Semi Annual Technical Report

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GPHS-RTGs in Support of the Cassini Mission

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Semi-Annual Technical Progress Report

The technical progress achieved during the period 28 March 1994 through 25 September on Contract DE-AC03-91SF18852, Radioisotope Generators and Ancillary Activities is described herein.

This report is organized by the program task structure as follows:

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Task 1

Spacecraft Integration and Liaison

PROGRESS BY MAJOR TASK

TASK 1 SPACECRAFT INTEGRATION AND LIAISON

The JPL Cassini orbiter RTG Requirements Specification (ES515802) negotiations were completed and the specification was approved by DOE and JPL and issued for use. This specification together with the JPL Environments and Testing Specification (ES515803), which is still in preparation, define the spacecraft derived requirements imposed on the RTG. Work to finish Specification ES515803 is continuing and is expected to be completed after further test results become available early next year.

As a result of the JPL RTG Inheritance Review, an evaluation of the Resistance Temperature Device (RTD) bracket bending (documented in Mound P/FR 5444) experienced on the GLL/ULS program was reviewed. The review concluded the bracket had adequate stiffness for launch and flight conditions and also for normal servicing of the RTD connector. However, experience on the last program showed that bending is possible if the bracket is inadvertently subjected to handling loads beyond those anticipated in normal procedures. To respond to the JPL concern arising from the experience of the last program, it was decided to increase the bracket thickness approximately 50% to 0.062 inches. The resulting greater bracket stiffness together with careful handling and diligent use of approved procedures is judged to provide adequate safeguard against bracket bending on the Cassini program.

DOE direction was received to modify the RTG protective cage for use at the launch facility with the JPL adapter ring installed. The added height of the ring (4 inches) brings the top of the RTG closer to the protective cage and necessitates that the cage be modified to restore needed clearance. At the close of this report period a proposed contract modification to cover the needed work had been prepared, submitted to DOE, and was under review.

Task 2

Engineering Support

TASK 2 ENGINEERING SUPPORT

Specifications/Drawings

Throughout this period ECNs were prepared and processed through CCB approval in support of ETG/RTG fabrication and uncouple assembly activities.

RTD Harness:

The design, fabrication, and checkout of the RTD cable vibration fixture was completed during this period. The qualification test program was started in September 1994. The RTD cable passed the acceptance thermal vacuum test.

Government Laboratories Interface

Under this task support is provided to the DOE National Laboratories and processing facilities for the fabrication and assembly of heat source parts, and assembly and testing of the RTGs. During this period, the fuel pellet and fueled clad specifications prepared by Los Alamos National Laboratory were approved. The General Purpose Heat Source Assembly specification was prepared at Martin Marietta and submitted to DOE for review and approval. Also the Flight Unit Test Plan was prepared to cover the RTG processing and testing at Mound. The Plan was also submitted to DOE for review and approval.

Task 3

Safety

TASK 3 SAFETY

Safety Analysis Reports

The most recent schedule for the Titan IV Databook necessitated a completed revision of the schedule for the safety analysis reports for the Cassini mission. the currently agreed upon schedule for the reports is as follows:

Preliminary Safety Analysis Report (PSAR)	1 December 1994
Draft Final Safety Analysis Report (Draft FSAR) (Replaces the Updated Safety Analysis Report - USAR)	1 July 1996
Final Safety Analysis Report (FSAR)	1 November 1996

These dates were reviewed with the INSRP by NASA and DOE during the latter part of this reporting period and were accepted.

During this reporting period, NASA considered the possible use of the older design solid rocket motors (SRMs) rather than the SRMUs for the Cassini launch. DOE was questioned about including the use of the SRMs in the USAR (now draft FSAR) along with the parallel treatment of the SRMUs in the safety analysis. In a meeting held in August 1994 between DOE, NASA, and their subcontractors on Cassini flight safety, the decision was made to pursue only the SRMU flight option for purposes of the draft FSAR. However, modeling for RTG response to accidents related to the use of SRMs will also be developed by Martin Marietta Astro Space for inclusion in the LASEP type of program. In the event that a late decision is made to change to SRMs for the Cassini launch, an addendum will then be prepared for the draft FSAR or the FSAR to present the effects of the change on the radiological risks for the mission. If the decision occurs earlier in the draft FSAR analysis and preparation, the FSAR can then be revised to address only the SRM application.

The decision on the need for a space vehicle destruct system (SVDS) for Cassini has not yet been made. NASA is planning to make that decision within the next two months. If the decision is made to include the SVDS, this could have a significant effect on the draft FSAR and FSAR dates. At present, the current status of the Titan Databook schedule makes the July 1996 date for the draft FSAR a considerable challenge. The above SAR dates are contingent upon receipt of the Titan Databook contents on the schedule agreed to by NASA during the meeting cited above.

Computational Fluid Dynamics Program

The development phase for the CFD analysis program has been completed. A scheme has been conceptualized for coupling the output from the CFD analysis to the SINRAP reentry

analysis. The primary approach in this scheme is to obtain a converged, coupled gas radiation/wall ablation flowfield as a function of wall temperature for sufficient temperature points to bracket the expected module wall temperature at a given altitude in the reentry trajectory. SINRAP would then iterate between these points to arrive at the converged wall temperature and corresponding ablation. As a secondary approach, SINRAP would first determine a wall temperature and heat conduction gradient based on the usual approach using the β' (effective mass transfer coefficient correlation). Then the CFD would determine a converged solution for wall temperature and heat input rate. The CFD output would then be input to SINRAP for a second iteration on wall temperature and conduction. This in turn would be input to the CFD analysis for another iteration on heating rate. The iterative transfer process between CFD and SINRAP would continue until SINRAP and CFD results yielded surface temperatures within a reasonable tolerance when compared with each other. While both of these approaches will require considerable computing time, it is considered that the latter, or serial iterative approach between CFD and SINRAP, will require excessive overall time in which to obtain a solution. Therefore, the primary approach is preferred.

A recommendation for the follow-on effort to complete the EGA reentry analysis for Cassini based on the CFD analysis approach has been given to DOE. The approach is to pursue the wall temperature–heating rate/ablation rate matrix approach in order to complete the SINRAP reentry analysis. In this approach, once the heat input rate to the module approached the chemical equilibrium regime and coupling effects become small, SINRAP would then revert to the usual β' correlation and off-line radiation determination scheme for the remainder of the reentry trajectory.

LAURA Flowfield Code Modifications

A coupled wall ablation model was implemented into the LAURA flowfield code. Mass flow is calculated from a wall energy balance,

$$\dot{m} = \frac{(q_{\text{convection}} + q_{\text{gas radiation}} - q_{\text{conduction}} - \epsilon T_w^4)}{(h_w - h_s) T_w}$$

and the local wall temperature is calculated from the Knudsen-Langmuir mass loss relationship

$$\dot{m} = \sum \alpha_i \sqrt{\frac{M_i}{2\pi RT_w}} * (P_i^v - P_i)$$

where

α_i	=	species vaporization coefficient
M_i	=	carbon species molecular weight
P_i^v	=	carbon species vapor pressure
P_i	=	partial pressure of carbon species in adjacent gas layer

The ablation model has been formulated and, along with material properties, has been encoded into LAURA-C. The routine was debugged, and a converged, coupled gas-radiation/wall-ablation flowfield calculation was completed for the 7 degree, face-on-stable entry, at the peak heating altitude. Global convergence, i.e., number of combined LAURA-C/LORAN-C calculations to get convergence between the flowfield and the radiation field, was rapid, requiring about three global passes. Flowfield convergence (number of iterations within the LAURA-C code) was lengthened somewhat, because of the more complex wall boundary condition.

Figure 3-1 shows convective and radiative heat flux levels for the last global iteration. Figure 3-2 shows the variation of convective heating during the global iterations. Figure 3-3 shows the convergence of the radiative flux to the GPHS surface. Figure 3-4 shows the effect of ablation products on incident radiation; the result is about a 25% reduction to the heat flux reaching the surface. Figure 3-5 shows wall temperature and wall mass flux levels during iterations. The front face temperature is fairly uniform; wall mass flux varies by about a factor of 2 across the front of the GPHS. Figure 3-6 shows element concentrations at the surface for the last iteration. Figure 3-7 shows carbon species distributions along the stagnation streamline.

An initial run was made for the peak heating point for the steep (90°) trajectory, but it was not successful. Convergence problems were encountered. These problems are believed to be caused by the flowfield reactions approaching chemical equilibrium at the relatively low altitude (122 kft); this results in numerical problems with non equilibrium solution schemes, as the species diffusion equations get extremely stiff. Solutions to this problem are being investigated.

Meeting with INSRP Reentry Subpanel

A meeting was attended with the Reentry Subpanel of INSRP at the Aerospace Corporation on 15-16 June 1994. An in-depth presentation was made by Martin Marietta Astro Space on the development of the computational fluid dynamics (CFD) computer programs to be used in the reentry analysis of the GPHS modules arising from potential spacecraft malfunctions during the gravity assist maneuver about Earth for the Cassini mission. The presentation was received with much interest. The Reentry Subpanel agreed to provide their comments and observations on the CFD approach and techniques, but these had not been received at the end of this reporting period.

Figure 3-1. Heat Flux Levels for Final Iteration

Figure 3-2. Convective Heating During Iterations

Figure 3-3. Radiative Heat Flux

Figure 3-4. Effect of Ablation Products on Incident Radiation

Figure 3-5. Wall Temperature and Mass Flux During Iterations

Figure 3-6. Element Concentrations for Last Iteration

Figure 3-7A. Carbon Species Distributions Along Stagnation Streamline

Figure 3-7B. Carbon Species Distributions Along Stagnation Streamline

Global 3d Wind Field - GRAM90

Development of 3D time-varying wind fields on a global scale was accomplished using NASA's GRAM90 database and code. 3D time-varying data fields are called "4D" data fields in these applications, as contrasted with static 3D data fields, which are averages over a specified time period, usually monthly, seasonal, or annual. Since the GRAM90 code was designed to produce wind data along a launch vehicle track, it was necessary to adapt it to GEOTRAP by reprogramming it to produce output over a complete, global scale grid. The feasibility of doing so was successfully demonstrated by testing. However, even though a complete grid of data can be generated, the validity of the time varying aspect of the correlations used in GRAM90 remained in question. For this reason, the initial databases developed are 3D monthly averages (not time varying), one for the scheduled launch month, October, and another for December.

Due to the large number of grid points for the global-scale wind field, GRAM-90 was tested with a scheme of mesh generation. The code provides wind components at all latitudes, except near the poles (larger than 85°). Either interpolation will be needed, or individual runs must be added for these extreme coordinates.

KSC Meteorology Data

An interactive data base was created for the KSC multi-tower meteorology data. This data was previously supplied to Astro Space Division by NUS in the form of ASCII files stored in 3.5" diskettes; the whole body of data was loaded into a formatted binary data base. Approximately 55 Mbytes of data were successfully reduced to less than 4 Mbytes. This working database not only will provide easy access to any specific data item but also will permit rapid interpolations to grid points of the reference grid of SATRAP. The accessing program or user can request the meteorology data at a wind station by inputting the desired time and day information and the wind station number.

Plans were made with Brown and Root NUS personnel to develop 10 to 20 fully 3D time varying wind fields simulating the complex sea-river breeze conditions at the KSC Cassini launch site. These will be used as input data to the SATRAP code. Together with the multi-tower KSC Meteorology data input files discussed above, these files will cover the complete set of conditions that are credible for launch. These simulations have been fully tested, and documentation of the test runs was completed. Effort continued to identify sea and river breeze conditions in the recorded data that, if successful, would permit an accurate estimate of the frequency of these conditions.

Internal Radiation Dosimetry

ICRP Publication 66 was ordered; it was expected to become available from the publisher in August 1994. This publication explains the latest model for calculating radiation doses due to inhalation or ingestion. The intent is to acquire the computer code implementing this mode (if necessary) to obtain the needed dose conversion factors for plutonium 238 dioxide. While the recent government documents such as 10CFR20 and EPA Federal Guidance Report 11 have adopted the dated (1970s) values of organ weighting factors from ICRP-26 and the internal dosimetry from ICRP-30, the ICRP recommends the much more recent ICRP-60.

