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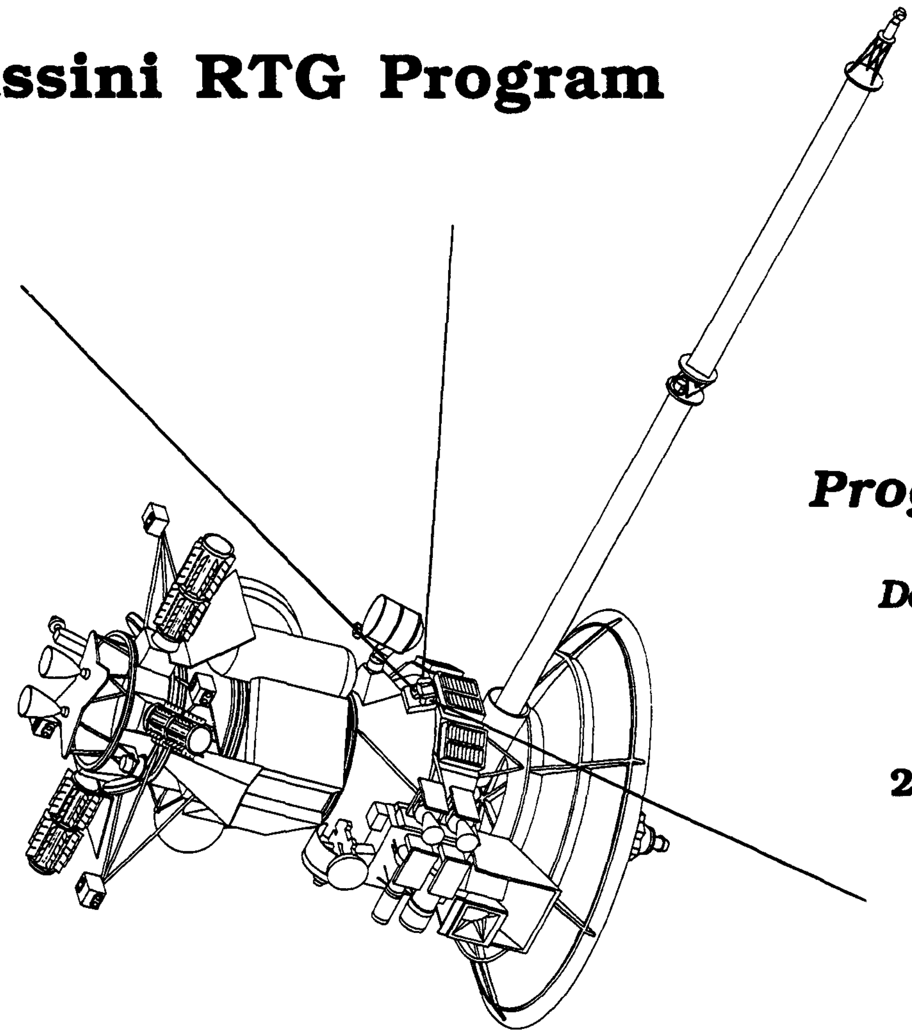
Contract No.
DE-AC03-91SF18852

GPHS - RTGs

In Support of the

Cassini RTG Program



Semi Annual Technical Progress Report

Document No. RR16

26 September 1994 through 2 April 1995

20 April 1995

Space Power Programs

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Cassini RTG Program CDRL Transmittal

TO:
U.S. Department of Energy
6633 Canoga Avenue
Canoga Park, California 91303
Attention: K. Vijaiyan
Project Manager

Cassini RTG Program
Contract No: DE-AC03-91SF18852

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INTRODUCTION

The technical progress achieved during the period 26 September 1994 through 2 April 1995 on Contract DE-AC03-91SF18852 Radioisotope Thermoelectric Generators and Ancillary Activities is described herein. Monthly technical activity for the period 27 February 1995 through 2 April 1995 is included in this Semi Annual Technical Progress Report.

This report is organized by program task structure.

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

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

Approved: R. J. Hemler, Manager
Space Power Programs

Internal Distribution:
Technical Report List
J. Daywitt U4019
D. Brandt U4019

From: Martin Marietta Astro Space
Room 10B50 Building B
720 Vandenberg Road
King of Prussia, PA 19406

Signature: Joseph M. Waks
Contracts Manager

T50

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Semi Annual Technical Report

Contract No. DE-AC03-91SF18852

GPHS-RTGs in Support of the Cassini Mission

Document No. RR16

26 September 1994
through
2 April 1995

Prepared for:

U.S. Department of Energy
P.O. Box 7922, MS BA95
Canoga Park, CA 92309-7922

Prepared by:

Martin Marietta Astro Space
P.O. Box 8555
Philadelphia, PA 19101

LOCKHEED MARTIN

Space Power Programs

MASTER

Semi Annual Technical Progress Report

The technical progress achieved during the period 26 September 1994 through 2 April 1995 on Contract No. 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

Semi Annual Technical Report
Progress by Major Task

TASK 1 SPACECRAFT INTEGRATION AND LIAISON

A plan has been agreed upon which will lead to the eventual establishment of the JPL Cassini Orbiter RTG Environments and Testing Specification (ES 515803). First, it was agreed with JPL that the launch RTG temperatures would be determined using the thermal environment defined by JPL. From this information Lockheed Martin will calculate the RTG temperatures needed for the launch loads analysis. The environments information is planned for inclusion in the RTG Environments and Testing Specification presently in preparation. JPL provided a draft of the information and a review was performed by Lockheed Martin. Several questions were identified and resolved through discussions with JPL. The next step will be to put the information in final form for incorporation into the specification.

Another input into the preparation of the Environments and Testing Specification was the completion of the F-5 low level dynamic test at Mound in early March. Testing was conducted in both the lateral and longitudinal axes of the RTG. Overall dynamic characteristics of the generator were very similar to those of the qualification RTG tested in 1984. The F-5 low level test was the first testing of the barometrically activated Pressure Relief Device (PRD) attached to the RTG. The response of the new PRD was much less severe than that of the design employed for the Galileo and Ulysses programs. The new PRD should not require additional notching of the flight acceptance (FA) random level dynamic environments. Further, the acceleration and force measurements obtained during this testing are expected to be adequate for JPL and Lockheed Martin to reach agreement on acceptance test levels for the Cassini RTGs. FA level random vibration environments for the Cassini mission have been proposed, and will be the subject of further discussions with JPL as preparation of the RTG Environments and Testing Specification is completed.

Also during this reporting period, JPL provided clarification on the method to be used to demonstrate compliance with the requirement of limiting the neutron emission rate to 7000 neutrons per second per gram of Pu-238. JPL is allowing the use of emission data for the 72 individual fuel capsules loaded into each RTG rather than measurements taken for the entire assembled RTG.

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 unicouple assembly activities. Toward the end of this period, the number of ECNs decreased as the unicouple production is finishing. Also, the ETG Product Specification was completed and is in the review cycle.

Qualification RTD Harness and Cable Assembly

The qualification RTD harness passed the acceptance thermal/vacuum and vibration tests and the qualification vibration test. During the last environmental test (qualification thermal/vacuum) insulation resistances less than the required 10 megaohms were measured. A Non Conformance Report (NR79240) was initiated and, after the specified re-testing verified the failure, a Failure Review Board (FRB) was convened. The FRB activities are reported in Task 9.2, Quality Assurance.

RTG Fuel Form, Fueling, and Test Support/Liaison

Support of heat source fabrication activities at the DOE National Laboratories continued through the review and disposition of production related non-conformances. In addition, specifications were also reviewed and an analysis was performed to determine the maximum allowable capsule length (exclusive of the decon cover) for revision of the fueled clad specification. Lockheed Martin also participated in a review of the Savannah River Plant fuel production activities. The purpose of the review was to observe operations and identify possible sources of the elevated levels of trace impurities. A report was drafted by the review participants and is under review by DOE.

Task 3

Safety

TASK 3 SAFETY

Safety Analysis Reports

Issuance of the Cassini Mission RTG PSAR (Preliminary Safety Analysis Report), Ref. CDRL C.1, in December 1994, was a major accomplishment completed during this reporting period. An intensive effort was required to complete the PSAR, since details needed from the Cassini Titan IV/Centaur Databook were not received until October 1994. An INSRP review of the PSAR was held at OSC, Germantown, MD, 14-15 February 1995. A total of 353 comments from all the INSRP subpanels were collected into a single document and made available for review. Since the intent of the meeting was to listen to INSRP's evaluation, no specific response to these comments was made. A final decision on how to address the comments is being formulated, however it is speculated that each comment will be addressed through either a special review meeting, a documented report, or specific detail in the FSAR document. Responses to the PSAR comments will be an active effort over the next several reporting periods.

Launch Accident Evaluation

As discussed previously, delays in receiving accident/environment detail from the Databook or the substitute data packages have hampered meaningful progress in the development of the launch accident scenario program, LASEP-T. To put the impact on the LASEP-T work in perspective, it should be recalled that the initial plan for the Databook, established at the June 1992 kickoff meeting, was the draft Databook in September 1993, the Draft Final in September 1994 and the Final in January 1995. Because of the delays in the Databook, a compromise plan was worked out between DOE and NASA to provide accident and environment data packages in advance of the Databook. A portion of these submittals providing full environment description was finally received in February and March 1995, with the balance of accident and environment data to be received in April 1995. One exception to this situation, which further pressures the LASEP-T development effort, is that environment data for SRMU fragmentation and propellant fallback will not be available until late June 1995. An intermediate delivery of propellant fragment details is planned to be completed by 24 April 1995. It is hoped that this intermediate submittal will provide useful information to complete the propellant fallback accident modeling work.

The revised dates for the Draft FSAR to be issued on 1 July 1996, and the FSAR to be issued on 1 November 1996 have not changed. Thus, as a consequence of delays in receiving Databook definition, the time window to complete the launch accident analysis and the subsequent consequence and risk analyses has been compressed making the overall schedule very challenging. The modification of internal analysis plans has been an ongoing effort during this reporting period in order to accommodate the Databook delays. As addressed in the February 1995 Monthly Technical Report, there is essentially no margin available to accommodate further slips. This message was communicated to the pertinent organizations at a Titan Databook/RTG Panel Working Group meeting on 7-8 February 1995 at the Martin Marietta SLS Denver facility. The session addressed the methods used to determine the probabilities for the occurrence of particular accident events. At this meeting, the priority to have accident definition and environment data first, to be followed later by probability data was stressed. Also an activity was initiated to define the interface points between the Databook accident definition and the LASEP-T code.

As a significant indicator of progress, full environment specifications were received from JPL during the February/March 1995 time frame, covering the topics as listed below:

- Centaur Blast and Fragments with Payload Fairing Attached (Received 2 February 1995)
- Core Hypergol Blast (Received 28 March 1995)
- Surface Impact of Space Vehicle (Received 28 March 1995).

These specifications are currently under evaluation and will serve as the basis for future accident modeling work.

As another significant activity during this reporting period, the evaluation of potential source terms resulting from a SV (space vehicle) intact impact (end-on, launch vehicle adapter into ground at 300 ft/sec, with SV long axis normal to ground) was completed and presented at the 28 February 1995 SVDS (Space Vehicle Destruct System) Recommendation Meeting held at JPL, Pasadena, CA. Based on new information provided at the SVDS TIM, the impact evaluation was updated showing a reduction in source terms consistent with the improved knowledge of reduced blast environments. The updated analysis was forwarded to DOE on 15 March 1995. Both the original analysis and the updated analysis supported the recommendation of JPL not to incorporate a SVDS on the Cassini spacecraft.

Consequence and Risk Analysis

A major area of effort over this six month reporting was the preparation of model documents which describe the analytical techniques used by the transport and dispersion analysis codes. Draft versions of the SATRAP, GEOTRAP, and HIAD method documents were completed and issued to DOE for internal review in the December 1994/January 1995 time frame. A summary table providing a top level description of SATRAP, GEOTRAP and HIAD codes is provided in Table 3-1. At the end of the February 1995, review comments had been incorporated into the HIAD and GEOTRAP methods documents. The SATRAP methods document was updated during the March 1995 reporting period.

Table 3-1. Description of Dispersion Codes

___	SATRAP:	Site-Specific Analysis of Transport and Dispersion of Radioactive Particles
___	GEOTRAP:	Global Transport and Dispersion of Radioactive Particulates, and
___	HIAD:	High Altitude Aerosol Dispersion

Dispersion Scale	Example of Scenarios	Particle Size Range	Dispersion Time/Distance	Applicable Code
Local	Explosion at Launch Pad	≤ 6000 μm	100 km*	SATRAP
Local	Random Surface Impact	≤ 6000 μm	100 km*	SATRAP
Global	Explosion during Ascent	d > 10 μm	1-2 Weeks +	GEOTRAP
Global	Orbit or Flyby Reentry	d < 10 μm	Weeks to Years	HIAD

*: Depending on conditions of release and receptor data base

+: Depending on altitude of release and particle size

The preparation of input databases needed by the transport and dispersion codes also continued during this reporting period. One significant area of progress was the GRAM 90 code that applies wind field data which will be used by GEOTRAP. At the end of the March 1995 monthly reporting period, work was continuing on the GRAM 90 world wide wind data evaluation. Monthly mean data for January, October, and December were processed to allow comparison/verification. All cases produced reasonable wind field data except locations near ±5 degrees of latitude and 20 km of altitude, where zonal wind speed data shows excessive values of 170 m/sec. A verification with the code's author at Marshall Space Center indicated that this aberration might be due to the existing data base. While the problem is examined, the recommended fix is to obtain the updated version of GRAM 90, namely GRAM 95. The alternative solution is to replace the out of range values with average values from adjacent points since only a few grid points are affected. Efforts to obtain the new GRAM 95 data base from the National Climatic Data Center are in progress.

Work on the dose model methods document is continuing. For the dose calculation, dose conversion factors (DCF) for groundshine or cloudshine pathways have been reviewed to implement contributions from neutrons and gamma rays of $^{238}PuO_2$. However, it is expected that these external doses will remain several orders of magnitude lower than internal doses from inhalation or ingestion. Also, an option for improving the de-minimis dose level calculation has been identified. In the past, a fixed de-minimis dose level has been set at one mrem/year and the assumption of proportionality to the number of exposed years has created a high value criterion for multi-year exposure. In the new version, the user can change the value of de-minimis dose level, and doses of multi-year exposure are separately computed for each year to obtain a better prediction. During this most recent March 1995 reporting month, a survey of literature was performed for key parameters used in the radiological dose calculation. Values cited by various codes or publications were compared to determine the possible range of variability. Whenever possible, applicability to plutonium fuel and southeastern environment are the main criteria of selection.

As an activity supporting the site specific dose model for the SATRAP code, the collection of vegetable, citrus, field crop and livestock data for the 10 counties within the 100 km radius from the Kennedy Space Center has been initiated. The production data including total acreage, were assigned at specific geographic locations and stored in a spreadsheet. The description of this database is being included in the dose calculation methods document.

Progress associated with the uncertainty analysis of the consequence and risk analyses were also made during this reporting period. In November 1994, a random sampling code from SANDIA National Laboratories was acquired and tested on the Micro Vax computer platform. Written in standard FORTRAN 77, this program has the option to sample variables from statistical distributions with either Latin hypercube or random techniques.

After resolving machine dependent language problems, the porting of the Latin Hyper cube/random sampler code (LHS) to the Sun Workstation was successfully completed in February 1995. The code was modified to add the option for parametric sensitivity study. Samples can be generated to provide either mean values of all variables or combination of perturbation values of selected variables and mean values for the remaining. With this capability, the shell code can be used either for Latin Hyper cube sampling, random sampling, or a sensitivity studies. Additional interface coding will be minimized because the interface file to SPARRC will be the same and only one LHS input file is required for the variables and their distribution functions. If accident probabilities are to be provided as non-standard cumulative probability distribution functions instead of defined standard distribution functions, coding to augment the capability of user's input distribution functions will be required.

Computational Fluid Dynamics (CFD) Reentry Program

Introduction

In a previous contract modification (M020), CFD techniques and flowfield radiation codes were developed to accurately predict the complex chemically reacting flow about a general purpose heat source (GPHS) in the event of accidental reentry. These techniques, for the first time, provide a means to rigorously model the severe flyby reentry environment by:

- Fully coupling the ablation products flowfield and radiation
- Treating non-equilibrium air-carbon thermochemistry and radiation
- Coupling wall-temperature, mass-addition, and internal conduction to the flowfield

As part of the M020 study, several test cases were performed to gain confidence in these new codes and to validate the techniques where data was available. In addition, a few critical trajectory points were analyzed to assess code performance and demonstrate the capability to treat the flight environment. In November 1994, DOE issued direction to continue with CFD analyses, thereby providing a more thorough safety evaluation of accidental reentry. Per this direction, three trajectories that bound the gravity assist flight envelope will be evaluated. Ten baseline points per trajectory will be computed. In addition, for each of these trajectory points, the wall-boundary condition will be perturbed to expand the database for subsequent SINRAP analyses. Totaling both the baseline points and their perturbations, a matrix of approximately one-hundred fully coupled solutions of the face-on-stable (FOS) reentry orientation will be performed. This matrix of solutions is intended to provide sufficient data to allow application of the SINRAP code for the specified trajectory paths.

Development of Production CFD/Radiation Analysis Codes

In the previous M020 study phase, a nonequilibrium, air-carbon, chemically reacting flowfield code (LAURA-C), together with a coupled flowfield radiation technique (LORAN-C), were developed and successfully demonstrated. In this current work phase, these techniques are being optimized for computational efficiency. The extensive case matrix can only be completed by drastically reducing run-time requirements. This is being accomplished through the development of a new flow solver, improvements to the radiation code, and the acquisition of a high-performance dedicated workstation (HP 735/125).

Selection of New Flow Solver

In the previous study, the LAURA Navier-Stokes flowfield code, developed at NASA Langley, was chosen as the flow solver based on a thorough assessment of existing Navier-Stokes codes. Extensive modifications of LAURA were developed to address: wall mass-addition, non-equilibrium air-carbon chemistry, and the coupling of surface chemistry and heat-balance with flowfield and radiation contributions. The NASA Langley LORAN code was selected as the baseline flowfield radiation technique. This code also required significant modifications to treat the radiation of air-carbon ablation products. As shown in Figure 3-1, a rigorous solution of the shallow-trajectory, peak-heating case was obtained. This solution incorporates a 19-species, 46-reactions, air-carbon, nonequilibrium thermochemical model with coupled radiation. The curves labeled "LAURA-C-1" are the result of one-pass (the first iteration) with radiation fluxes based on the LAURA-C-0 (no radiation) solution. The unlabled curves are the final result. Usually, only two-to-three radiation passes are required with LORAN to achieve convergence. For this solution, the wall-boundary condition included a coupled chemistry, mass-addition, and heat-balance solution so that both the wall-temperature and mass-addition rate distributions were computed. Satisfaction of the heat-balance was achieved by setting the internal-conduction heat-flux term to zero (in practice, this term would come from a SINRAP solution). In contrast to the LORAN code, the LAURA flow solver code was found to require extensive computational time. More than 10,000-iterations per trajectory point were needed. Because of the need to do frequent restarts and adjust code parameters, this translated to 2-3 days per case on a workstation. Thus application of the LAURA as a "production" code would not be efficient. Fortunately, through the subcontract with AeroTechnologies, Inc. (Dr. Bilal Bhutta) a new Navier-Stokes flowfield code, that offers vastly improved convergence properties with no loss in accuracy was recently developed.

Initial estimates are that solutions of comparable or better accuracy can be obtained in 1/10th or better the CPU time required by LAURA, plus the need for frequent user intervention has been eliminated. Several reasons for this improved performance have been identified.

