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Semi-Annual Technical Progress Report

The technical progress achieved during the period 27 September 1993 through 27 March 1994 on Contract DE-AC03-91SF18852, Radioisotope Generators and Ancillary Activities is described herein.

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

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Task 1

Spacecraft Integration and Liaison

PROGRESS BY MAJOR TASK

TASK 1 SPACECRAFT INTEGRATION AND LIAISON

The new launch loads information was received from JPL and has been reviewed. The data indicates that loads subsequent to lift-off are significant and furthermore occur at times where RTG case temperatures have risen causing reductions in material properties relative to prelaunch values. The latest loads data, however, are less severe than previous levels and will act to improve flight safety margins. To support the determination of the flight margins, a thermal analysis was undertaken to define RTG temperatures at the times of key flight events. Using the results of the thermal analysis, safety margins were calculated and found to be positive for those flight events where the combination of loads and temperatures are thought to be most severe. The results of the study were documented and forwarded to JPL where they were under review at the close of this report period.

In December 1993, precision case length measurements were made at Mound of the Q-1, E-2, and F-5 generators. The need for these measurements developed when preliminary measurements of the Q-1 shell and analysis of new launch loads information suggested that the heat source axial preload remaining on the F-5 generator may have been less than previously thought. To clarify the situation, a recommendation was made to DOE to measure the F-5 and E-2 converter shell lengths and to remeasure Q-1. A variety of precision measurement methods were investigated, a preferred technique was selected, and the measurements were accomplished. Based on the outcome of the detailed measurements and analysis of the new launch loads, it has been concluded that the preload remaining on F-5 is greater than earlier thought when reliance was placed solely on the preliminary Q-1 length measurements. The result of the measurements and loads analysis was that the remaining F-5 axial preload is adequate for the Cassini mission and that adjustment is not necessary.

Work was performed to demonstrate the structural adequacy of the RTGs for the Cassini mission. JPL requires such a demonstration and has suggested that a static load test be performed to accomplish the task. JPL has also indicated that a demonstration relying on previous dynamic testing and appropriate analysis may be an alternate method of establishing structural adequacy. Consistent with the latter approach, an analysis has been performed using previously obtained sine transient test data. The analysis presents an argument demonstrating positive margins of safety for the latest Titan IV launch limit loads provided by JPL. Initial review comments received from JPL have raised questions

regarding assumptions used in the analysis. Supporting information related to the assumptions is currently being reviewed to gather clarifying data with which to respond to the JPL inquiries. The information concerning the assumptions will be documented and forwarded to JPL.

Also during this report period, a test specification was drafted for the low level dynamic testing of the F-5 generator. The specification was based on inputs from JPL and discussions with DOE and Mound personnel. The resulting draft was circulated for comment at JPL and Mound and was subsequently submitted to DOE. Pending the concurrence of DOE, the plan will be used by Mound as a basis for preparing test procedures and for the conduct of the test later in 1994.

Task 2

Engineering Support

TASK 2 ENGINEERING SUPPORT

Specifications/Drawings

Throughout this period ECNs were prepared and processed through CCB approval in support of uncouple production activities and ETG/RTG fabrication. The number of ETG/RTG ECNs has increased as assembly of the E-6 ETG is underway.

Engineering Tests

PRD Bellows Testing:

The seven reworked bellows, received from Parker Metal Bellows and acceptance leak tested in the last reporting period, were acceptance force tested at both room and operating temperature verifying the success of the rework.

F-5 RTD Harness:

As a result of the F-5 RTD harness failure analysis, the cable assembly was redesigned to use a Cannon insertable pin/wire crimp connector, thus eliminating the wire to connector pin braze which was found to be the cause of the failure. A CDR on the new design was held in mid October co-chaired by R. Furlong (U.S. DOE) and D. Elliott (Martin Marietta Astro Space). The conclusion of the Design Review was that the proposed modifications to the RTD cable assembly will prevent the types of problems observed in the old design. All action items from this Design Review have been closed out.

The detail drawings, assembly drawing, and specification for the RTD cable assembly have been completed and issued. A fixture for the dynamic testing of the RTD cable assembly has been designed. The detail and weldment drawings are completed and issued. Advanced order information for purchased parts has also been released.