Code Testing and Validation

SATRAP Validation

Validation testing of SATRAP's 3D wind field interpolation module was conducted. With simulated data being used for sea breeze at Cape Canaveral, a sequence of half-hour data of wind components, from 9:00 am to 5:00 pm, were loaded into binary database to perform trajectory computations. This exercise demonstrated a very efficient coding method for large data file interfaces. The code execution time was less than a few seconds for 5 hours of particle tracking. As an option, SATRAP will print the trajectories in the form of successive coordinates to an output file for post-processing. This is particularly useful when the wind field is complex and the user needs to know more about the transport of various particle sizes. Initial results for parameters important in sea breeze conditions, such as release height, timing, and particle size, were presented in an April 1994 meeting with the Meteorological and Biological/Environmental Effects Subpanels of INSRP. In addition to verifying that the code correctly tracks this complex fully 3D time varying wind field, testing also processed the wind field data files into a form usable for future SAR analysis.

GEOTRAP Testing/Update

A performance test of GEOTRAP was conducted with several cases of multi-particulate releases at high altitudes. For each case, an Inventory of 3 to 10 particle sizes was released between a range of altitudes from 10 to 40 Km. This exercise was conducted to verify the results of concentration calculations and to improve the running time. With a combination of increase in dynamic memory and improvement in reference scheme, an excellent response time was achieved with less than 10 sec per particle size. Results produced for the ground level concentration were as expected and post-processed in the form of profiles or contour lines for documentation.

Previously, only one final position of each released cloud was written to an output file for the footprint pattern. As a result, the lack of information on time of transport or location of deposition near ground level induced many assumptions for the evaluation of concentrations.

Now, successive positions of the diffused cloud are recorded whenever it arrives at the mixed layer at ground level. The code computes the gradual transfer of mass to this layer and uses the time spent over each position to calculate time integrated concentrations. This implementation not only improves the deposition results but also provides realistic footprint patterns. As an option, combination of deposition values from source clouds of different characteristics can be set up to provide information such as total activity or total affected area.

HIAD Validation

Validation of results of the HIAD code's outputs against hand calculations of worldwide deposition of small particles (less than 3 microns) was conducted with excellent agreement. Verification of the full equations implemented in the code is being done using spreadsheets. Documentation of the underlying scientific validity of the input parameters for the equations will be included in the HIAD METHODS DOCUMENT, which will be issued as a program document for reference. The validity is largely based on studies of 1960's era atmospheric nuclear test fallout plus a few ad hoc studies, including the inadvertent SNAP-9A RTG burnup.

Deposition Validation

An analysis of the most recent deposition velocity measurements and theory was conducted. The analysis was focused on data for particles between 0.1 and 2 μ m since this is a range where knowledge of deposition has the greatest uncertainty and is not yet fully understood by researchers. Deposition of particles larger than this is dominated by gravitational settling, which is a well understood phenomenon, while in the range of 0.1 to 2 μ m, it occurs due to microturbulence and brownian motion. Real deposition in this field is affected by many factors local to the site studies, especially vegetation and humidity.

In order to have current data that reflects conditions typical of Florida, field data related to grass covered surfaces or vegetation canopies was obtained from current journal reports. The goal of this effort was to determine whether the minimum value of deposition observed in field data is comparable to the predicted values of the Sehmel - Hodgson model used in SATRAP. It is known that certain factors not included in the Sehmel - Hodgson model can increase deposition. Hence, under these conditions, the model will give values below the measured ones. The intent is to identify when this will occur so that the SATRAP model can be supplemented appropriately. Also, two other prediction models were examined. The results of this deposition study will be documented in the SATRAP METHODS DOCUMENT, also to be issued as a program document.

Documentation

During this reporting period, a number of documents were in preparation for the various code modules and techniques to be used in the Space Accident Radiological Release code (SPARRC) for the Cassini Draft FSAR and FSAR. these include Methods Documents for SATRAP, GEOTRAP, HIAD, and PARDOS, the Dose Methods Document.

SATRAP has been designed for the analysis of release scenarios at the launch site. SATRAP is a large code involving many more models than the GEOTRAP and HIAD codes used for worldwide scale analysis. It also has many usage options. Models documented include: source cloud transport, cloud diffusion, concentration at grid locations, and dose calculations. Models implemented and their theoretical basis are described and their validity is evaluated. Also, since extensive effort is required for data preparation, pre-processing activities are also described in detail. The document's features include:

- Code overview with description of the main modules,
- Description of transport calculation with trajectory method for multi-particles,
- Options for diffusion coefficients,
- Deposition and resuspension models,
- Nested grids for concentration calculation, and
- Review of methods to compute atmospheric parameters such as stability, friction velocity, mixing height, and wind components interpolation.

The SATRAP methods document also gives a summary of the dose and health effects calculation, since the somewhat complex interface makes it an integral part of the computer code.

Designed as an analysis code for the global dispersion of particulates, GEOTRAP has gone under several modifications to add capabilities in both major areas: transport and dosimetry. Improvements have also been made which substantially improve the code's response time. Some of the main features include:

- A capability to input a synoptic wind field from either external monthly mean data or from a built-in model with seasonal mean data.
- Recording of cloud positions near ground level at a sequence of points in time, rather than just recording initial touchdown time, so as to create more realistic ground footprints of the clouds' deposition.
- An option to input user-specified deposition velocities, rather than use built-in calculated deposition velocities, to take account of possible variations due to mode of deposition.

- Resuspension calculations for all particle sizes based on the recent INSRP model for rural wet climate conditions.
- Internal dosimetry calculations per ICRP-30 methods with a built-in calculation model for inhalation dose conversion factors (DCF) dependent on particle size.

The GEOTRAP methods document gives a detailed description of various calculations required for the transport analysis, from particle fall velocity to time integration of ground level concentrations. Several verification results are discussed in the methods document and graphically illustrated for easier understanding of each code module. The section on wind data input was revised since the option of interface with external database was recently implemented. The description of the existing wind field model, applicable for seasonal averages, was rearranged with heavy mathematic formulas grouped in the appendix. Test results on long range transport of various particle sizes were explained in detail. A new section for the concentration calculation was added to describe the new approach mentioned above.

Details of environmental transport and human dosimetric considerations are discussed in the separate Dose Methods document. Documentation of the ingestion dose and areas of food production continued. With the intention to implement the recent dosimetry model from ICRP-66, revisions of several dose pathways are required.

PSAR Nuclear Risk Analysis Document

A detailed description of the SPARRC codes and techniques to be used for the Cassini risk analysis was being prepared for the PSAR. This input was nearly complete at the end of this reporting period.

Safety Test Program

During this reporting period, the following tasks were completed:

- All detailed parts and assembly drawings for the safety test converter hardware were completed and furnished to LANL.
- Drawings for the Martin Marietta Astro Space recommended heat source stack configurations, along with their piece parts, were completed and furnished to LANL.
- Manufacturing of all piece parts for the test converters was completed.
- Assembly of the engineering test converter and the two end-on test converters was completed. One end-on test converter and the engineering test converter were shipped to LANL. The decision has been made to keep the second end-on test converter at Martin Marietta Astro Space temporarily in the event that trouble shooting is needed for problems that may arise during test preparation for the first end-on test.

- A mass simulated heat source stack was designed and the unit was built. The unit was used to check out the insertion into the converter shell and the latching mechanism to hold it in place.

During the assembly of the latch assemblies for the test converter, a problem was discovered in which the latch springs were not strong enough to ensure a firm latch. The latch mechanism was subsequently modified to incorporate stronger springs to provide proper latching action. The test for insertion of a dummy heat source into the converter and check of the latching mechanism was performed successfully, and the latch mechanism operated as intended.

Earlier in this reporting period, LANL indicated that they would be responsible for fabricating the stack hardware for the test units, including any parts needed for the test modules and the dummy mass components. In their review of the Martin Marietta proposed heat source stack design, LANL proposed a change to the dummy mass simulator to be used behind the test modules for the end-on tests. Instead of a single POCO AXF5Q block and moly mass as proposed by Martin Marietta Astro Space, LANL suggested using individual POCO AXF5Q blocks (i.e., the same size as the GPHS modules) with moly simulated fueled clads. Fairchild Space analyzed the dummy module stack proposed by LANL using their hydrocode models and found that this configuration would not produce the correct distribution of distortions in the test modules. Martin Marietta Astro Space then provided the following alternative to LANL; 1) use single POCO block with moly slug proposed by Martin Marietta Astro Space, or 2) use individual FWPF blocks with simulated moly fueled clads. The latter did not appear practical because of the requirement for additional FWPF material which did not then appear available.

In a related issue, LANL also proposed making changes to the heat source support assembly to be used in the RTG end-on impact test. The first involved modifying the outboard heat source plate to permit the tie rods to thread into the plate rather than use nuts to secure the plate to the rods. Martin Marietta initially agreed to this modification prior to receiving the results of the Fairchild analysis for the dummy stack mass. This change was put on hold pending agreement on the dummy mass configuration.

Another proposed change by LANL was to use a pyrolytic graphite plate as an insulator in place of Cerablanket insulation at the inboard end of the converter section. This change was not acceptable to Martin Marietta Astro Space because it would interfere with the inner moly frame and prevent proper seating of the test heat source.

The remaining modification proposed by LANL was to use all FWPF tie rods for the heat source stack as opposed to mixed FWPF and POCO tie rod sections proposed by Martin Marietta Astro Space to accommodate differences in thermal expansion between the FWPF

test modules and the dummy POCO mass. LANL stated that past experience has shown that POCO rods of the size needed would be prone to breakage in handling because of the fragility of the rods. LANL was concerned about maintaining stack integrity during the test.

DOE has recently made the decision to use FWPF aeroshells for all positions in the heat source stack for the end-on impact tests. The inboard end module or block (i.e., the end away from the impact surface) will have to be POCO (AXF-5Q), however, since this block must be narrower in thickness because of the heat source length restriction required by the shortened length of the half converter sections. The dummy modules, now having FWPF aeroshells, will have POCO (AXF-5Q) GISs containing moly slugs for fuel clad simulants. This revision to the stack makeup will require some revision to the tie rod scheme used to hold the stack together for purposes of heat up and insertion into the converter section. These design changes are currently being worked out by Martin Marietta Astro Space in coordination with LANL.

Task 4

Qualified Uncouple Production

TASK 4 QUALIFIED UNICOUPLE FABRICATION

Three modules were on life test during this reporting period. Test temperatures and life test hours are shown in Table 4-1. All modules continued to show normal performance. The most significant events during this reporting period are:

- 18-10** Reached the 6,000 hour qualification test milestone on 12 April 1994.
- 18-11** Reached the 2,000 hour acceptance test milestone on 27 April 1994.
- 18-12** Started life testing on 16 June 1994.

Table 4-1. Test Temperatures and Life Test Hours

Module	Unicouple Source	Test Temperature Hot Shoe	Status as of 26 September 1994
18-10	Early Qualification Run	1135°C	9,830 hours Performance Normal
18-11	Full Qualification Run	1135°C	5,276 Hours Performance Normal
18-12	Early Flight Production Run	1035°C	1,842 Hours Performance Normal

18 Couple Module: 18-10

As of 26 September 1994, the module has achieved 9,833 hours at the accelerated hot shoe temperature of 1135°C. During this reporting period, measured performance continued to fall within the data base established by MHW and GPHS 18 couple modules. The module will reach 10,000 hours on 3 October 1994. A final series of measurements will be made and testing will be terminated in October.

The thermoelectric performance is evaluated primarily by the trends of the internal resistance and power factor. Figures 4-1 and 4-2 show these trends in comparison to GPHS module 18-8, the last module built during the 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 initial and 9,830 hour performance.

