPACECRAFT INTEGRATION AND LIAISON

JPL elected not to relocate the magnetometers closer to the generator for F-2 magnetics testing at Mound. JPL did agree to specification revisions dealing with instrumentation accuracy, sequencing of the magnetics test in relation to the other acceptance tests, and which magnetometers will be used for determining compliance with acceptance limits. Subsequent to these agreements, the magnetics test was satisfactorily performed at Mound.

TASK 2 ENGINEERING SUPPORT

Specifications/Drawings

Several ECNs for the ETG/RTG and in support of RTG system testing were prepared and processed through CCB approval. The gas management hose could not be removed from the F-2 gas management valve assembly in preparation for magnetic testing. An evaluation of the hose to fitting saver joint has been initiated.

RTG Fuel Form, Fueling, and Test Support/Liaison

The additional information requested from Oak Ridge National Laboratory concerning the widening of the clad vent set (CVS) vent notches was received and evaluated. As a result, the CVS hardware in question has been found satisfactory and released for flight use.

Work continued, as necessary, on the evaluation and disposition of fuel processing related nonconformances.

During this reporting period LMMS continued to provide support for test operations at Mound. Changes to the test operation manuals for magnetics testing and mass measurement were reviewed and approved. Consultation and direct assistance was provided to Mound in resolving the cause of problems with the vacuum control system for the IAAC and in defining proposed modifications. LMMS also assisted Mound in preparing documentation for the F-5 Buy-Off Review which was held on 30 April 1996.

TASK 3 SAFETY ANALYSIS TASK

The safety analysis task is comprised of four major activities: 1) Launch Accident Analysis; 2) Reentry Analysis; 3) Consequence and Risk Analysis and 4) the Safety Test Program. An overview of the significant issues related to this task for this period, followed by details in each of the four major activities, is provided in the following subsections.

A listing of the INSRP meetings held this year through May 1996 is provided in Table 3-1.

Table 3-1. Safety Analysis Task – Completed INSRP Reviews

Date	*Review*
17-19 January 1996	INSRP Review of LASEP-T and Out-of-Orbit Preliminary Analysis Results
13-14 February 1996	RESP Review of VVEJGA and Out-of-Orbit Preliminary Reentry Analysis Results
7-8 May 1996	INSRP Review of the Sandia National Laboratory Liquid Propellant FIREBALL Model

Draft Final Safety Analysis (DFSAR) Report

A review copy of the DFSAR, Volume I (Reference Design Document) was submitted to DOE-HQ during this reporting period. Effort continued on preparation of DFSAR Volume II (Accident Model Document) and Volume III (Nuclear Risk Analysis Document) to be provided for DOE review and approval in June.

Launch Accident Analysis

Additional hydrocode data regarding SRMU propellant fragments impacting aeroshells was received from Orbital Sciences Corporation (OSC). Relatively large distortions were noted for small propellant fragments impacting modules. Work is continuing on integrating the SRMU propellant fallback environment into the LASEP-T source term results.

A meeting was held at Sandia National Laboratories (SNL) to discuss the Full Stack Intact Impact (FSII) accident scenario. INSRP members were briefed on the analyses that have been performed to-date, as well as those that are planned to complete the preliminary evaluation of this scenario. A detailed approach to be used for the nominal source term analysis has been finalized.

A second meeting was also held at SNL to review Sandia's FIREBALL model, developed for Lockheed Martin in support of the Launch Accident Analysis activity. The model review went well and INSRP was impressed with the modeling effort put forth by the Sandia analysis team. The Sandia FIREBALL model will be used to assist in the consequence assessment for the FSAR. The Draft FSAR will show results based on the Lockheed Martin interim FIREBALL model.

Planning has been initiated regarding the comparative studies to be performed between the Lockheed Martin FIREBALL model and the SNL FIREBALL model. The types of data, format of the data, and the method to interpret the results are outlined in the plan. Additionally, comparison of consequences along with source terms and particle size distributions will be evaluated as part of this study.

Reentry Analysis

Aeroshell Response: CFD

Intermediate Trajectory: Thermostructural failure criteria have been used to define a trajectory between the shallow (g = -7°) and steep (g = -90°) extremes. A flight-path angle of -20° was selected and three-degree trajectory analyses were performed. The resulting trajectory is shown in Figure 3-1.

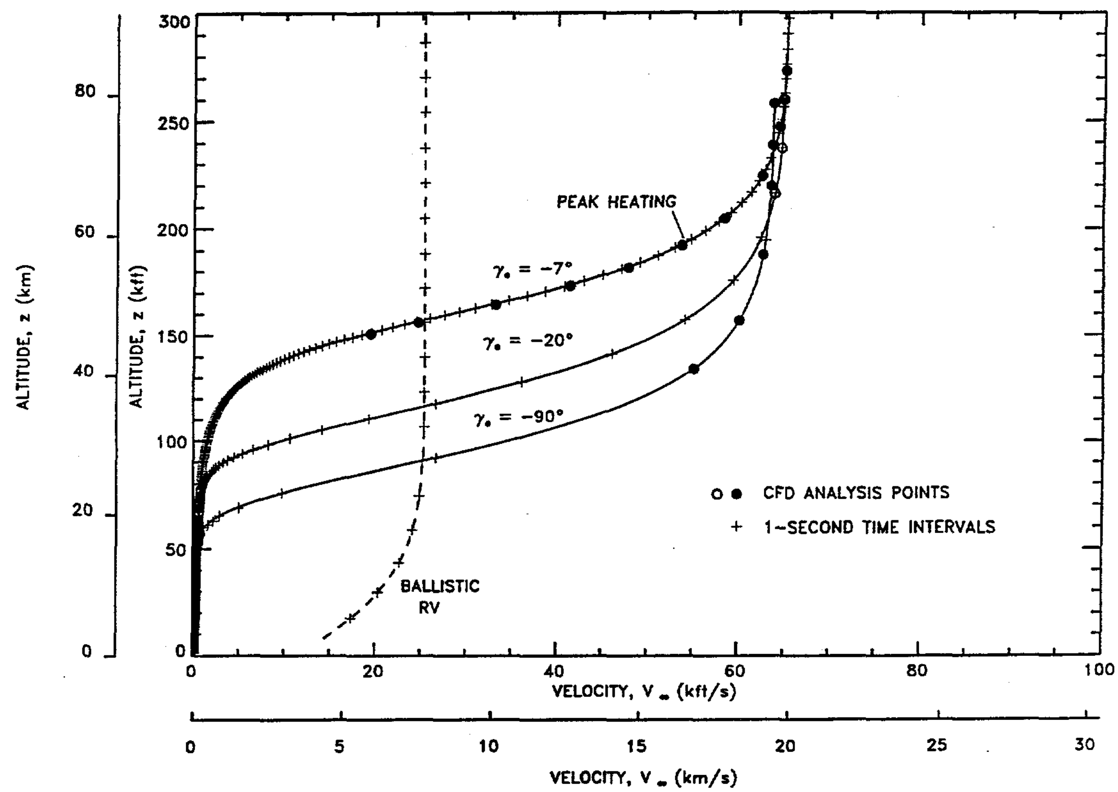

Figure 3-1. Comparison of Freestream Velocity

Preliminary SINRAP in-depth, transient-heating analyses were performed using approximate heating relations. The results of these SINRAP calculations were used to select trajectory points for detailed CFD computations and also to provide surface temperature estimates (three front and side-wall temperatures at each trajectory point). The first three selected trajectory points are shown in Figure 3-1 and the corresponding freestream conditions listed in Table 3-2. The chosen front-face temperatures at each trajectory point are shown as a function of time in Figure 3-2. The values for the front and side-wall temperatures are listed in Table 3-2.

Table 3-2. Intermediate Trajectory Cases

Trajectory point	Time (sec)	Velocity (kft/sec)	Altitude (kft)	T_{front} (°R)	T_{side} (°R)
1	1.0	65.010	259.257	4760	2660
				5060	3160
				5360	3660
2	2.0	64.740	237.710	5460	3260
				6060	3760
				6460	4260
3	3.0	64.054	216.454	6260	3860
				6660	4460
				7060	5060

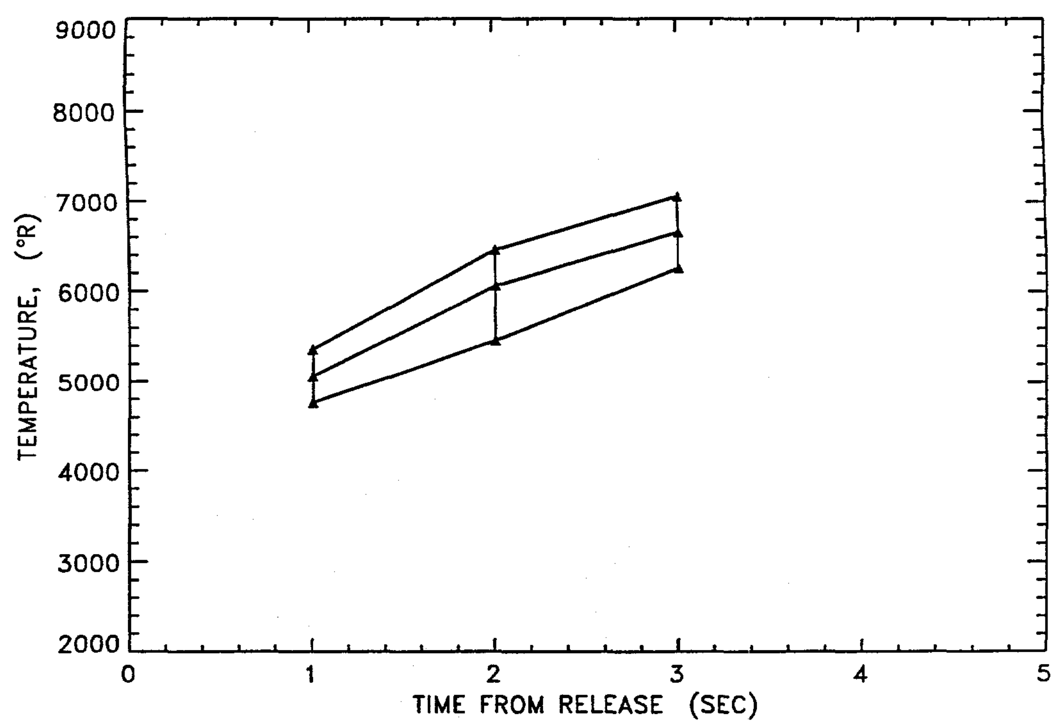

Figure 3-2. Computational Matrix Intermediate Trajectory

RACER (flowfield) and LORAN-C (radiation) were globally iterated at each trajectory point and wall temperature condition. All nine cases have been converged and tables of computed surface-energy balance terms are now available for SINRAP. Figure 3-3 shows the surface temperature distribution (a boundary condition for RACER) corresponding to the highest wall temperature case at the 1.0, 2.0, and 3.0 sec. trajectory points. Figures 3-4 through 3-8 show the RACER / LORAN-C computed surface distributions for these three cases. The surface pressure, Figure 3-4, is the aero-loading used by ABAQUS for thermostructural analyses. The front-face pressure reaches 0.5 atm at 216 kft. The pressure distribution is consistent with previous steep and shallow solutions. The gas-conduction plus species-diffusion component of surface heating is shown in Figure 3-5. At 216 kft, the combined effects of a higher wall temperature and ablation rate cause a decrease in this component of the surface-energy balance. The radiation component of the wall heat flux is shown in Figure 3-6. Radiation is increasing with a decrease in altitude and, by 216 kft, it exceeds the gas-conduction plus diffusion component. The total heat flux, Figure 3-7, is increasing for the early portion of the $\gamma = -20°$ trajectory and is approaching 2000 BTU/ ft^2sec at 216 kft. at the stagnation point. The total heating peaks in the vicinity of the rounded shoulder, are consistent with previous GPHS results. The ablation rate, shown in Figure 3-8, is increasing dramatically with a decrease in altitude (and increase in wall temperature). However, at 3.0 sec., the magnitude of the mass-flux is still small (0.05 lb_m/ft^2sec at the stagnation point to 0.098 lb_m/ft^2sec near the corner).