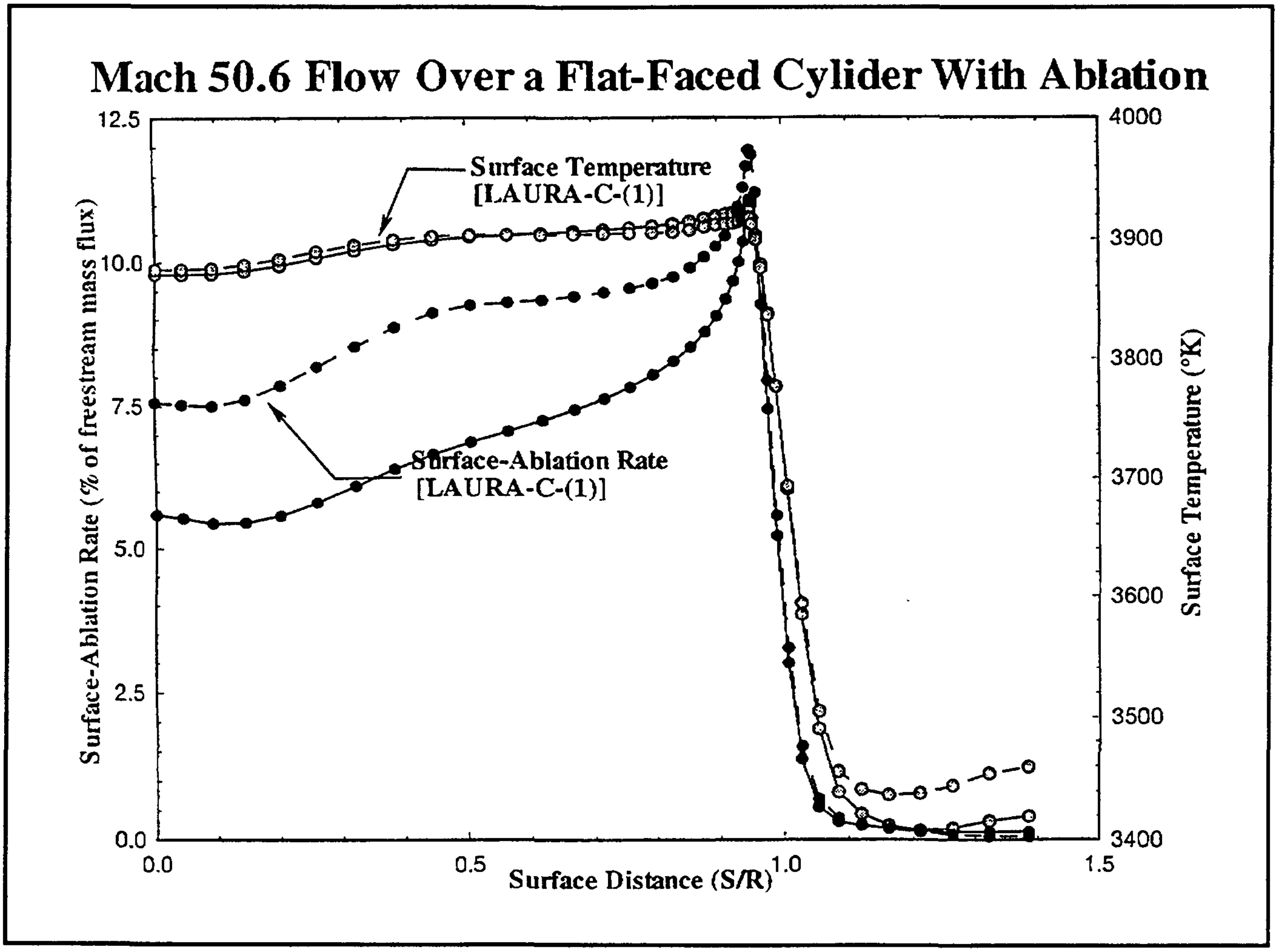


Figure 3-1. Surface Temperature and Ablation-Rate Distributions from LAURA-C/LORAN-C with Coupled Wall-Boundary Technique

First, the governing equations are solved in finite-difference, not finite-volume form. Boundary conditions are imposed more precisely with a finite-difference scheme because the grid points lie on the boundary, unlike finite-volume schemes where the cell-centers are not on the boundary and "pseudo-cells" are required. Second, a novel "scaling" of the Navier-Stokes equations is employed to remove the geometric and flowfield singularity along the stagnation streamline. This eliminates the usual numerical oscillations and fluctuations associated with the stagnation region solution when fine grids are employed. Third, during the solution iterations, the grid is continuously adapted to the evolving bow shock. This results in a sharply captured bow shock and enhanced stability and accuracy of the flux-vector-splitting (FVS) differencing algorithm. Fourth, a new hybrid finite-difference scheme is used with the fully upwind FVS approach. Fifth, the new Navier-Stokes code uses a unique predictor-corrector (P-C) algorithm that features an implicit streamwise approach with body-normal coupling terms. For second-order accuracy, this P-C scheme is more than twice as fast as the point-implicit scheme in LAURA. Sixth, a pseudo-unsteady approach is used with the "delta-form" of the differenced equations. The "delta-form" computes solution changes at each grid point during the iteration process. Matrix inversions are needed only when local solution changes are large. When changes are small, the local implicit left-hand side matrices and their inverted form are kept "frozen" at the previous iteration value. This approach results in a reduction of computational time by a factor of 5 or better without affecting accuracy and is also very effective in filtering high-frequency solution oscillations in the pseudo-time iterations.

Validation of the New Flow Solver

Prior to launching the extensive case matrix using the new flow solver, validation cases are being performed to insure that solutions will be comparable to the LAURA code predictions. Test and validation cases, reported in previous monthly reports, have been performed to gain confidence in the accuracy of the new code as well as substantiate its greatly enhanced convergence capability. Previously shown shock-tunnel test cases have verified that the new code produces results that match surface-heat transfer measurements in a high Mach number ground-test environment. To assess the new code for a more stressing environment, without introducing the complexities of the air-carbon model, an existing LAURA 7-species nonequilibrium-air case has been selected as a benchmark for comparison. Freestream conditions: Mach = 50.6, altitude = 58.6 km, and velocity = 16.4 km/sec, are near the peak-heating location for the shallow trajectory ($\gamma = 7$ degrees). The gas model results in very high shock-layer temperatures (because only one ionized species is included) and does not simulate the true flight thermochemistry. Surface pressure and heat-transfer rate comparisons are shown in Figure 3-2a and 3-2b, respectively. Results from the new flow solver code are plotted as the solid line with LAURA results represented by the circular data points. The surface predictions obtained using the new flow solver are in excellent agreement with the LAURA results. The surface pressures are within 3% and the heat-transfer rates are even closer. However, the LAURA code required 10,000 iterations to converge to the same level of accuracy achieved in only 500 iterations with the new flow solver. Both codes started from freestream initial conditions. The LAURA code consumed at least 15 times more CPU time than the new code. This test case adds confidence in the new code, as well as LAURA, because excellent agreement was obtained using these independent and dissimilar techniques.

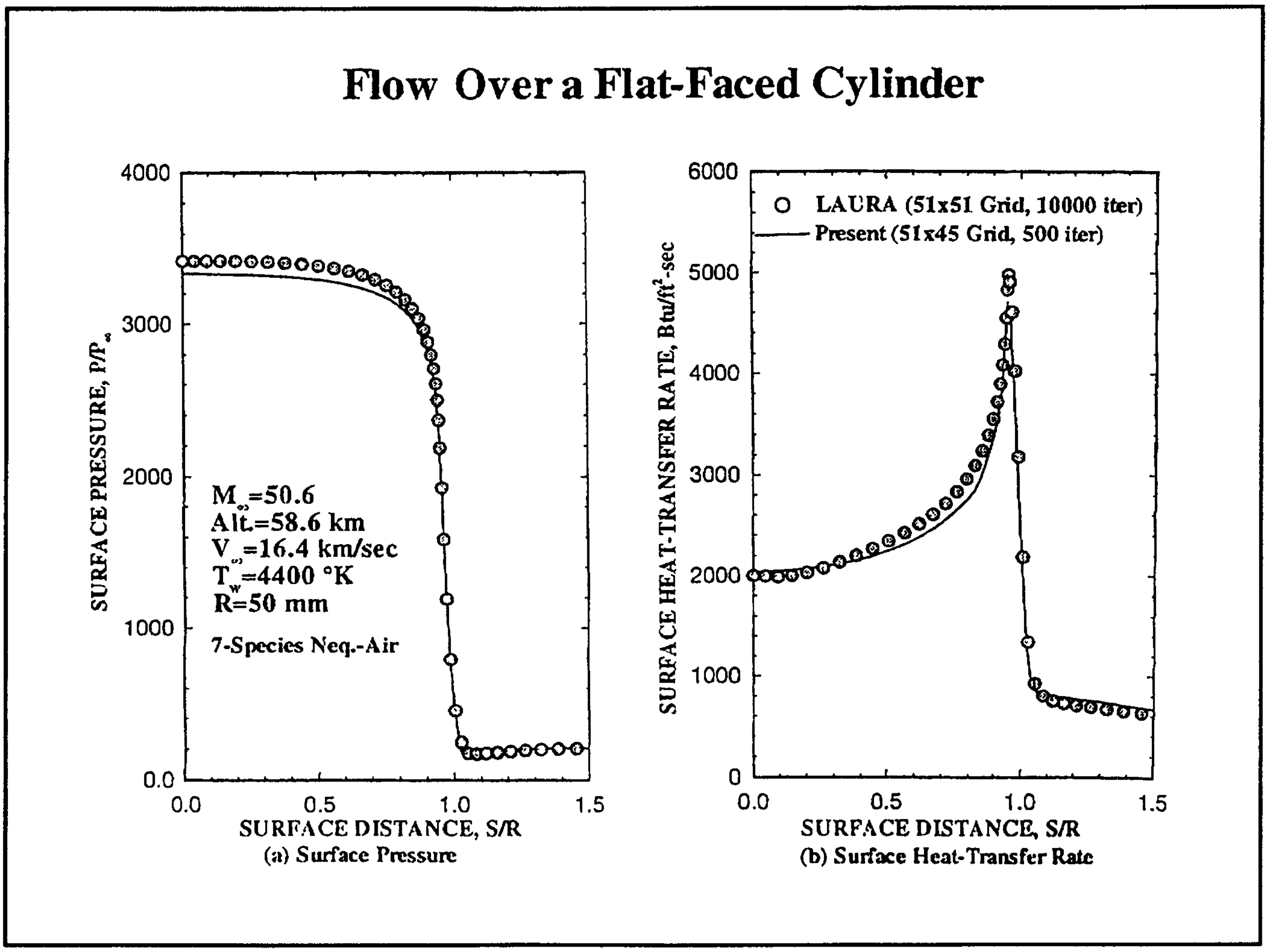


Figure 3-2. Comparison of LAURA with the New Flow Solver

Incorporation of Mass-Addition in the New Flow Solver

The modular air-carbon thermochemistry system, developed under the previous study, was readily incorporated into the new flow solver. In addition, the mass-addition body-boundary condition scheme was added to the new code. Figure 3-3 shows a wall-blowing case used to test the new code. This case imposes high air-into-air blowing rates (15% of the freestream mass flux) and demonstrates the code's capability to treat the extreme GPHS reentry environment.

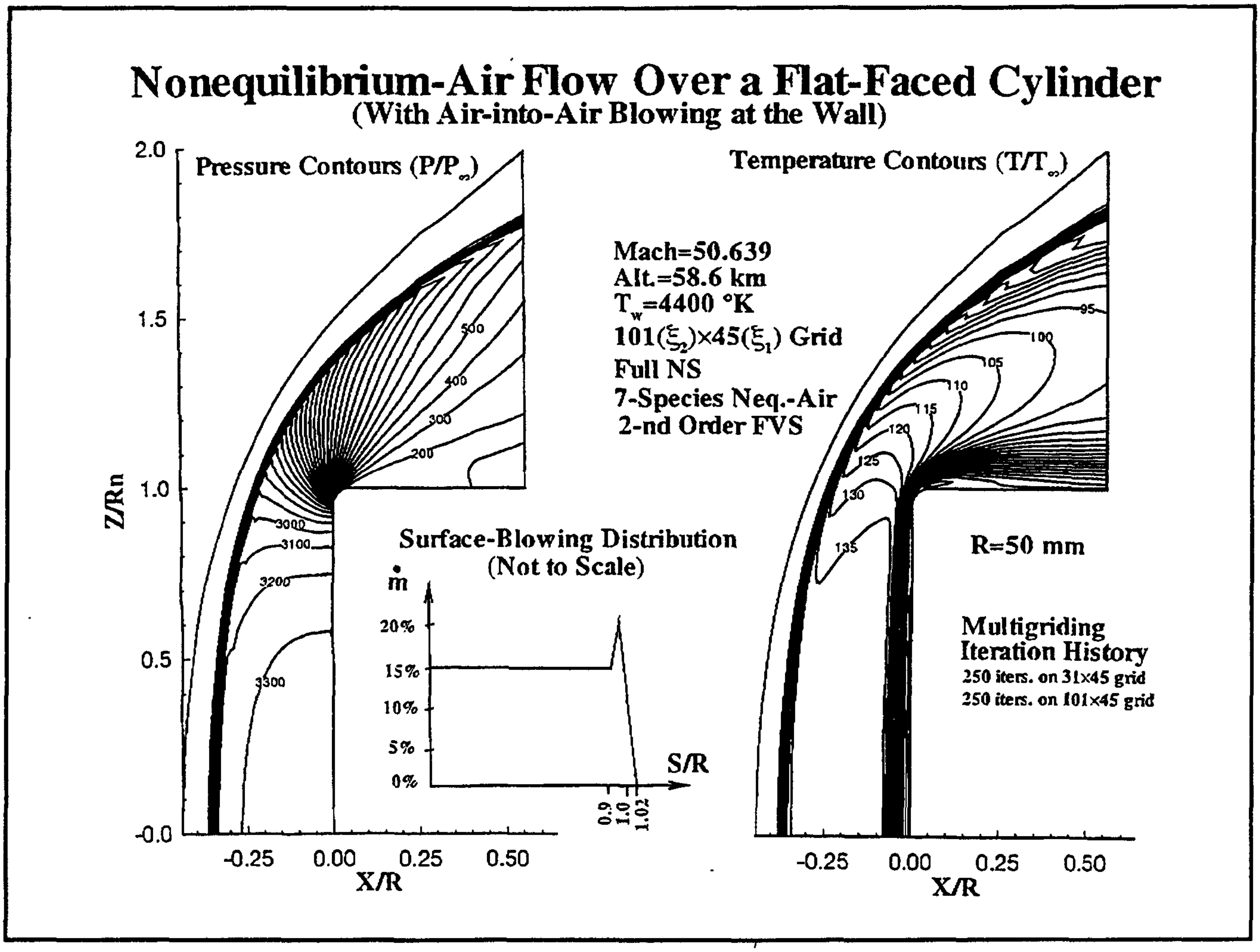


Figure 3-3. Test of Extending the New Flow Solver to Treat Mass-Addition New Flow

Extension of Flowfield Chemistry Algorithm

Work on the last planned modification of the new flow solver is nearing completion. This modification addresses concerns with the chemistry solver portion of the flowfield code and its affect on solution convergence rates as well as difficulties in obtaining solutions for flows in chemical-equilibrium and near-equilibrium. The earlier implementation of the element boundary conditions in the LAURA code used an indirect formulation at the wall because LAURA does not solve the element conservation equations. This typically resulted in very slow convergence. In the new flow solver, solution of the element conservation equations across the entire shock layer has been incorporated as part of the complete flowfield solution. This will enhance convergence by directly imposing the equality of element convection and diffusion effects at the ablating surface. Furthermore, another important advantage of this approach is that it enables computation of equilibrium and near-equilibrium flows present at the lower altitude portion of the GPHS trajectories where the LAURA code is extremely difficult to apply.

Code Performance on the HP 735/125

The ability to achieve rapid solution turnaround is vital to accomplishing the case matrix. A Hewlett Packard HP-735/125 workstation has been acquired and dedicated to this program. This HP model performs at twice the speed of the SUN SPARC 20 on standard floating-point algorithm benchmarks. The new flow solver and LORAN have been successfully ported to the HP workstation. The subcontractor, AeroTechnologies, Inc., has an identical HP-735 configuration and identical versions of the software. This eliminates code compatibility problems and enhances case turnaround. Tailoring of the flow-solver FORTRAN to make better use of the HP-compiler's optimizer has yielded substantial improvements in run time. To date, times have been cut in half and further reductions may be possible. LORAN is now far more time consuming than the flow solver, so an effort is underway to optimize LORAN. Typical LORAN times on the SUN SPARC 20 are in the 5-6 hour range. Use of the SUN compiler's optimization options has reduced this to about 3 hours. Unfortunately, LORAN makes use of several nonstandard FORTRAN features that inhibit optimization on the HP. These features are being replaced to fully utilize the capabilities of the HP because three hundred or more LORAN solutions are required.

Plans

Prior to launching the matrix of cases, an archival file structure is being defined so that all pertinent flowfield and surface quantities for each trajectory point will be saved. These files will be available to help assess and extend engineering correlations. The procedures linking SINRAP solutions with the sequence of trajectory computations are also being established. Test cases are now in progress to verify the planned approach so that the computation of the extensive case matrix can begin.

A separate task, to examine the reentry-vehicle flight-database on carbon nosetip performance relative to the GPHS environment, has been started in parallel with the analysis activities.

Safety Test Program

End-on-Test

A significant amount of progress was accomplished in the safety testing task during the reporting period, with the most notable progress associated with the end-on impact testing of a simulated RTG. Specifically for the end-on test, the task went from concept through to testing of the engineering unit during this six month reporting period. The monthly technical reports detail several of the mechanical interface and thermal problems which were overcome during this time period. In February 1995, the two end-on test articles were delivered to LANL, thus completing the shipment of all end-on test hardware. Velocity checks were completed in early February followed by the actual impact test of a mock-up converter (aluminum cylinder) in mid-February. Following this successful mock-up test, an impact test with the engineering unit was conducted in March 1995. Results of this test were successful. The proper heat source temperature was obtained and no difficulties were encountered with insertion and latching of the heat source and positioning of the test unit on the sled. The proper impact velocity was achieved and the test article passed cleanly through the aperture plate. An end-on impact test of the first actual test unit is planned for mid-April.

For the edge-on thin fragment impact test, technical difficulties associated with attaining the desired 1000 ft/sec fragment velocity in a controllable manner curtailed progress. A test conducted at Sandia in December 1994 showed that at 600 ft/sec the thin fragment experienced large deflections and tore away from the sled holding fixture. Alternate methods of holding the fragment would need to be explored, however, following this undesirable December 1994 test, work on this effort was essentially halted since all LANL and Sandia resources were focused on the end-on test. At the end of March 1995 LANL received direction from DOE to once again develop methods for completing the edge-on fragment impact test.

Task 4

Qualified Unicouple Fabrication

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 were:

18-10 Reached 10,000 hours on 19 October 1994 and testing was terminated.

18-11 Reached the 6,000 hour qualification test milestone on 4 November 1994.

18-12 Reached 5,000 hours on 17 March 1994.

Table 4-1. Test Temperatures and Life Test Hours

Module	Unicouple Source	Test Temperature Hot Shoe	Status as of 2 April 1995
18-10	Early Qualification Lot	1135°C	10,400 hours Performance Normal Test Terminated October 1994
18-11	Full Qualification Lot	1135°C	9,570 Hours Performance Normal
18-12	Early Flight Production Lot	1035°C	5,385 Hours Performance Normal

18 Couple Module Testing

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

Module 18-11 (1135°C)

On 2 April 1995 the module reached 9,570 hours at the accelerated hot shoe temperature of 1135°C. Measured performance during this reporting period continued to fall within the data base established by MHW and GPHS 18 couple modules. The 10,000 hour milestone is expected to be reached on 20 April 1995.