Figure 4-1. Initial Resistance Ratio (18-10, 18-11, and GPHS 18-8 Modules)
 1135°C Operation

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

**Table 4-2. Comparison of Initial and 9,830 Hour Performance of
 Module 18-10 at 1135°C**

	Initial 8/4/93	t = 9,830 hours 9/26/94
Heat Input, Watts	191	192.5
Hot Shoe, °C Average	1136.2	1127.8
Hot Shoe Range, °C	3.9	7.0
Cold Strap, C Average (8 T/Cs), °C	309.5	308.0
Cold Strap Range (8T/Cs), °C	10.8	13.2
Cold Strap Average (12 T/Cs), °C	304.6	302.6
Cold Strap Range (12 T/Cs), °C	22.3	23.0
Load Voltage, Volts	3.501	3.517
Link Voltage, Volts	0.189	0.175
Current, Amps	3.168	2.920
Open Circuit Voltage, Volts	7.151	7.530
Normalized Open Circuits (8T/Cs)	6.324	6.716
Normalized Open Circuits (12 T/Cs)	6.284	6.670
Average Couple Seebeck Coefficient (12)	499×10^{-6}	529.4×10^{-6}
Internal Resistance, Ohms	1.093	1.315
Internal Resistance Per Couple (Avg.)	0.0607	0.0730
Power Measured, Watts (Load + Link)	11.691	10.78
Power Normalized, Watts (8 T/Cs)	9.143	8.58
Power Normalized, Watts (12 T/Cs)	9.028	8.46
Power Factor	40.987×10^{-5}	38.37×10^{-5}
Isolation		
Circuit to Foil, Volts	-1.676	-1.063
Circuit to Foil, Ohms	5.22K	1.08K

Isolation resistance trend between the thermoelectric circuit and the foil is shown in Figure 4-3 with modules from the MHW and GPHS programs. Upon restart after the 23 June 1994 shutdown to regenerate the cryopump, the isolation resistance plateaued at 10.1 k Ω . This plateauing had been observed in some previous modules, however, the records are not readily available to determine if a shutdown preceded it. It should be kept in mind that at the accelerated temperature of 1135°C the same amount of sublimation occurs in about 1,650 hours as would occur in the Cassini mission in 16 years. Consequently, the module test has long ago shown the adequacy of the silicon nitride coating.

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

To make a more direct comparison of the 18-10 and 18-8 trends, differences in hot shoe operating temperature as shown in Figure 4-4 must be taken into account. The rate at which materials sublime from the hot shoe and hot junction region has an exponential temperature dependence. A 15°C increase in temperature raises the sublimation rate by 50%. Analyses were performed to correct the 18-10 data to the same temperature level as 18-8. The 18-10 times are shifted to the right by an amount proportionate to the difference in sublimation rates at the two temperatures. Results are shown in Figure 4-5.

Figure 4-4. Hot Shoe Temperature - Modules 18-10, 18-11 and GPHS 18-8
 1135°C Operation

* 18-10 and 18-11 Times Normalized to 18-8 Time With Respect To Sublimation

Figure 4-5. Isolation Resistance Versus Normalized Time
 for Modules 18-8, 18-10 and 18-11 - 1135°C Operation

Individual Unicouple Performance: Observations continue to be made of the performance of individual couples and rows of couples. 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 couples in rows 2 and 5. As shown, the unicouples continue to perform in a narrow band.

Table 4-3. Module 18-10 Internal Resistance Changes

Position	Serial #	2nd Bond Milliohm	Preassy Milliohm	Deltari Milliohm	T = 0 Milliohm	T=1,500 Hours	Deltari Milliohm	Percent Increase	T=9,830 Hours	Deltari Milliohm	Percent Increase
1.0	H0148	22.90	22.60	-0.30							
2.0	H0149	22.90	22.70	-0.20							
3.0	H0150	22.80	22.50	-0.30							
					183.00	198.70	15.70	8.60	219.9	36.9	20.2
4.0	H0250	23.20	22.80	-0.40	61.60	66.80	5.20	8.40	73.7	12.1	19.6
5.0	H0256	23.10	22.70	-0.40	61.60	67.00	5.40	8.80	73.9	12.3	20.0
6.0	H0172	22.80	22.80	0.00	61.20	66.90	5.70	9.30	73.8	12.6	20.6
					184.00	200.00	16.00	8.70	220.7	36.7	19.9
7.0	H0044	23.00	22.30	-0.70							
8.0	H0145	22.50	22.20	-0.30							
9.0	H0113	22.50	22.30	-0.20							
					181.00	197.60	16.60	9.20	218.1	37.1	20.5
10.0	H0103	22.60	22.40	-0.20							
11.0	H0184	22.80	22.40	-0.40							
12.0	H0146	22.70	22.40	-0.30							
					183.00	198.60	15.60	8.50	219.2	36.2	19.8
13.0	H0125	22.30	22.00	-0.30	60.00	65.80	5.80	9.70	72.8	12.8	21.3
14.0	H0290	23.10	22.20	-0.90	61.20	66.80	5.60	9.20	73.8	12.6	20.6
15.0	H0201	22.50	22.10	-0.40	60.90	66.70	5.80	9.50	73.7	12.8	21.0
					182.00	198.70	16.70	9.20	219.6	37.6	20.7
16.0	H0176	22.60	22.10	-0.50							
17.0	H0129	22.50	22.20	-0.30							
18.0	H0215	22.60	22.00	-0.60							
					182.00	198.60	16.60	9.10	219.3	37.3	20.5

18 Couple Module: 18-11

Module 18-11 reached 5,276 hours at the accelerated hot shoe temperature of 1135°C on 26 September 1994. Internal resistance and power factor trends are shown in Figures 4-1 and 4-2 along with modules 18-8 and 18-10. Table 4-4 summarizes performance initially and at 5,276 hours.

The measured isolation resistance trend shown in Figure 4-3 and the trend normalized for temperature of Figure 4-5 both show steeper slopes than 18-10. The module experienced two uncontrolled shutdowns during this reporting period. On 24 June 1994 (at 3,400 test hours), there was a vacuum controller failure. On 14 August 1994, there was a power outage and a time delay relay in the vacuum valve circuitry failed. A close examination of the data showed that the slopes were not significantly different before and after the shutdowns. It is concluded that the coating effectiveness lies at the low end of the data base. However, as was previously noted, the accelerated 1135°C temperature testing simulates the Cassini mission in terms of sublimation in 1,650 hours.

**Table 4-4. Comparison of Initial and 5,276 Hour Performance of
 Module 18-11 at 1135°C**

	Initial 2/2/94	t = 52 hours V_L = 3.5V 2/4/94	t = 5,276 hours 9/26/94
Heat Input, Watts	190	192.9	193.7
Hot Shoe, °C Average	1137.8	1137.5	1132.6
Hot Shoe Range °C	5.4	5.2	5.4
Cold Strap, °C Average (8 T/Cs)	311.9	314.3	310.4
Cold Strap Range (8T/Cs), °C	2.6	2.5	2.8
Cold Strap Average (12 T/Cs), °C	306.5	308.9	305.0
Cold Strap Range (12 T/Cs), °C	20.1	20.3	20.4
Load Voltage, Volts	3.895	3.499	3.518
Link Voltage, Volts	0.108	0.121	0.112
Current, Amps	2.842	3.174	3.020
Open Circuit Voltage, Volts	7.140	7.160	7.507
Normalized Open Circuits (8T/Cs)	6.319	6.359	6.678
Normalized Open Circuits (12 T/Cs)	6.276	6.316	6.630
Average Couple Seebeck Coefficient (12)	498 X 10 ⁻⁶	501 X 10 ⁻⁶	526.3 X 10 ⁻⁶
Internal Resistance, Ohms	1.104	1.115	1.284
Internal Resistance Per Couple (Avg.)	0.0613	0.0620	0.0713
Power Measured, Watts (Load + Link)	11.375	11.492	10.96
Power Normalized, Watts (8 T/Cs)	8.909	9.065	8.67
Power Normalized, Watts (12 T/Cs)	8.789	8.942	8.55
Power Factor	40.452 X 10 ⁻⁵	40.557 X 10 ⁻⁵	38.82 X 10 ⁻⁵
Isolation			
Circuit to Foil, Volts	-1.68	-1.36	-1.40
Circuit to Foil, Ohms	6.29K	5.95K	1.5K

Consequently, the module has sublimed about three times the amount that will be sublimed in the entire 16 year Cassini mission and 2.7 kΩ isolation level confirms the adequacy of the coating for this mission.

Individual Unicouple Performance: Module 18-11 is instrumented identically to 18-10. The Performance trends of the six individual rows and six individual couples are being monitored with results shown in Table 4-5. All individual rows and couples are performing within a narrow band.

Table 4-5. Module 18-11 Internal Resistance Changes

Position	Serial #	2nd Bond Milliohm	Preassy Milliohm	Deltari Milliohm	T = 0 Milliohm	T=1,509 Hours	Deltari Milliohm	Percent Increase	T= 5,276 Hours	Deltari 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	212.6	30.3	16.6
4.0	H0439	23.20	22.70	-0.50	62.30	67.90	5.60	8.99	72.2	9.9	15.9
5.0	H0587	22.50	22.40	-0.10	61.00	66.50	5.50	9.02	70.6	9.6	15.7
6.0	H0657	22.70	22.50	-0.20	61.40	67.30	5.90	9.61	71.7	10.3	16.8
					184.10	201.10	17.00	9.23	213.8	29.7	16.1
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	216.4	30.7	16.5
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	214.1	29.2	15.8
13.0	H0428	23.10	22.70	-0.40	62.10	67.90	5.80	9.34	72.2	10.1	16.3
14.0	H0326	22.60	22.00	-0.60	62.20	68.30	6.10	9.81	72.8	10.6	17.0
15.0	H0232	22.60	22.00	-0.60	60.90	66.60	5.70	9.36	70.9	10.0	16.4
					184.70	202.30	17.60	9.53	215.3	30.6	16.6
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	213.9	29.7	16.1

18 Couple Module: 18-12

The module reached 1,842 hours at the normal operating temperature of 1035°C on 26 September 1994. Table 4-6 shows a comparison of initial and 1,842 hour performance. Internal resistance and power ratio trends shown in Figure 4-6 and 4-7, respectively, are in good agreement with GPHS module 18-7. The small drop in internal resistance at 190 hours was due to some dopant redistribution following a shutdown and restart.

Isolation resistance is still increasing and falls within the data base established by the MHW and GPHS programs as shown in Figure 4-8.

Individual Unicouple Performance: A review of the individual row and couple internal resistances and open circuit voltages shows that all couples are showing very similar behavior with time.

**Table 4-6. Comparison of Initial and 1,842 Hour Performance of
 Module 18-12 at 1035°C**

	Initial 6/16/94	t = 1,842 hours 9/26/94
Heat Input, Watts	169.15	169.2
Hot Shoe, °C Average	1035.9	1034.2
Hot Shoe Range, °C	5.7	4.8
Cold Strap, °C Average (8 T/Cs), °C	287.1	284.4
Cold Strap Range (8T/Cs), °C	5.0	5.1
Cold Strap Average (12 T/Cs), °C	282.7	280.0
Cold Strap Range (12 T/Cs), °C	19.8	19.8
Load Voltage, Volts	3.578	3.500
Link Voltage, Volts	0.155	0.157
Current, Amps	2.548	2.574
Open Circuit Voltage, Volts	6.431	6.664
Normalized Open Circuits (8T/Cs)	6.307	6.526
Normalized Open Circuits (12 T/Cs)	6.268	6.486
Average Couple Seebeck Coefficient (12)	497 X 10 ⁻⁶	514.8 X 10 ⁻⁶
Internal Resistance, Ohms	1.053	1.168
Internal Resistance Per Couple (Avg.)	0.0588	0.0649
Power Measured, Watts (Load + Link)	9.510	9.414
Power Normalized, Watts (8 T/Cs)	9.146	9.03
Power Normalized, Watts (12 T/Cs)	8.011	8.89
Power Factor	42.06 X 10 ⁻⁵	40.84 X 10 ⁻⁵
Isolation		
Circuit to Foil, Volts	-1.71	-0.908
Circuit to Foil, Ohms	21.3K	43.8K

Figure 4-6. Initial Resistance Ratio Versus Time Temperature (Modules 18-12 and 18-7)
 1135°C Operation

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

Figure 4-8. Isolation Resistance - Module Circuit to Foil (18-12, GPHS and MHW Modules)
1035°C Operation

Task 5

ETG Fabrication, Assembly, and Test

TASK 5 ETG FABRICATION, ASSEMBLY, AND TEST

Unicouple Production

As a significant milestone during this six month reporting period, the production of E-7 uncouples was completed during May 1994. Substantial progress has also been made on E-8 uncouple production with completion expected by the end of January 1995. An overall status of flight uncouple production is shown in Table 5-1. A summary of accomplishments for E-8 is shown in Table 5-2. Significant issues related to the production of flight uncouples during this reporting period are discussed in the following paragraphs.

Hydrogen Brazing Furnaces

During the July-August period, both hydrogen furnaces were shut down, cleaned and refurbished with new cooling sections and other minor upgrades. The maintenance work was necessitated due to cooling water leaks. Although the work was staggered between the two furnaces, approximately a month of production was lost. Reference the July 1994 and August 1994 monthly technical reports for specific details.