Reports/Meetings: Presentations are being prepared for the 6 June 1996 INSRP/RESP meeting. The final steep trajectory results and status on the intermediate trajectory will be discussed. In addition, a presentation and detailed report on the formulation of the surface-energy balance has been prepared.

A paper entitled "A New Technique for the Computation of Severe Reentry Environments," has been approved for presentation at the 31st AIAA Thermophysics Conference to be held 17-19 June 1996. This paper describes RACER and LORAN-C and their application to the reentry of the GPHS aeroshell.

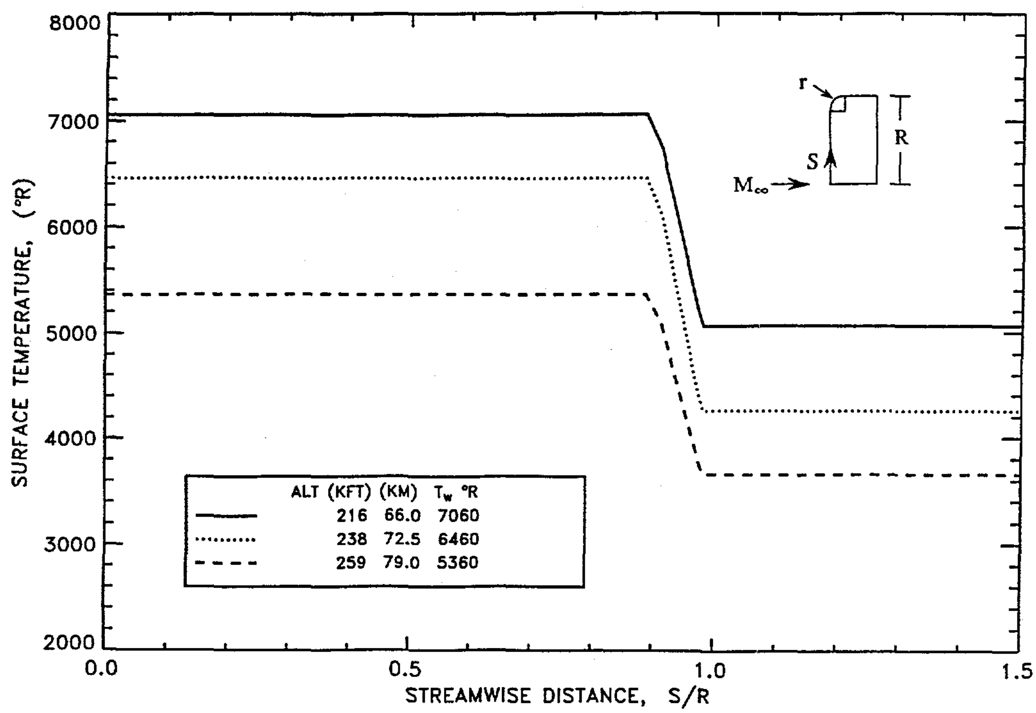

Figure 3-3. Specified (from SINRAP) Surface Temperature Distributions (High T_w) for the Intermediate Trajectory.