The thermoelectric performance evaluation primarily studies the trends of the internal resistance and power factor. Figures 4-1 and 4-2 show these trends in comparison to module 18-8, the last module built during the Galileo/Ulysses program. Agreement is excellent and provides a high degree of confidence that the unicouple manufacturing processes have been successfully replicated. Table 4-2 summarizes the initial and 9,570-hour performance data.

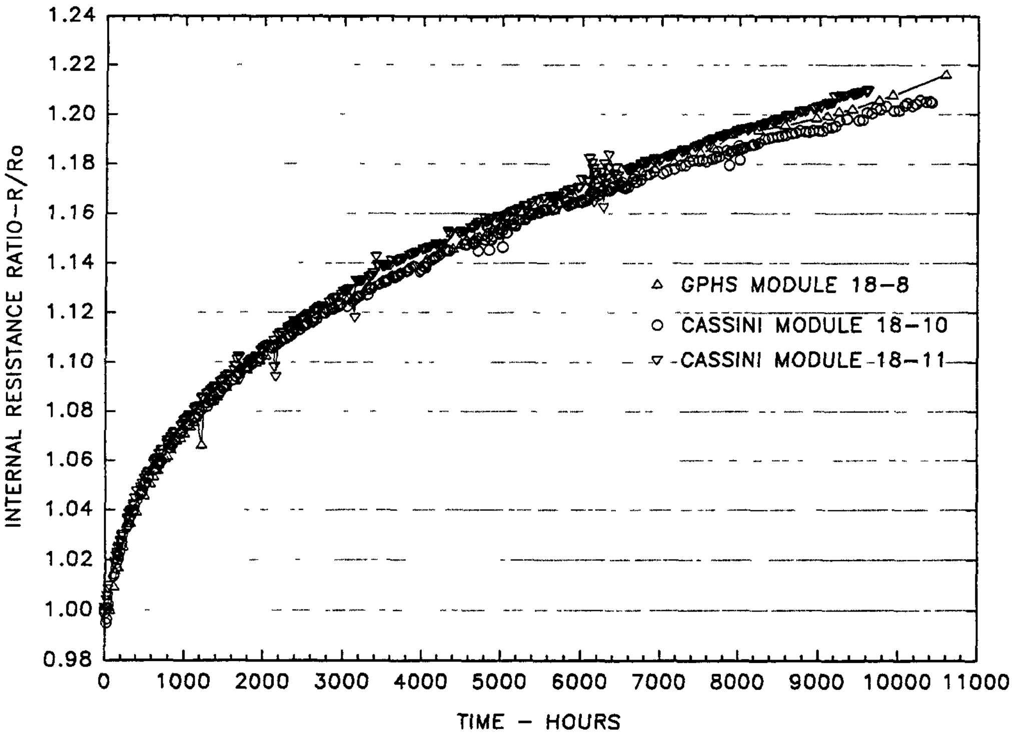


Figure 4-1. Internal Resistance Ratio Versus Time (Modules 18-10, 18-11, GPHS Module 18-8) - 1135°C Operation

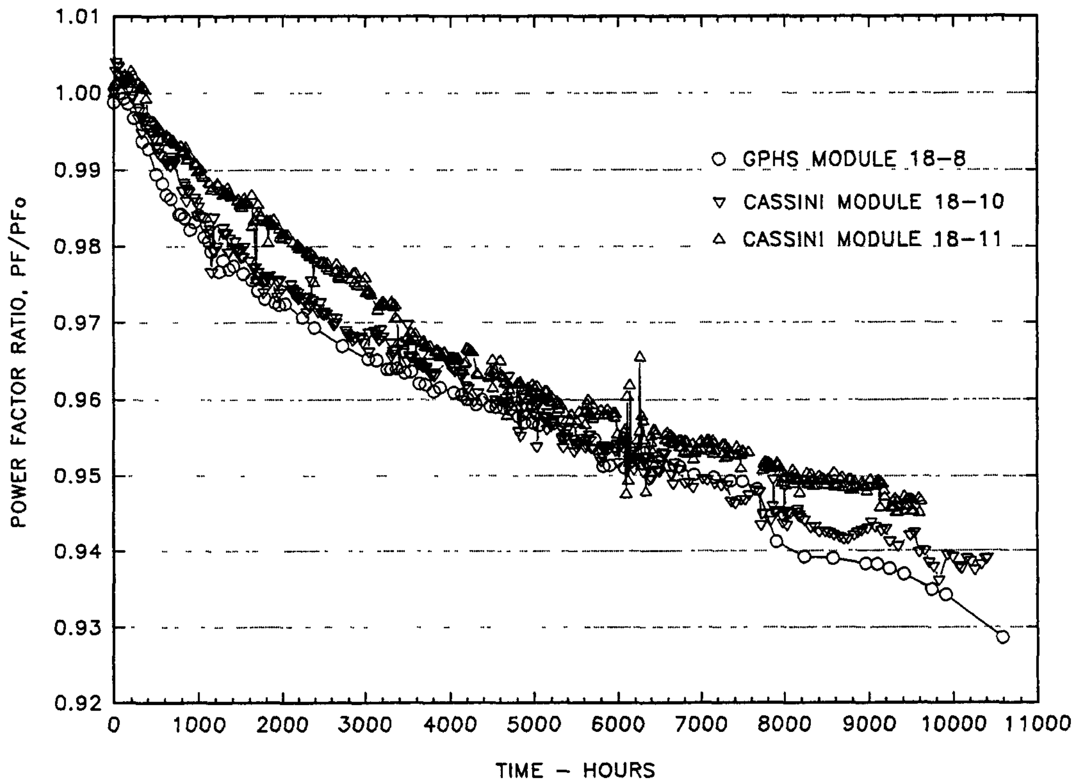


Figure 4-2. Power Factor Ratio Versus Time (Modules 18-10, 18-11, GPHS Module 18-8) - 1135°C Operation

Table 4-2. Comparison of Initial and 9,570 Hour Performance of Module 18-11 at 1135°C

	Initial 2/2/94	t = 52 hours V_L = 3.5V 2/4/94	t = 9,570 hours 4/2/95
Heat Input, Watts	190	192.9	193.1
Hot Shoe, °C Average	1137.8	1137.5	1120.8
Hot Shoe Range °C	5.4	5.2	7.2
Cold Strap, °C Average (8 T/Cs)	311.9	314.3	308.4
Cold Strap Range (8T/Cs)	2.6	2.5	2.4
Cold Strap Average (12 T/Cs)	306.5	308.9	303.2
Cold Strap Range (12 T/Cs)	20.1	20.3	19.7
Load Voltage, Volts	3.895	3.499	3.502
Link Voltage, Volts	0.108	0.121	0.101
Current, Amps	2.842	3.174	2.926
Open Circuit Voltage, Volts	7.140	7.160	7.509
Normalized Open Circuit (8T/Cs)	6.319	6.359	6.761
Normalized Open Circuit (12 T/Cs)	6.276	6.316	6.716
Average Couple Seebeck Coefficient (12)	498×10^{-6}	501×10^{-6}	533.0×10^{-6}
Internal Resistance, Ohms	1.104	1.115	1.335
Internal Resistance Per Couple (Avg.)	0.0613	0.0620	0.0742
Power Measured, Watts (Load + Link)	11.375	11.492	10.54
Power Normalized, Watts (8 T/Cs)	8.909	9.065	8.55
Power Normalized, Watts (12 T/Cs)	8.789	8.942	8.43
Power Factor	40.452×10^{-5}	40.557×10^{-5}	38.30×10^{-5}
Isolation			
Circuit to Foil, Volts	-1.68	-1.36	-1.44
Circuit to Foil, Ohms	6.29K	5.95K	1.05K

The isolation resistance trend between the thermoelectric circuit and the foil is shown in Figure 4-3 with modules from the MHW and GPHS programs. The isolation resistance has plateaued at about 1000 ohms as did Module 18-10. At the accelerated temperature of 1135°C the same amount of sublimation occurs in about 1,650 hours of testing as would occur in a 16 year Cassini mission.

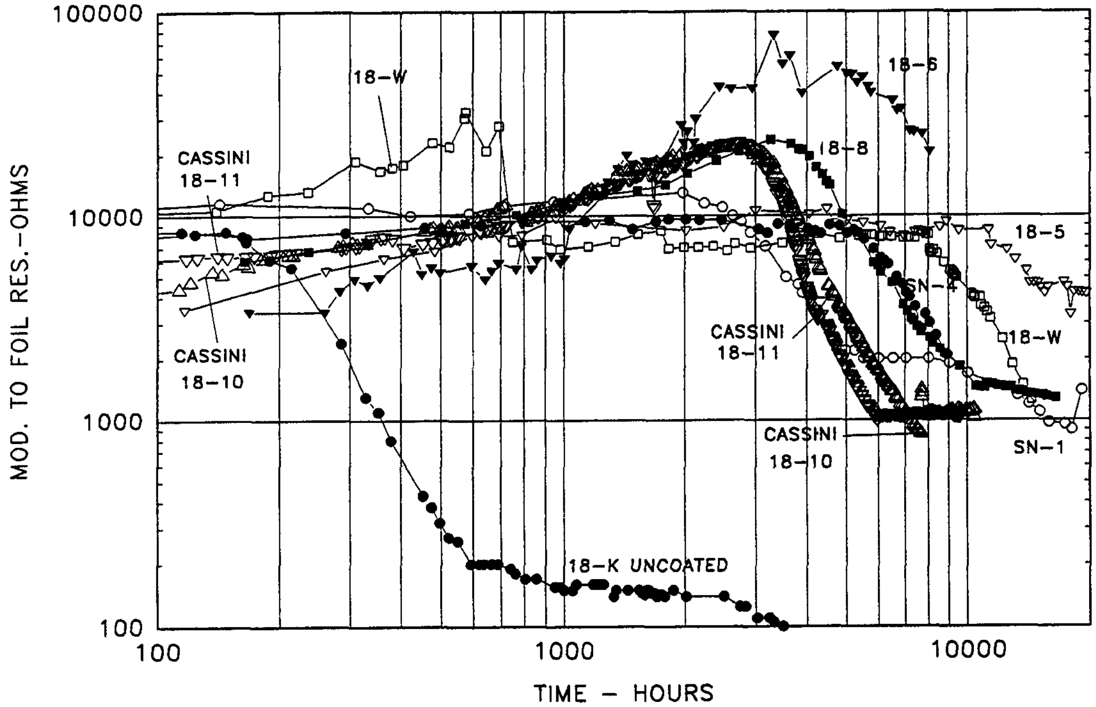


Figure 4-3. Isolation Resistance - Module Circuit to Foil (Modules 18-10, 18-11, GPHS Module 18-8) - 1135°C Operation

Consequently, approximately 5.8 times as much sublimation has occurred during the test duration of module 18-11 as will occur during the Cassini mission. The module performance, therefore, confirms the adequacy of the silicon nitride coating on the qualification unicouples.

Individual Unicouple Performance:

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

Module 18-12 (1035°C Operation)

The module reached 5,385 hours at the normal operating temperature of 1035°C on 2 April 1995. Thermoelectric performance, as measured by internal resistance and power factor trends, continues to be normal as shown as Figures 4-4 and 4-5, respectively. Table 4-4 shows initial performance and performance as of 2 April 1995.

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

Position	Serial #	2nd Bond Milliohm	Preassy Milliohm	Delta ri Milliohm	T = 0 Milliohm	T=1,509 Hours	Delta ri Milliohm	Percent Increase	T=9,590 Hours	Delta ri Milliohm	Percent Increase
1.0	H2006	22.50	22.10	-0.40							
2.0	H0507	22.40	21.90	-0.50							
3.0	H0512	22.7	22.20	-0.50							
					182.30	199.70	17.40	9.54	221.20	38.90	21.34
4.0	H0439	23.20	22.70	-0.50	62.30	67.90	5.60	8.99	75.00	12.70	20.39
5.0	H0587	22.50	22.40	-0.10	61.00	66.50	5.50	9.02	73.40	12.40	20.33
6.0	H0657	22.70	22.50	-0.20	61.40	67.30	5.90	9.61	74.50	13.10	21.34
					184.10	201.10	17.00	9.23	222.10	38.00	20.64
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	225.30	39.60	21.32
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	222.40	37.50	20.28
13.0	H0428	23.10	22.70	-0.40	62.10	67.90	5.80	9.34	75.00	12.90	20.77
14.0	H0326	22.60	22.00	-0.60	62.20	68.30	6.10	9.81	75.80	13.60	21.86
15.0	H0232	22.60	22.00	-0.60	60.90	66.60	5.70	9.36	73.80	12.90	21.18
					184.70	202.30	17.60	9.53	224.10	39.40	21.33
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	222.10	37.90	20.58

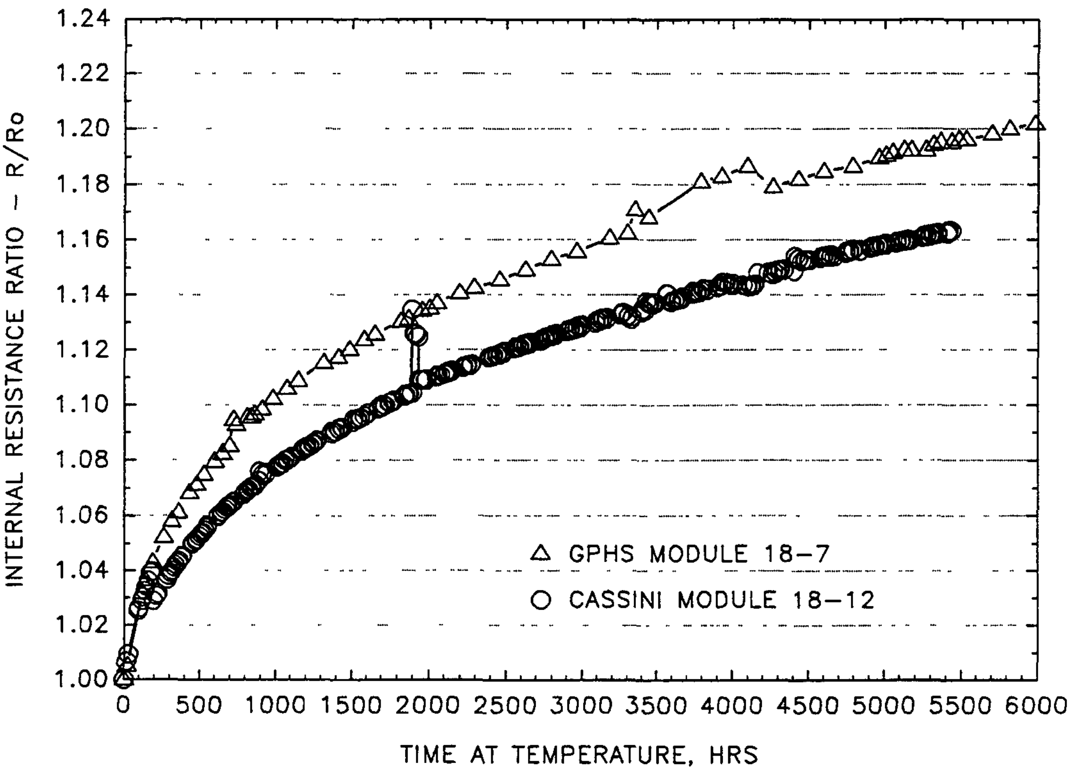


Figure 4-4. Internal Resistance Ratio Versus Time Temperature (Modules 18-12, and 18-7) – 1035°C Operation

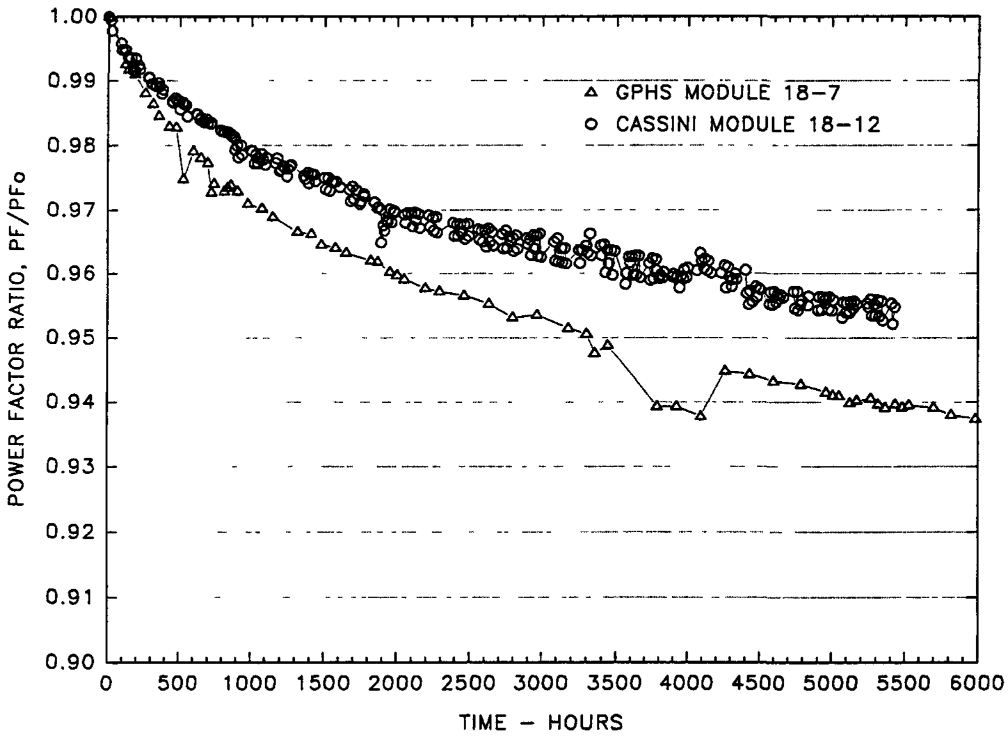


Figure 4-5. Power Factor Ratio Versus Time at Temperature (18-7 and 18-12) - 1035°C Operation

Isolation Resistance

There was some concern indicated in the November report about the isolation resistance due to the combination of high temperature and chamber pressure associated with the 28 September 1994 shutdown. The isolation resistance was 28,000 ohms at the time of re-start compared to 43,000 ohms at shutdown as shown in Figure 4-6. The isolation resistance, however rapidly returned to its pre-shutdown value and its upward trend has continued indicating no permanent effect.

Individual Unicouple Performance

A review of the individual unicouple internal resistances and open circuit voltages shows that all unicouples are exhibiting very similar behavior with time (See Table 4-5).