N-P Bonding in Hot Press #2 (HP-2)

With the start of E-8 N-P bonding/hot shoe fabrication, a slight downward shift of hot shoe strengths was noted. The strength has stayed above the 30 kg minimum and no changes in other properties have been noted. As a result of this situation, a cautious production mode has been implemented to obtain hot shoe inspection/test data from N-P bonds before initiating another N-P bond. This approach is aimed at optimizing the bonding parameters to increase the hot shoe strength. Some progress has been made in this area, but the cautious production mode is still being followed. Due to the availability of hot shoes from E-7 work, the cautious production mode does not impact production goals.

Staining at the Pellet/Hot Shoe Interface

During April 1994, approximately 50 uncouples and couple preassemblies were placed on non-conformance report due to staining at the pellet/hot shoe interface. The cause of the staining was identified as slow solvent drying from a cleaning operation at the first bond assembly level. Use of an improved drying rack has eliminated this problem. Due to the large number of assemblies affected, it was decided to conduct TGA testing to determine if the stains were detrimental to the silicon nitride coating. Four samples were selected and sent to Battelle-Columbus for 800-hour TGA testing. Tests are currently under way with no conclusions yet.

**Table 5-1. Cassini RTG Program Unicouple Hardware Production Status
(Through 21 September 1994)**

	Qual Lot			E-6				
	Total Accepted	Actual Yield *	Planned Yield	Cumulative ITD			Total Planned Starts	Planned Yield
				Total Starts	Total Accepted	Actual Yield *		
Vacuum Castings	90	98.9%	92.9%	54	54	100%	54	95.0%
Powder Blends	42	93.3%	94.3%	26	26	100%	26	96.0%
Hot Pressing	165	95.9%	85.7%	149	143	96.0%	149	90.0%
N-P Bonds	34	85.0%	85.7%	40	35	87.5%	40	90.0%
Pellets	1838	67.0%	78.6%	3020	2444	80.9%	3020	85.0%
Segments	2739	89.1%	78.6%	3921	3629	92.6%	3921	85.0%
Hot Shoes	1235	88.6%	78.6%	1541	1358	88.1%	1541	85.0%
First Bonds	736	93.2%	74.3%	1245	1172	94.1%	1245	82.0%
Coated First Bonds	591	85.9%	85.7%	1168	1086	93.0%	1168	90.0%
Second Bonds	411	91.3%	85.7%	1012	846	83.6%	1012	90.0%
Nickel Plating	2300	96.1%	90.0%	8568	8503	99.2%	8568	93.0%
Couple Preassembly	367	92.4%	85.7%	835	735	88.0%	835	90.0%
Brazed Radiator Assembly	455	91.9%	90.0%	1103	955	86.6%	1103	93.0%
Machined Radiator Assembly	351	98.0%	88.6%	961	825	85.8%	961	92.0%
Cold Stack	290	85.5%	90.0%	817	749	91.7%	817	93.0%
Coated Spacers	405	92.0%	85.7%	840	742	88.3%	840	90.0%
Unicouple Assembly	234	84.2%	87.1%	750	662	88.3%	750	91.0%
Wrapped Unicouple Assembly	225	97.0%	95.8%	652	647	99.2%	652	97.0%

	E-7					E-8 (and Contingency)						
	Cumulative ITD			Total Planned Starts	Planned Yield	Started This Week	Accepted This Week	Cumulative ITD			Total Planned Starts	Planned Yield
	Total Starts	Total Accepted	Actual Yield *					Total Starts	Total Accepted	Actual Yield *		
Vacuum Castings	59	58	98.3%	59	96.0%	♦	♦	82	78	95.1%	82	96.8%
Powder Blends	28	27	96.4%	28	96.8%	♦	♦	35	33	94.3%	35	97.4%
Hot Pressing	141	139	98.6%	141	92.0%	♦	0	175	171	98.3%	175	93.6%
N-P Bonds	39	35	94.6%	39	92.0%	1	0	26	23	100%	49	93.6%
Pellets	3885	3396	87.4%	3885	86.5%	483	171	4631	2284	87.3%	4835	87.9%
Segments	3624	2937	91.0%	3624	86.5%	0	0	4708	3121	88.8%	4708	87.9%
Hot Shoes	1740	1454	88.4%	1740	86.5%	41	85	1050	884	95.6%	1875	87.9%
First Bonds	1201	1132	94.3%	1201	85.6%	78	87	1173	997	95.4%	1516	88.5%
Coated First Bonds	1008	948	94.0%	1008	92.0%	96	31	848	755	96.3%	1256	93.6%
Second Bonds	944	907	96.7%	944	92.0%	24	25	734	597	91.6%	1122	93.6%
Nickel Plating	9954	9835	98.8%	9954	94.4%	546	504	6867	6191	98.9%	10836	95.5%
Couple Preassembly	807	745	93.8%	807	92.0%	29	48	445	251	78.7%	1014	93.6%
Brazed Radiator Assembly	1071	984	91.9%	1071	94.4%	63	39	808	620	90.9%	1140	95.5%
Machined Radiator Assembly	946	872	92.2%	946	93.6%	78	55	600	489	93.7%	1060	94.9%
Cold Stack	865	730	84.4%	865	94.1%	30	94	448	366	91.7%	976	94.9%
Coated Spacers	840	817	97.3%	840	92.0%	80	0	680	484	80.7%	1024	93.6%
Unicouple Assembly	716	630	89.6%	716	92.8%	30	37	295	219	85.2%	908	94.2%
Wrapped Unicouple Assembly	637	595	97.4%	637	97.6%	38	0	222	63	100%	810	98.0%

* Cumulative Actual Yield is computed as the ratio of the Total Number Accepted (ITD) to the Total Number Completed and processed through Inspection (ITD). The difference between Total Starts (ITD) and Total Accepted (ITD) is a combination of hardware in-process that has not been completed through Inspection, and hardware that has been rejected.

♦ Production complete.

Table 5-2. Summary of Accomplishments for E-8 Unicouple Production (Excluding Contingency)

	<i>Percent of E-8 Production Completed through Inspection</i>	
	End of March (3/23/94)	End of September (9/21/94)
First Bonds	15%	93%
Second Bonds	2%	71%
Cold Stack	0%	49%
Couple Preassembly	0%	33%
Unicouple Assembly	0%	32%
Wrapped Unicouple Assembly	0%	10%

Post TGA Blue Discoloration

During April 1994, a review of post TGA (silicon nitride coated) test specimens identified a bluish tinge on the SiMo P side of the hot shoe. No variation in TGA test results was related to this observation, however an investigation into its occurrence was initiated. Oxidation of the silicon nitride coating is the most probable cause for the discoloration. A review of oxygen levels and operation of the CVD and TGA furnaces was conducted to determine the source of the oxygen. Samples were also sent to Martin Marietta Labs for XPS testing. The tests have been completed and data analysis is in-process. A final report on this issue will be completed by mid-November 1994.

Second Bond - Static Load Fixture

A review of inspection data for 200 plus second bond assemblies, of which approximately half were fabricated using the static load fixture and half using tungsten clips, revealed almost identical results. Production of second bond assemblies using the static load fixtures was resumed, alternating one week using the static load fixtures and one week using tungsten clips. Subsequent monitoring of inspection data confirms nearly identical yields. While overall yields were similar, assemblies fabricated using the static load fixtures had a slightly higher incidence of misalignment. An engineering evaluation was conducted to determine if the use of heavier weights would alleviate this condition. Satisfactory results were obtained and ECNs are being processed to permit use of heavier weights. The selection of which fixture to use for product is at the discretion of the process engineer. As noted before, the availability of different segment lots will be a major factor in this decision.

Machining of Electrical Insulators

Machining of electrical insulators at the vendor (Sheffield) has continued with satisfactory results during this reporting period. The parallel effort to develop an alternate vendor (INSACO) has progressed to the point where a proprietary agreement has been reached and development work started. INSACO has delivered an initial lot of parts (non-prime) for in-house evaluation. The evaluation will continue into next month. Preliminary results are encouraging.

Cold Stack Assembly

During this reporting period, 367 assemblies have been accepted at a yield of 91.8%. This confirms that the improvements in machining the radiator assemblies (discussed during the last reporting period) have provided control over the previously experienced braze problems.

EMQ Productivity Improvement Team

In April, a weekly EMQ team review session was established to evaluate the past week's inspection results. The purpose of the meeting is to evaluate ways to improve the initial process yields and eliminate rework of hardware. The result of this focused approach to process problems has shown a steady improvement in process yields and a reduction in the amount of rework required.

Procurement of Additional Unicouple Parts

Tungsten Cold Shoes: Procurement of cold shoes fabricated via wire EDM slicing then lapping from Schwarzkopf has been troubled with evidence of microcracks. Microcracks are generated during wire EDM slicing, and proper lapping of both sides is necessary to provide crack-free surfaces. Of six separate lots, only one lot was accepted. An EMQ team has been working with Schwarzkopf and their lapping vendor to resolve this issue. Consideration is also being given to pursuing an abrasive wheel cut-off process.

Amzirc Heat Shunts: Another lot of 3700 parts was fabricated and delivered in May. In-house inspection and acceptance testing is in-process.

Tungsten Compensators: An order was placed in August with the original vendor (Osram Sylvania). Delivery is promised in mid-November 1994.

Hot Shoe Spacers: An order was placed for 1100 parts in April with AISiMag, the original supplier. All of the parts have been delivered. The first lot has completed inspection and acceptance testing and has been released to production. Inspection and acceptance testing of the remaining parts is in-process.

E-6 Thermopile Assembly

During this reporting period, assembly of the E-6 thermopile was successfully completed. In the final stages of thermopile fabrication during May 1994, it was discovered that some of the unicouple pairs exceeded the engineering flag of .40 m Ω difference between the calculated and measured resistance values. From a performance standpoint, converter output is not impacted since rivet joint resistance is insignificant to the thermopile resistance. (The typical room temperature unicouple to joint resistance ratio is 30 to 1.) Furthermore, it has been concluded that failure of a rivet joint (producing an open circuit) is not credible. The primary concern with rivet joints which exhibit resistance behavior outside the norm is that the resistance value may change (increase) during vibration testing, thereby complicating data interpretation.

As a conservative position, it was decided to replace rivets where resistance exceeded an established criteria. This decision resulted in the replacement of twenty-three rivets. Subsequent to this replacement, re-measurement of all the unicouple pairs in the thermopile showed additional pairs whose resistance exceeded the 0.40 m Ω engineering flag. At that time it was decided to put replacement of additional rivets on hold pending determination of the cause of the increasing resistance. At this point, technical exchanges with rivet manufacturers, as well as in-house consultants, were conducted. As a result of this, a new rivet lot with a slightly different eyelet configuration was obtained and samples prepared. It was initially thought that these rivets would provide superior performance and be candidates for use on all subsequent riveting. As discussed later, these new rivets were not satisfactory.

Sample rivets joints using the same lot of rivets (5215P1 manufactured by Marson) in E-6 thermopile, but with varied pulling and swaging forces, were also evaluated. These (E-6) Marson samples included two configurations – a "loose" fit and a "tight" fit between the rivet mandrel and eyelet. In addition to these samples, residual rivets and a cherry rivet lot were installed in samples and evaluated. Solid rivets were also obtained and samples prepared in order to get a performance comparison between pop rivets (current design) and solid rivets. Figure 5-1 illustrates a few of the sample rivet joints fabricated.

Figure 5-1. Rivet Joint Samples

Accounting for all combinations of rivet types, approximately 700 sample rivet joints were fabricated and evaluated. This evaluation included thermal vacuum simulation of converter processing and operating conditions. The results of this rivet evaluation program clearly indicated that the Marson (E-6) "loose" rivets have superior electrical performance in comparison to the other rivet types evaluated. While a substantial amount of knowledge was gained in terms of selecting a rivet type and optimizing the pulling and swaging forces, an explanation for the cause of increasing resistance was not produced. As a result, the conservative option to once again proceed with replacement was selected. An additional forty high resistance rivet joints were replaced. Replacement rivets were the Marson (E-6) "loose" fit rivets. Replacement continued into early August 1994. Following replacement, additional pairs of unicouples were found to exceed the 0.4 m Ω flag. At this point in time, however, the parallel effort to understand the cause for the rivet joint resistance increase finally yielded some meaningful results.