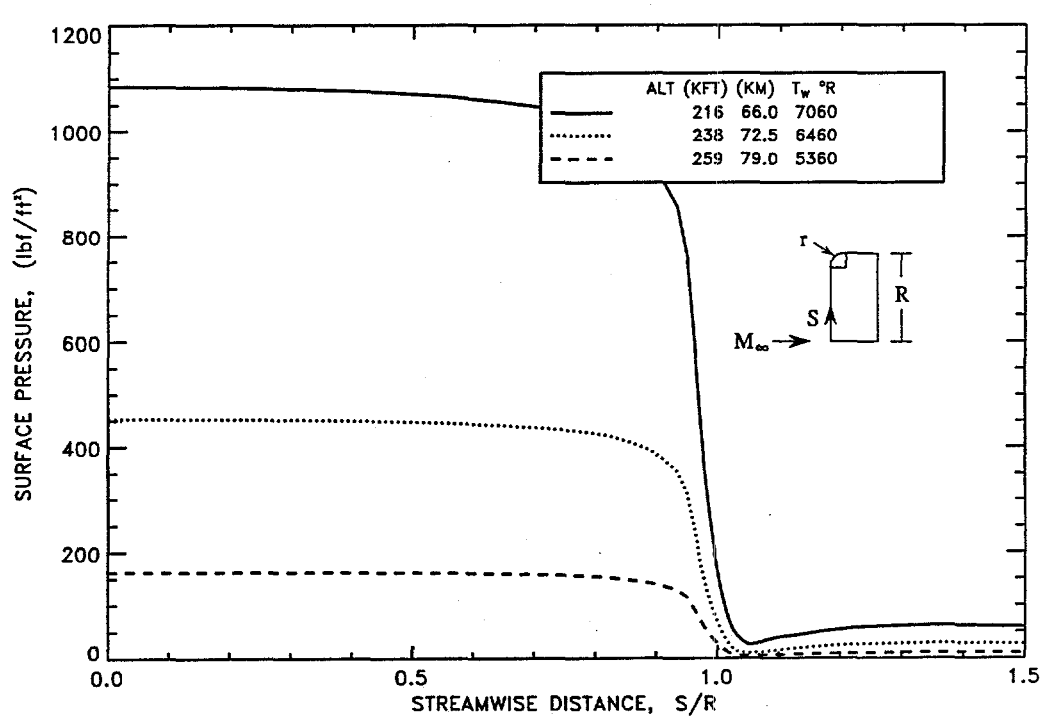

Figure 3-4. Effect of Altitude and T_w on Surface Pressure

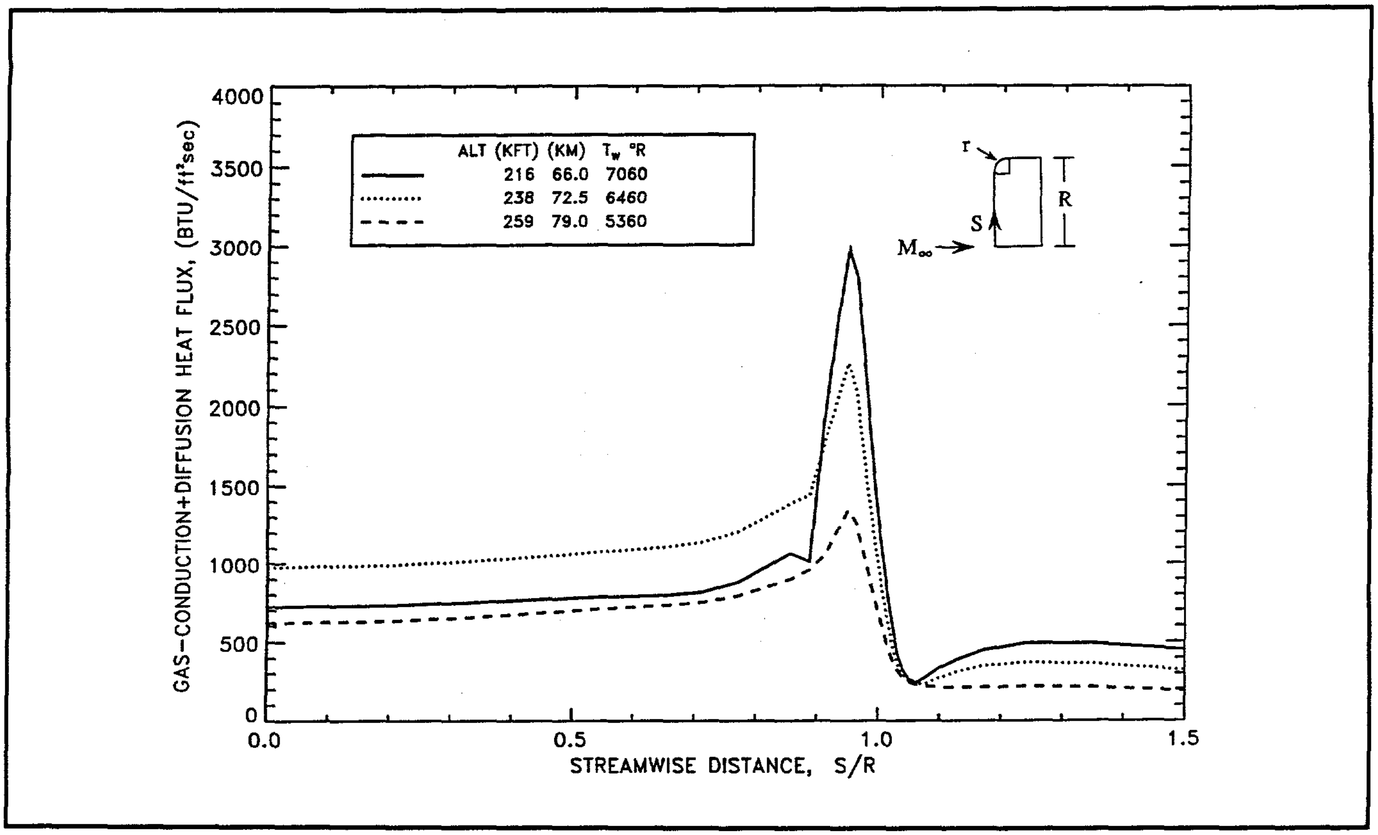

Figure 3-5. Effect of Altitude and T_w on Gas-Conduction+ Diffusion Heating

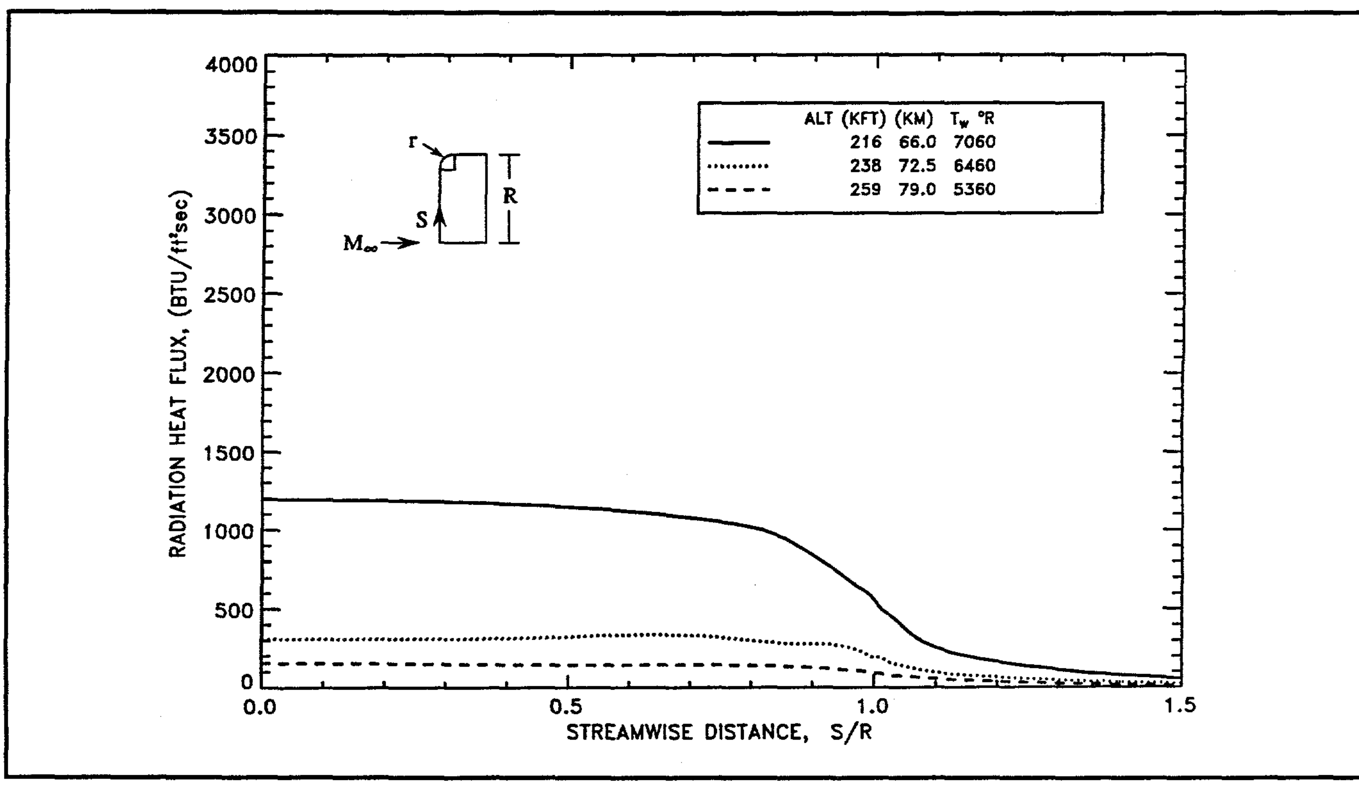

Figure 3-6. Effect of Altitude and T_w on Radiation Heating

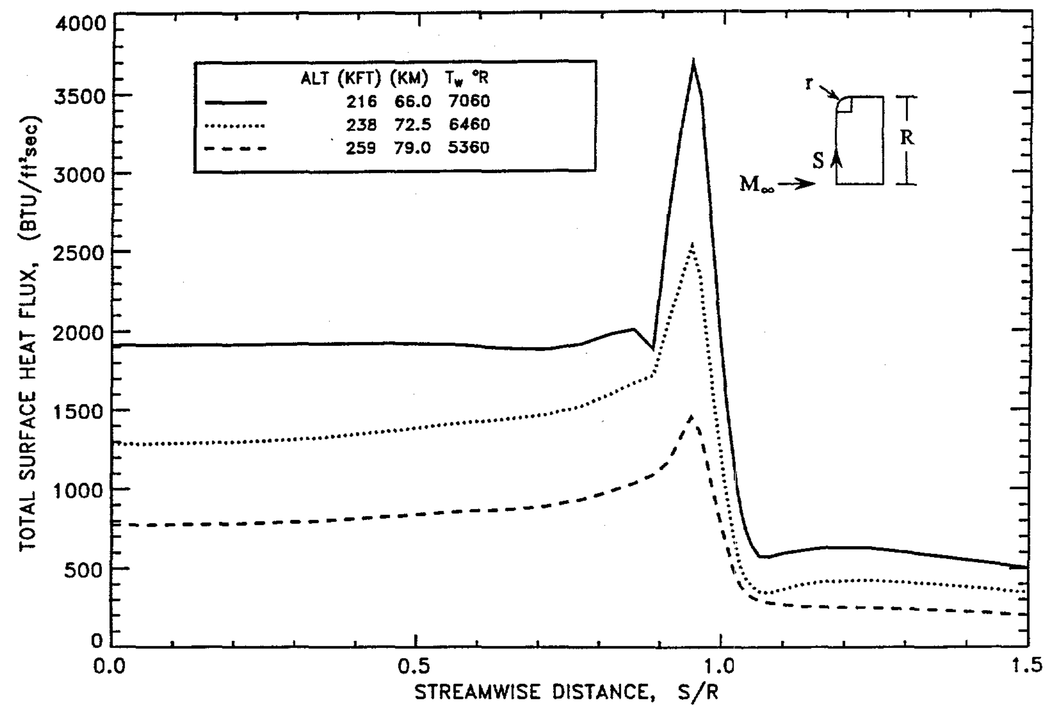

Figure 3-7. Effect of Altitude and T_w on Total Surface Heat Flux

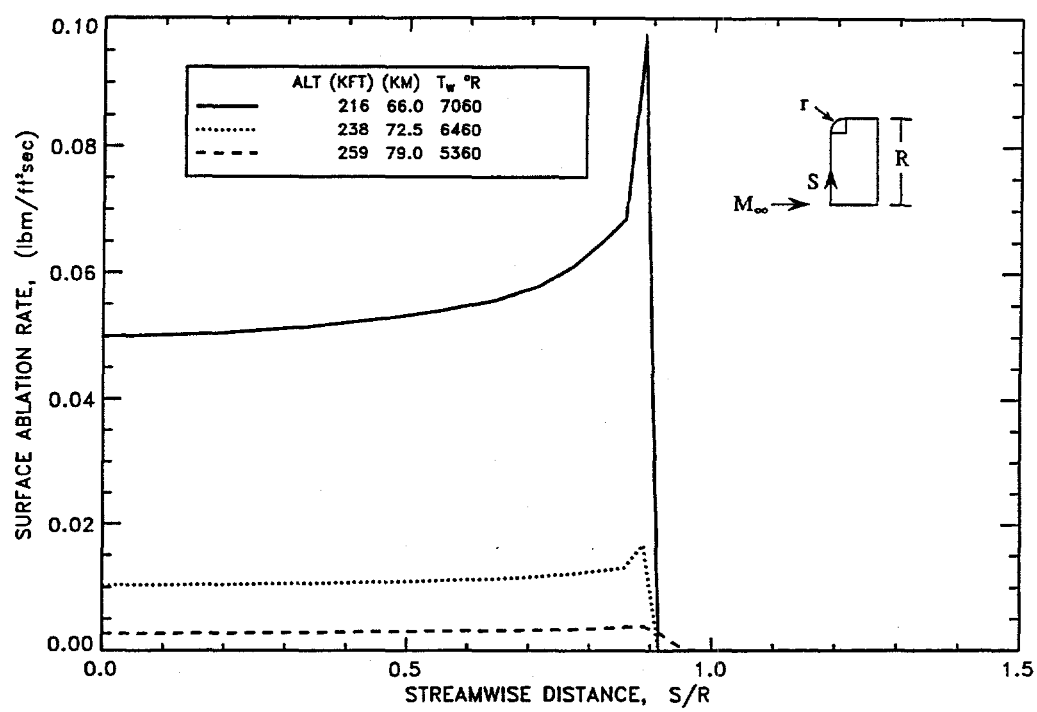

Figure 3-8. Effect of Altitude and T_w on Surface Ablation Rate

Aeroshell Response

Aeroshell Analysis: The structural analysis of the aeroshell for the steep case, based on thermal analysis results up to and including 2.0 seconds, predicted aeroshell failure at 1.9 seconds. The steep results will be used as release conditions for starting the GIS analysis.

For the intermediate entry angle of 20°, SINRAP runs were made, without CFD input, for the face-on stable and random tumbling orientations. Surface temperatures from these runs formed the basis for selecting imposed CFD temperatures for the first three trajectory points. The first three points with imposed side wall temperature are as follows:

				Imposed Surface Temperatures	
Trajectory Point No.	Time (Sec)	Altitude (Ft)	Velocity (Ft/Sec)	Front (°F)	Side (°F)
1	1.0	259257	65010	4300 4600 4900	2200 2700 3200
2	2.0	237710	64740	5000 5600 6000	2800 3300 3800
3.	3.0	216454	64054	5800 6200 6600	3400 4000 4600

GIS Analysis: The plan for the GIS analysis presented in last month's report is being implemented. Modification of the off-line radiation and convection codes has been completed. For the steep case, a GIS analysis has begun based on a release time of 2.0 seconds from the aeroshell. This analysis employs REKAP (without CFD) with convection and radiation input from the previously mentioned codes. Once this run is verified, a similar run will be made based on a release time of 1.9 seconds. Temperatures from this run will be used to select imposed surface temperatures for the first three CFD trajectory points. The comparison between recession results for 2.0 and 1.9 seconds will also provide preliminary uncertainty effects due to time of GIS release.

SINRAP Documentation: PIRs describing SINRAP Rev. C, Verification of SINRAP, and the CONVERT and CORRECT programs were written and are scheduled for release next month.

Aeroshell Response: Structural Analysis

Documentation of the thermostructural analysis of the steep (90°) trajectory was completed, reviewed, and issued. Analysis for the intermediate trajectory will be initiated when the combined CFD/SINRAP analysis results become available

Consequence and Risk Analysis

Consequence analysis was completed for three launch accident cases with source term and weather variability sampled by Latin Hypercube Sampling (LHS). The three accident cases analyzed were: 0.1 on-pad explosion; 1.1 - total boost vehicle destruct, and 1.3 - total boost vehicle destruct with SRMU aft segment impact. These cases are expected to be the dominant contributors to launch accident risk. A total of 900 consequence calculations were performed for each accident case, from three (3) source term clusters and ten (10) weather day clusters. Complementary cumulative distribution functions were developed for 50-year exposure with and without de minimis, set at 1 mrem/yr. Comparison of LHS CCDF curves with those from a scaling model developed to screen accident cases for subsequent consequence determination showed acceptable agreement for 50-year collective dose and health effects. This indicates that the scaling model provides an acceptable approximation of collective dose and health effects for those launch accident cases not analyzed by LHS methods.