Table 4-4. Comparison of Initial and 5,385 Hour Performance of Module 18-12 at 1035°C

	Initial 6/16/94	**t = 5,385 Hours 4/2/95**
Heat Input, Watts	169.15	169.5
Hot Shoe, °C Average	1035.9	1033.3
Hot Shoe Range °C	5.7	4.6
Cold Strap, °C Average (8 T/Cs)	287.1	284.6
Cold Strap Range (8T/Cs)	5.0	5.1
Cold Strap Average (12 T/Cs)	282.7	280.2
Cold Strap Range (12 T/Cs)	19.8	19.6
Load Voltage, Volts	3.578	3.499
Link Voltage, Volts	0.155	0.157
Current, Amps	2.548	2.533
Open Circuit Voltage, Volts	6.431	6.773
Normalized Open Circuit (8T/Cs)	6.307	6.644
Normalized Open Circuit (12 T/Cs)	6.268	6.603
Average Couple Seebeck Coefficient (12)	497×10^{-6}	524.1×10^{-6}
Internal Resistance, Ohms	1.053	1.231
Internal Resistance Per Couple (Avg.)	0.0588	0.0684
Power Measured, Watts (Load + Link)	9.510	9.259
Power Normalized, Watts (8 T/Cs)	9.146	8.91
Power Normalized, Watts (12 T/Cs)	8.011	8.78
Power Factor	42.06×10^{-5}	40.17×10^{-5}
Isolation		
Circuit to Foil, Volts	-1.71	-0.888
Circuit to Foil, Ohms	21.3K	62.0K

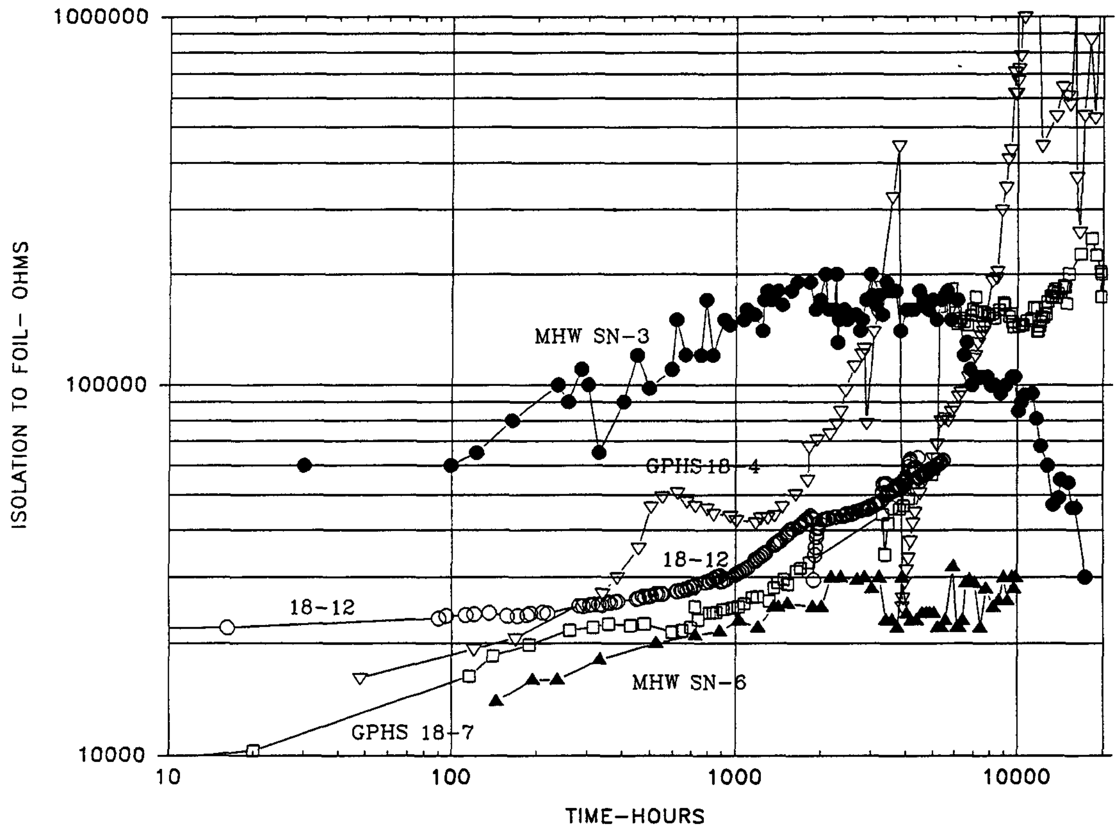


Figure 4-6. Isolation Resistance - Module Circuit to Foil (18-12, GPHS and MHW Modules) - 1035°C Operation

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

Position	Serial #	2nd Bond Milliohm	Preassy Milliohm	Delta ri Milliohm	T = 0 Milliohm	T=1,505 Hours	Delta ri Milliohm	Percent Increase	T=5,409 Hours	Delta ri Milliohm	Percent Increase
1.0	H2594	23.80	22.90	-0.90							
2.0	H2634	22.70	22.60	-0.10							
3.0	H2606	23.50	22.40	-1.10							
					176.80	192.10	15.30	8.65	203.60	26.80	15.16
4.0	H2168	22.20	21.70	-0.50	57.50	63.30	5.80	10.09	67.50	10.00	17.39
5.0	H2151	22.40	21.90	-0.50	57.40	62.90	5.50	9.58	66.90	9.50	16.55
6.0	H2256	22.20	21.70	-0.50	57.00	63.10	6.10	10.70	67.40	10.40	18.25
					171.20	188.60	17.40	10.16	201.10	29.90	17.46
7.0	H2597	24.40	23.20	-1.20							
8.0	H2680	22.60	23.00	0.40							
9.0	H2658	22.70	23.00	0.30							
					178.00	193.60	15.60	8.76	205.20	27.20	15.28
10.0	H1506	23.50	23.20	-0.30							
11.0	H1392	23.80	23.00	-0.80							
12.0	H1606	23.60	22.60	-1.00							
					176.20	193.40	17.20	9.76	205.50	29.30	16.63
13.0	H1344	23.60	23.50	-0.10	59.20	64.80	5.60	9.46	68.80	9.60	16.22
14.0	H1618	23.30	24.00	0.70	58.60	64.50	5.90	10.07	68.70	10.10	17.24
15.0	H1262	23.70	23.30	-0.40	59.40	65.00	5.60	9.43	69.00	9.60	16.16
					176.60	193.70	17.10	9.68	205.90	29.30	16.59
16.0	H1580	23.00	23.70	0.70							
17.0	H2127	22.80	22.10	-0.70							
18.0	H2113	22.90	22.20	-0.70							
					174.50	191.30	16.80	9.63	203.50	29.00	16.62

Task 5

ETG Fabrication, Assembly, and Test

TASK 5 ETG FABRICATION, ASSEMBLY, AND TEST

UNICOUPLE PRODUCTION

E-8 unicouple production was completed during this reporting period and production of contingency unicouples is continuing. The contingency unicouple production is expected to be completed in April 1995. An overall status of the flight unicouple production is shown in Table 5-1 and a summary of the accomplishments for the E-8 and contingency unicouples are shown in Tables 5-2a and 5-2b. Significant issues related to the production of the flight unicouples during this reporting period are discussed in the following paragraphs.

Hydrogen Brazing Furnaces

Early in this reporting period problems were experienced with brazing preassemblies in Furnace #1. An EMQ evaluation resulted in an ECN that lowered the minimum allowable braze temperature. This, coupled with a clarification of the steel wool scrubbing of the preassemblies, has greatly improved yields. The majority of production brazing has been done in Furnace #1 this reporting period. A water leak was detected in Furnace #2 which was repaired by replacing cooling zone #1. Furnace #2 was profiled and used to support production during February 1995.

CVD Furnaces

The quartzware was replaced in Furnace #1. Wafer calibration was completed and all remaining production hardware was coated.

Numerous problems have inhibited the full qualification of CVD Furnace #2. The Haake temperature bath has been repaired after being returned to the vendor several times. The mass flow controllers were contaminated by an improper gas mixture and one reworked unit caused a short in the monitoring circuit. The mass flow controllers have been returned to the vendor. Efforts to qualify this furnace are continuing.

Reduction of Voids in Unicouple Brazes

Unicouple braze voids increased during the 4Q94. An investigation revealed three problem areas, all of which have been resolved. The improvements were documented in Cassini Memos 312 and 337. In brief, improvements were made as follows:

- A screw in the unicouple fixture was intermittently binding in the hole in the radiator assembly causing the cold stack to be out of parallel during the brazing cycle. The "-1" screw was replaced with a smaller diameter "-7" screw . This eliminated the binding condition and the rejection for braze voids dropped from ~11% to ~2% following the screw change.
- Cold stacks were inspected more carefully for parallelism by adding a measurement data sheet to the cold stack traveler.
- Unicouple fixture nut plates were examined for binding due to burrs. Defective nut plates were removed.

Table 5-1. Cassini RTG Program Unicouple Hardware Production Status

(For Period 29 September 1994 through 29 March 1995)

	E-8						
			Cumulative ITD				
	Started This Period	Accepted This Period	Total Starts	Total Accepted	Actual Yield *	Total Planned Starts	Planned Yield
Vacuum Casting	♦	♦	61	57	93.4%	61	96.8%
Powder Blend	♦	♦	27	25	92.6%	27	97.4%
Hot Pressing	♦	♦	137	135	98.5%	137	93.6%
N-P Bond	12	9	39	34	91.9%	39	93.6%
Pellet	230	868	4289	3345	88.6%	4289	87.9%
Segment	114	488	4026	3242	89.4%	4026	87.9%
Hot Shoe	450	381	1546	1265	95.8%	1546	87.9%
First Bond	39	153	1212	1151	95.0%	1212	88.5%
Coated First Bond	112	167	1008	968	96.0%	1008	93.6%
Second Bond	144	176	900	781	88.0%	900	93.6%
Nickel Plating	1554	2427	8862	8702	99.1%	8862	95.5%
Couple Preassembly	361	377	821	645	78.9%	821	93.6%
Brazed Radiator Assembly	126	207	955	869	91.0%	955	95.5%
Machined Radiator Assembly	249	316	849	805	94.8%	849	94.9%
Cold Stack	357	374	805	749	93.0%	805	94.9%
Coated Spacer	480	462	1160	1018	87.8%	1160	93.6%
Unicouple Assembly	410	384	739	642	86.9%	739	94.2%
Wrapped Unicouple Assembly	410	568	650	642	98.8%	650	98.0%

	Contingency						
			Cumulative ITD				
	Started This Period	Accepted This Period	Total Starts	Total Accepted	Actual Yield *	Total Planned Starts	Planned Yield
Vacuum Casting	6	6	27	27	100.0%	27	96.8%
Powder Blend	3	0	11	8	100.0%	11	97.4%
Hot Pressing	5	1	43	37	86.0%	43	93.6%
N-P Bond	♦	♦	0	0	N/A	0	N/A
Pellet	441	98	1053	98	92.5%	1053	87.9%
Segment	129	501	925	868	93.8%	925	87.9%
Hot Shoe	♦	♦	0	0	N/A	0	N/A
First Bond	358	230	358	230	92.0%	358	94.1%
Coated First Bond	336	298	336	298	93.1%	336	93.0%
Second Bond	307	270	307	270	87.7%	307	83.6%
Nickel Plating	2604	2527	2604	2527	99.4%	2625	98.0%
Couple Preassembly	258	204	258	204	89.1%	265	78.7%
Brazed Radiator Assembly	315	289	315	289	91.7%	333	86.6%
Machined Radiator Assembly	268	241	268	241	97.6%	289	85.8%
Cold Stack	224	162	224	162	98.2%	239	84.4%
Coated Spacer	280	265	280	265	94.6%	280	87.8%
Unicouple Assembly	157	99	157	99	97.1%	185	88.0%
Wrapped Unicouple Assembly	87	54	87	54	100.0%	162	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 5-2a. Summary of Accomplishments for E-8 Unicouple Production (Excluding Contingency)

	Percent of E-8 Production Completed Through Inspection	
	End of September (9/21/94)	**End of March (3/29/95)**
First Bonds	93%	100%
Second Bonds	71%	100%
Cold Stack	49%	100%
Couple Preassembly	33%	100%
Unicouple Assembly	32%	100%
Wrapped Unicouple Assembly	10%	100%

Table 5-2b. Summary of Accomplishments for Contingency Unicouple Production

	Percent of Contingency Production Completed Through Inspection	
	End of September (9/21/94)	**End of March (3/29/95)**
First Bonds	0%	70%
Second Bonds	0%	100% *
Cold Stack	0%	69%
Couple Preassembly	0%	86%
Unicouple Assembly	0%	55%
Wrapped Unicouple Assembly	0%	33%

* It should be noted that E-8 hardware was available to be used for contingency second bonding allowing contingency second bonding to be completed prior to contingency first bonding.

Reduction of Voids in Preassembly Brazes

Also during 4Q94, the rejection of couple preassemblies had increased due to braze voids and non-wetting problems. Various aspects of the fabrication process were investigated. The scrubbing technique used to prepare the tungsten cold shoes was found to be operator sensitive. A more aggressive scrubbing method was found to provide the best braze quality. Other items helpful in improving braze quality were reducing the quantity of M50A1 binder used to position the braze shims and optimizing the brazing temperature through a slight reduction. Yields have improved significantly following these improvements. These improvements will be incorporated into the preassembly specification.

Long Term Packaging Plans

Packaging methods for long term storage of unicouple parts were documented in Cassini Memo 333. The memo describes the means to protect the parts and assemblies from corrosion during storage through the use of special corrosion inhibiting paper and bag products. Procurement of these products will be initiated during the next reporting period.

E-6 Converter Assembly

Mating of the thermopile to shell was initiated at the start of this reporting period . After extensive vacuuming, the thermopile was fully inserted into the shell. While the unicouple mounting screws and C-seals were being installed, an electrical short between the thermopile circuit and ground was detected. The magnitude of the resistance was in the 1 to 2 ohm range. The isolation resistance requirement is 27 megohm, minimum. Electrical diagnostic measurements were completed and the cause of the low isolation resistance was traced to one of the circumferential (cross-over) straps.

As a result of the small clearance between the strap and the shell, the insulation on the strap became frayed during thermopile insertion, thereby allowing direct contact between the thermopile circuit and ground. There was concern about the condition of other circumferential straps which have a similar tight fit during thermopile insertion. It was decided to remove the thermopile from the shell and double insulate the straps, as required. Following thermopile removal, re-insulation of critically located straps was completed using quartz yarn or Varglas sleeving. An ECN was issued to include the double wrap on all circumferential straps which have the potential to contact the shell. Prior to re-insertion (during a standard pre-insertion electrical measurement), a short between the thermopile circuit and heat shunt on one of the unicouples was detected. The isolation resistance between the heat shunt and circuit for all other unicouples was satisfactory. A particle shorting across the high voltage insulator was observed in the area of the unicouple connector wrap. The particle was removed by unwrapping and vacuuming. The particle was caught by the vacuum filter and submitted for SEM analysis. Utilizing standard techniques, the unicouple was re-wrapped and insertion of the thermopile back into the shell was successfully completed. No low resistance or shorting problems were detected after re-insertion.

Installation of the C-seals and sealing screws was initiated following re-insertion. With the exception of one sealing screw, all screws were installed without difficulty. Rework of the nut plate facilitated installation of the troublesome screw.

Helium leak testing and pressure decay testing were successfully completed. Two unicouple screws were found to be slightly over the 1×10^{-6} SCC/sec allowable leak rate but were re-torqued . All leak rate and pressure decay requirements were met.

Installation of the outboard heat source support assembly and the inboard latches were successfully completed. A customer walk-through of the EHS installation was completed prior to the installation of the EHS. The EHS was installed in the converter in mid-

November and the inboard and midspan heat source supports were installed and appropriate pre-loads were set. Connection of the instrumentation leads to the spool piece electrical connectors was completed and the RTD cable and flex hose assemblies were installed. This completed the assembly of the E-6 converter. The assembled converter was shipped in late December 1994 to Building 800 to begin processing.

E-6 ETG Processing (Building 800)

The E-6 ETG was received in Building 800 for processing and testing on 22 December 1994. Due to the holidays, the ETG was left in the converter shipping container until 5 January 1995.

Beginning on 3 January, the Building 800 facility was brought on line, including start-up of the Gas Management System (GMS) and the Readout Console (ROC). Installation of appropriate tooling into the Loading and Assembly Station #2 (LAS-2) was completed.

The converter shipping container was opened on 5 January, and the ETG was removed and installed on the transfer cart. ETG resistance measurements were completed, and the data obtained compared favorably with resistance data obtained in Building B prior to shipment to Building 800. The ETG was installed in LAS-2, GSE cables were connected, and the ROC and cable interface to the ETG checkout were completed successfully on 6 January.

A segment readiness review was held on 9 January (chaired by the Cassini Product Assurance Manager) and approval was granted for test start-up. LAS-2 pumpdown was then initiated. ETG pressure was monitored hourly until 14 January when the ETG pressure was 2.3×10^{-5} torr, and power inputs to the EHS were started.

Normal processing continued with appropriate EHS power inputs until 25 January, when an automatic argon gas backfill began. The isolation valves for the cryo and turbo pumps closed, the automatic argon gas backfill system was activated, and the power to the EHS was deactivated. The EHS average temperature was ~600°C at this time. After ensuring that the LAS sealing integrity was not degraded and the turbo and cryo pumps were fully operational, the pumps were opened to the LAS and re-evacuated. The argon pressure inside the LAS was approximately 4 psia at that time. Within a few minutes, the LAS partial pressure was in the 10^{-6} torr range indicating that the backfill system operated normally to protect the ETG. Input power to the EHS was terminated until further investigation was performed to determine the reason for the automatic gas backfill. It was found during leak testing of the gas backfill lines that a small leak existed at the manual valve stem that isolates the LAS from the gas backfill system. It was determined that, by moving this valve stem, the backfill system could be activated. To improve the sealing integrity of the backfill system, a packing material was placed around the manual valve stem and the adjacent solenoid valve was replaced. The seating surfaces of the replaced solenoid valve were examined and found to be in good condition. It was concluded the leaky stem in the manual valve was the most likely cause of the gas backfill.

EHS power inputs were re-started on 28 January. Normal ETG processing continued until E-6 reached full power at 4415 ± 5 watts on 11 February. There was one facility problem encountered during this period when it was necessary to switch the cryo pump compressor from LAS-1 to LAS-2 on 9 February. This was accomplished by closing the hi-vac valve and isolating the cryo pump from the LAS for a short period of time. The turbo pump maintained LAS-2 at acceptable vacuum levels during this time and did not impact the ETG processing.

After completion of a 24-hour "soak" period at the 4415 watt heat input, the EHS power was reduced to 4402 watts on 12 February and the 76-hour performance test was started. The test proceeded normally and was completed on 15 February. All ETG performance data were normal and the ETG power output was measured at 291.8 watts at the end of the 76-hour test. The EHS power was then reduced to 4258 ± 5 watts (expected Cassini BOM fuel loading) and a 4-hour performance test was conducted. Again, all ETG performance data were normal and the ETG power output was measured at 276.1 watts at the end of the 4-hour test. LAS-2 was backfilled with argon gas on 16 February and a 4-hour ETG performance test in an argon atmosphere was conducted. The ETG power output was measured at 146.8 watts at the end of the 4-hour test with an EHS power input of 4402.9 watts. The ETG performance data were reviewed and accepted by Engineering and approval was obtained to initiate power-down in preparation for outboard dome and midspan cap installation. Doming operations were completed on 18 February and midspan cap installation was completed on 19 February. The midspan caps were removed after the initial installation and the O-rings had to be re-centered about the cap before an adequate seal could be achieved. The ETG was then pressurized and a 4-hour pressure decay test and a 6-hour pressure decay test were performed with acceptable decay rates. On 20 February the ETG was removed from the LAS (Figure 5-1) and a series of electrical measurements were performed. The ACS proof pressure test and ETG weighing were completed and the ETG was placed into the converter shipping container (CSC) on 23 February. The ACS leak test was completed and another ETG pressure decay test was performed with acceptable results. The CSC dome was temporarily installed to protect the ETG until an open NR for minor scratches and abrasions on the emissive coating on the ETG were dispositioned.