Government Laboratories Interface

Under this task support is provided to the DOE National Laboratories and processing facilities for the fabrication and assembly of heat source parts, and assembly and testing of the RTGs. During this report period, review of clad vent set hardware fabrication processes, procedures, and specifications, as well as the evaluation and disposition of hardware non-compliances were performed. In addition, fuel powder, fuel pellet, and fueled clad specifications were reviewed. Activities at Mound were also supported for the processing of converter and generator hardware. This effort included review and approval of procedures for the precision case length measurements of Q-1, E-2, and F-5. Support was also provided for upgrading the Mound dynamic test facility by providing the controller specification used for the Martin Marietta test facility.

Task 3

Safety

TASK 3 SAFETY

RTG Risk Assessment

In October, a meeting with the DOE Cassini safety program contractors was held to discuss the results of the recent fuel particle reentry study conducted for NASA/JPL by Foils Engineering. Subsequent to that meeting the draft sequence event tree for the unplanned reentry of the GPHS-RTG arising from a spacecraft malfunction during the VVEJGA maneuver was revised based on the results of that study. This tree, along with the resulting source terms and consequent risks, was submitted to NASA by DOE for use in the Cassini EIS.

Computational Fluid Dynamics Program

LAURA Flowfield Code Modifications: A 13 species carbon air version of the LAURA code was used to calculate flow around the configurations for the three test cases described in Table 3-1. Case 1 was a sphere-cone with a 12.7 mm nose radius at $M=20/A\dot{m}=30$ km. These are standard ICBM reentry conditions, and the results can be compared directly with simpler flowfield techniques. The blowing level was set to 15% of $p_{\infty} V_{\infty}$. Figure 3-1 shows the LAURA computation grid, and Figures 3-2 through 3-6 compare the LAURA results with viscous shock layer calculations for the same chemistry and free stream conditions. Agreement can be seen to be good.

Two cases were run with the GPHS configuration. Both were made at 58 km/16.4 km/s. Blowing was set to 4% and 40% of $p_{\infty} V_{\infty}$. Figure 3-7 shows the computational grid, and Figures 3-8 through 3-12 show various parameters along the GPHS stagnation line. Both cases demonstrate numerical stability with massive blowing and expanded chemistry.

The LAURA chemistry subroutine was expanded to include ionizing reactions. Data for chemical reaction rates, coefficient cross sections for diffusion coefficient and viscosity, and thermodynamic properties were added. The expanded chemistry includes $O^+, N^+, O_2^+, N_2^+, C^+, CO^+$. Partition function data was extended to cover the required temperature range for this application (500 - 40,000°K). Collision cross sections, used to calculate viscosity and diffusion coefficients, were completed for most of the species of interest.

Extensive restructuring of the LAURA code was made to include the ablating wall boundary condition. The mass flux boundary condition is coupled to the main flowfield by the species mass conservation equations, which govern the diffusion of species from the wall.

Table 3-1. Nonequilibrium Carbon Ablation Test Cases

13 Species Carbon-air Model Specified T_w , $\dot{m}_w$, and Wall Fuel/Air Ratio Equilibrium Catalytic Wall	
Case 1 Sphere: Comparison with Thin Viscous Shock Layer Solution	
<ul style="list-style-type: none"> • $R_n = 12.7$ mm • ICBM Reentry Conditions <ul style="list-style-type: none"> $M_\infty = 20$ Alt = 30.5 km • $\dot{m}_w = 15\%$ $\dot{m}_\infty$, Fuel/Air = 1%, $T_w = 3000$ K 	
GPFS – Demonstrate Capability to Address Wide Range of $\dot{m}_w$ and Fuel/Air <ul style="list-style-type: none"> • Peak Heating Conditions <ul style="list-style-type: none"> $M_\infty = 50.6$ Alt = 58.6 km 	
Case 2:	$\dot{m}_w = 4\%$ $\dot{m}_\infty$, Fuel/Air = 1%, $T_w = 4400$ K
Case 3:	$\dot{m}_w = 40\%$ $\dot{m}_\infty$, Fuel/Air = 25%, $T_w = 4400$ K