The analysis approach for ground impact of GPHS modules has been defined. Trajectory analysis along the nominal flight path suggests that for out-of-orbit accident scenarios, modules could disperse along a footprint nearly 500 km in length and 25 km wide. Since this footprint size is on the order of the global receptor grid (typically 1100 km X 640 km), ground impacts can be considered uncorrelated (i.e., the probability of any one module striking a surface capable of producing a release is independent of the probability of any other module similarly hitting the same surface type).

A modified version of the site specific SATRAP code has been completed to provide local transport information for worldwide impacts. Consequence calculations have been performed for the following out-of-orbit reentry cases using LHS sampling methods: 3.1 - CSDS, Sub-orbital Reentry, 5.2 - Nominal Orbital Reentry, and 5.3 Off-nominal, Elliptical Decayed Reentry. A total of 300 simulations have been performed for each case utilizing probabilities of impacting a given receptor cell, based on orbit inclination, from separate Monte Carlo anonymous impact simulations. (Source terms were generated from a Monte Carlo simulation of surface impacts utilizing sub-models from the LASEP-T code.) LHS sampling was performed for population density class, wind stability, and source term release to produce CCDF curves for each case. Evaluation of analysis results are in progress.

TASK 4 QUALIFIED UNICOUPLE FABRICATION

The remaining efforts in Task 4 are associated with testing of 18 couple modules. Test temperatures and life test hours are shown in Table 4-1.

Table 4-1. Test Temperatures and Life Test Hours

Module	Unicouple Source	Test Temperature Hot Shoe	Status as of 26 May 1996
18-10	Early Qualification Lot	1135°C	10,400 hours Performance Normal Test Terminated October 1994
18-11	Full Qualification Lot	1135°C	19,655 Hours Performance Normal
18-12	Early Flight Production Lot	1035°C	15,473 Hours Performance Normal

18 Couple Module Testing

Two modules remain on life test. Testing of module 18-10 was terminated at the end of October 1994 after 10,400 hours.

Module 18-11 (1135°C)

On 26 May 1996, the module reached 19,655 hours at the accelerated hot shoe temperature of 1135°C. Measured performance during this period continues to fall within the data base established by MHW and GPHS 18 couple modules.

The thermoelectric performance evaluation primarily studies the trends of the internal resistance and power factor. Figures 4-1 and 4-2 show these trends in comparison to module 18-8, the last module built during the GPHS program. Agreement is excellent and provides a high degree of confidence that the GPHS unicouple manufacturing processes have been successfully replicated. Table 4-2 summarizes the initial and 19,607 hour performance data.

The isolation resistance trend between the thermoelectric circuit and the foil is shown in Figure 4-3 with modules from the MHW and GPHS programs. The isolation resistance plateaued at about 1000 ohms between 6,000 and 7,000 hours. It then started a slow decrease and is presently at 449 ohms. A similar plateau and gradual decline were observed in MHW module SN-1. At the accelerated temperature of 1135°C the same amount of sublimation occurs in about 1,650 hours of testing as would occur in a 16-year Cassini mission.

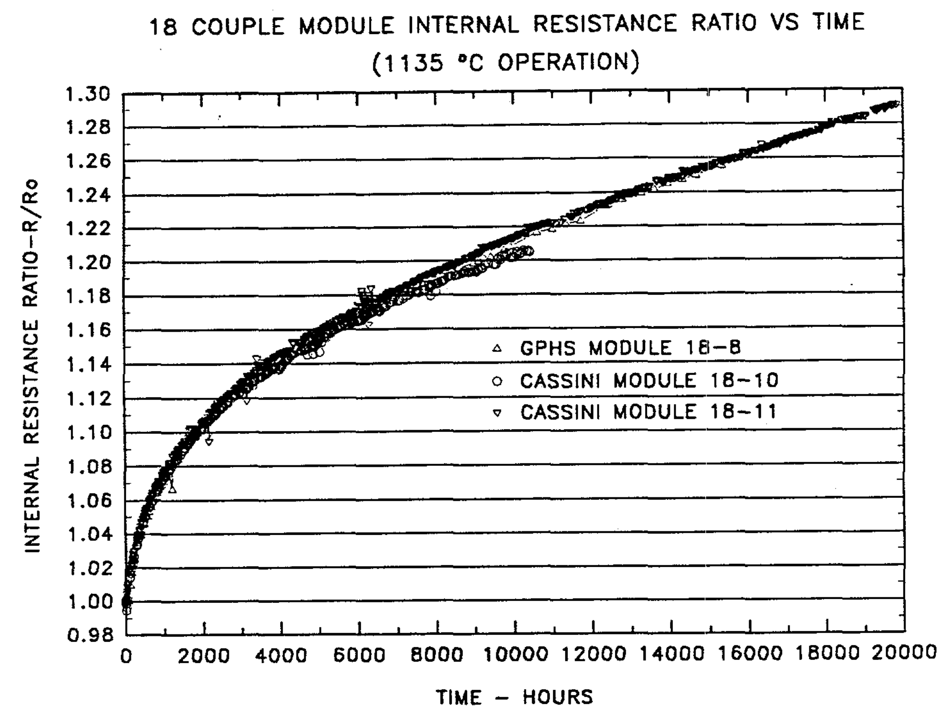

Figure 4-1. Internal Resistance Ratio Versus Time (Modules 18-10, 18-11, GPHS Module 18-8) – 1135°C Operation

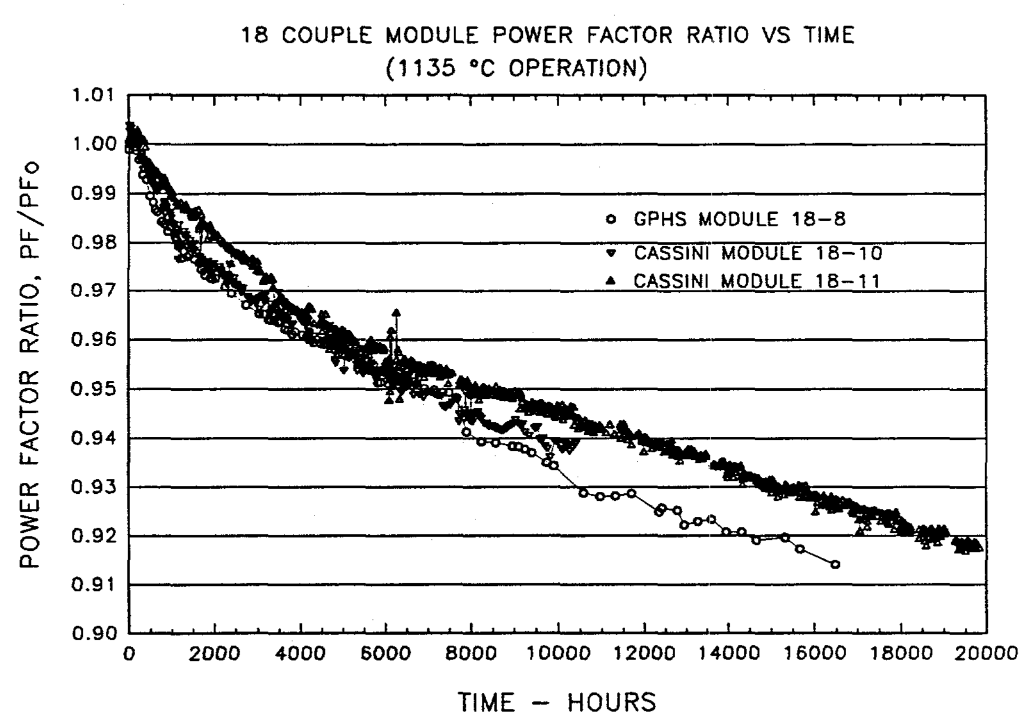

Figure 4-2. Power Factor Ratio Versus Time (Modules 18-10, 18-11, GPHS Module 18-8) – 1135°C Operation

Table 4-2. Comparison of Initial and 19,607 Hour Performance of Module 18-11 at 1135°C

	Initial 2/2/94	t = 52 hours V_L = 3.5V 2/4/94	t = 19,607 hours 5/24/96
Heat Input, Watts	190	192.9	192.7
Hot Shoe, °C Average	1137.8	1137.5	1105.9
Hot Shoe Range °C	5.4	5.2	9.4
Cold Strap, °C Average (8 T/Cs)	311.9	314.3	306
Cold Strap Range (8T/Cs)	2.6	2.5	2.0
Cold Strap Average (12 T/Cs)	306.5	308.9	301
Cold Strap Range (12 T/Cs)	20.1	20.3	18.3
Load Voltage, Volts	3.895	3.499	3.507
Link Voltage, Volts	0.108	0.121	0.096
Current, Amps	2.842	3.174	2.746
Open Circuit Voltage, Volts	7.140	7.160	7.514
Normalized Open Circuits (8T/Cs)	6.319	6.359	6.876
Normalized Open Circuits (12 T/Cs)	6.276	6.316	6.836
Average Couple Seebeck Coefficient (12)	498×10^{-6}	501×10^{-6}	542.2×10^{-6}
Internal Resistance, Ohms	1.104	1.115	1.424
Internal Resistance Per Couple (Avg.)	0.0613	0.0620	0.0791
Power Measured, Watts (Load + Link)	11.375	11.492	9.9
Power Normalized, Watts (8 T/Cs)	8.909	9.065	8.29
Power Normalized, Watts (12 T/Cs)	8.789	8.942	8.18
Power Factor	40.452×10^{-5}	40.557×10^{-5}	37.16×10^{-5}
Isolation			
Circuit to Foil, Volts	-1.68	-1.36	-1.70
Circuit to Foil, Ohms	6.29K	5.95K	0.45K

Consequently, approximately 12 times as much sublimation has occurred during the test duration of module 18-11 as will occur during the Cassini mission. The module performance, therefore, confirms the adequacy of the silicon nitride coating on the qualification unicouples.