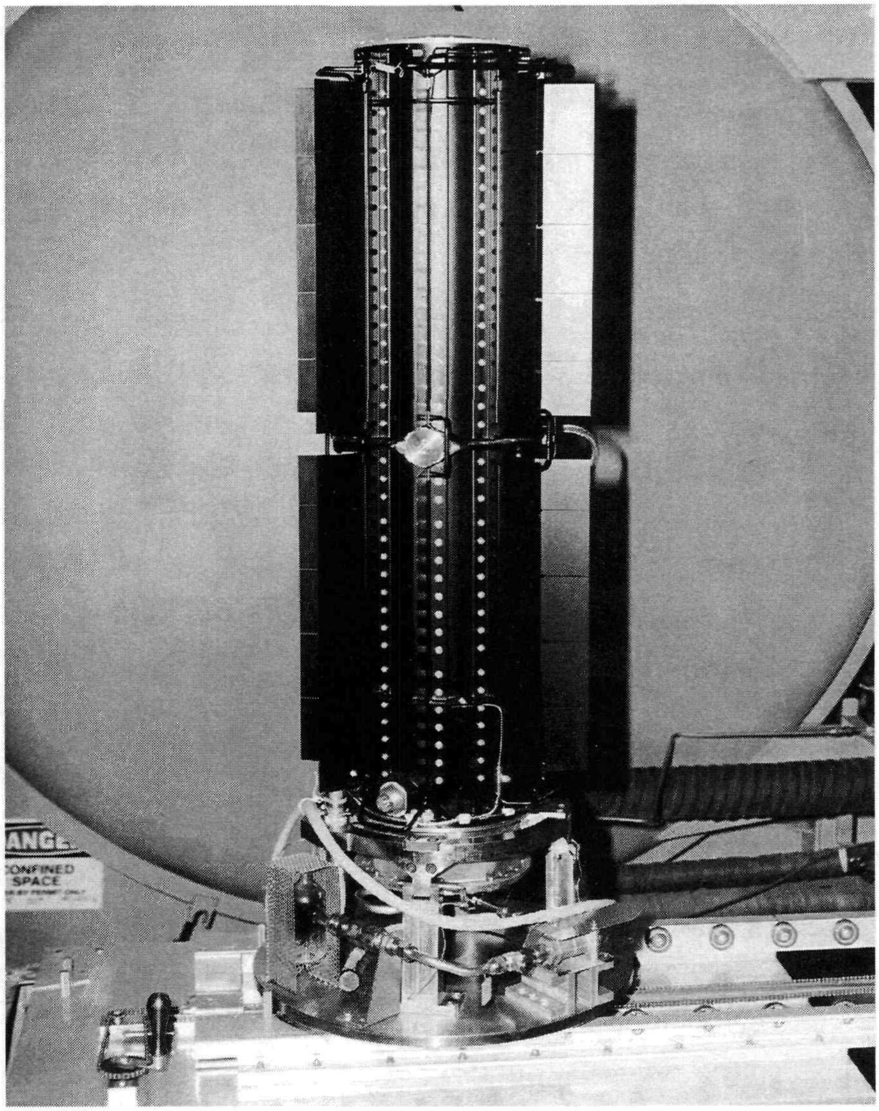


Figure 5-1. E-6 ETG after Removal from the LAS

On 8 March the emissive coating touch-up of the ETG was performed by Manufacturing personnel. Following touch-up, the ETG and gas lines were serviced and ETG pressure was again measured and found to be 23.22 psia. The elapsed time since the previous pressure decay test was 287.5 hours. This results in a pressure decay rate of 0.033 psi/6 hours when corrected for temperature effects. This is significantly less than the requirement of 0.20 psi/6 hours, indicating a well sealed unit. The shipping container dome was then installed, the CSC and gas lines were serviced, and the CSC was pressurized. This completed acceptance testing of the E-6 ETG. Final inspection of the shipping container indicated thread damage on the vent valve. It will be replaced prior to shipping the E-6 ETG to Mound.

E-7 Converter Assembly

Planning was updated to incorporate "lessons learned" from the E-6 thermopile fabrication. The E-7 foil and cloth insulation assembly was transferred to the forming and riveting fixture and moved to the "new" converter assembly area. Unicouple insertion and base wrapping was initiated in mid-October 1994.

In order to select the rivets for the E-7 thermopile, a task was initiated to compare electrical resistance and manufacturing parameters for pop rivets using varied installation parameters (pulling and swaging forces). In addition, solid rivet samples were fabricated and evaluated. As a related activity, engineering work continued to identify the mechanism(s) for the decrease in rivet joint resistance following thermal/vacuum processing. Test results obtained thus far confirm the previous assessment that increasing joint resistance behavior is related to oxidation of the joint. It is believed that the effects of the oxidation are nullified after thermal/vacuum processing. The forming and riveting planning package was updated to include the results of the rivet installation parameter study previously mentioned. A report (Ref. PIR-Cassini-80) was issued which recommended "tight fit" pop rivets with specific pulling and swaging forces for the E-7 and subsequent converters.

Electrical measurements of the unicouples after insertion into the thermopile were well within specification requirements. Borescope inspection of the unicouple hot shoe to inner-moly frame clearance was also completed and met the minimum requirements. Connector forming, riveting, and swaging operations were completed and rivet joint resistance readings were well within the allowable range.

Resistance measurements of the unicouple pairs indicate that all resistances are within $\pm$ 0.03 mΩ of the value recorded subsequent to installation of the unicouples into the thermopile. This is well within the acceptable range. This data confirms that the rivets selected for the E-7 thermopile and installed with modified parameters produce "gas tight" joints which are less susceptible to resistance drift due to oxidation.

The total resistance of the E-7 thermopile is stable between 822 and 826 mΩ. The E-6 thermopile resistance was in the 828 mΩ range at this stage of assembly and unstable. The yarn wrapping of the unicouple electrical connectors was successfully completed for all eight double rows. The thermopile pre-inspection, and unicouple hot shoe location mapping process will be initiated early in the next reporting period.

The E-7 converter shell and fin assembly was machined to comply with Note 15 requirements of drawing 47J306130. This machining corrects the inboard mounting hole locations and was necessary due to dimensional changes resulting from thermal treatments during shell processing. E-7 shell subassembly operations were started and have been completed through the preload alignment of the outboard heat source support system and the inboard latch alignment.

The gas management valve assembly for E-7 was welded, polished, and radiographed per drawing requirements. Leak testing was completed and all requirements were satisfied. Flow cleaning of the valve assembly was completed and is currently awaiting final acceptance.

Power cables for E-7 and E-8 were fabricated, inspected, and accepted. The cables were electron beam welded to the electrical receptacles for E-7 and E-8. Radiographic examination of the welds was acceptable, however, a metallographic sample exhibited a crack in one of the three welds. The sample was re-mounted and polished through an adjacent weld per MRB disposition. This weld showed no sign of cracks after polishing and both electrical receptacle assemblies were accepted.

E-8 Converter Assembly

All panels for the foil insulation package were fabricated, inspected, and accepted. Work has been initiated on the thermopile lay-up. Progress on the lay-up has proceeded without any technical issues and will be completed by mid-April 1995. The foil insulation assembly will be transferred to the storage/transfer fixture and stored per DOE direction.

The E-8 shell and fin assembly has completed clean-up of the EB welds in preparation for completing the ACS closure welds. Upon completion of the welding, the unit will undergo PD224 painting and be placed in long-term storage.

Significant Procurement Issues

There were two significant procurement issues this reporting period. Problems were experienced with lapping at Schwarzkopf Technology's subcontractor. This caused several lots of tungsten cold shoes to be rejected. A Martin Marietta EMQ team worked with the vendor to develop a lapping process which provided acceptable parts and eliminated an adverse schedule impact. Secondly, Engelhard Corporation continued to experience problems manufacturing iridium midspan can assemblies. Engelhard was able to provide acceptable hardware to meet the E-7 ETG requirements, but have not yet provided E-8 hardware despite having been provided iridium material from ORNL. Martin Marietta Astro Space continues to work with this supplier to finish the E-8 can assemblies.

Task 6

Ground Support Equipment (GSE)

TASK 6 GROUND SUPPORT EQUIPMENT (GSE)

All GSE required to support ETG processing was made ready for use during this reporting period. The GSE is inherited from the previous RTG program. Table 6-1 identifies the GSE and the efforts performed on each item to ensure its readiness.

New data acquisition systems have been installed into the Readout Consoles (ROCs). New software was generated and a potentiometer was used to verify proper data processing by inputting simulated signals and comparing results through the data acquisition systems of the ROCs. All emergency alarms and automatic shutdown modes were verified as operational. Two of the three ROCs have completed acceptance testing and customer C of I and are available for ETG processing.

Table 6-1. Building 800 GSE Status

Equipment	Qty	Dwg. No.	Prior C of I	Hard-ware	Ping	Inspect	Calibrate	Test	Rework	Clean	Ready for Use
S/C Lifting Yoke	1	47C305560G1	GP347A	√	√	√	N/A	√	N/A	√	X
Shorting Connector	2	47C305992G1	N/A	√	√	√	N/A	√	N/A	N/A	Xn
GSC Adaptor Fitting	2	47D303116G3,G7	GP341A	√	√	√	N/A	N/A	√	√	X
OB Handling Fixture	4	47D305498G4	GP321A	√	√	√	N/A	√	√	√	S/N F01, F02 X
Interface Tool	1	47D305552G1	N/A	√	√	√	N/A	N/A	N/A	√	Xn
LAS Cables	14	47D305841	N/A	√	√	√	√	√	N/A	√	Xn
Mid Ring Assembly	2	47D306262G1	GP321A	√	√	√	N/A	N/A	N/A	√	X
Handling Bracket Assembly	1	47C306261G1	N/A	√	√	√	N/A	N/A	N/A	√	Xn
OB Dome Clamping Ring	1	47D306444	N/A	√	√	√	N/A	N/A	N/A	√	Xn
Gas Service Cart	2	47E302921	GP341A	√	√	√	√	N/A	N/A	√	S/N 2,3 X
Shorting Module Ass'y	5	47E305051G1	GP328A	√	√	√	N/A	N/A	N/A	√	X
Ship Cont Base	2	47E305499G2	GP316F GP335D	√	√	√	N/A	√	S/N 5	S/N 2 √	S/N 2 X
Ship Cont Dome	2	47E305499G1	GP316F GP335D	S/N 2	√	√	N/A	√	N/A	√	S/N 3 X
ETG Lifting Sling	1	47E305505G1	GP333A	√	√	√	N/A	√	√	√	X
ETG Lifting Sling	2	47E305505G2	GP333A	√	√	√	N/A	S/N 2	N/A	√	S/N 1 X
Readout Console (ROC)	3	47E305854G3	GP336C	√	√	√	√	√	N/A	N/A	S/N 4754NR Xc
RTG Slide Tray Cart	1	47J305514G1	N/A	√	√	√	N/A	N/A	√	√	Xn
Pneumatic Comp Plate	1	47J305514G2	N/A	√	√	√	N/A	N/A	N/A	√	Xn
Receptacle Gage	1	X47D303461P1	N/A	√	√	√	N/A	N/A	N/A	√	Xn
Plug Gage	1	X47D303460P1	N/A	√	√	√	N/A	N/A	N/A	√	Xn
Balance Scale	1	41-1650CE	N/A	√	√	√	√	N/A	N/A	√	Xn
Shop Aids	45	—	N/A	√	√	N/A	√	N/A	N/A	√	Xn

Xn = COI Not Required   X = COI   Xc = Conditonal COI   √ -= Item Complete

Task 7

RTG Shipping and Launch Support

TASK 7 RTG SHIPPING AND LAUNCH SUPPORT

Launch Support

Design drawings have been issued to modify the protective cage that will be used at the launch facility for transferring the RTGs from one facility building to another. Additional cage height must be provided to accommodate the JPL mounting adapter. This will be accomplished by adding a 4-inch elevated center section to the top of the cage. Materials are being ordered for the required cage modifications.

Plans are being reviewed for a Trailblazer which is expected to be performed next year. The purpose of the Trailblazer is to investigate and confirm the routing and handling approach for moving the RTGs at the launch pad. Activities to be covered include unloading, rigging, hoisting and handling a simulated RTG and related ground equipment.

RTG related data was provided to JPL for the Phase 2 Safety Review. The review meeting was held at the Kennedy Space Center in October 1994.

RTG Shipping

Reviews were conducted of the 18-inch drop test procedure and the preliminary design review information package for the facility transporter subsystem of the new RTG transportation system. Comments on both documents were forwarded to Westinghouse Hanford Company, the developer of the new system.

Task 8

Designs, Reviews, and Mission Applications

TASK 8 DESIGNS, REVIEWS, AND MISSION APPLICATIONS

8.1 Galileo/Ulysses Flight Performance Analysis

Galileo and Ulysses RTGs continue to meet performance requirements. Figure 8-1 indicates the F-1 RTG performance (Galileo) is better than predicted. Figure 8-2 shows the F-4 RTG performance (Galileo) to be nominal. The combined power performance, as indicated by the telemetry, is within the model predictions (see Figure 8-3). The Galileo RTG power systems are predicted to provide end of mission power well within the required levels. Figure 8-4 shows the F-3 RTG performance (Ulysses). This spacecraft carries a single RTG. The data indicate the performance to be somewhat better than predicted. The Ulysses RTG power system is predicted to provide end of mission power well within the required levels.