During mid-August 1994, the parallel engineering effort focused on materials/chemistry issues as a cause for the resistance problem. Tests of high resistance rivet joints, representative of joints in the E-6 thermopile, confirmed earlier scoping experiments which showed that, when exposed to converter processing/operating (i.e., thermal/vacuum) conditions, the rivet joint resistance decreased to an acceptable level and remained at that level throughout the converter processing and operating scenarios. A full discussion of the tests conducted and results is provided in the following paragraphs. The conclusion provided by the tests was that additional rivet replacement was not required. A chronological recap of the rivet resistance concern discussed above is illustrated in Figure 5-2.

Three test sets have been completed which demonstrate that E-6 representative rivet joint resistances are reduced by factors of 6 to 10 when exposed to converter processing (thermal/vacuum). The resistance remains low through simulated converter processing steps and converter operating conditions in which the test joints remain in vacuum or argon environments.

A schematic of the test setup is shown below.

Representative test conditions/sequence were as follows.

- Assemble in air; ambient temperature (measure resistance).
- Apply current, 2.5 amps.
- Backfill with argon; ambient temperature (measure resistance).
- Vacuum; ambient temperature (measure resistance)
- Vacuum; 300°C; hold ≥ 8 hours (measure resistance)
- Lower temperature to ambient; backfill with argon; hold ≤ 24 hours (measure resistance).
- Vacuum (measure resistance); increase temperature to 300°C; hold ≥ 8 hours (measure resistance).
- Backfill with argon at 300°C; decrease temperature to 190°C; hold 1 hour (measure resistance).
- Vacuum; 300°C (measure resistance)

Figure 5-2. Chronological Recap of the Resolution of the E-6 Rivet Resistance Concern

Test results are provided in the following tables. Note that the increase in resistivity of copper with increasing temperature is also a factor in comparing high temperature versus low temperature data after thermal vacuum cycle.

Test Results – Rivet Test #1 (Units in mΩ)

E-6 Representative Rivets		In Air in Chamber	In Vacuum in Chamber	In Vacuum 300°C	In Vacuum 17.5 Hours 300°C	Vacuum 51°C	Argon 66 Hours 20°C	Air 158 Hours 20°C
Triple #13	Parallel (R12)	1.74	1.66	0.23	0.20	0.14	0.10	0.10
	Parallel (R23)	2.16	1.84	0.24	0.21	0.15	0.10	0.10
	Series (R13)	0.83	0.72	0.15	0.13	0.09	0.06	0.05
Double #28 (R45)		3.86	3.82	0.15	0.11	0.08	0.05	0.05
Double #29 (R67)		3.83	3.64	0.16	0.13	0.09	0.06	0.06

Test Results – Rivet Test #2 (Units in mΩ)

E-6 Representative Rivets		In Air in Chamber	In Vacuum in Chamber	In Vacuum 300°C	In Vacuum 42 Hours 300°C	Vacuum 58°C	Argon 24 Hours 20°C	Vacuum 300°C	Argon 1 Hour 190°C	Vacuum 138 Hours 300°C
Triple #3	Parallel (R12)	6.90	3.07	0.18	0.17	0.13	0.08	0.17	0.12	0.17
	Parallel (R23)	7.75	3.53	0.19	0.18	0.13	0.08	0.18	0.12	0.17
	Series (R13)	2.04	1.03	0.14	0.13	0.09	0.06	0.13	0.09	0.13
Double #24 (R45)		1.77	0.86	0.09	0.08	0.06	0.04	0.08	0.06	0.08
Double #30 (R67)		0.76	0.45	0.11	0.10	0.07	0.05	0.10	0.06	0.10

Test Results – Rivet Test #3 (Units in mΩ)

E-6 Representative Rivets		In Air in Chamber	In Vacuum in Chamber	In Vacuum 300°C	In Vacuum 20 Hours 300°C	Vacuum 55°C	Argon 112 Hours 20°C
Triple #10	Parallel (R12)	1.64	1.32	0.22	0.20	0.14	0.09
	Parallel (R23)	0.67	0.62	0.22	0.20	0.14	0.10
	Series (R13)	1.03	0.80	0.14	0.13	0.09	0.06
Double #31 (R45)		0.11	0.17	0.12	0.11	0.07	0.05
Double #32 (R67)		0.08	0.11	0.10	0.09	0.06	0.04

The conclusions are:

- All rivet joints with initially high and low resistances are reduced to low values after testing in vacuum at 300°C.
- Resistance remained at low levels after further testing in argon, vacuum, and air (with no agitation during measurement).
- Rivets in E-6 thermopile will have acceptable resistances during testing, fueling, storage, and flight conditions.

The cause for the decrease in resistance after thermal vacuum cycling is related to the oxide which is formed on the nickel plating. Rivet joints which are not "gas tight" are continually subjected to oxidation which causes resistance to increase as function of time. Presently, the major factor to explain the rivet joint resistance changes is that the nickel oxide absorbs moisture forming a high resistance barrier. This moisture is eliminated during thermal vacuum cycle and a corresponding decrease in resistance is achieved. If maintained in an inert or vacuum environment the resistance remains low since moisture is not present to re-form the barrier. Other factors may also be involved as listed below.

- Resistivity of nickel oxide decreases as temperature is increased.
- The oxide itself is eliminated during thermal vacuum processing.
- Dielectric breakdown of the oxide barrier.

As shown in Figure 5-2, engineering work is continuing to definitize which mechanisms are responsible for the rivet joint resistance behavior.

Loose protruding mandrels, which have sufficient length to contact the case and cause a short, were also addressed during this reporting period. A total of twelve loose protruding mandrels were identified in E-6. The initial approach of resolving this problem was to wrap quartz cloth around the mandrels. Later an improved method of trimming the mandrels to reduce their height and permanently eliminate the possibility of an electrical short was selected as the preferred approach.

On Tuesday, 16 August 1994, a reduction in isolation resistance between the thermopile circuit and ground was observed while wrapping uncouple electrical connectors. The isolation resistance was in the 13-15 K Ω range. The requirement is 2 M Ω minimum. Immediately after the short appeared, the instrumentation was checked and a close visual inspection of each double row in the thermopile was completed. A recreation of the sequence of events leading up to the short was performed in an attempt to locate the short and/or determine the cause. After an intensive effort to locate the short was unsuccessful, it was decided to continue with the uncouple connector wrapping. After a vacuuming operation conducted several hours later, the isolation resistance returned to its normal value (above 20 M Ω). Following this, exhaustive diagnostic work was conducted over a two week period to determine the cause for the short. No specific reason was found. A special EMQ session was also held to review this matter. The conclusion reached from these evaluations was that particulates or moisture contamination, which was subsequently eliminated during vacuuming was the cause for the reduced isolation resistance.

For the high resistance, test results for the rivet joints demonstrate that, when rivet joints are exposed to simulated converter processing and operating conditions, the rivet joint resistance decreases to a satisfactory level.

A review of the rivet resistance and reduced isolation resistance issues was conducted with DOE on 8 September 1994. The testing and evaluations conducted in both of these areas was presented in conjunction with Martin Marietta recommendation to proceed with converter assembly (i.e., mating of the thermopile to the shell). Following the review, DOE concurrence with the Martin Marietta recommendation to proceed was granted.

Preparation of the thermopile (305037-10) planning package and preparation of the shell (305032-20) planning package have been completed. The mating operation (305032-30) planning package has been initiated.~ Figure 5-3 illustrates the thermopile and shell in position to be mated. Figures 5-4, 5-5, and 5-6 illustrate the tooling at each end of the thermopile and the interface between the thermopile and shell.

Figure 5.3. Thermopile and Shell in Position to Be Mated

Figure 5-4. Interface Between Thermopile and Shell Prior to Mating

Figure 5-5. Thermopile Support Tooling

Figure 5-6. Thermopile Guide Support

Solid Rivet Development

As previously mentioned, solid rivet development was initiated during the rivet evaluation task. Additional samples were fabricated and electrical performance and metallographic sections were evaluated. Results showed that solid rivets look promising.

During September 1994, efforts proceeded toward developing the tooling needed for the installation of solid rivets into the thermopile electrical circuit. While existing tooling was available to fabricate individual solid rivet joint samples outside the thermopile fixture, the swaging (setting) of solid rivets on the thermopile fixture required the design of new tooling. Due to the geometry limitations with the thermopile fixturing, several iterations were required before a final tooling setup was achieved. The machining and heat treatment of the necessary tooling was completed. During the tools trials it was identified that the solid rivet required modification. The head of the solid rivet must be reduced (machined down) to provide the necessary clearance between the top of the rivet and the shell. A group of solid rivets is presently being machined (to be followed by deburring and cleaning) for use in the upcoming demonstration tests. The verification plan (Ref. CON 1020) was completed detailing the demonstration tests to be performed and the demonstration tests have been initiated.

E-6 Converter Shell Assembly

Assembly of the Gas Management, PRD diaphragm and Electrical Receptacle assemblies to the E-6 shell assembly has been completed. Cleaning and vacuuming of the E-6 shell assembly, in preparation for delivery to the converter assembly area, is complete.

The E-6 converter shell assembly has been moved to the converter assembly area and converter shell prep for thermopile insertion has been completed.

E-6 Converter Shell Subassembly

The outboard heat source support assembly, less foil insulation or yarn wrapping, was assembled in preparation for preloading/alignment. The installation of the inboard and outboard latches and the outboard heat source support to the E-6 shell was completed. Preloading of the outboard heat source support assembly was then performed. Measurements of alignment were taken and the necessary shimming of the outboard heat source support was completed. The alignment was rechecked and found to be acceptable after shimming. Alignment of the inboard latches required an ECN which permitted increasing the latch hole diameters in order to meet the parallelism requirements. The hole diameters in the latches were then enlarged and inspected. The latches were reinstalled and the parallelism check was found to be acceptable.

E-7 Unicouple Map

The E-7 unicouple map has been completed and formally released following Engineering and Quality review.

E-7 Thermopile Assembly

The E-7 foil and cloth insulation assembly was completed with a significantly reduced cycle time as compared to E-6. This is attributed to improved procedures and increased operator experience. In addition, transfer of the foil assembly to the thermopile assembly fixture has been successfully completed. Figure 5-7 illustrates the thermopile assembly fixture including the foil insulation package just after transfer of the foil package.

Figure 5-7. E-7 Foil Insulation Assembly Prior to Unicouple Insertion

E-7 Shell/Fin Assembly

PD224 emissivity coating has been applied to the E-7 shell/fin assembly. Also, the boron nitride coating of the inboard end dome sealing surface has been applied. The shell/fin assembly was packaged and shipped to the thermal vacuum vendor for coating bakeout.

The unit was repackaged and return shipped to Martin Marietta for further disposition. Final disposition of the bent fins required straightening which was successfully completed with a non-impact method. Post rework X-rays of the reworked fins revealed no cracks. Touchup or repair of the reworked, painted surfaces was not necessary. The unit was repackaged with a tamper proof seal on the shipping container to prevent undetectable opening of the shipping container. The unit arrived at the vendor without damage, unpacked by Martin Marietta personnel, and thermal vacuum processed.

Flow cleaning, evacuation and inert gas backfilling of the Auxiliary Cooling System (ACS) was completed.

E-8 Shell/Fin Assembly

Electron beam welding of the cooling fin assemblies to the E-8 shell assembly was completed. X-rays of the welds revealed two (2) small out-of-tolerance porosity defects. These porosity defects were reviewed by Engineering and accepted by MRB action.

RTD Qualification Cable and E-6 RTD Cable Production

During this reporting period, two RTD cables were fabricated, one for the qualification testing and one for E-6 production requirements. During the production of the cables, all critical operations were inspected to assure conformance to the drawing requirements. Upon the successful fabrication of both units, the qualification cable was delivered to Quality Assurance for acceptance and qualification testing. The final buyoff of the E-6 units will be completed after the completion of the qualification testing.

Both units successfully passed post fabrication x-ray. During the electrical checkout of the cables, an anomaly was noted on both units. Engineering reviewed the data concluded that it was acceptable and issued an ECN to eliminate the anomaly. Subsequently the qualification unit was subjected to the thermal vacuum test.

The RTD cable passed the acceptance thermal vacuum test in September 1994.

Task 6

Ground Support Equipment

TASK 6 GROUND SUPPORT EQUIPMENT (GSE)

Read Out Console (ROC)

Following the rework to include the new Data Acquisition System (DAS), the ROCs have been inspected and accepted by QA including final calibration of all instruments. One of the ROCs was used for the operating training phase where it was interfaced with the Loading and Assembly Station (LAS) and the Qual ETG. This was a demonstration that verified all ETG processing operations including emergency alarm functions. A formal functional checkout is planned for all three ROCs during FW 41, 42 and 43 utilizing the new software for the DAS. ROCs will then be ready for buyoff.