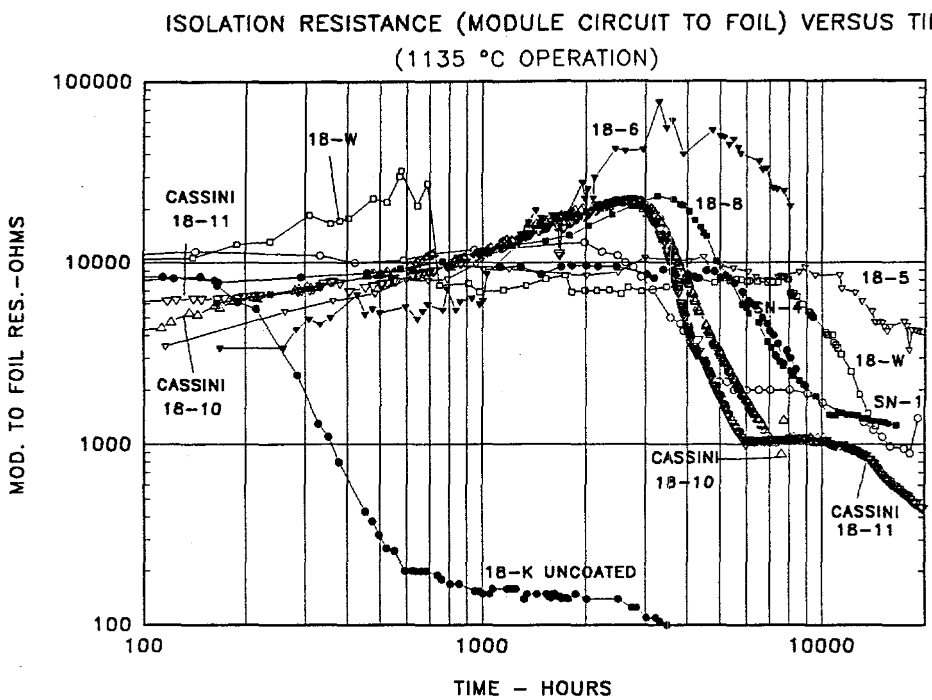

Figure 4-3. Isolation Resistance – Module Circuit to Foil (Modules 18-10, 18-11, GPHS Module 18-8) – 1135°C Operation

Individual Unicouple Performance:

The performance of individual unicouples and rows of unicouples continues to be observed. Table 4-3 shows the room temperature resistance changes and the internal resistance changes observed during operation for each of the six rows and for individual unicouples in Rows 2 and 5. The unicouples continue to perform within a narrow band.

Module 18-12 (1035°C Operation)

The module reached 15,425 hours at the normal operating temperature of 1035°C on 26 May 1996 . Thermoelectric performance, as measured by internal resistance and power factor trends, continues to be normal as shown as Figures 4-4 and 4-5, respectively. Table 4-4 shows initial performance and the performance on 24 May 1996.

Isolation Resistance

The isolation resistance between the circuit and foil continues to show the normal trend as shown in Figure 4-6.

Individual Unicouple Performance

A review of the unicouple internal resistances and open circuit voltages indicates that all unicouples are exhibiting very similar behavior with time (See Table 4-5). The data for the six individually instrumented unicouples in Rows 2 and 5 are shown in Figure 4-7.

Table 4-3. Module 18-11 Internal Resistance Changes

Position	Serial #	2nd Bond Milliohm	Preassy Milliohm	Delta ri Milliohm	T = 0 Milliohm	T=1,509 Hours	Delta ri Milliohm	Percent Increase	T=19,607 Hours	Delta ri Milliohm	Percent Increase
1.0	H2006	22.50	22.10	-0.40							
2.0	H0507	22.40	21.90	-0.50							
3.0	H0512	22.7	22.20	-0.50							
					182.30	199.70	17.40	9.54	236.20	53.90	29.57
4.0	H0439	23.20	22.70	-0.50	62.30	67.90	5.60	8.99	80.00	17.70	28.41
5.0	H0587	22.50	22.40	-0.10	61.00	66.50	5.50	9.02	78.00	17.00	27.87
6.0	H0657	22.70	22.50	-0.20	61.40	67.30	5.90	9.61	79.30	17.90	29.15
					184.10	201.10	17.00	9.23	236.60	52.50	28.52
7.0	H0585	22.90	22.50	-0.40							
8.0	H0459	22.50	22.10	-0.40							
9.0	H0562	22.70	22.30	-0.40							
					185.70	203.20	17.50	9.42	241.00	55.30	29.78
10.0	H0248	22.70	22.30	-0.40							
11.0	H0163	22.90	22.40	-0.50							
12.0	H0282	22.70	22.40	-0.30							
					184.90	201.70	16.80	9.09	236.70	51.80	28.02
13.0	H0428	23.10	22.70	-0.40	62.10	67.90	5.80	9.34	79.80	17.70	28.50
14.0	H0326	22.60	22.00	-0.60	62.20	68.30	6.10	9.81	81.10	18.90	30.39
15.0	H0232	22.60	22.00	-0.60	60.90	66.60	5.70	9.36	79.40	18.50	30.38
					184.70	202.30	17.60	9.53	239.60	54.90	29.72
16.0	H0590	22.60	22.40	-0.20							
17.0	H0393	22.60	22.10	-0.50							
18.0	H0496	22.50	22.30	-0.20							
					184.20	201.40	17.20	9.34	236.30	52.10	28.28

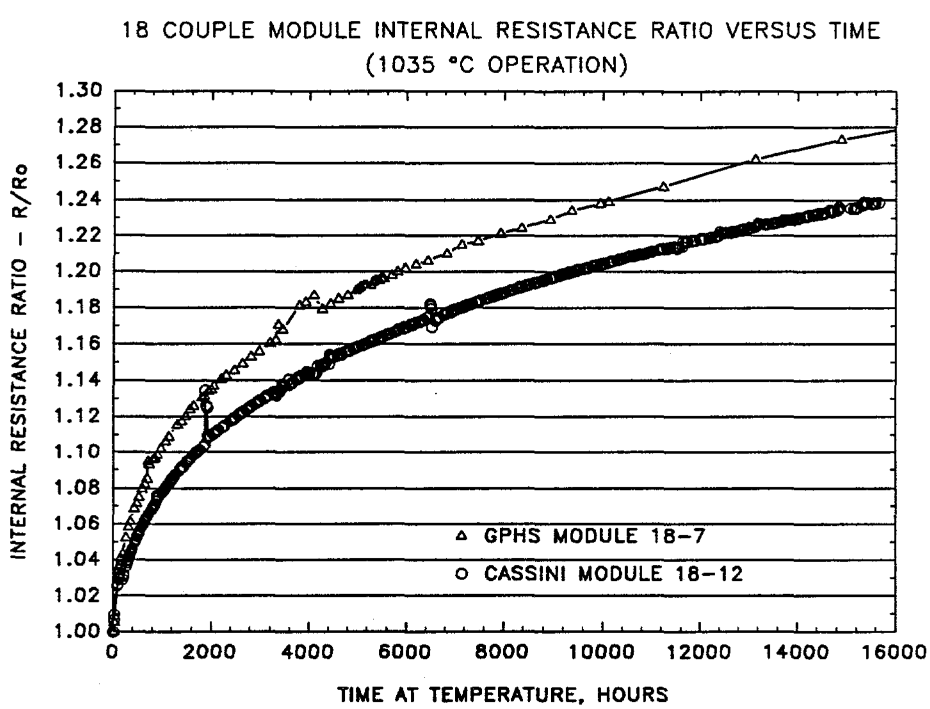

Figure 4-4. Internal Resistance Ratio Versus Time (Modules 18-12, and 18-7) – 1035°C Operation

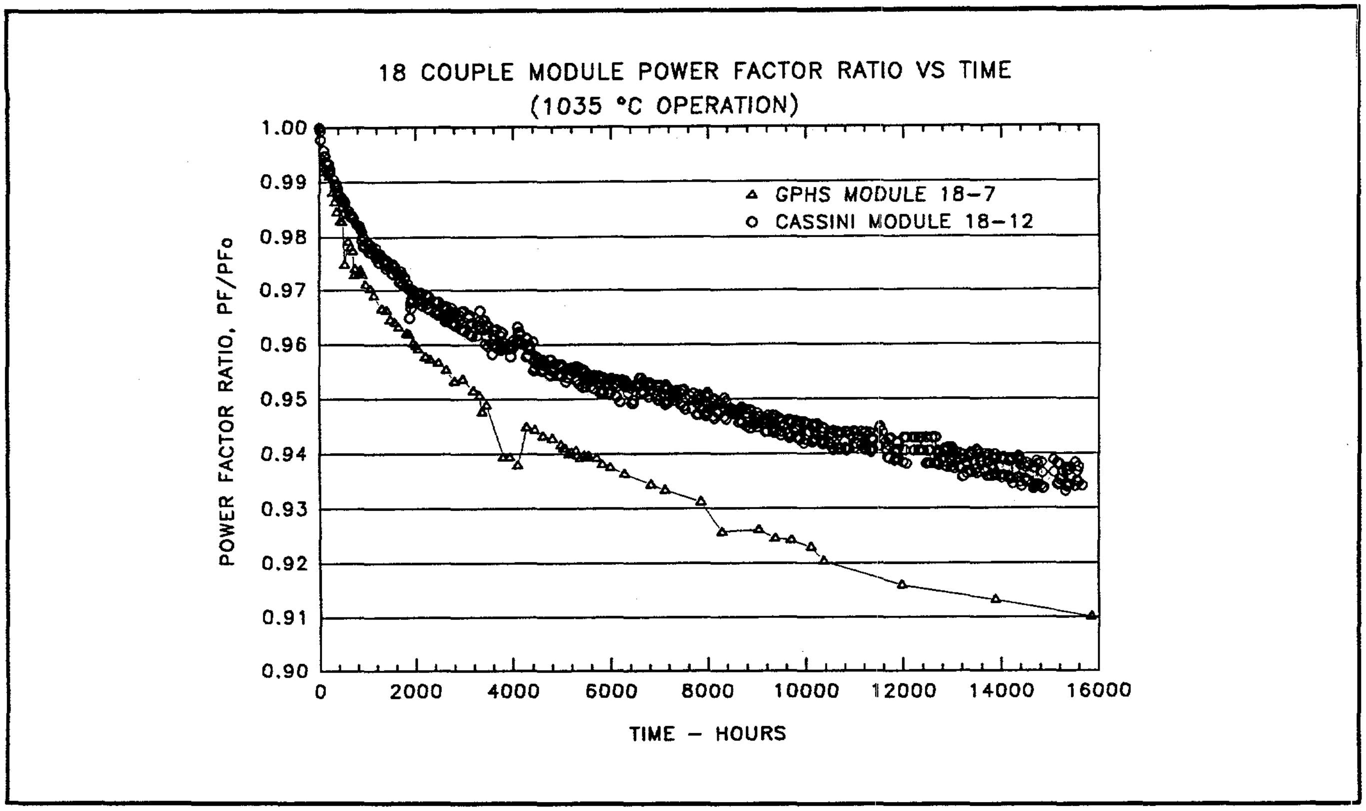

Figure 4-5. Power Factor Ratio Versus Time at Temperature (18-7 and 18-12) – 1035°C Operation