Figure 3-1. Ablating Graphite Sphere-Cone LAURA Grid

Figure 3-2. Thin Viscous Shock Layer Solution Nonequilibrium Carbon Ablation (Air Species)

Figure 3-3. LAURA Solution Nonequilibrium Carbon Ablation (Air Species)

Figure 3-4. LAURA Solution Nonequilibrium Carbon Ablation (Carbon Species)

Figure 3-5. Thin Viscous Shock Layer Solution Nonequilibrium Carbon Ablation (Carbon Species)

Figure 3-6. LAURA Stagnation – Streamline Temperature Nonequilibrium Carbon Ablation

Figure 3-7. LORAN Computational Grid for RTG

Figure 3-8. Stagnation - Streamline Pressure Nonequilibrium Carbon Ablation

Figure 3-9. Surface Pressure Nonequilibrium Carbon Ablation

Figure 3-10. Stagnation - Streamline Temperature Nonequilibrium Carbon Ablation

Figure 3-11. Stagnation - Streamline CO Mass Fraction Nonequilibrium Carbon Ablation

Figure 3-12. Stagnation - Streamline Mass Fractions Nonequilibrium Carbon Ablation
 $\dot{m} = 49\%$ $\dot{m}_{\infty}$, 25% Fuel/Air

Modifications have also been made in the LAURA code to include radiation source terms from the LORAN radiation code. This allows the LAURA code to account for radiant emission and absorption redistributing heat within the shock layer and to calculate the resultant changes in the flowfield around the RTG. A dummy test case has been run to verify the numerical procedure; the solution proceeds as expected.

A clean air test case, (coupled radiation and flowfield, no ablation) is being run. This will provide 1) a baseline for comparison with empirical correlations, and 2) a starting point for the fully coupled calculation, accounting for both radiation and ablation chemistry. Results should be ready for review during the next reporting period.

LORAN Code Modifications: The LORAN code has been modified to include most of the important carbon species in its radiant heating calculation. Absorption and emission from molecular species is treated with a smeared band approximation. This approximate calculation is much faster than explicitly calculating the rotational-vibrational transitions and is believed sufficiently accurate for the high temperature regime of interest. The code has been modified to calculate the CN red and CN violet bands for the molecular species cyanogen (CN). Spectroscopic and vibrational transition data have been acquired and added to the code for the following bands:

Species	Band	Spectral Region. nm
C ₂	Swan	340-785
	Phillips	672-1519
CO	Fourth Positive	130-190
	Asundi	496-1239

All of these are important molecular emitters in the high temperature regime of interest for RTG reentry applications. Spectroscopic data are from Reference 1, which is also the source of the NEQAIR data incorporated into the original LORAN code.

Several test cases are presented in Figures 3-13 through 3-18. These cases were run for an isothermal slab of gas 1 cm thick at 1 atm pressure and 10000°K. Figures 3-13 and 3-14 show the effect of increasing ionization on radiant flux reaching the wall for pure monatomic nitrogen. Radiation from the gas layer should increase with ionization. Increases in atomic line and bound-free contributions are indirectly due to increased ionization; increased electron density results in more electron impact excitation and increases the population of the highly excited electron states. Continuum free-free transitions are directly dependent on electron density. Figure 3-13 shows the spectral radiant heat flux from the gas layer to the wall for 5%, 10%, and 20% ionization. The flux increases sharply with ionization level, as expected. Figure 3-14 shows the integrated flux at the wall from the gas layer.

Figures 3-15 and 3-16 show the effects of adding monatomic carbon and CN molecules to the nitrogen gas slab. Both species are expected to be substantial emitters. The ionization levels were held constant at 10%. The addition of 10% CN is shown to increase the flux to the wall by nearly a factor of 2. The contribution of CN is confined to the visible wavelengths, the well known CN red and CN violet bands. The figures show a pure continuum emission. This is due to the molecular smeared band approximation used by the LORAN code.

Monatomic carbon contributes both line and continuum emissions. The main effect of the carbon is in the vacuum ultraviolet range, where the calculations show a very broad, very intense line emission at about 8 ev. Note that the addition of 1% C and 1% C+ increases the flux to the wall by nearly a factor of 5. This increase is greater than expected and is being reviewed.