Other GSE

All handling equipment and the Converter Shipping Container (CSC) have been subjected to proof load testing. Also, the RTG Shipping Container and Cage has been proof loaded to meet the Cape launch site requirements. Following inspection, it has been noted that some minor rework is required on the CSC base. All other GSE is being reinspected and cleaned prior to returning to Building 800.

Task 7

RTG Shipping and Launch Support

TASK 7 RTG SHIPPING AND LAUNCH SUPPORT

Support for the development of the new RTG Transportation System was continued this reporting period. The Safety Analysis Report was reviewed along with design review data packages for the licensed containment hardware as well as the transport trailer and auxiliary systems. Comments were provided to Westinghouse Hanford Company and design review meetings were attended at Hanford in September.

Launch support activity in this report period focused on planning the handling operations and the route the RTGs will follow at the launch facility (Cape Canaveral Air Force Station Pad 40). It has been decided that the RTGs will be lifted into the launch facility with facility cranes rather than the facility elevator. The RTG routing is generally the same as that used for the payload fairing. Further refinement of the lifting and handling operations is continuing.

Task 8

Designs, Review, and Mission Applications

TASK 8 DESIGNS, REVIEWS, AND MISSION APPLICATIONS

8.1 Galileo/Ulysses Flight Performance Analysis

GPHS-RTGs flying aboard the Galileo and Ulysses spacecraft continue to perform well. Their performance when compared to previous systems flown on Voyager, LES, etc. is shown on Figure 8-1. The power system performance on Galileo falls well within the previous flight performance. The Ulysses performance falls on the low side of the bulk data. However, the Ulysses data has considerable uncertainty due to the way the data are measured. Models generated by Martin Marietta indicate the performance is as expected and the power unit will deliver the required energy at the end of mission (see Figure 8.2).

8.2 Individual and Module Multicouple Testing

All multicouple life tests were terminated during this reporting period based on direction received from DOE (reference Ser RTG-052). The accumulated hours of testing for each of the five multicouples are shown in Table 8-1.

Table 8-1. Multicouple Life Test Summary

Multicouple	Test Completion	Accumulated Test Hours
Build 3 - M/C 1026-8	8/14/94	25,012
Build 5 - M/C M042-G4	8/14/94	9,070
Build 5 - M/C M043-18	9/9/94	7,878
Build 5 - M/C N042-5 (No GaP)	8/31/94	16,406
Build 5 - M/C M043-19	8/31/94	16,858

All multicouples except M043-19 operated at normal RTG operating temperatures and with a -6 volt bias applied between the negative multicouple terminal and ground. Multicouple M043-19 operated at reduced, normal, and accelerated hot side temperatures as shown in Table 8-2. The multicouple performance trends are shown in Figures 8-3 and 8-4.

Figure 8-1. Comparison of All Silicon-Germanium RTG Power Data

Figure 8-2. Measured and Predicted Power Output from the GPHS-RTG on the Ulysses

Figure 8-3. Performance Trend for Build 3 Multicouple

Figure 8-4. Performance Trends for Build 5 Multicouples

Table 8-2. Multicouple M043-19 Test History

Hot Junction Operating Temp (°C) .	Time at Operating Temp (hours.)
1000	1838
1050	3753
950	11,267
Total	16,858

During the next reporting period, the multicouples will be removed from their test stations for careful visual examination. These post test observations, and an analysis of the multicouple performance data, will be reported in subsequent Technical Progress reports. These activities will be reported under Task 8.5 and are shown in the Task 8.5 schedule.

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

A paper titled "Cassini RTGs - Small Scale Module Tests" by C. Edward Kelly and Paul Klee was presented at the 29th Intersociety Energy Conversion Engineering Conference which took place in Monterey, California on 7-11 August 1994.

8.5 Evaluation of an Improved Performance Unicouple

The objective of this task is to fabricate an improved performance unicouple and to evaluate its performance in an 18 couple test module. The development and fabrication plan for this task is shown in Figure 8-5. The plan was revised in May in order to reduce development costs. The revisions included reducing the quantity of second bond development samples from 16 to 10 and the quantity of unicouples to be built for rivet trials from 3 to 2.

Two methods for fabricating the improved SiGe N material were evaluated during this reporting period. A composition of Si 0.7712, Ge 0.1928, Ga 0.0072, P 0.0288 was prepared by Martin Marietta using the vacuum casting/hot pressing method. This composition, designated as CAS 4887, was heat treated at 1225°C for 50 hours in an attempt to further enhance its high temperature properties. A composition of Si 0.784, Ge 0.197, Ga 0.005, P 0.015 was prepared at Ames Laboratory using a mechanical alloying (MA) and hot isostatic pressing (HIP) method. No additional heat treatment was applied to the Ames composition.

Figure 8-5. Cassini Task 8.5 Improved Unicouple Development and Fabrication Plan (5/25/94 - Rev. A)

High temperature property measurements were performed by Ames Laboratory on both compositions. The HIP compacts (HIP-15, HIP-17) exhibited superior properties; i.e. $Z = 0.86 \times 10^{-3}/^{\circ}\text{C}$ vs. $0.78 \times 10^{-3}/^{\circ}\text{C}$ for the CAS 4887 composition (reference Table 8-3). The heat treatment applied to the CAS 4887 compact did not improve its properties and resulted in unacceptable porosity. Consequently, the Ames composition produced by mechanical alloying and hot isostatic pressing was selected for the improved unicouples.

The SiGe P material selected for the improved unicouples has the following composition: Si 0.796, Ge 0.199, B 0.005. Compacts of this composition (designated as CAS 4882) were fabricated at Martin Marietta using the vacuum chill cast/hot press method. The high temperature properties of this composition were also measured at Ames Laboratory and are shown in Table 8.4.

High temperature property measurements were also made at Ames Laboratory on the standard Cassini uncouple materials to serve as a basis of comparison. Measurements were made on samples from the thermoelectric material compacts for both the improved materials and the Cassini materials. Electrical property measurements were also made on N and P pellets removed from completed uncouple assemblies; i.e., improved unicouples and Cassini unicouples. The purpose of these measurements was to determine if the thermoelectric materials retained their electrical properties after being subjected to the uncouple manufacturing temperature cycles.

The high temperature property data comparisons are summarized in Table 8-5. The figure-of-merit for the improved N material was $0.86 \times 10^{-3}/^{\circ}\text{C}$ vs. $0.76 \times 10^{-3}/^{\circ}\text{C}$ for the standard Cassini N material. The figure-of-merit for the improved P material was $0.59 \times 10^{-3}/^{\circ}\text{C}$ vs. $0.52 \times 10^{-3}/^{\circ}\text{C}$ for the standard Cassini P material. The improvement in both materials was primarily due to a reduction in thermal conductivity.

Table 8-3(a). SiGe-N Property Data

Sample ID	Sample Source	Meas'd by	Nominal Composition				Sample Config	Sample Size (mm)	Heat Treatment	Reset Treatment	Dens (g/cc)
			Si	Ge	Ga	P					
1 BaselineMOD	MMAS	JPL	77.12%	19.28%	0.72%	2.88%	Bar&Disk	50.8 & 12.5	None	20min@1050	
2 BaselineCAS	MMAS	Ames	78.46%	20.95%	0.00%	0.59%	Bar	15	None	None	
3 BaselineCAS	MMAS	Ames	78.46%	20.95%	0.00%	0.59%	Bar&Disk	15 & 12.5	None	20min@1050	
4 BaselineCAS	MMAS	Ames	78.46%	20.95%	0.00%	0.59%	Bar	15	Unicouple Fab	None	
5 BaselineCAS	MMAS	Ames	78.46%	20.95%	0.00%	0.59%	Bar	15	Unicouple Fab	20min@1050	
6 MOD4202N	MMAS	JPL	77.12%	19.28%	0.72%	2.88%	Bar&Disk	50.8 & 12.5	None	None	
7 MOD4202N	MMAS	JPL	77.12%	19.28%	0.72%	2.88%	Bar	12.5	None	None	
8 MOD4202N	MMAS	JPL	77.12%	19.28%	0.72%	2.88%	Bar&Disk	50.8 & 12.5	15hrs@1225	20min@1050	
9 MOD4202N	MMAS	JPL	77.12%	19.28%	0.72%	2.88%	Bar&Disk	50.8 & 12.5	None	None	
10 MOD4202N	MMAS	Ames	77.12%	19.28%	0.72%	2.88%	Disk	12.5	20hrs@1225	20min@1050	
11 HIP-5	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Horizontal	(Anisotropic)	None	20min@1050	2.99
12 HIP-7	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Bar&Disk	15 & 12.5	None	20min@1050	3.00
13 HIP-8	Ames	Ames	78.40%	19.60%	0.50%	1.50%					
14 HIP-8	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Bar	15	Unicouple Fab	None	
15 HIP-8	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Bar	15	Unicouple Fab	20min@1050	
16 HIP-10	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Disk	12.5	None	None	3.00
17 HIP-10 (1A)	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Bar&Disk	15 & 12.5	None	20min@1050	
18 HIP-10 (1B)	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Disk	12.5	None	20min@1050	
19 HIP-10 (2)	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Bar&Disk	15 & 12.5	None	20min@1050	
20 HIP-15	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Bar&Disk	15 & 12.5	None	20min@1050	3.01
21 HIP-16	Ames	Ames	78.40%	19.60%	0.50%	1.50%					3.01
22 HIP-17	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Bar&Disk	15 & 12.5	None	20min@1050	3.00
23 HIP-18	Ames	Ames	78.40%	19.60%	0.50%	1.50%	Disk	12.5	None	20min@1050	
24 A101-2	Ames	Ames	78.82%	19.70%	0.37%	1.11%	Bar&Disk	15 & 12.5	None	20min@1050	
25 A101-3	Ames	Ames	78.82%	19.70%	0.37%	1.11%	Bar&Disk	15 & 12.5	None	20min@1050	
26 A101-4	Ames	Ames	78.82%	19.70%	0.37%	1.11%	Disk	12.5	None	20min@1050	
27 CAS4887B1	MMAS	Ames	77.12%	19.28%	0.72%	2.88%	Disk	12.5	None	None	2.98
28 CAS4887B1	MMAS	Ames	77.12%	19.28%	0.72%	2.88%	Bar&Disk	15 & 12.5	None	20min@1050	
29 CAS4887B2	MMAS	Ames	77.12%	19.28%	0.72%	2.88%	Disk	12.5	50hrs@1225	None	2.57
30 CAS4887B2	MMAS	Ames	77.12%	19.28%	0.72%	2.88%	Disk	12.5	50hrs@1225	20min@1050	

Table 8-3(b). SiGe-N Property Data

Sample ID	RT n (10*20/cc)	RT μ (cm2/Vs)	RT Rho (m Ω cm)	HT Rho (m Ω cm)	HT See (μ V/K)	HT K (mW/cmK)	HT Z Avg (1/K)	HT μ (cm2/Vs)	HT n (10*20/cc)	Porosity (%)	Grain Size (μ m)		
											Min	Avg	Max
1 BaselineMOD	2.42	26.75	0.96	1.71	-218.1	36.40	0.770	13.34	2.6				
2 BaselineCAS				1.76	-241.9								
3 BaselineCAS	1.64	57.43	0.66	1.63	-238.9	45.60	0.760				?	25	80
4 BaselineCAS				2.05	-249.3								
5 BaselineCAS				1.97	-232.1								
6 MOD4202N	1.77	29.65	1.19	1.48	-227.3	36.46	0.962						
7 MOD4202N				1.30	-215.8	36.46	0.989						
8 MOD4202N	2.91	35.75	0.60	1.45				14.97	3.35				
9 MOD4202N	3.26	23.85	0.80	1.47	-192.9	36.46	0.699						
10 MOD4202N	2.81	40.80	0.54										
11 HIP-5	2.45	50.00	0.51	1.12	-215.5	44.57	0.940						
12 HIP-7	3.45	40.00	0.45	1.26	-200.8	38.61	0.840			<1%	15	20	25
13 HIP-8										<1%	20		30
14 HIP-8				1.51	-215.9								
15 HIP-8				1.41	-197.4								
16 HIP-10	2.09	51.14	0.59										
17 HIP-10 (1A)	3.03	42.20	0.49	1.25	-201.0	35.29	0.938						
18 HIP-10 (1B)	3.54	38.90	0.45										
19 HIP-10 (2)	3.45	39.20	0.45	1.30	-203.2	39.50	0.800						
20 HIP-15	3.45	40.00	0.46	1.25	-200.9	38.70	0.860						
21 HIP-16										<1%			
22 HIP-17	3.37	39.60	0.47	1.22	-201.2	39.45	0.850			<1%			
23 HIP-18	3.47	38.40	0.47							<1%			
24 A101-2	2.95	41.40	0.51	1.28	-210.7	38.70	0.916						
25 A101-3	2.79	41.50	0.54	1.32	-210.3	40.50	0.850						
26 A101-4	2.76	41.20	0.55										
27 CAS4887B1	1.98	32.44	0.97							<1%	1.5	?	30
28 CAS4887B1	3.02	30.67	0.67	1.31	-199.3	38.66	0.783						
29 CAS4887B2	1.70	40.12	0.91							6 - 12 %	2.5	?	30
30 CAS4887B2	3.13	30.37	0.66										