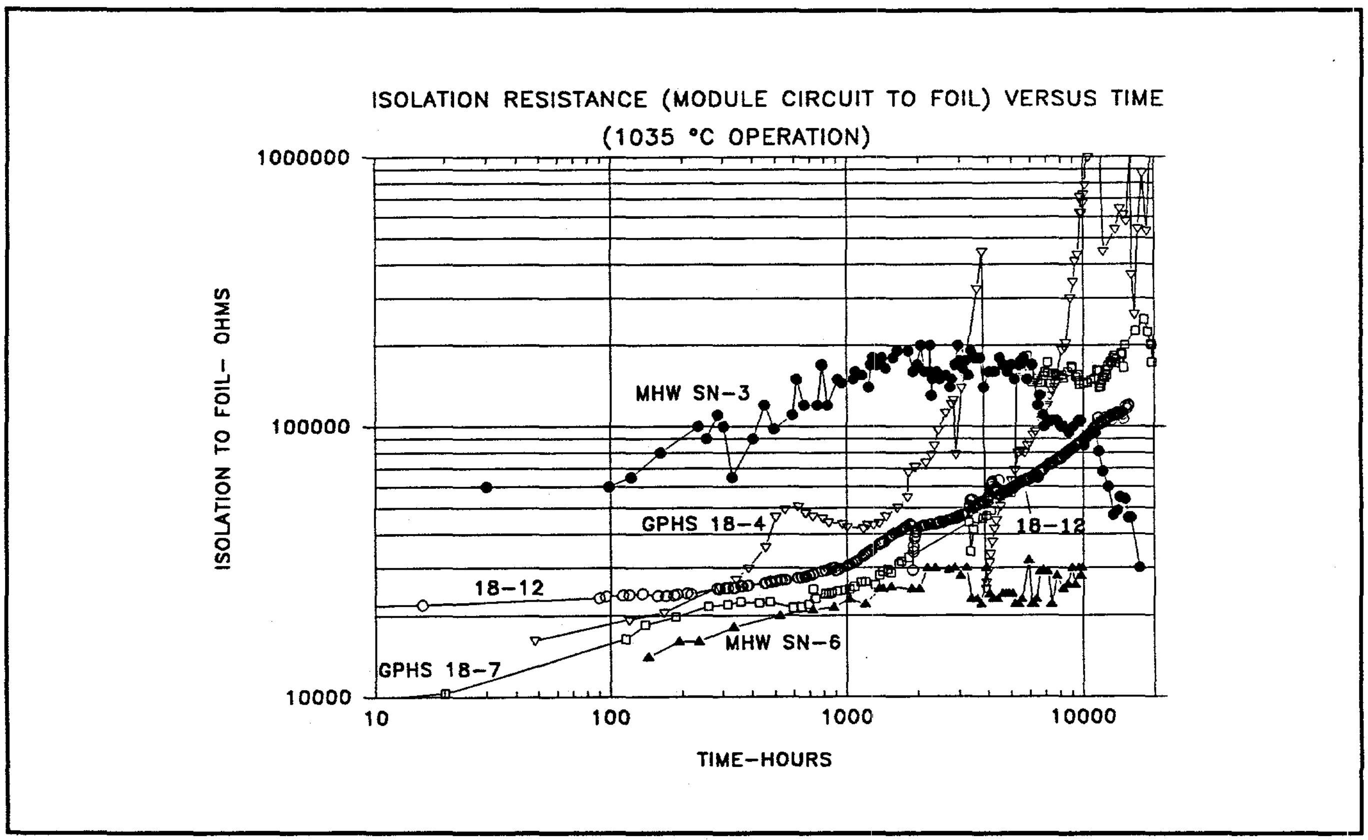

Figure 4-6. Isolation Resistance – Module Circuit to Foil (18-12, GPHS and MHW Modules) – 1035°C Operation

Table 4-4. Comparison of Initial and 15,425 Hour Performance of Module 18-12 at 1035°C

	Initial 6/16/94	t = 15,425 Hours 5/24/96
Heat Input, Watts	169.15	169.0
Hot Shoe, °C Average	1035.9	1026.9
Hot Shoe Range °C	5.7	3.7
Cold Strap, °C Average (8 T/Cs)	287.1	284.3
Cold Strap Range (8T/Cs)	5.0	4.6
Cold Strap Average (12 T/Cs)	282.7	280
Cold Strap Range (12 T/Cs)	19.8	19.3
Load Voltage, Volts	3.578	3.497
Link Voltage, Volts	0.155	0.154
Current, Amps	2.548	2.452
Open Circuit Voltage, Volts	6.431	6.866
Normalized Open Circuit (8T/Cs)	6.307	6.792
Normalized Open Circuit (12 T/Cs)	6.268	6.751
Average Couple Seebeck Coefficient (12)	497×10^{-6}	535.8×10^{-6}
Internal Resistance, Ohms	1.053	1.311
Internal Resistance Per Couple (Avg.)	0.0588	0.0729
Power Measured, Watts (Load + Link)	9.510	8.95
Power Normalized, Watts (8 T/Cs)	9.146	8.76
Power Normalized, Watts (12 T/Cs)	9.011	8.63
Power Factor	42.06×10^{-5}	39.41×10^{-5}
Isolation		
Circuit to Foil, Volts	-1.71	-0.85
Circuit to Foil, Ohms	21.3K	116K

Table 4-5. Module 18-12 Internal Resistance Changes

Position	Serial #	2nd Bond Milliohm	Preassy Milliohm	Delta ri Milliohm	T = 0 Milliohm	T=1,505 Hours	Delta ri Milliohm	Percent Increase	T=15,425 Hours	Delta ri Milliohm	Percent Increase
1.0	H2594	23.80	22.90	-0.90							
2.0	H2634	22.70	22.60	-0.10							
3.0	H2606	23.50	22.40	-1.10							
					176.80	192.10	15.30	8.65	216.70	39.90	22.57
4.0	H2168	22.20	21.70	-0.50	57.50	63.30	5.80	10.09	72.10	14.60	25.39
5.0	H2151	22.40	21.90	-0.50	57.40	62.90	5.50	9.58	71.30	13.90	24.22
6.0	H2256	22.20	21.70	-0.50	57.00	63.10	6.10	10.70	72.10	15.10	26.49
					171.20	188.60	17.40	10.16	214.70	43.50	25.41
7.0	H2597	24.40	23.20	-1.20							
8.0	H2680	22.60	23.00	0.40							
9.0	H2658	22.70	23.00	0.30							
					178.00	193.60	15.60	8.76	218.20	40.20	22.58
10.0	H1506	23.50	23.20	-0.30							
11.0	H1392	23.80	23.00	-0.80							
12.0	H1606	23.60	22.60	-1.00							
					176.20	193.40	17.20	9.76	218.20	40.20	22.58
13.0	H1344	23.60	23.50	-0.10	59.20	64.80	5.60	9.46	73.20	14.00	23.65
14.0	H1618	23.30	24.00	0.70	58.60	64.50	5.90	10.07	73.30	14.70	25.09
15.0	H1262	23.70	23.30	-0.40	59.40	65.00	5.60	9.43	73.50	14.10	23.74
					176.60	193.70	17.10	9.68	219.40	42.80	24.24
16.0	H1580	23.00	23.70	0.70							
17.0	H2127	22.80	22.10	-0.70							
18.0	H2113	22.90	22.20	-0.70							
					174.50	191.30	16.80	9.63	216.90	42.40	24.30

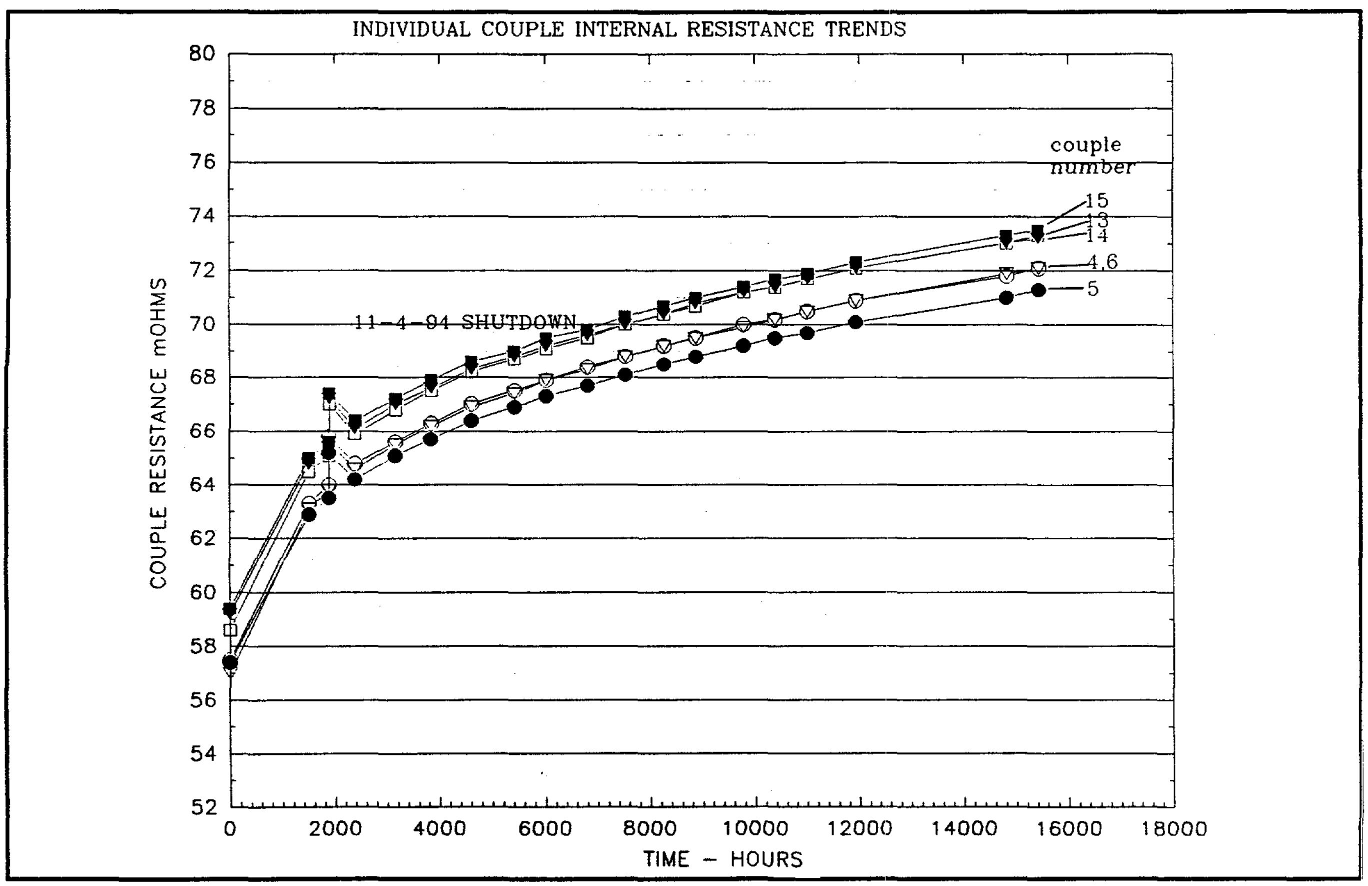

Figure 4-7. Individual Unicouple Internal Resistance Trends (Module 18-12)

TASK 5 ETG FABRICATION, ASSEMBLY, AND TEST

E-6 and E-7 ETGs

The E-6 and E-7 ETGs were successfully shipped to Mound on 29 April and 6 May, respectively. ETG electrical and pressure measurements performed by Mound indicted no adverse effects from shipment.