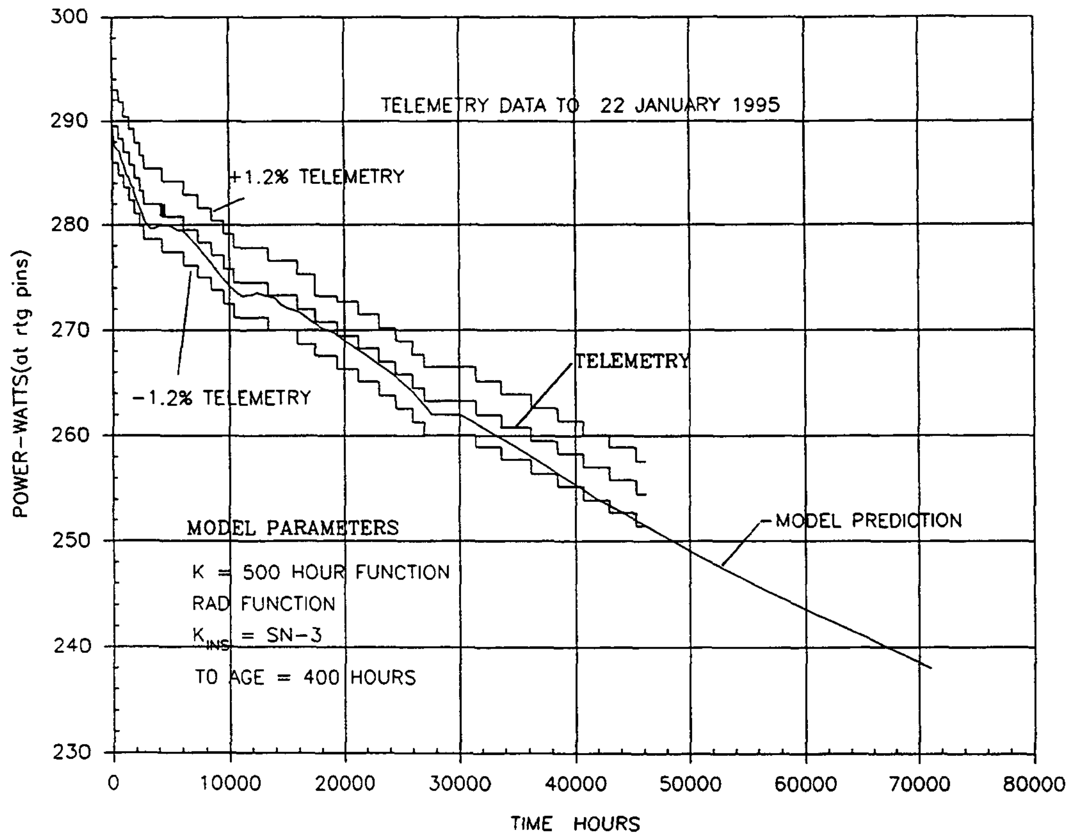


Figure 8-1. Galileo RTG F-1 Performance

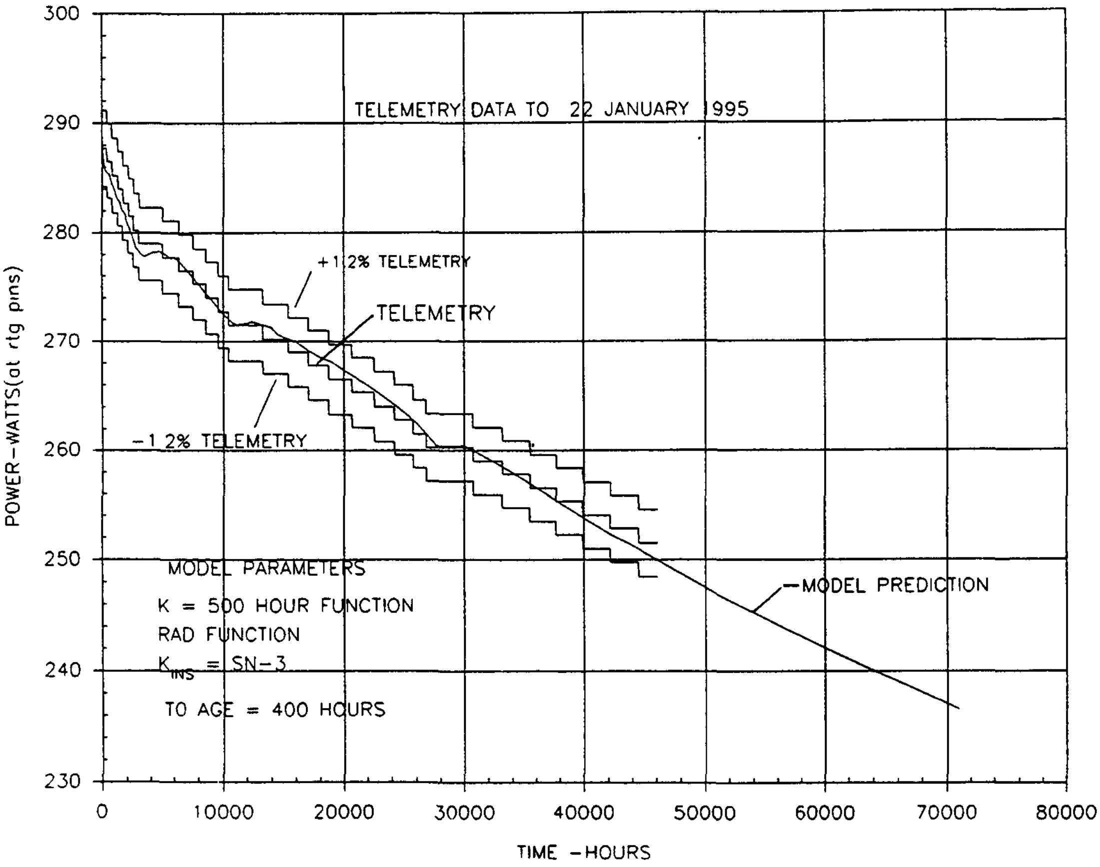


Figure 8-2. Galileo RTG F-4 Performance

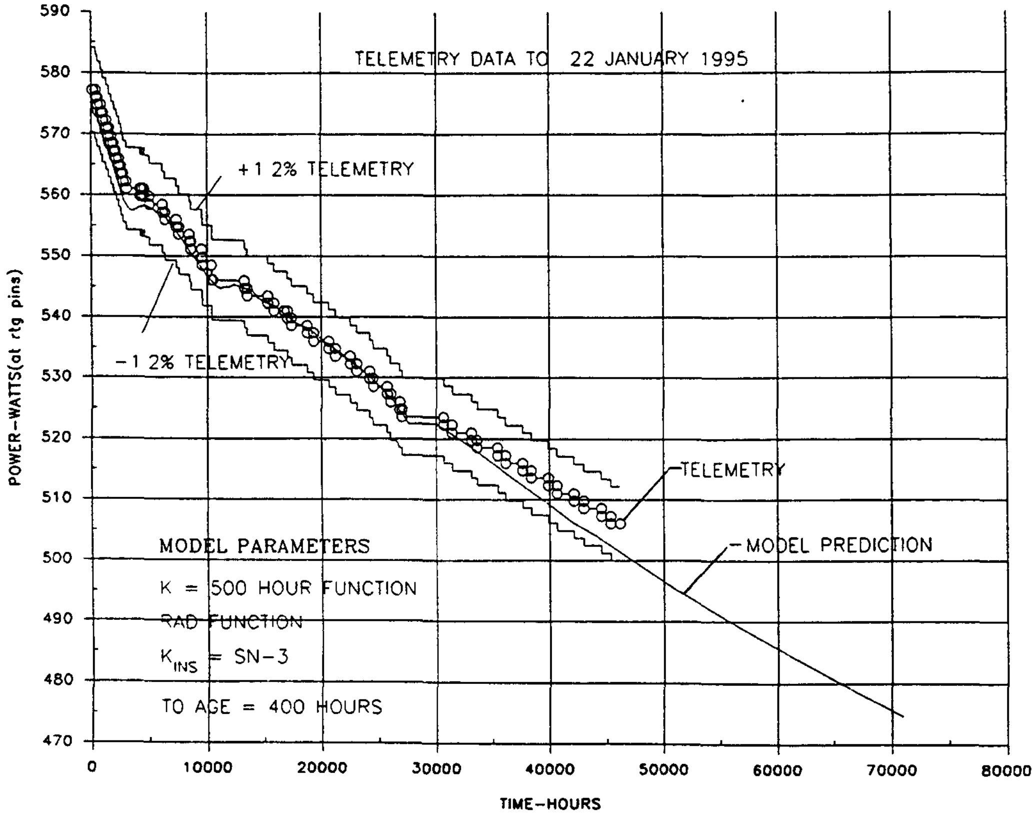


Figure 8-3. Galileo RTG F-1 and F-4 Combined Performance

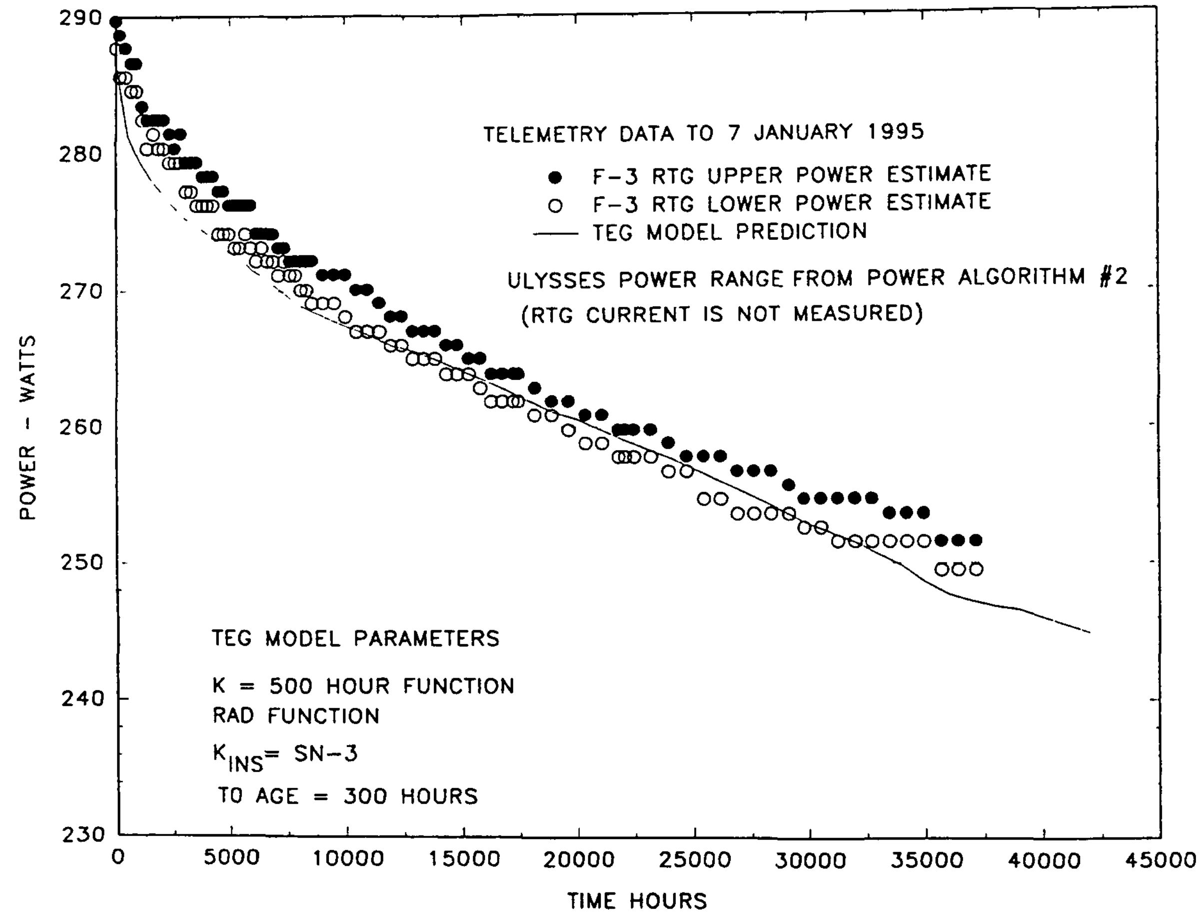


Figure 8-4. Ulysses RTG F-3 Power

8.2 Individual and Module Multicouple Testing

This task ended in September. Post test analyses were performed under Task 8.5.

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

Internal reviews and approvals are underway for the following papers. These papers have been approved by DOE for preparation under Task 8.4:

- "Cassini/RTGs Small Scale Module Tests - Part Two" by C. Edward Kelly and Paul M. Klee.
- "Evaluation of an 18-Couple Module Composed of Improved Performance SiGe Unicouples" by C. Edward Kelly, Paul M. Klee, and Robert F. Hartman.
- "Radioisotope Thermophotovoltaic Generator for Space Power Applications" by Dr. S. Loughin

8.5 Evaluation of an Improved Performance Unicouple

Multicouple Life Testing

A topical report entitled "Multicouple Life Test Results" summarizing the long term performance of five multicouples and the results of post test visual examinations was issued on 31 January 1995 (refer to CON 1128). This concluded the multicouple work which was being performed in Task 8.2.

Improved Performance Unicouple

Fabrication and assembly of 18 couple module 18-Z, which contains unicouples with improved thermoelectric materials, was completed on schedule in January 1995. A test readiness review was successfully completed and module heat-up began on 25 January 1995.

Predicted Performance

Performance predictions which were reported in the October 1994 monthly report were updated when additional property data were provided by Ames Laboratory. The data indicated an expected improvement in the figure-of-merit in the range of 7 to 10% for the N-type material and a 10 to 14 % improvement for the P-type material. In terms of couple efficiency, the expected improvement was in the range of 5 to 7 %. The property data predicted little change in the power output but the operating point would be shifted to a lower voltage per couple. The expected gain in performance was due to a lower thermal conductivity of both the N- and P-type materials. Predictions from the property data indicated the heat input required to achieve the same cold to hot junction delta temperature should be 10 to 12 watts lower in module 18-Z. Predictions are summarized in Table 8-1.

Test Summary

The module heat-up was accomplished over a twenty day period and it reached the operating hot shoe temperature of 1035°C (1000°C hot junction) on 15 February 1995. As of 2 April 1995, the module has been operating for 1,100 hours. Initial module performance, in terms of power output and heat input, fell within the existing 18 couple module data base and did not show the expected improvement.

Life test results show that the power output degradation is more rapid than in standard 18 couple modules. Both the internal resistance and open circuit voltage are also increasing more rapidly. This indicates a more rapid loss of charge carriers, possibly due to the combination of overdoped alloys with a fine grain structure leading to accelerated dopant precipitation. Metallographic examination of N legs from fabricated couples showed melted regions associated with the GaP. It is theorized that this also may be playing a part in the accelerated loss of the N leg phosphorus dopant. The electrical uniformity of all unicouples measured within the module was excellent. All internal resistances and open circuit voltages fell within a one percent band.

Table 8-1. Comparison of Predicted Performance of Cassini and Improved Materials

	Approach #1		Approach #2 (Post Unicouple Fabrication)	
	Cassini Reset Compact	Improved Reset Compact	Cassini No Reset Pellet	Improved No Reset Pellet
Maximum Couple Efficiency, %	7.96	8.34	7.25	7.77
Module Efficiency, % (Incl. 35.9 watts heat loss)	6.28	6.44	5.68	5.98
Maximum Couple Efficiency Increase, %	-	4.8	-	7.2
Module Efficiency Increase, %	-	2.5	-	5.3
Heat Into 18 Unicouples, watts	134.0	122.1	130.0	119.9
Heat Into Module, watts	169.9	158.0	165.9	155.8
Module Power, watts	10.67	10.18	9.42	9.32
Output Voltage at Maximum Couple Efficiency, volts	3.30	2.95	3.30	2.90
Open Circuit Voltage, volts	5.94	5.31	6.01	5.12
Internal Resistance, ohms	.818	.683	.950	.692

Initial Test Results

The twenty-day controlled heat-up is a standard procedure for 18 couple modules. It accomplished the slow desorption of water vapor, oxygen, and other gasses while avoiding oxidation of the molybdenum foils which would increase their emissivity. It was particularly important to replicate the thermal characteristics of the foil insulation system because the basic property measurements made on the improved thermoelectric materials indicated that the improved performance would be due primarily to a lower thermal conductivity. This would be reflected in a lower heat input required to reach the operating hot junction temperature. Therefore, care was taken both in the fabrication and heat-up processes to duplicate the condition of the foil system of previous modules.

The first stable operating temperature point is shown in column 4 of Table 8-2. The ratio of load resistance to module internal resistance (RL/RI = 1.446) was not optimum to obtain the maximum efficiency. Maximum efficiency occurs at an RL/RI = 1.25 which also corresponds to a load voltage to open circuit voltage ratio (VL/EOC) = 0.555. A second test point obtained at this condition is shown in column 5. Shown in columns 1 to 3 of Table 8-2 are the initial performance of Cassini modules 18-10, 18-11 and 18-12. Module heat input ranged from 162.6 watts to 169.2 watts. Module 18-Z required 167.25 watts. Module efficiency corrected to a hot to cold junction temperature difference of 700°C is shown as the last entry in the table. It is seen that the efficiency of 18-Z falls within the data base and shows at most about a 1% improvement over module 18-12.

Table 8-2. 18-Z Comparison with Cassini Modules

		Module 18-10	Module 18-11	Module 18-12	Module 18-Z	Module 18-1Z
Date		**7/29/93**	**1/27/94**	**6/16/94**	**2/15/95**	**2/15/95**
Heat Input	Watts	162.6	163.4	169.15	165.9	167.25
Hot Shoe	°C	1033.4	1034.6	1035.9	1036.6	1034.7
Hot Junction	°C	998.4	999.6	1000.9	1001.6	999.7
Cold Junction	°C	285.4	291.5	287.1	286.9	288.0
Outer Shell	°C	266.0	272.0	267.5	268.6	269.7
Delta T (HJ-CJ)	°C	713.0	708.1	713.8	714.7	711.7
Current	Amps	2.596	2.586	2.548	2.802	3.035
Voltage						
Load	Volts	3.654	3.601	3.733	3.331	3.111
Open Circuit	Volts	6.365	6.381	6.431	5.634	5.636
VL/EOC		0.574	0.564	0.580	0.591	0.552
Internal Resistance	Ohms	1.041	1.075	1.059	0.822	0.832
Load Resistance	Ohms	1.408	1.392	1.465	1.189	1.025
RL/RI		1.352	1.295	1.383	1.446	1.232
P Measured	Watts	9.485	9.311	9.510	9.333	9.443
P Norm. ($\Delta T = 700$)	Watts	9.142	9.099	9.146	8.953	9.134
P Maximum	Watts	9.729	9.469	9.763	9.654	9.545
P Max Norm ($\Delta T = 700$)	Watts	9.377	9.254	9.390	9.261	9.233
Module Efficiency						
P Meas/Q	%	5.830	5.698	5.622	5.626	5.646
$\Delta T = 700$	%	5.72	5.63	5.51	5.51	5.55

Also noted is the lower internal resistance and open circuit voltage of 18-Z relative to previous modules. Initial internal resistance was 0.83 ohms compared to about 1.06 ohms for the other modules and the open circuit voltage was 5.6 volts compared to 6.4 volts. These lower values were expected from the basic property measurements and result in the maximum efficiency point occurring at a lower load voltage. It is also noted that the normalized power output for all the modules fall within a narrow band.

Life Test Results

Figures 8-5 through 8-10 show the life test performance to 1,100 hours as of 2 April 1995. Both the load voltage and heat input (167 ± 1.5 watts) are held constant during the test. Figures 8-5 through 8-7 show measured performance normalized to a temperature difference of 700°C while Figures 8-8 to 8-10 show this data normalized to their initial values. Shown for comparison are Cassini module 18-12 and GPHS module 18-7 (the last GPHS module operated at 1035°C). Normalized maximum power has degraded about 7.5% (Figure 8-8) compared to about 3% for standard modules. The internal resistance is rising more rapidly in module 18-Z(Figure 8-9), i.e., 25% versus 10% and the open circuit voltage is also increasing faster (Figure 8-10). These trends represent a more rapid loss of charge carriers. A probable cause is the high doping level combined with a fine grain structure resulting in accelerated dopant precipitation.

Since the dopant precipitation process is primarily diffusion controlled, the power ratio data can be fit to the function form:

$$P/Po = A - B \times 10^{-3} t^{1/2}$$

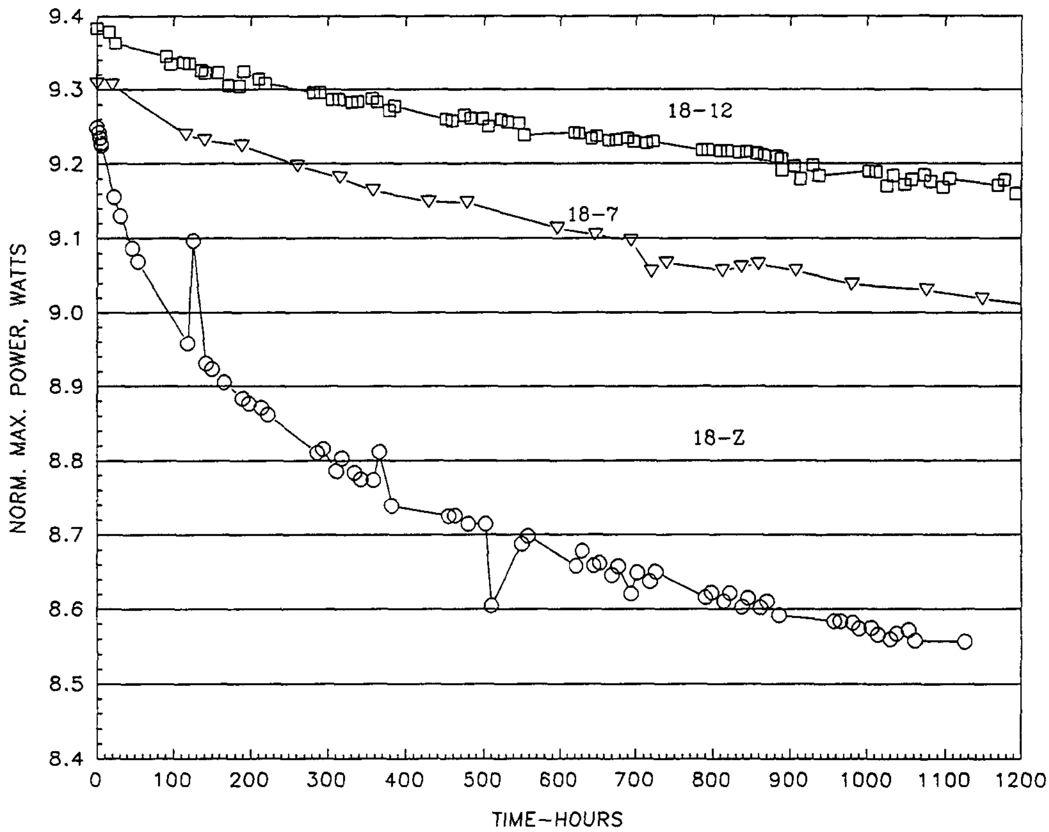


Figure 8-5. Module 18-Z – Normalized Maximum Power

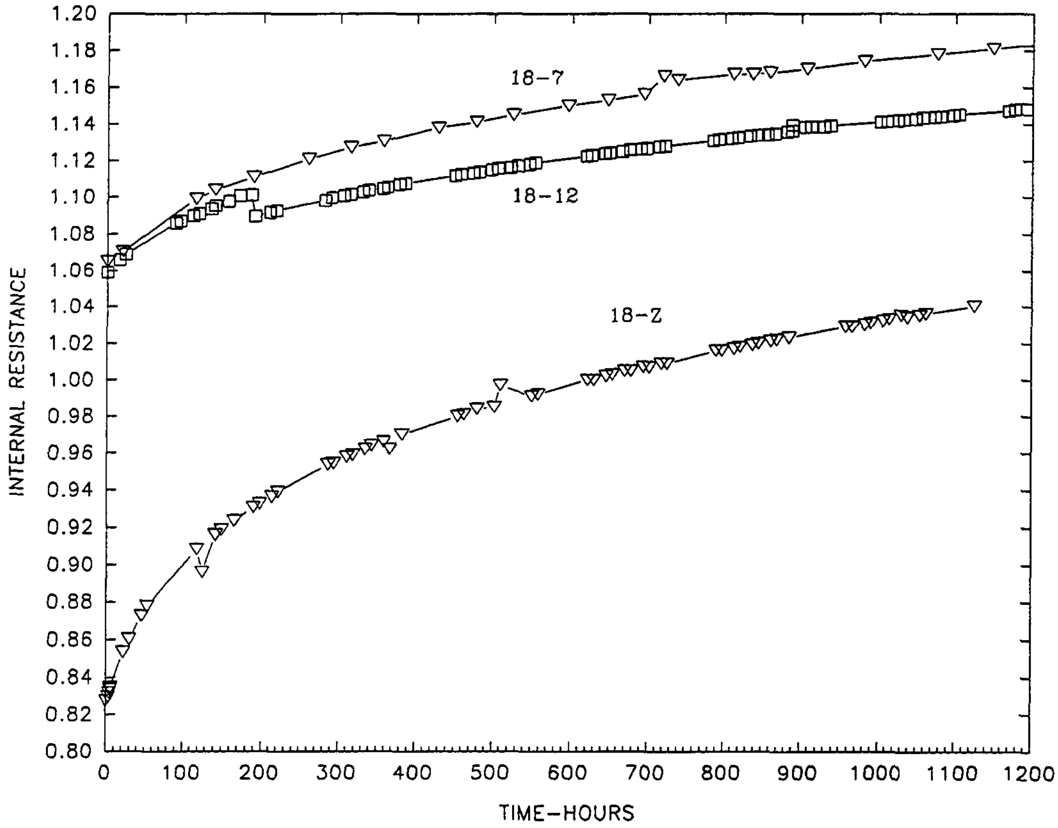


Figure 8-6. Module 18-Z - Internal Resistance

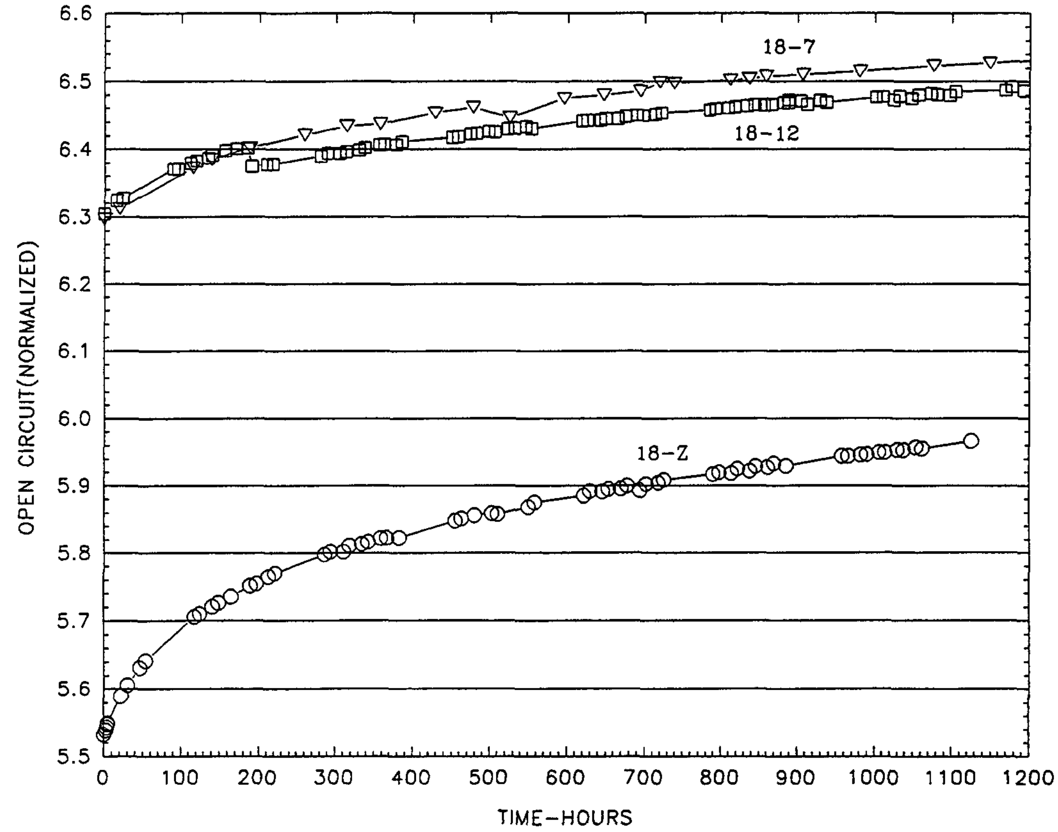


Figure 8-7. Module 18-Z - Normalized Open Circuit Voltage

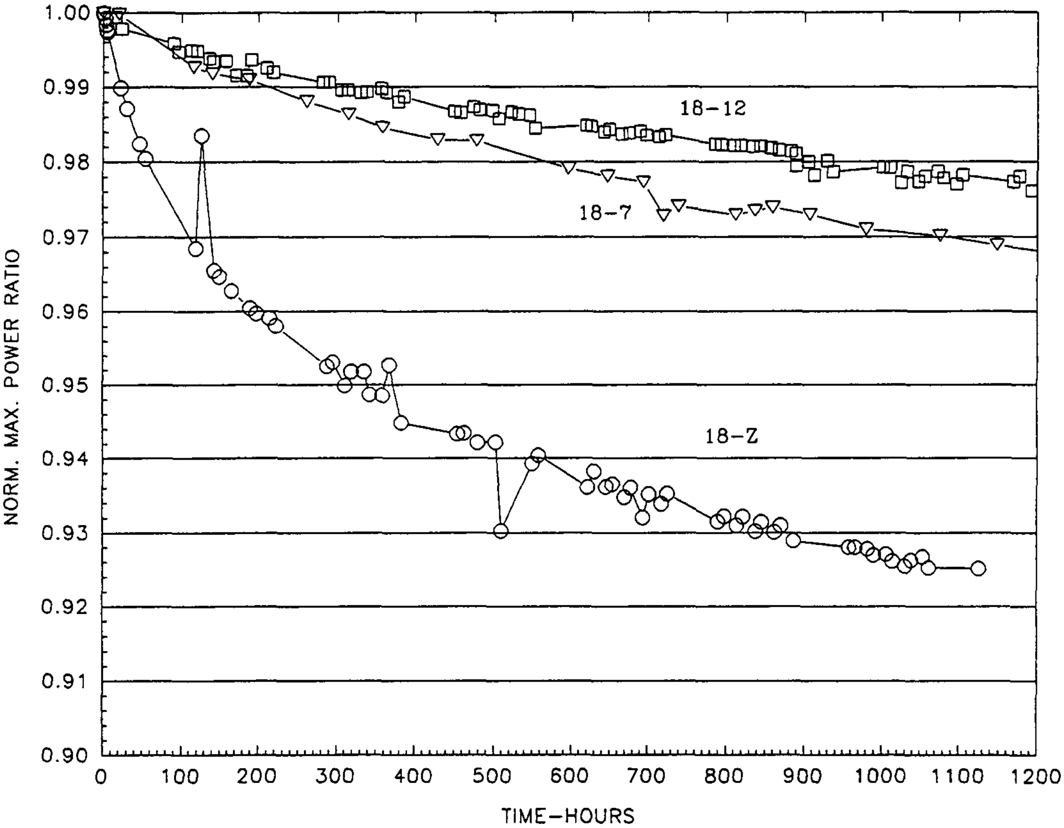


Figure 8-8. Module 18-Z – Normalized Maximum Power Ratio

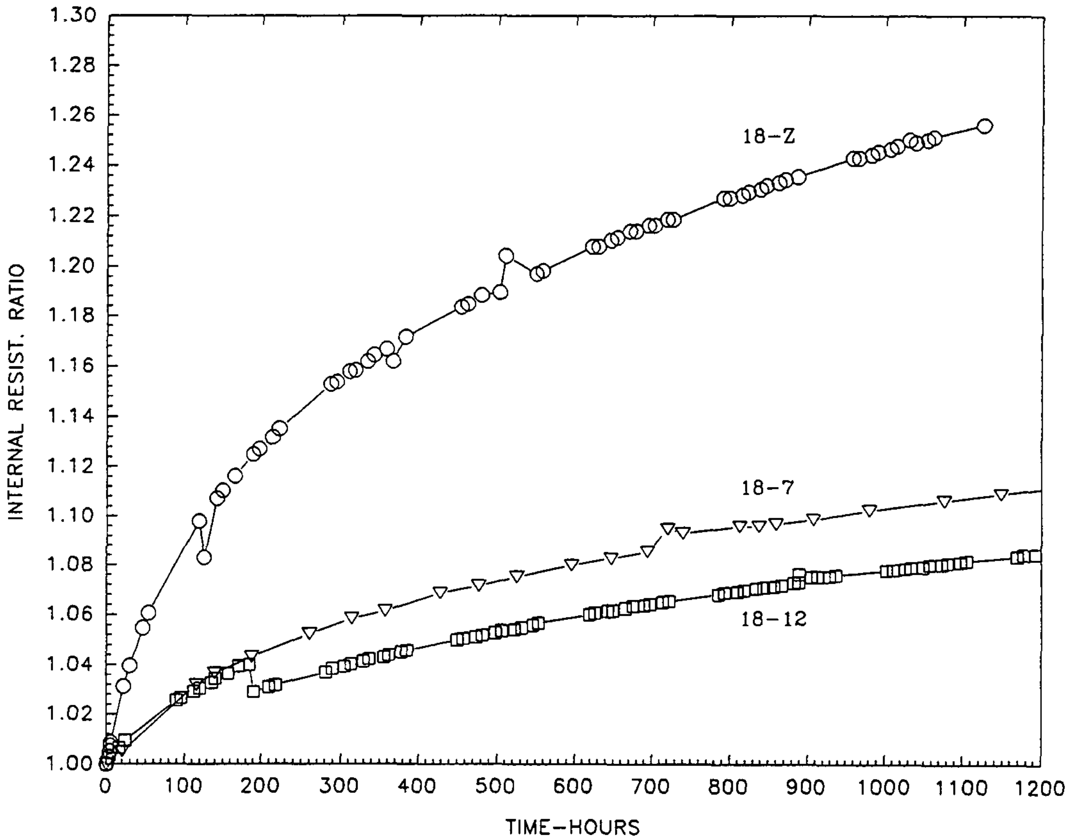


Figure 8-9. Module 18-Z – Internal Resistance Ratio

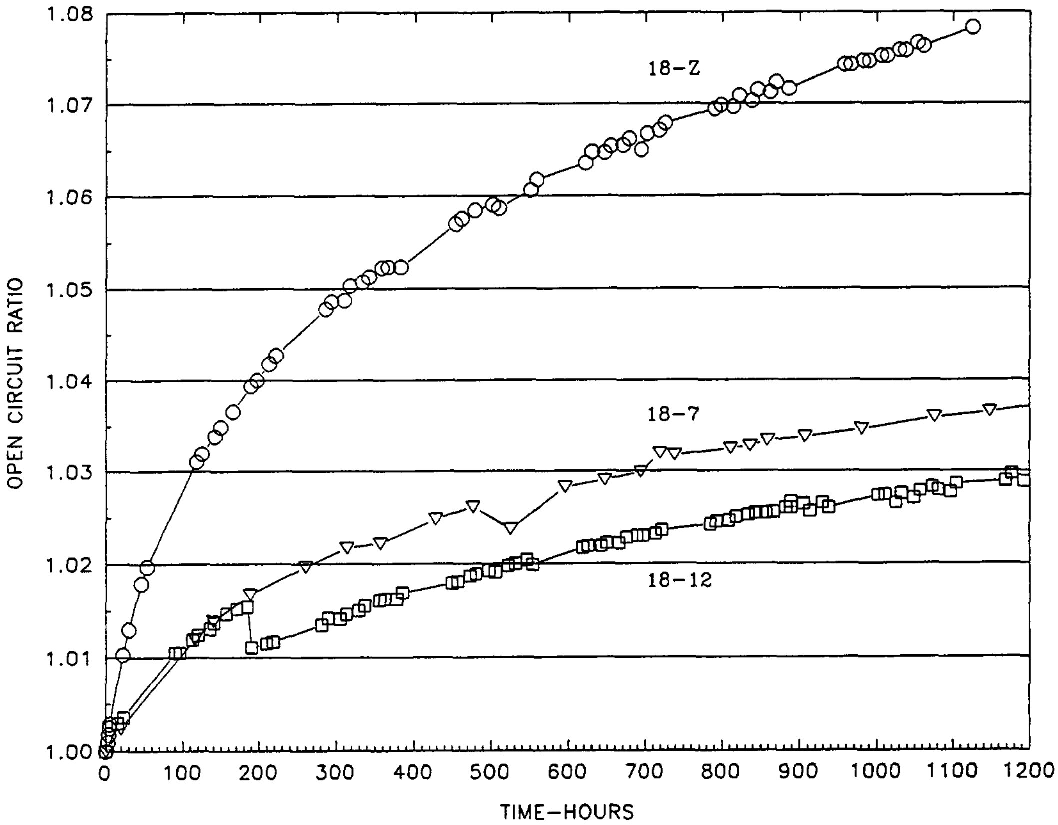


Figure 8-10. Module 18-Z – Normalized Open Circuit Voltage Ratio

When this is done, the coefficient B can be used to compare module degradation rates. Table 8-3 shows such a comparison for modules 18-7, 18-12, and 18-Z. As seen from Figure 8-8, the relative rate difference is diminishing and Table 8-3 shows that the B coefficients are converging in magnitude. In the interval from 200 to 700 hours the ratio was 3:1 and in the 600 to 1100 hour interval the ratio has decreased to 1.5:1.

Table 8-3. Degradation Rate Comparison

								Rate Ratio	
								B Ratio	
	18-Z		18-12		18-7			18-Z / 18-12	18-Z / 18-7
Range	A	B	A	B	A	B			
200 - 700 Hours	.9888	2.059	1.003	.724	---	---		2.84	---
300 - 800 Hours	.985	1.927	1.002	.7074	---	---		2.72	---
500 - 950 Hours	.978	1.611	1.005	.825	1.006	1.13		1.95	1.42
600 - 1100 Hours	.973	1.462	1.008	.905	1.002	.9859		1.61	1.48

Uniformity of the 18-Z Test Data

The uniformity of the thermocouple readings and the electrical characteristics of the unicouples within the module were excellent. The 18-Z instrumentation is identical to previous modules. Six hot shoe thermocouples and eight cold strap thermocouples are used to obtain the average junction temperatures. The initial range of the six hot shoe thermocouple readings was 6.5°C and, after 1,100 hours the range was 5.2°C. The cold strap range was 7.3°C initially and 8.7°C after 1,100 hours.

Cold side average temperature trends and average hot shoe and heat input are shown in Figures 8-11 and 8-12. Heat Input has been controlled to within ± 1 watt of its initial value of 167.3 watts established at the maximum efficiency point.

Voltage taps allow the measurement of the internal resistance and open circuit voltage of each of the 6 axial rows of unicouples. In addition, the individual unicouples in two rows are measured. Table 8-4 shows the internal resistance values at times of 0, 500, and 1,000 hours. The spread in values is at any point in time less than 1%.

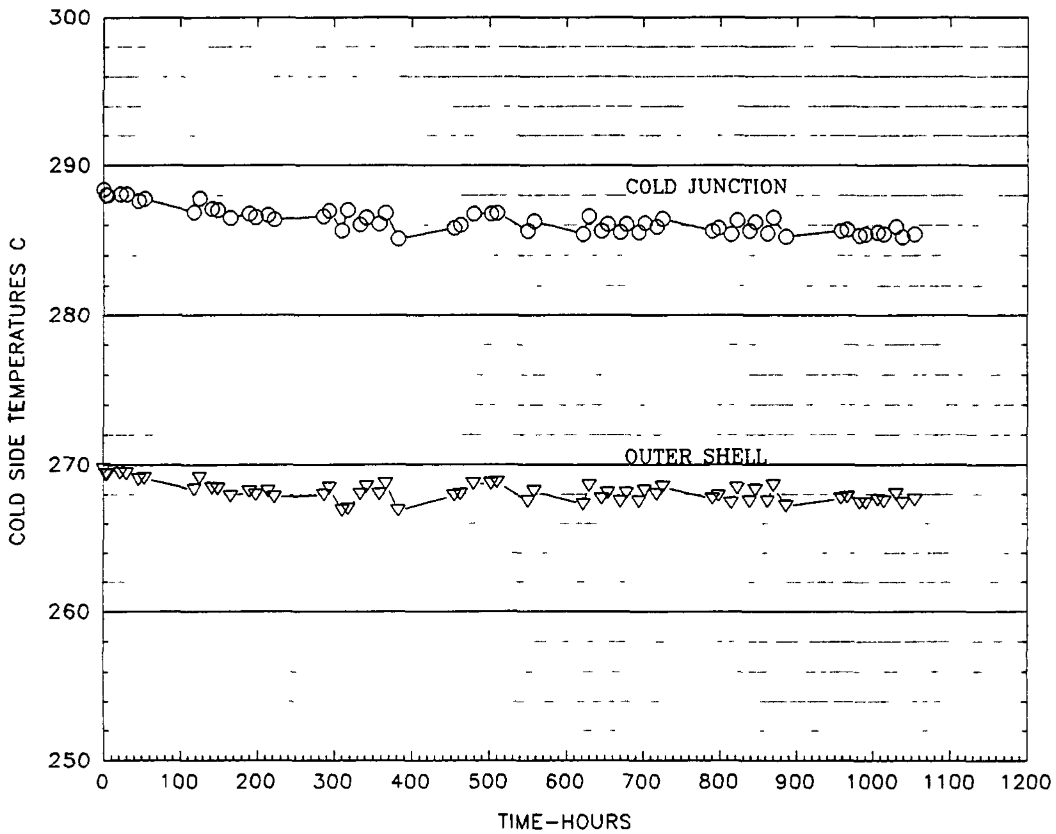


Figure 8-11. Module 18-Z – Cold Side Temperature History

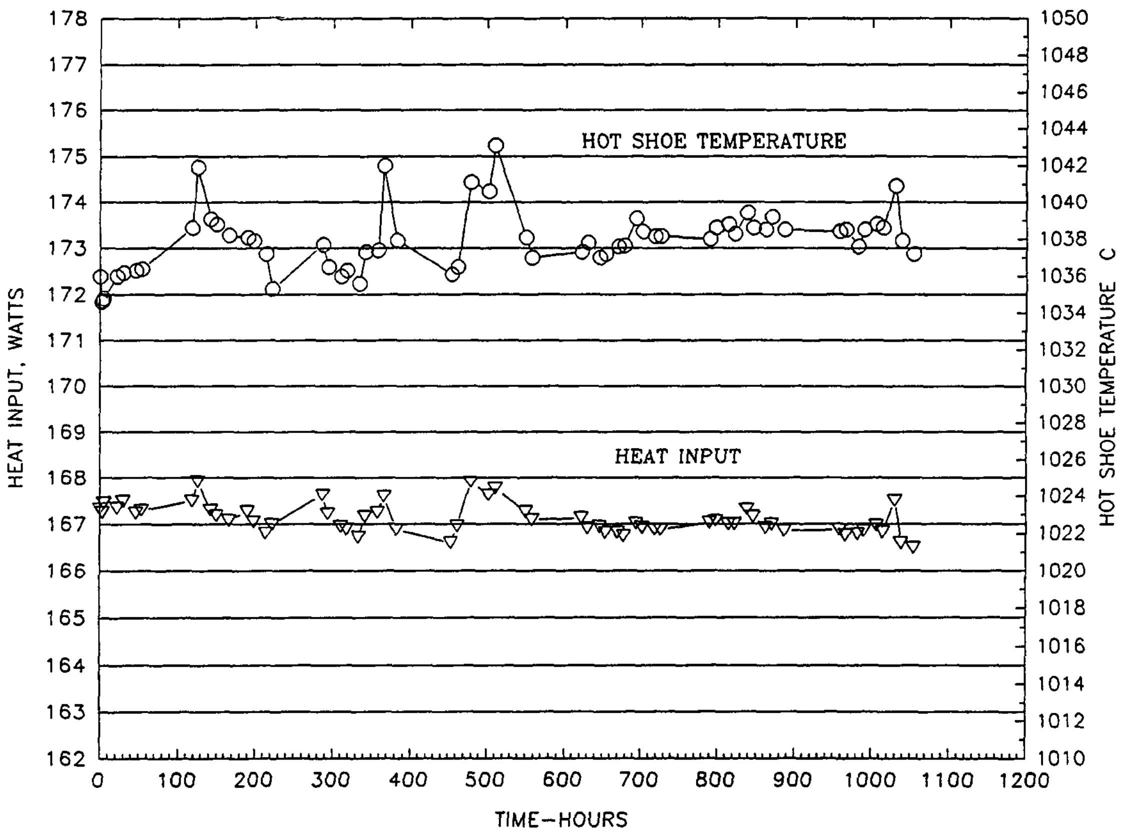


Figure 8-12. Module 18-Z – Hot Shoe Temperature and Heat Input History

Task Schedule

The overall task schedule is shown in Figure 8-13. The task is scheduled to be completed 17 April 1995. A request has been made to extend the task by two months, at no additional cost, to accumulate 2,000 hours of life test data and to perform minimal post test diagnostic analyses.