Table 8-4. SiGe P Property Data

	Sample ID	Sample Source	Meas'd by	Nominal Composition			Sample Config	Sample Size (mm)	Heat Treatment	Reset Treatment	Dens (g/cc)
1	BaselineMOD	MMAS	JPL	78.40%	21.36%	0.24%	Bar&Disk	50.8 & 12.5	None	20min@1100	3.00
2	BaselineCAS	MMAS	Ames	78.40%	21.36%	0.24%	Bar	15	None	None	
3	BaselineCAS	MMAS	Ames	78.40%	21.36%	0.24%	Bar&Disk	15 & 12.5	None	4hr@1000	
4	BaselineCAS	MMAS	Ames	78.40%	21.36%	0.24%	Bar	15	Unicouple Fab	None	
5	BaselineCAS	MMAS	Ames	78.40%	21.36%	0.24%	Bar	15	Unicouple Fab	4hr@1000	
6	MOD3298P	MMAS	JPL	78.96%	19.74%	1.30%	Bar&Disk	50.8 & 12.5	None	20min@1100	
7	MOD3298P	MMAS	JPL	78.96%	19.74%	1.30%	Bar&Disk	50.8 & 12.5	50hr@1250	4hr@1000	
8	MOD3298P	MMAS	JPL	78.96%	19.74%	1.30%	Bar&Disk	50.8 & 12.5	50hr@1250	30min@1000	
9	MOD3298P	MMAS	JPL	78.96%	19.74%	1.30%	?	?	20hr@1275	?	
10	MOD4236P	Ames/MM	JPL	79.36%	19.84%	0.80%	Bar&Disk	50.8 & 12.5	None	RTYes/HTNo	
11	MOD4236P	Ames/MM	JPL	79.36%	19.84%	0.80%	Bar&Disk	50.8 & 12.5	20hr@1225	None	
12	MOD4236P	Ames/MM	JPL	79.36%	19.84%	0.80%	Bar&Disk	50.8 & 12.5	20hr@1250	None	
13	CAS4882B1	MMAS	Ames	79.60%	19.90%	0.50%	Disk	12.5	None	None	
14	CAS4882B1	MMAS	Ames	79.60%	19.90%	0.50%	B3 & S1	15 & 12.5	None	4hr@1000	
15	CAS4882B1	MMAS	Ames	79.60%	19.90%	0.50%	B5 & S3	15 & 12.5	None	4hr@1000	
16	CAS4882B1	MMAS	Ames	79.60%	19.90%	0.50%	Bar	15	Unicouple Fab	None	
17	CAS4882B1	MMAS	Ames	79.60%	19.90%	0.50%	Bar	15	Unicouple Fab	4hr@1000	

	Sample ID	RT n (10^20/cc)	RT μ (cm2/Vs)	RT Rho (mΩcm)	HT Rho (mΩcm)	HT See (μV/K)	HT K (mW/cmK)	HT Z Avg (1/K)	HT μ (cm2/Vs)	HT n (10^20/cc)	Grain Size (μm)			
											Min	Avg	Max	
1	BaselineMOD	1.45	33.04	1.310	2.37	225.2	43.91	0.495	12.08	2.47	1	10	30	
2	BaselineCAS	1.59	40.19	0.980	2.07	226.0	47.80	0.519	11.10	3.08		2	3	50
3	BaselineCAS				2.16	228.5						2	30	
4	BaselineCAS				2.34	220.6								
5	BaselineCAS	2.51	224.2											
6	MOD3298P	1.41	174.7	47.29	0.469									
7	MOD3298P	2.12	32.52	0.856	1.77	214.0	46.91	0.565			2	20	50	
8	MOD3298P	3.01	32.52	0.641										
9	MOD3298P	3.04	22.03	0.931	1.79	180.1	36.87	0.502						
10	MOD4236P				1.16	139.3	42.64	0.400						
11	MOD4236P				1.61	165.2	40.00	0.437						
12	MOD4236P	2.85	33.18	0.660	1.81	208.4	42.10	0.575		1.5	?	30		
13	CAS4882B1								1.82				213.0	42.50
14	CAS4882B1				2.10	33.70	0.88	1.53	174.6				1.78	197.8
15	CAS4882B1	2.10	33.70	0.88	1.78	197.8								
16	CAS4882B1													
17	CAS4882B1													

Table 8-5. High Temperature Property Data Comparisons

Integrated Average (300 - 1000°C) Compact Properties (With Reset)

Material	Seebeck (μ V/°C)	Resistivity (m Ω - cm)	Power Factor (μ W/cm°C ²) (S ² /r)	Thermal Conductivity (mW/cm°C)	Figure of Merit (Z) (X10 ⁻³ /°C) (S ² r/k)
N type - Standard Cassini	-238.9	1.63	35.0	45.6	0.76
N Type - Improved	-200.9	1.25	32.3	38.70	0.86
P Type - Standard Cassini	228.5	2.16	24.2	47.80	0.52
P Type - Improved	213.0	1.82	24.9	42.5	0.59

Integrated Average (300 - 1000°C) Unicouple Properties (Without Reset)

N Type - Standard Cassini	-249.3	2.05	30.3
N Type - Improved	-215.9	1.51	30.9
P Type - Standard Cassini	220.6	2.34	20.8
P Type - Improved	174.6	1.53	19.9

Integrated Average (300 - 1000°C) Unicouple Properties (With Reset)

N Type - Standard Cassini	-232.1	1.97	27.3
N Type - Improved	-197.4	1.41	27.6
P Type - Standard Cassini	224.2	2.51	20.4
P Type - Improved	197.8	1.78	22.3

Also shown in Table 8-5 are the electrical properties measured on pellets removed from completed unicouples. Thermal conductivity measurements could not be made due to the limitations of the pellet geometry. The table lists the properties with and without reset. The N type material was reset at 1050°C for 20 minutes and the P type material at 1000°C for 4 hours. The materials were reset to re-dissolve all precipitate phases, thereby providing a more uniform thermodynamic condition from which to begin the measurements. The data showed the improved N and P type materials retained more of their electrical properties than the standard Cassini materials but the Power Factors (S²/p) were about the same after unicouple fabrication. The effect of the unicouple fabrication cycle on the thermal conductivity properties was not measured. It is not expected to change significantly from its compact properties but this cannot be verified until the performance of the 18 couple test module is evaluated.

Many additional thermoelectric material compositions were characterized by Ames Laboratory during this reporting period. Table 8-3 and 8-4 document all high temperature property measurements made by Ames Laboratory in support of this task. Figures 8-6 through 8-12 show the high temperature properties of the improved materials and the standard Cassini materials as a function of temperature.

Five SiGe N compacts were fabricated by Ames using the MA/HIP process and three SiGe P compacts were fabricated by Martin Marietta in support of this task to be used for property measurements, bond development studies and unicouple fabrication.

First and second bond development studies were completed during this reporting period. A two stage bonding process was developed for making first bonds due to the disparity in melting temperature of the improved materials. The optimum bond temperatures were found to be 1321°C for the improved P material and 1248°C for the improved N material. Approximately 20 first bond samples were successfully made, some of which were used for second bond development.

Figure 8-6. Seebeck Coefficient of Improved P-Type SiGe (a) and N-Type SiGe/GaP (b)

Figure 8-7. Electrical Resistivity of Improved P-Type (a) and N-Type SiGe/GaP (b)

Figure 8-8. Thermal Conductivity of Improved P-Type SiGe (A) and N-Type SiGe/GaP (b)

Figure 8-9. Seebeck Coefficient of Standard Cassini P-Type SiGe (a) and N-Type SiGe (b)

Figure 8-10. Electrical Resistivity of Standard Cassini P-Type (a) and N-Type SiGe (b)

Figure 8-11. Thermal Conductivity of Standard Cassini P-Type SiGe (a) and N-Type SiGe (b)

Figure 8-12. Figures-of-Merit of the Improved Materials and Standard Cassini Materials Compared for P-Type SiGe (a) and N-Type SiGe and SiGe/GaP (b)

Ten second bond samples were fabricated and several were destructively examined to determine hot shoe bond strength and bond integrity. The hot shoe bond strength was determined to be 20-25% lower than the Cassini production bonds, but still had adequate margin over the minimum strength required. Metallographic examination showed all bonds to be good; however, the N pellet to segment bond and the cold shoe to segment bond exhibited a higher percentage of bond voids than the Cassini production bonds. It was also observed that the SiGe-GaP N material exhibited more blistering than the Cassini SiGe N material after bonding. Blistering primarily occurred at the hot end of the pellet. Attempts were made to remove these blisters. Most of the blisters on the outer surfaces of the pellet could be removed but they could not be removed from the surface facing the P pellet because of access limitations.

TGA tests were conducted to evaluate the long term effect of the N pellet blisters. Two coated samples with blisters (best and worst case) were heated to 1150°C for 40 hours. The measured weight loss for these samples was compared to the typical weight loss for coated Cassini uncouple materials and to the Cassini weight loss requirements specification (RQ24B1). The measured weight loss of the coated blistered samples was 3.7×10^{-6} and 9.04×10^{-6} g/hour-cm². The weight loss for the coated Cassini production material is typically between 2 and 3×10^{-6} g/hour-cm² and the Cassini specification requirement is 12.0×10^{-6} g/hour-cm² maximum. While the improved material exhibited higher weight loss than the typical Cassini material, it was shown to be less than the maximum allowed by the Cassini specification.

In accordance with the development plan, two uncouples were fabricated with the improved materials and new bonding parameters for the purpose of performing rivet trials. The purpose of the rivet trials was to verify that the new bonds have adequate strength to withstand the loads induced during riveting of the uncouples into the 18 couple module assembly. Both uncouples successfully withstood the loads induced during riveting.

Approximately 25 improved uncouples have been fabricated in accordance with the fabrication plan. During the next reporting period, six of the uncouples will be instrumented and all will be stuffed and wrapped in preparation for insertion into an 18 couple module. Fabrication of the 18 couple module has been started and is expected to be completed in January 1995. Test evaluation of the improved uncouples is expected to begin in February 1995. The schedule for the improved uncouple development and fabrication is shown in Figure 8-13 and the schedule for the fabrication and testing of the 18 couple module is shown in Figure 8-14.

Figure 8-13. Task 8.5 Schedule - Improved Uncouple Development and Fabrication

Figure 8-14. Task 8.5 Schedule - 18 Couple Module Fabrication and Testing

Task 9

**Project Management,
Quality Assurance,
Reliability,
Contract Changes,
CAGO Acquisition,
and
CAGO Maintenance/Repair**

TASK 9 PROJECT MANAGEMENT, QUALITY ASSURANCE, AND RELIABILITY

This task includes the management of the project, quality assurance management and general support, reliability work, operational maintenance and repair of CAGO and proposal effort in response to Modifications.

Task 9.1 Project Management

All contract weekly and monthly reports were delivered on schedule.

During this reporting period, Martin Marietta supported safety meetings at Albuquerque with INSRP, OSTP, NASA, and DOE headquarters. A safety hardware meeting was also held at Los Alamos and a review of the accident environments was supported at Fairchild. In addition, launch planning and Titan Databook meetings were attended. A Reentry Subpanel meeting and a Dynamics Interchange meeting at Aerospace Corporation were supported.

Quarterly and Monthly Cassini RTG program reviews were supported. Martin Marietta witnessed the DTM test at JPL in July. QA Status meetings were held at Valley Forge in July and September.

Vendor visits were made to Hebb Spring and Hygrade Precision, and Engelhard to aid in correction of vendor problems.