E-7 Processing Investigation

The investigation to identify the cause and source of the lower than expected isolation resistance of the E-7 ETG continued in May. The cause of the lower isolation resistance is believed to be a conductive deposit on the silica wrap between the unicouple and multifoil insulation. The source of the conductive deposit is from the interaction of the alumina and graphite components in the electric heat source (EHS) with elevated levels of water vapor and carbon monoxide during processing. Three possible conductive species predicted by equilibrium thermodynamic modeling include: 1) Al, originating from the condensation of Al vapor at 933K which is generated by the interaction of Al_2O_3 with H_2 and CO at 1448K; 2) Si, originating from the interaction of CO with SiO at 1273K; and 3) C, originating from the interaction of CO with SiO between 923 and 573K.

Analysis of the available data indicate that the deposit is most likely Al and/or C. Silicon is not considered since the isolation resistance for E-7 dropped off more steeply and faster compared to the resistance trend of uncoated unicouples in an 18 couple module test during the MHW program.

A meeting was held at Valley Forge on 9 May with DOE and Battelle Columbus to review the background of E-7 processing, thermodynamic assessment and the proposed Knudsen cell test plan. Battelle recommended that the Knudsen cell tests be replaced with Thermogravimetric Analysis (TGA) tests. The former tests would provide information on equilibrium thermodynamics and would not be different from the results obtained from the model used. On the other hand, TGA tests would provide reaction rates (or kinetics) for the generation of materials in the E-7 EHS. The TGA test plan for E-7 EHS materials is shown in Table 5-1. The mass loss experiments with the graphite and alumina in contact and noncontact were completed this reporting period, however, the results of the data analysis will be reported next month.

Table 5-1. TGA Test Plan to Simulate E-7 EHS Environment

Run	Sample	Configuration	Temperature (K)	P_{O2}/P_{CO}	P_{total} (mtorr)
1	Alumina 7-1 T/C Clamp Graphite	In Physical Contact	1403 to 1723 Ramp in 50K increment	0.54	2.5, 10, 20
2	Alumina 7-2 T/C Clamp Graphite	Not In Physical Contact	1403 to 1723 Ramp in 50K increment	0.54	2.5, 10, 20

E-8 Converter Hardware

The EHS ceramics, heater ballast, and end cap were reworked per MRB direction in preparation for final assembly. All the ceramic rework to remove the staining on the ceramics was acceptable except for one support ring which will require additonal rework. The heater ballast and end cap were reworked and forwarded to inspection. In parallel with this effort, the heater leads were welded to the heater elements and accepted.

The spare PRD successfully completed dynamic testing. Preparations are underway for performing the bellows force and leak tests.

TASK 6 GROUND SUPPORT EQUIPMENT (GSE)

The two shipping container bases that were previously used to store E-6 and E-7 ETGs were proof loaded with the RTG cage and new attachment bolts. After customer acceptance, they will be sent to Mound in exchange for the two bases at Mound which require additional rework.

The second converter support ring assembly was fabricated and was shipped to Mound for the new RTG transportation system.

TASK 7 RTG SHIPPING AND LAUNCH SUPPORT

Launch Activity

Test planning and test procedure documents were reviewed in preparation for the RTG Transportation System acceptance test. The test will be conducted by Westinghouse Hanford personnel at the Kennedy Space Center. The test is presently planned during the next reporting period.

TASK 8 DESIGNS, REVIEWS, AND MISSION APPLICATIONS

8.1 Galileo/Ulysses Flight Performance Analysis

No significant activity this reporting period.

8.2 Individual and Module Multicouple Testing

This task has been successfully completed.

8.3 Structural Characterization of Candidate Improved N- and P-Type SiGe Thermoelectric Materials

This task has been successfully completed.

8.4 Technical Conference Support

No significant activity this reporting period

8.5 Evaluation of an Improved Performance Unicouple

This task has been successfully completed.

8.6 Solid Rivet Feasibility Study

This task has been successfully completed.

8.7 Computational Fluid Dynamics (CFD)

Work continues on the CFD task. Because this task is closely related to the Task 3 safety activities, technical progress is reported under that task.

8.8 Technical International Conference Support

This task has been successfully completed.

8.9 Additional Safety Tasks

Additional safety efforts have been assigned to this task. Because these efforts are closely related to the Task 3 safety activities, technical progress is being reported under that task.

8.10 Small RTG Design Study

Work continued during this reporting period on development of concepts for a small RTG suitable for future planetary missions. The approach used in this design study is to develop concepts that take maximum advantage of the proven technologies and design features of the larger GPHS-RTG. Various design options have been considered as potential mass reductions, at the expense of added technical risk and engineering development. Options were selected that addressed components that were major mass contributors and, therefore, offered the best opportunity for significant mass reduction.

Figure 8-1 summarizes mass estimates for some of the design options considered. (Option 2 is still under study and mass estimates have not yet been completed.) Figure 8-2 illustrates the configuration of Option 1A, as typical of the design options being evaluated. Structural and thermal analyses have been initiated to support these design studies.

Figure 8-3 shows the results of a design study to minimize the mass of one component, the Pressure Relief Device (PRD). For this study, the existing (and flight qualified) design for the Cassini mission was scaled according to the volume of gas to be vented, while retaining the same materials and component design details. This is typical of the approach used in looking at major components of the RTG that can be scaled to a smaller size.