8.6 Solid Rivet Feasibility Study

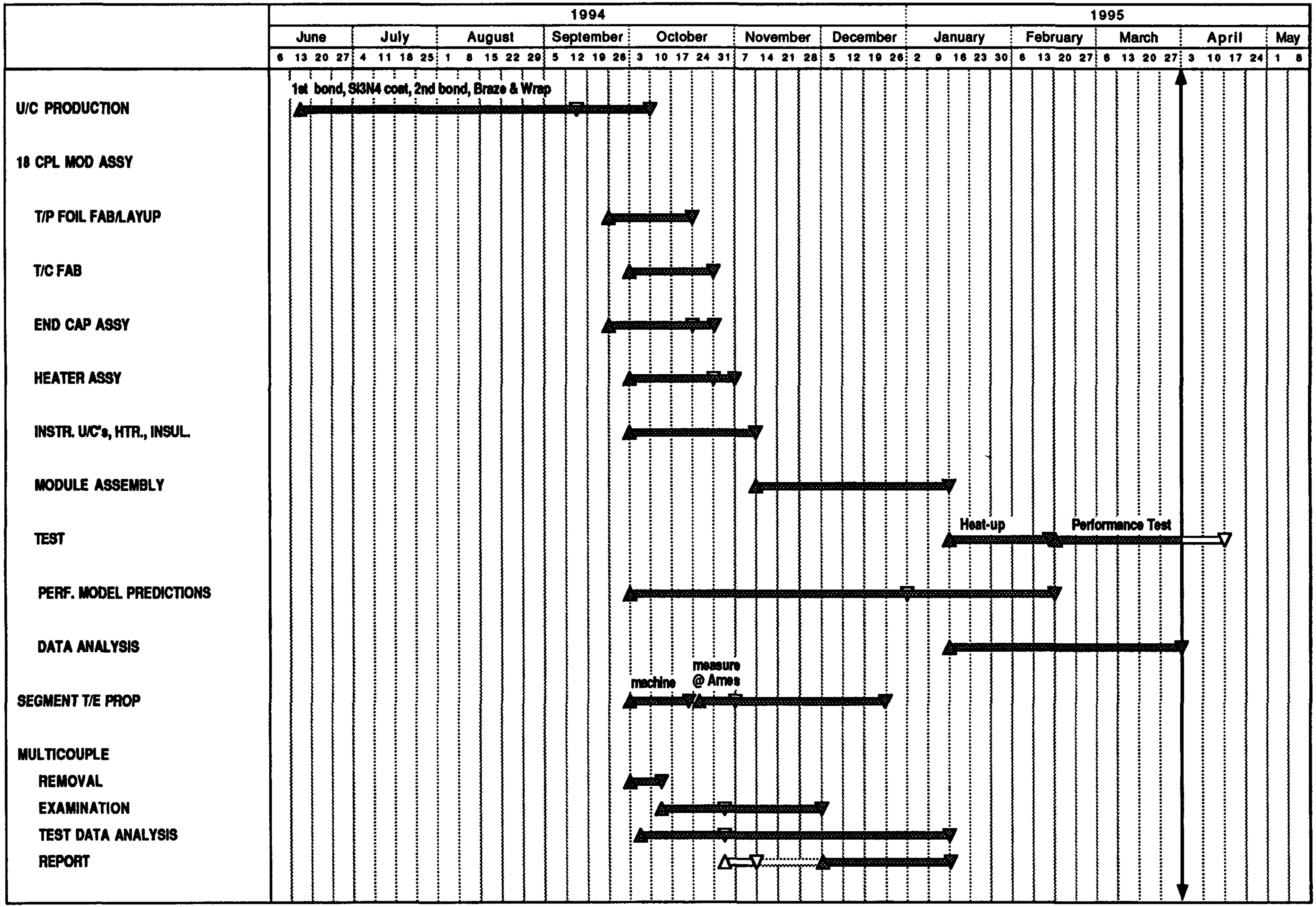
The solid rivet technical evaluation task, including development and implementation work, was concluded in October 1994. It was determined that, given the size constraints of fixtures used to install solid rivets into the thermopile, solid rivets offered little advantage over pop rivets currently in use. A detailed technical report on this task was prepared and issued as a program topical report in January 1995 (Refer to CON #1127). This task is complete.

8.7 Computational Fluid Dynamics (CFD)

Work continues on the CFD task with a projected completion of October 1995. Because this task is closely related to the Task 3 safety activities, progress is reported under that task.

Table 8-4. Uniformity of Internal Resistance within Module 18-Z

Position	Serial #	Wrapped Room Temp. Milliohm	T = 0 at Temp Milliohm	500 Hours Milliohm	Delta RI Milliohm	Percent Increase	1000 Hours Milliohm	Delta RI Milliohm	Percent Increase
1.00	4935-36	17.50							
2.00	4935-27	17.50							
3.00	4935-28	17.60							
			137.70	164.10	26.40	19.17	171.80	34.10	24.76
4.00	5019-11	17.46	45.90	54.70	8.80	19.17	57.30	11.40	24.84
5.00	4935-23	17.66	46.20	55.10	8.90	19.26	57.70	11.50	24.89
6.00	4935-25	17.60	46.10	55.00	8.90	19.31	57.60	11.50	24.95
			137.60	164.10	26.50	19.26	172.00	34.40	25.00
7.00	5019-4	17.60							
8.00	5019-40	17.60							
9.00	5019-30	17.60							
			138.40	164.90	26.50	19.15	172.80	34.40	24.86
10.00	5019-39	17.70							
11.00	5019-40	17.60							
12.00	5019-5	17.50							
			138.90	165.30	26.40	19.01	173.10	34.20	24.62
13.00	5019-15	18.47	45.80	54.60	8.80	19.21	57.30	11.50	25.11
14.00	5019-12	18.42	45.90	54.80	8.90	19.39	57.50	11.60	25.27
15.00	4935-24	18.34	46.30	55.20	8.90	19.22	57.80	11.50	24.84
			137.60	164.10	26.50	19.26	171.90	34.30	24.93
16.00	5019-14	18.20							
17.00	5019-13	17.70							
18.00	5019-38	17.90							
			138.50	164.90	26.40	19.06	172.80	34.30	24.77



Cassini #1 - CTUL

Figure 8-13. Task 8.5 Improved Unicouple Schedule and Status

Task 9

Project Management, Quality Assurance and Reliability, Contract Changes, Non-Capital CAGO Acquisition, and CAGO Maintenance

TASK 9 PROJECT MANAGEMENT, QUALITY ASSURANCE, AND RELIABILITY

9.1 Project Management

Task 9.1 Project Management

During this reporting period, all contract weekly, monthly, and quarterly reports were delivered on schedule. Cassini Quarterly Reviews were supported in October 1994 and January 1995. Monthly reviews were supported in December 1994 and March 1995.

The E-6 ETG successfully completed processing. All acceptance test results are within specifications and the ETG is being prepared for shipment on 15 April 1995. It is anticipated that all E-7 converter milestones will be met. Direction was received from DOE to complete E-8 component assembly but to delete the thermopile and converter assembly tasks. This direction is being implemented.

Attached are the Cassini RTG program calendars for 4Q94, 1Q95, and 2Q95 showing program meetings and important mission related events.

No significant Environmental, Health, and Safety incidents occurred in this period.

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 issued. The Software Management Plan (CDRL A.7) and Quality Assurance Program Plan (CDRL A.3) have received DOE approval and have been issued. The Sampling Plan, approved at the start-up of the program but not formally submitted as a CDRL, was submitted as CDRL A.15.

Process Readiness and Production Readiness Reviews

No process or production readiness reviews were conducted this period, however, a test readiness review for ETG processing in Building 800 was conducted in November 1994.

Quality Control in Support of Fabrication

Converter Assembly: Fabrication of the E-6 converter was completed in December 1994 and was moved to Building 800 in preparation for processing and acceptance testing. Processing commenced in January 1995 and all acceptance tests were successfully completed by the end of February. The converter is currently in Building 800 and is being prepared for delivery. The deliverable data package is being prepared and a Pre-ship Review is scheduled for 6 April 1995.

Fabrication of the E-7 converter is continuing with no major problems. The unicouples have been installed into the thermopile and base wrapping was completed. Connector forming and riveting operations were completed in January. Connector wrapping was completed in March with converter fabrication currently expected to be completed in June.

Fabrication of the E-8 converter is proceeding with no technical problems.

Hardware is being reviewed for acceptability and traceability prior to 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. In-process inspection support has been provided to all converter fabrication processes throughout this period.

During qualification testing of the RTD cable assembly, low isolation resistance was noted during the qualification thermal vacuum testing. A Failure Review Board was established, through MRB, to determine the cause of the low isolation resistance. Destructive and non-destructive evaluations have been conducted on the qualification cable assembly and components. The effort is continuing, but results, to date, indicate that the problem is in a single RTD sensor. Evaluation of this problem is continuing.

Unicouple Production: Throughout this reporting period most processes performed at or above established yield goals. Processes that did not meet yield goals were second bond, preassemblies, and unicouples. Initially, the majority of defects were related to bad brazes. These processes were addressed by EMQ teams and yields have improved significantly in all processes. Currently, brazes are generally good and yields are higher. Defects are varied and include foreign material and damage.

The manufacturing of unicouples for the E-8 converter has been completed and there are currently sufficient unicouples to process a map. The E-8 unicouple map will be completed during April.

Material Review Board: There were no Class I (major) non conformances generated this month.

Quality Assurance Audits

The Quality Systems organization performed two audits to evaluate compliance to general Astro Space quality standards, and the Quality Assurance organization audited the control of software per the newly approved Cassini Software Plan. Unicouple process audits were performed on the second bond, preassembly, and unicouple processes. Converter process audits were performed on raw materials and training. A minimal number of findings were noted for these audits and all have been addressed and closed.

Quality Assurance Status Meetings

Meetings were held with DOE and Westinghouse representatives in October, December, January, and March during this reporting period. Topics included the status of audits, converter fabrication, unicouple production, E-6 converter processing, and other converter related topics.

Task H

Contract Acquired Government-Owned Property (CAGO) Acquisition

TASK H CONTRACTOR ACQUIRED GOVERNMENT OWNED (CAGO) PROPERTY ACQUISITION

Task H.1 CAGO Unicouple Equipment

Hydrogen Brazing Furnaces:

Furnace #1 is fully supporting production without difficulties.

Furnace #2: This furnace experienced leaks in the cooling system. These were resolved and during March the furnace was operational and supporting production.

CVD Furnaces:

Furnace #1 is on line and supporting production after replacement of the quartzware in November.

Numerous problems have inhibited the full qualification of CVD Furnace #2. The Haake temperature bath has been repaired after being returned to the vendor several times. The mass flow controllers were contaminated by an improper gas mixture and one reworked unit caused a short in the monitoring circuit. The mass flow controllers have been returned to the vendor. Efforts to qualify this furnace are continuing.

H.2 CAGO - ETG Equipment

A second ("new") ETG assembly area was put into operation, thereby enabling E-6 and E-7 ETG operations to be performed in parallel.

H.3 CAGO — Management Information System (MIS)

No significant activity during this reporting period.

H.4 CAGO – Building 800

The Test Readiness Review for ETG processing in Building 800 was held in November 1994. The review covered several areas including: ETG handling and removal from the converter shipping container (CSC); ETG installation into the LAS; and ETG installation back into the CSC. While in the LAS, the ETG was energized and controlled by the ROC thereby demonstrating the ROC software. The LAS was evacuated to the required vacuum levels and a demonstration of the LAS gas management system automatic backfill was performed. Also, a loss of facility electrical power was performed to demonstrate auxiliary power and shut-down actuation systems.

All action items identified during the Readiness Review of Building 800 were satisfactorily resolved and the facility, support equipment, and a qualified team of facility operators and test conductors were ready to process the E-6 ETG by the end of December 1994.

A new speed controller for the overhead crane was installed and checkout completed. This controller permits very slow movement of the shipping container dome or ETGs during engaging or disengaging operations thus preventing potential damage to the ETG. Procedures, approved by the Calibration Lab, are in place for all operator-calibrated instruments. Calibration gas is available for use in Building 800 and traceable to NIST.

Additional Refurbishment Items for Building 800

During the processing of E-6, it was noted that some facility items will require rework. (See details in Task 5, E-6 ETG Processing - Building 800). It is planned to refurbish the following prior to processing the E-7:

- Install new bellows type valves, new solenoid valve, tubulation, and a 60μ filter into the argon gas backfill system.
- Re-work cryopump compressor to eliminate oil and helium leakage paths.
- Install a deflector on inside of LAS to direct gas flow during backfills.

Program Calendars

Cassini RTG Program Calendar

As of 21 December 1994

4th Qtr 1994

	M	T	W	T	F	S	S	FW
OCTOBER	26	27	28	29	30	1	2	39
	3	4 ← Cassini RTG Safety Meeting at JPL - Pasadena - *Rosko* →	5 Quarterly Program Review - Fairchild - *Hemler/Braun/Reinstrom/Cockfield*	6	7	7	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 ← INSRP BEES Meeting - Fort Collins, CO - *Ha/Deane* →	19	20 Engelhard Vendor Visit *Dower/Sardaro/Schreiber*; Executive Status Review - Valley Forge - *Teets, Morgan, Hemler, et al*	21	22	23	42
	24 **Monthly and Semi-Annual Reports Due to DOE**	25 Engelhard Vendor Visit *Schreiber/Sayell*	26	27 Launch Safety Review - Cape Canaveral, FL *Reinstrom*	28 ← Assabet Vendor Visit - Boston, MA - *Franklin/Dadd* →	29	30	43
NOVEMBER	31	1	2	3	4	5	6	44
	7	8 ← Building 800 Walk-Through *Martin Marietta/DOE/Orbital Sciences Corp.* →	9	10	11	12	13	45
	14 Sandia Lab Meeting High Power Satellites - Albuquerque - *Vicente*	15	16	17 Safety Test Meeting - LANL - *Bradshaw/Hartman/Cockfield/Gosling*; Assabet (Vendor Visit) - Boston, MA - *Schreiber/Dadd*	18 Laboratory Testing, Inc. Vendor Visit - Dublin, PA - *Fenton/Dower/Nakahara*	19	20	46
	21 PSAR Review - DOE HQ - *Hemler/Bradshaw*	22	23 **Monthly Reports Due to DOE**	24 ***Holiday***	25 ***Holiday***	26	27	47
DECEMBER	28	29 ← Fuel Impurities Task Force - LANL - *Reinstrom* →	30	1 DOE Management Review w/ Newhouse - Germantown, MD - *Hemler/Peterson/Vicente/Loughin*	2	3	4	48
	5 ← F-5 Walk-Through - Mound - *Haley/Kauffman* →	6 Schwarzkopf Vendor Visit - Boston, MA - *Dower/Dadd/Franklin* →	7 QA Status Mtg - Valley Forge - *Saydah, et al*; ← Fuel Impurities Task Force - Savannah River - *Reinstrom* →	8 Hi-Pwr COMSAT - Germantown - *Josloff/Hemler*; ← RTG Safety Databook → - OSC, Germantown - *Bradshaw/Rosko*	9	10	11	49
	12	13 ← Bi-Modal Review - Phillips Lab, ALBQ - *Hemler/Josloff* →	14 Cassini Program Review - Orbital Sciences - *Braun/Reinstrom/Cockfield*	15 INSRP PSSP Meeting - Valley Forge - *Hemler/Bradshaw/Braun/Rosko/Cockfield, et al*	16	17	18	50
	19	20 Schwarzkopf Vendor Visit - Boston, MA - *Dadd/Franklin*	21	22	23 **Monthly Reports Due to DOE**	24	25	51
	26 ***Holiday***	27	28	29	30	31	1	52

Cassini RTG Program Calendar

As of 29 March 1995

1st Quarter 1995

	M	T	W	T	F	S	S	FW
JANUARY	2	3	4	5	6	7	8	1
	9 ← Ground Operations Planning Meeting - Kennedy Space Center - *Reinstrom* → (9–10); ← 12th Symposium on Space Nuclear Power - Albuquerque, New Mexico - *Hemler/Josloff/Nakahara* → (9–13)	10	11	12	13	14	15	2
	16	17	18 Quarterly Cassini Program Review - Germantown - *Hemler/Cockfield/ Reinstrom/Braun*	19	20	21	22	3
	23 Monthly Reports Due to DOE	24 Risk Analysis - DOE Germantown - *Hemler/Bradshaw Braun/Ha*	25	26 QA Status Mtg - Valley Forge - *Saydah, et al*; Safety - LAS Meeting - Cape Canaveral, FL - *Braun/Rosko*	27	28	29	4
FEBRUARY	30	31	1	2	3	4	5	5
	6	7 RTG Installation Platform Review - Martin Marietta - Denver - *Reinstrom*; ← Safety Meeting Titan Databook with RTGWG - Martin Marietta, Denver CO - *Braun/Rosko/Loughin* → (7–8)	8 GPHS MRB Meeting - Mound Labs - *Reinstrom*	9 Coleman Labs Vendor Visit - West Chester, PA - *Fenton/Dower/Nakahara*	10	11	12	6
	13	14 ← PSAR Review w/INSRP - Germantown - *Hemler/Bradshaw Braun/et al* → (14–16)	15	16	17	18	19	7
	20	21	22 ← Bi-Modal Power Meeting – Phillips Lab - Albuquerque, NM - *Hemler/Josloff* → (22–23)	23 Monthly Reports Due to DOE	24	25	26	8
MARCH	27 ← F-5 Low Level Test Preps - EG&G Mound - *Reinstrom, et al* → (27–28)	28 ← SVDS Review at JPL - Pasadena, CA - *Braun/et al* → (28–2)	1	2	3	4	5	9
	6	7	8	9	10	11	12	10
	13	14	15	16	17	18	19	11
	20	21 Cassini Monthly Review - Germantown, MD - *Hemler/Braun/ Cockfield/Reinstrom*	22 Safety Analysis Uncertainty Meeting w/HNUS - Germantown, MD - *Braun/Loughlin*	23 ← Eng. End-On Safety Test - Sandia Laboratories - *Hartman/Cockfield* → (23–24); ← Energy Conversion Technology Meeting - NASA HQ, Washington DC - *Hemler/Morgan* → (23–24)	24	25	26	12
	27	28	29	30	31	1	2	13

Cassini Calendar

As of 20 April 1995

2nd QTR 1995

	M	T	W	T	F	S	S	FW
APRIL	3  ← Daylight Savings	4 ←	5 Transporter Design Review - WHC – Pasco, WA - *Reinstrom*	6 → E-6 Pre-Ship Review Meeting w/DOE - Lockheed Martin, VF -	7	8	9	14
	10	11 RTG Safety Consequence Uncertainty Meeting Martin Marietta, San Jose *Braun/Loughin*	12	13 End-On Impact Safety Test Review - Sandia - *Hartman/Cockfield*	14	15	16 	15
	17	18	19 1995 Space Power Workshop - Albuquerque, NM - *Vicente*	20 Semi-Annual Reports Due to DOE INSRP PSSP Review LASEPT Algorithms - Lockheed Martin, VF - *Braun, et al* ESR Review w/Morgan	21	22	23	16
	24 Monthly Reports Due to DOE	25 Cassini Quarterly Review - LANL - *Hemler/Hartman/ Reinstrom/Braun*	26  Secretaries' Day	27 INSRP RESP Review - Lockheed Martin, VF - *Braun, et al* Tech Integ Meeting (TIM) for Trailblazer Plan - Cape Canaveral - *Reinstrom*	28	29	30	17
MAY	1	2	3	4	5	6	7	18
	8	9	10	11	12	13	14	19
	15	16	17	18	19	20	21	20
	22	23	24 Monthly Reports Due to DOE	25	26	27	28	21
JUNE	29  ***HOLIDAY***	30	31	1	2	3	4	22
	5	6	7	8	9	10	11	23
	12	13	14	15	16	17	18	24
	19	20	21	22	23 Monthly Reports Due to DOE	24	25	25
	26	27	28	29	30	1	2	26

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