Figures 3-17 and 3-18 compare the emission of pure carbon and nitrogen. The carbon spectra can be seen more clearly on these plots. Note the dramatic increase in both continuum and line contributions for carbon vapor, compared to nitrogen, for the same pressure, temperature and degree of ionization.

Figure 3-13. Spectral Radiant Heat Flux - Monatomic Nitrogen

Figure 3-14. Integrated Flux at Wall - Monatomic Nitrogen

Figure 3-15. Monatomic C and CN Molecule Added Effect

Figure 3-16. C and CN Integrated Emission

Figure 3-17. Pure Carbon and Nitrogen Spectral Emission

Figure 3-18. Carbon and Nitrogen Integral Emission

Figures 3-19 and 3-20 show the effects of adding CO molecules to the nitrogen gas slab. The ionization level was held constant at 10%. The addition of 10% CO is shown to increase the flux to the wall by about 5% over pure nitrogen. Reduced atomic nitrogen content results in reduced atomic emissions. The CO 4+ band contributed about 25% of the radiation to the wall in the ultraviolet spectral range as expected. The CO Asundi band makes little contribution. The minor effect of the second CO band was not expected. Its cause is being reviewed. Note the figures show the molecular contribution as pure continuum emission. This is due to the smeared band molecular module used in LORAN, which approximates the very fine line structure of vibrational-rotational transitions as a continuum.

Figures 3-21 and 3-22 show the effects of adding C₂ molecules to the nitrogen gas slab. The ionization level was also held constant at 10%. The addition of 10% C₂ is shown to increase the flux to the wall by nearly a factor of 4 over pure nitrogen. The contribution of C₂ is confined to the visible wavelengths, the well known C₂ Swan and C₂ Phillips bands. The magnitude and spectral regions of the C₂ contribution are as expected.

The LORAN code was expanded also to make the required excitation and radiation calculations for the CO⁺- CT molecular band. Code modifications were verified using dummy input data. Similar test cases for this species should be ready for the next report period.

The C₃ and CO₂ species still need to be added to the LORAN code. Addition of these species should complete inclusion of all-important emitters for the C-N-O chemistry system. Spectral and electron-level-excitation data are being collected for the important molecular bands, and code modifications will proceed as the data are acquired.

Initial attempts to run the LORAN code with the monatomic carbon modification failed. Review of the source code revealed many calculations that were specifically coded to calculate only the nitrogen-oxygen emission. The code was then systematically reviewed to expand these calculations to include carbon, and the code was successfully modified.

Another related problem was discovered such that, when any species was not present, its contribution should have been suppressed by a flag in the input deck. This flag was, however, ignored for certain calculations for the N and O atomic species. As a result, the code attempted to calculate line emission contributions for these species, whether they were present or not. Various divide-by-zero errors would result. This error did not affect clear air calculations, where both of these atomic species are always present in the high temperature shock layer. It would cause a significant error for the RTG application because ablating carbon at the wall binds all of the N and O species into various carbon compounds near the wall. To correct this error the code has been modified.

Figure 3-19. Effect of CO Molecule Addition

Figure 3-20. Integrated Emission from CO Addition

1 cm thk. Monatomic Nitrogen
 10000 K - 1 atm - 10 % Ionization

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Figure 3-21. Effect of C₂ Molecular Addition

Figure 3-22. Integrated Emission from C₂ Addition

Other: An in-depth review of progress to-date was held at Martin Marietta Astro Space in October. Representatives from DOE, JHU/APL, Fairchild, Halliburton NUS, and Martin Marietta attended. Numerous suggestions were received about the interface of the CFD analysis results with the mission reentry analyses, and these are being incorporated.

Risk Analysis Program

Inhalation Pathway: The direct inhalation pathway model for multiple particle sizes was implemented in all the codes. Initially tested on GEOTRAP, the module has been incorporated into HIAD and SATRAP. HIAD is the global small sized particle/gas code, while SATRAP is the KSC site code. As reported previously, SPARRC is capable of computing dose conversion factor (DCF) values as a function of particle size and user defined solubility class. For each source term released, the program retrieves these inputs from an ASCII file, sets the proper values of deposition in lung compartments and the applicable organ DCFs, then computes the new organ DCF values for that specific particle size and solubility class. In addition, the lung burden can be varied as a function of 4 age groups. The inhalation DCF databases available for SPARRC use are ICRP-30 and DOE-EH0071 publication.