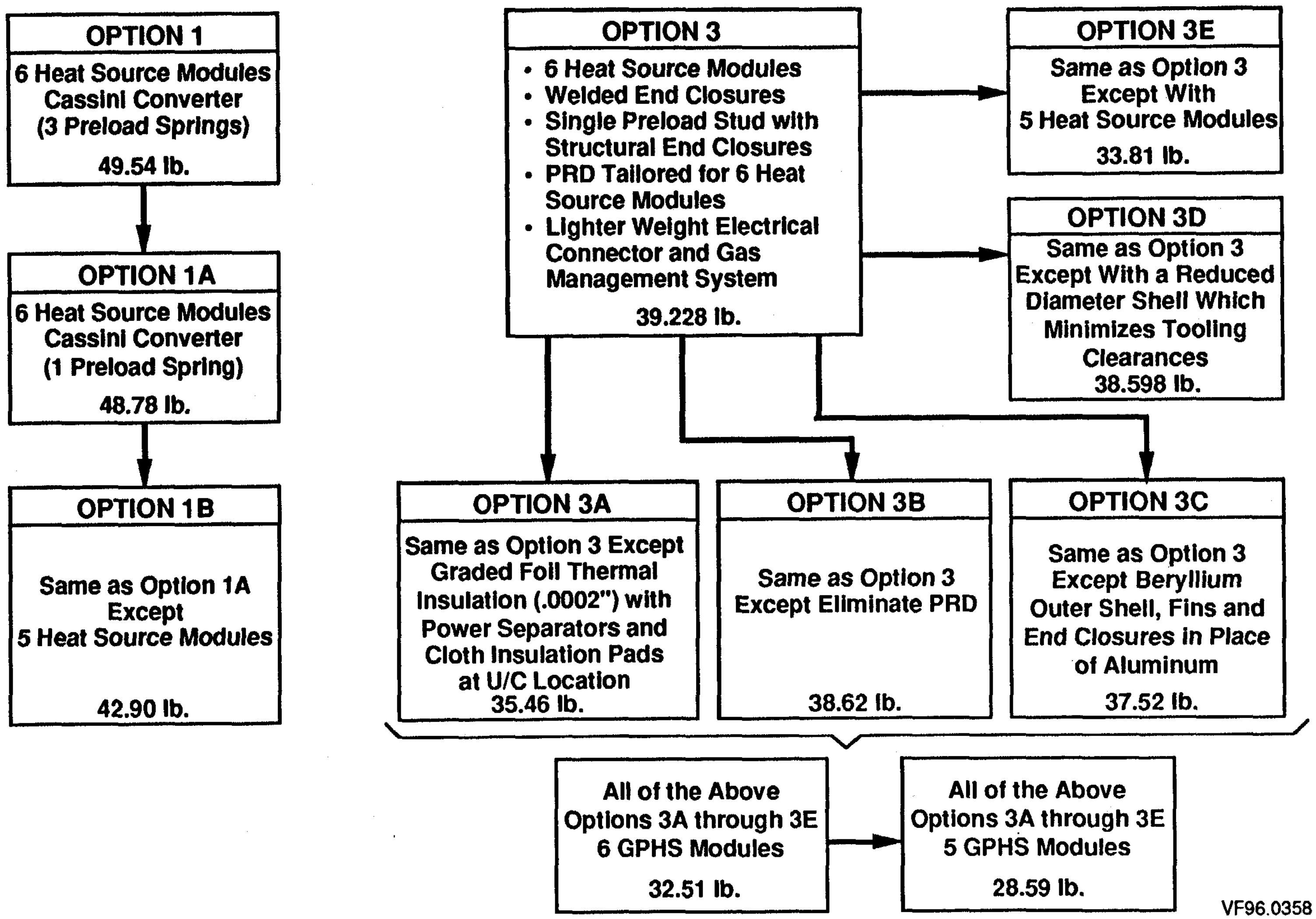

Figure 8-1. Concept Mass Estimates

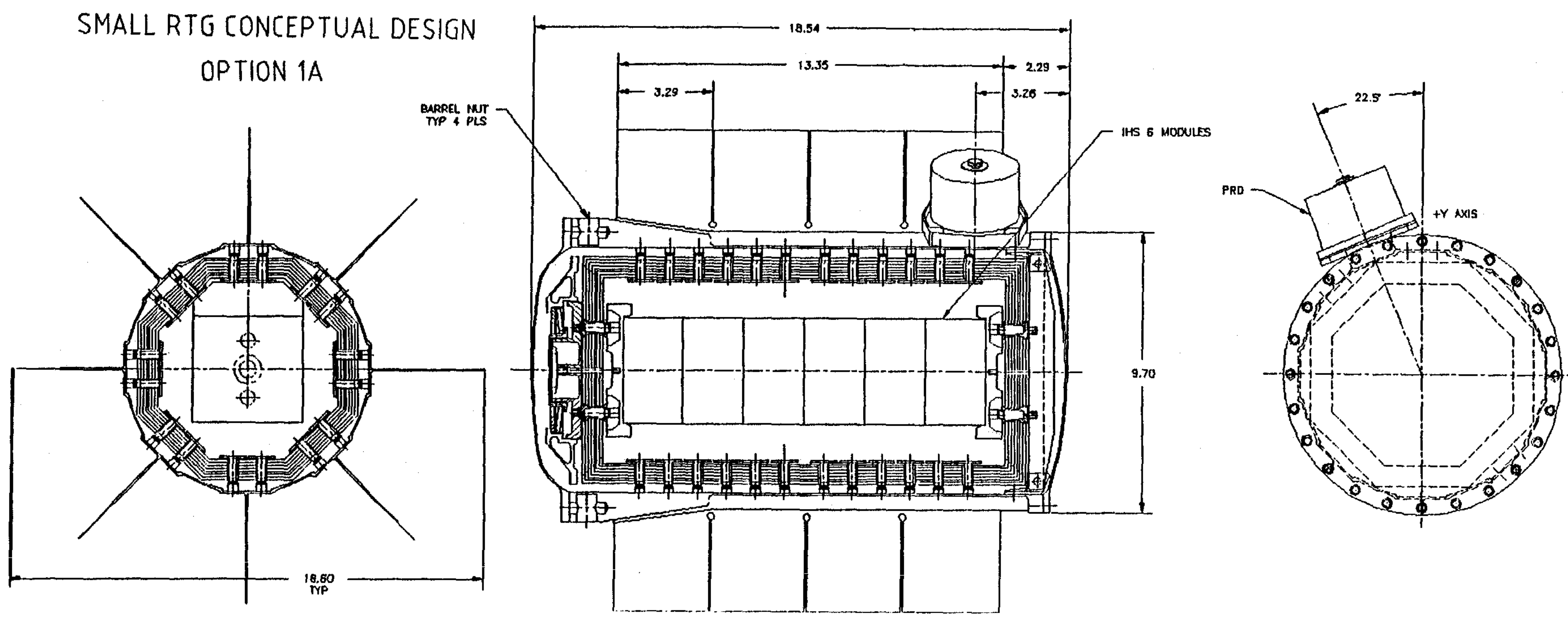

Figure 8-2. Typical Conceptual Design for Small RTG

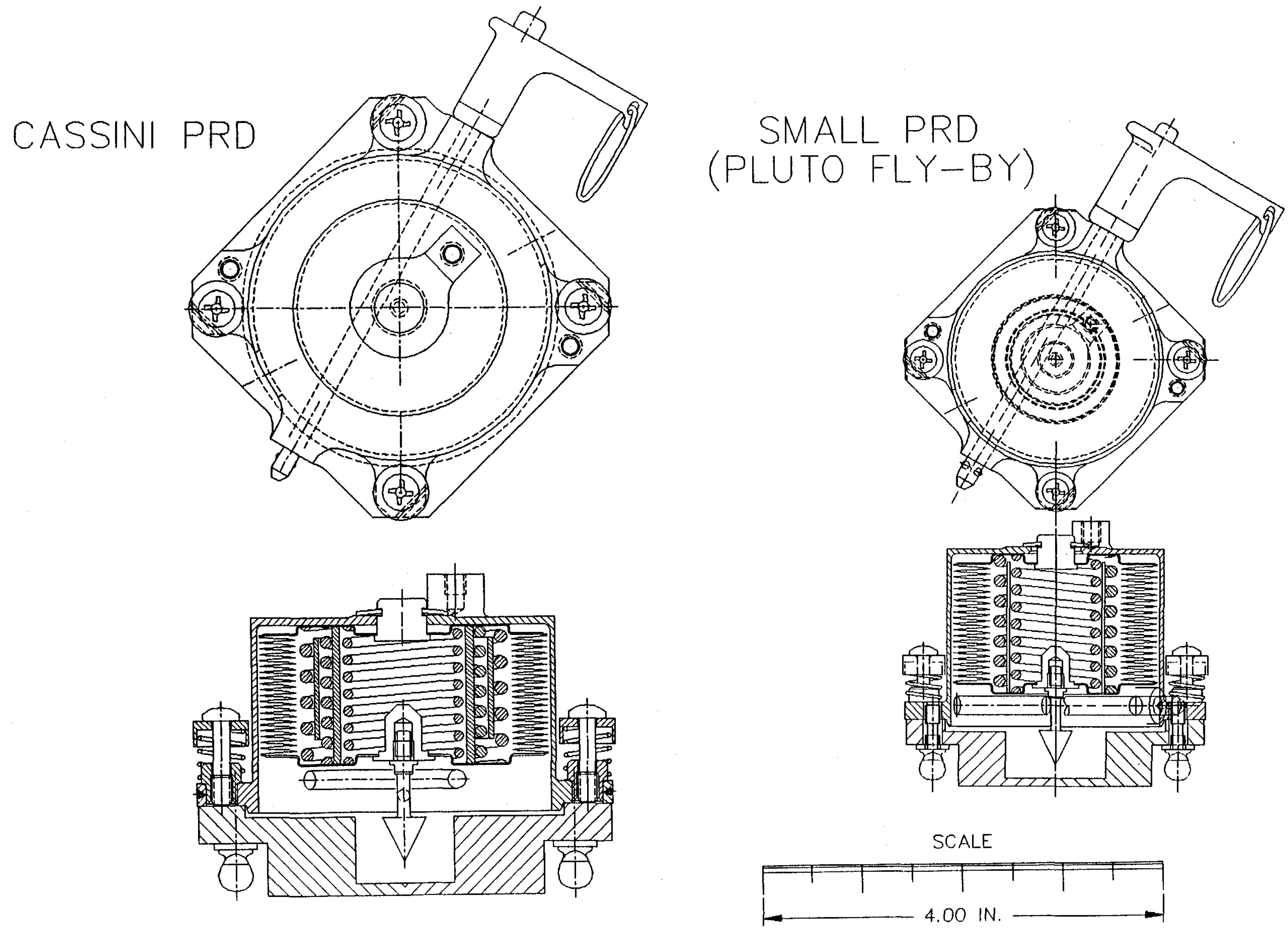

Figure 8-3. PRD Conceptual Design

TASK 9 PROJECT MANAGEMENT, QUALITY ASSURANCE, AND RELIABILITY

9.1 Project Management

All weekly, and monthly contractual reports and CDRLs were delivered on schedule.

Lockheed Martin personnel participated in the F-5 Cassini Program RTG Buy-Off, supported Mound during F-2 magnetics testing, and participated in an INSRP review of the FIREBALL Model.

The E-6 and E-7 ETGs were successfully shipped to Mound on 29 April and 6 May, respectively.

Attached is the current Cassini RTG program calendar for 2Q96 showing program meetings and important related events.

No significant environmental, health, or safety incidents occurred during this period.

9.2 Quality Assurance

Quality Plans and Documents

No plans were initiated or modified during this period.

Process Readiness and Production Readiness Reviews

No readiness reviews were conducted this month.

Quality Control in Support of Fabrication

Converter Assembly

E-8 Converter: Work on subassemblies for E-8 is continuing. E-8 hardware is being assembled into kits to be fully assembled at some point in the future, if required. Rework of EHS heater components to remove stains and foreign material is continuing. Dynamic testing of the spare PRD was successfully completed. Inspections and C of I's (where required) are continuing on miscellaneous hardware such as rivets, lock nuts, ceramics, washers, PRD, etc. Hardware is being accepted and returned to stock.

Unicouple Production

E-7 Unicouple Rework: Rework of the unicouples removed from E-7 is continuing. Unicouples are being unwrapped, unstuffed, and hydrogen fired to anneal the copper connectors. They will then proceed through the normal assembly and inspection steps in preparation for being returned to stock. Rework prior to commencing the wrapping operation is nearly completed and nonconformances are being addressed in MRB. Wrapping and stuffing operations should be initiated in the next reporting period.

E-6 Converter

The E-6 converter was successfully shipped to Mound for further processing and testing.

E-7 Converter

Class I Nonconformance Reports 79286 and 79348 were approved and a conditional C of I was received. The converter was shipped to Mound on 6 May.

Material Review Board

There were no Class I (major) nonconformances generated this month. Preliminary dispositions have been proposed for NRs 79286 and 79348.

Quality Assurance Audits

No audits were conducted during this period.

Cassini RTG Program Calendar

As of 20 June 1996

2nd QTR 1996

	M	T	W	T	F	S	S	FW
APRIL	1	2	3 Pre-Ship Review of E-7 ETG Converter - Valley Forge -	4	5	6	7	14
	Trailblazer Activities (1–5)							
	8	9 Dynamic Test - Mound - Miamisburg, OH *Rosko/Kauffman* (8–10)	10	11 Cassini Quarterly Program Review - JPL - CA - *Hemler, Cockfield, Reinstrom, DeFilipo, Kelly, Haley*	12	13	14	15
	Trailblazer Activities (8–12)							
	15	16 Fireball Meeting - Sandia Nat'l Labs - *DeFilipo/Chang*	17	18	19 Semi-Annual Reports Due to DOE	20	21	16
	22	23 Monthly Reports Due to DOE	24	25	26	27	28	17
MAY	29 Ship E-6 to Mound	30 F-5 Buy-Off - Mound - Miamisburg, OH *Reinstrom/Cockfield/Douglas*	1	2	3	4	5	18
	6 Ship E-7 to Mound	7 FSII Briefing - Kirtland AFB, NM - *DeFilipo/Rosko*	8 INSRP Review Fireball Model - Kirtland AFB, NM - *DeFilipo/Chang/Deane/Rosko* (8–9)	9 E-7 Processing Investigation Coupon Test - Valley Forge -	10	11	12	19
	13	14	15	16	17	18	19	20
	20	21	22 Magnetics Testing - EG&G Mound, Miamisburg, OH *Reinstrom/Kugler* (22–23)	23 Monthly Reports Due to DOE	24	25	26	21
JUNE	27	28	29	30	31	1	2	22
	3 DFSAR Vol I Review - DOE HQ - *Hartman*	4 RTG Transportation System Final System Acceptance Test - Cape Canaveral, FL - *Reinstrom/Cockfield/Haley* (4–7)	5	6 INSRP Review Reentry Analysis Results - Valley Forge - Bldg. B - *DeFilipo et al*	7	8	9	23
	10 Mass Properties Test - EG&G - Mound - *Gosling* (10–12)	11 Cassini Monthly Program Review - OSC - *Hemler, et al*	12	13	14	15	16	24
	17 Module Assembly Readiness Review - EG&G - Mound - *Cockfield*	18	19 Dynamic Test Check Out - Mound- *Kauffman*; Launch Planning - Cape Canaveral, FL - *Reinstrom* (18–21)	20 DFSAR Vol II Rev. - DOE HQ - *DeFilipo et al*	21 Monthly Reports Due to DOE	22	23	25
	24	25	26	27	28	29	30	26

TASK H CONTRACTOR ACQUIRED GOVERNMENT OWNED (CAGO) PROPERTY ACQUISITION

Task H.1 CAGO Unicouple Equipment

No significant activity during this reporting period.

H.2 CAGO - ETG Equipment

No significant activity during this reporting period.

H.3 CAGO - MIS

No significant activity during this reporting period.

DISCLAIMER