9.2 Quality Assurance

Quality Plans and Documents

No new plans were generated during this period. The Inspection and Test Plan (CDRL A.12) was approved by DOE and distributed. The Software Management Plan (CDRL A.7) was updated and is currently in the review cycle. The Quality Assurance Program Plan (CDRL A.3) is being updated and should be ready for final review during October.

Process Readiness and Production Readiness Reviews

No Process Reviews were conducted during this period.

Quality Control of Fabrication

Converter Assembly: During this period, Quality Assurance supported the effort to resolve the rivet questions in the E-6 converter. The rivet question was resolved with closure of the NR during September and the thermopile was ready for insertion into the shell during the first week of October.

Converter Assembly: (Cont'd)

The Unicouple map was completed for E-7 converter and the uncouples are available when needed. The map has been reviewed and approved.

The E-8 Fin and Tube Assemblies were pressure drop tested using temporary hose connections between joints. The resulting pressure drop was below 12 psid and was acceptable. Bake out and pressure test of the E-8 Fin and Tube Assembly was completed.

Efforts are continuing to review hardware for acceptability and traceability prior accumulating into planning packages. A higher-than-desired percentage of the hardware reviewed is requiring rework to make it conform to loose particle and burr requirements. Additional Inspection and QCE support has been applied to that effort. Thus far, the effort has kept pace with demand.

Inspection and acceptance of converter hardware piece parts has continued through the reporting period. Some of the hardware accepted are 'C' seals, plated straps, TC screws, yarn, gas management subassemblies, PRD parts, RTD cable hardware, converter structural hardware, etc.

Unicouple Production: During this period, over half of the processes operated with yields below the goals set for those processes. Many of the problems were one time occurrences which have since been rectified. The hot presses were affected by cooling water flow interlock failures caused by sediment accumulation on the flow meters. In these cases, the presses went into automatic shutdowns during runs. In most cases manual control was used to complete the runs and the product was unaffected. The water system has been flushed.

Machining of thermoelectric material was affected by contamination of a few lots out of the twenty which were processed. These were one time occurrences and, after some precautionary instructions to the operators, they did not reappear.

Second bonding operations for both the spring clip and static load fixture were slightly below the yield goals (84% versus 92% goal). The defects were not fixture related. Problems included a power outage, foreign material, voids and alignment. There is not a dominant defect or serious problem in this process.

Unicouple Production: (Cont'd)

Brazing processes were affected by foreign material, voids, a power outage, and dimensional defects. One power outage resulted in the loss of twenty-one cold stack assemblies. Foreign material problems have been addressed and improvements have been made in most processes during the past six months. Specification changes were made in the manner that parts are assembled in the unicouple process and improvements have been seen in cleanliness. The processes are being evaluated by the EMQ team and improvements in other areas are also being seen.

Other processes, such as coating of first bonds, plating, and machining of segments and hot shoes continue to have excellent yields.

Material Review Board

There have been no Class I (Major) NRs this period.

Quality Assurance Audits

Audits are being performed to the 1995 schedule which includes thermoelectric process audits, converter process audits and QA Systems audits. During this period, audits have been performed on the following processes: unicouple, thermoelectric machining, assembly procedures, mechanical inspection and facilities. QA Systems audits have been performed on configuration and special tools, and a general building audit was performed.

Quality Assurance Status Meetings

Three DOE QA Status meetings were held during this period. There are currently no open action items.

Task H

CAGO Acquisition (Capital Funds)

TASK H CONTRACTOR ACQUIRED GOVERNMENT OWNED PROPERTY (CAGO) ACQUISITION

Task H.1 CAGO Unicouple Equipment

Hydrogen Brazing Furnaces: As reported in Task 5, both hydrogen brazing furnaces required repair due to leaks in cooling water jackets.

Refurbishment and Calibration of Hot Press #3 (HP-3): During this period the effort was centered on finishing the requalification plan. As reported previously the physical refurbishment of HP-3 had been completed and the furnace was fully operational. During March 1994, HP-3 was used to fabricate the necessary SiGe GaP compacts for task 8 (the improved unicouple task). No difficulties were encountered. The requalification had been proceeding well when a leak was discovered in the heat exchanger. This necessitated its removal. It has been returned to the vendor for repair.

CVD Furnaces: As reported previously, the second CVD furnace was repaired. During this reporting period, the effort was directed toward qualifying this furnace for flight hardware production use. Coating of first bonds for Task 8E was accomplished in Furnace #2. Two difficulties with CVD #2 arose during this period. One was related to the ammonia mass flow controller and the other was a burn-out of the heater elements following power outages. The furnace vendor had a redesigned heater element which was used to repair that difficulty. The ammonia regulator controller was repaired to rectify the perceived problem with the mass flow controller. Following repair, CVD Furnace #2 completed its start-up run. Results indicate that the furnace is coating properly and the readiness demonstration coating runs will begin once again in October. CVD Furnace #1 also suffered a burned out heater element due to a power failure. This element was replaced with one of the redesigned elements. This furnace is currently fully operational.

Task H.2 CAGO - ETG Equipment

Because of facility problems and the requirement to build a portion of E-7 in parallel with E-6, a second ETG assembly area was prepared during this period. The facility was completed in September and the E-7 thermopile insulation assembly was moved into the new area. The E-7 unicouples and other accumulations are in process to begin operations in the new ETG assembly area in October.

Task H.3 CAGO - MIS

No significant activity during this reporting period.

H.4 CAGO - Building 800 Equipment Refurbishment/Upgrade

The Building 800 equipment has been exercised frequently since the completion of equipment refurbishment. All systems are now fully functional.

Operator training was conducted for approximately eight weeks and concluded with an informal walkthrough of all operations, including emergency alarm conditions. Eight personnel were trained and are qualified as test conductors and/or facility operators. The Qual ETG was utilized for this operator training phase which provided good hardware simulation and gave the test personnel excellent experience in handling ETGs.

A replacement turbomolecular pumping system has been received from Balzer and has been installed on LAS-2. Presently, it is undergoing system level checkout to determine its pumping characteristics as assembled in the LAS.

The ETG Acceptance Test Procedure (SI 249714) and the LAS Operating Instruction (SI 249697) have been updated and are in the approval loop.

The GSE cables between the ROC, LAS and ETG are existing cables from the GPHS-RTG Program. To verify their acceptability, the cables have undergone continuity, resistance, and Hi Pot and megger testing, and have been found to be acceptable.

The inside of the LAS has been wiped down with appropriate cleaning solutions and the vacuum lines flow cleaned to remove any hydrocarbons and particulates.

Final preparations are being made for the ETG Processing Test Readiness Review scheduled for 8-10 November 1994.

Program Calendars

Cassini RTG Program Calendar

As of 29 June 1994

2nd Qtr 1994												
M		T		W		T		F		S		FW
A P R I L	28	29	30	31	1	2	3	13				
			Baseline Recertification Meeting JPL - Pasadena, CA Hemler									
	4	5	6	7	8	9	10	14				
		Design Review Subsystem 180 - Hanford - Reinstrom/Cockfield										
	11	12	13	14	15	16	17	15				
M A Y	18	19	20	21	22	23	24	16				
		Gawltis Exec Status Review East Windsor - Hemler			Monthly/Quarterly/ Semi-Annual Reports Due to DOE							
	25	26	27	28	29	30	1	17				
	INSRP Review of Risk Code - DOE-HQ - Damon/Ha/ Bradshaw/Hemler/ Cockfield		Cassini RTG Program Review - Fairchild Space - Hemler/Braun Reinstrom/Cockfield									
	2	3	4	5	6	7	8	18				
J U N E			Launch Planning Meeting - KSC - Reinstrom Vendor Visit Osram, Sylvania - Towanda, PA - Braun/Dower/Schreiber									
	9	10	11	12	13	14	15	19				
		Vendor Visit Gulton Industries - Los Angeles, CA - Braun/Dower		Titan Databook Safety Meeting - Martin Marietta, Denver - Bradshaw / Rosko								
	16	17	18	19	20	21	22	20				
		Vendor Visit CAR Eng & Mfg. Centurioni/Ranney /Hofmeister	DOE Program Review - Valley Forge - Hemler, et al									
J U N E	23	24	25	26	27	28	29	21				
		Monthly & Semi Annual Reports Due to DOE	Vendor Visit Schwarzkopf Boyton/Dadd/Dower Hofmeister									
	30	31	1	2	3	4	5	22
		Holiday										
	6	7	8	9	10	11	12	23				
J U N E	13	14	15	16	17	18	19	24				
		Vendor Visit Hebb Spring - Newark, NJ - Dower/Hofmeister	Reentry Subpanel Meeting - Aerospace Corp. El Segundo, CA - Hemler/Bradshaw/Cockfield/Tobey Dynamics Technical Interchange Meeting - Aerospace Corp. El Segundo, CA - Cockfield/Kauffman	Vendor Visit Hygrade Perfection Tech - Plainville, CT - Dower/Hofmeister/Dadd								
	20	21	22	23	24	25	26	25				
					Monthly Reports Due to DOE							
					Vendor Visit Engelhard - Cartaret, NJ - Dower/Sayell/Ritter							

Cassini RTG Program Calendar

As of 21 September 1994

3rd Qtr 1994

	M	T	W	T	F	S	S	FW
JULY	27	28	29	30 Quarterly Program Review - Fairchild Space - Hemler/Braun Reinstrom/Cockfield	1	2	3	26
	4 HOLIDAY	5	6	7 QA Status Meeting - Valley Forge - Saydah, et al	8	9	10	27
	11	12	13	14	15	16	17	28
	18	19	20 Monthly Program Review w/DOE - Valley Forge - Hemler, et al	21	22 Monthly Reports Due to DOE	23	24	29
	25	26	27 Witness DTM Test at JPL - Pasadena, CA - Rosko	28	29	30	31	30
AUGUST	1	2	3	4	5	6	7	31
	8	9	10 IECEC Conference - Monterey, CA - Kelly/Hartman	11	12	13	14	32
	15	16 OSTP - Washington, DC - Hemler	17	18 Senior Management Review Hemler LANL Safety Hardware - Los Alamos, NM - Hartman/Bradshaw/Cockfield	19	20	21	33
	22	23	24 Monthly Reports Due to DOE	25	26	27	28	34
SEPT	29	30 Cassini Safety Meeting - DOE HQ, Washington DC - Hemler/Bradshaw/ Cockfield/Rosko	31	1 QA Status Meeting - Valley Forge - Saydah, et al	2	3	4	35
	5 HOLIDAY	6	7	8 Monthly Program Review w/DOE - Valley Forge - Hemler, et al	9 Review of Accident Environment - Fairchild, Germantown - Bradshaw, Rosko	10	11	36
	12	13 Management Meeting DOE/Martin Marietta - Germantown - Hemler/E. Morgan	14 Packaging System Final Design Review - Westinghouse Hanford Company - Reinstrom	15 Vendor Visit Engelhard Braun/Dower/Sayell/Schreiber	16	17	18	37
	19	20	21 Vendor Visit Engelhard Braun/Dower/ Sayell/Schreiber/ Sardaro	22	23 Monthly Reports Due to DOE	24	25	38

Cassini RTG Program Calendar

As of 12 October 1994

4th Qtr 1994									
	M	T	W	T	F	S	S	FW	
OCTOBER	26	27	28	29	30	1	2	39	
	3	4	5 Quarterly Program Review - Fairchild - Hemler/Braun/Rehstrom/Cockfield Cassini RTG Safety Meeting at JPL - Pasadena - Rosko	6	7	8	9	40	
	10	11	12 QA Status Review - Valley Forge - Saydah, et al	13	14 Schwarzkopf Vendor Visit - Boston, MA - Braun/Dower/ Dadd/Boyton	15	16	41	
	17	18	19 INSRP BEES Meeting - Fort Collins, CO - Ha/Deane	20 Executive Status Review - Valley Forge - Teets, Morgan, Hemler, et al	21	22	23	42	
	24 Monthly and Semi-Annual Reports Due to DOE	25	26	27	28	29	30	43	
NOVEMBER	31	1	2	3	4	5	6	44	
	7	8	9	10	11	12	13	45	
	14	15	16	17	18	19	20	46	
	21	22	23 Monthly Reports Due to DOE	24 Holiday	25 Holiday	26	27	47	
DECEMBER	28	29	30	1	2	3	4	48	
	5	6	7	8	9	10	11	49	
	12	13	14	15	16	17	18	50	
	19	20	21	22	23	24	25	51	
	26 Holiday	27	28	29	30	31	1	52	