Resuspension: A subroutine to calculate the time-integrated air concentration due to resuspension combined with radioactive decay was implemented. Since the time integration of this combination has no defined analytical function, the integration was numerically evaluated using the Gauss-Legendre quadrature with adaptive intervals. This robust algorithm provides a better evaluation of the 50 year long term exposure than a crude Simpson's integration. The resuspension factor recommended at the INSRP Meteorological Subpanel Meeting in September was $K=10^{-6}/t$ in units of per meter, with t in days. K (/m) times the ground deposition D (in curies/sq.m) gives the air concentration of resuspended Pu 238. The integral of this with decay is:

$$(10^{-6}/t) e^{-at}$$

which is a difficult integral to implement. It is necessary to integrate this quantity to get the amount of resuspended Pu 238 inhaled over the 50 years following deposition.

The rural resuspension model suggested in the INSRP Meteorological Subpanel Meeting was also implemented in HIAD for consistency with the remaining SPARRC codes. With a resuspension factor K , this model presented difficulty in implementation because the basic formulation of HIAD attempts to describe a continuous deposition process, sometimes over several years, rather than a short dispersion deposition phase as usually applied for releases

near the ground level. In that respect, a resuspension rate is more adequate for the differential equations of HIAD. In order to apply the proposed model, the following approach has been adopted.

- 1) The total deposition from high altitudes is discretized in small packets. Instead of calculating until the end of the exposure time, say 50 years, the deposited mass is accumulated at the mid-point of each interval, set by default at 3 months.
- 2) Once the lumped mass for each interval is obtained, the contribution to resuspension can be calculated with numerical analysis from the interval until the last year of exposure;
- 3) Finally, contributions are added from each of these 3 month intervals to a total resuspension, in terms of integrated air concentration, to compute the inhalation dose.

Since the mass deposited in any interval of 1-3 months is very small, this approach will introduce only small errors compared to a truly continuous deposition-resuspension process.

This model originated out of the Garland-Ruud-Shinn review of resuspension data that included recent European studies of Chernobyl Cs-137. The resuspension, however, is limited to source particles whose original diameter exceeds a user-supplied input. The current limit is 30 microns physical diameter. The reason for this limit is that such particles are too heavy to resuspend; and, in addition, over the 50 year maximum exposure period being considered, only a small fraction of such large particles will break down into smaller ones. Source particles whose original diameters were less than this will break down in the environment, but also the fragments will become attached to the soil particles and to vegetation and so will exhibit a normal behavior.

Bio/Food Databases: A geographic database for the Florida area is being designed to allow the SATRAP program to retrieve the amount of each food type produced in any area element that the dose calculation may require.

Health Effects: The health effects calculation has been revised and implemented in all modules of the SPARRC code system, including both the KSC site code, SATRAP, and the two global scale codes, GEOTRAP and HIAD. This new dose method, based on guidance from ICRP-60, BEIR IV and BEIR V, will provide a state-of-the-art comprehensive evaluation of the total health effect, unlike many dose evaluation codes which are only valid for a limited set of pathways or radiation types. In addition, the output provides detailed results including pathway and organ dose contributions. These are not merely useful but essential in checking the validity of results.

In SPARRC, both database and code structures are designed to manage multi-organ dose evaluation. The population dose calculation is carried out in detail for seven body organs: lung, liver, bone, red bone marrow, gonad, thyroid, and skin. Hence, the health effects can be evaluated at the level of each pathway using the exact organ cancer risk predicted by either BEIR IV (Internal dose from alpha emitters) or BEIR V (non alpha emitters or external dose from alpha emitters).

As output, for each pathway, the organ doses [person-rem] are printed along with a total health effects per BEIR IV and BEIR V. This output is repeated for each exposure time interval defined by the user. Finally, the code provides a total health effect from all pathways and the maximum contributing pathway in population dose for each organ. Since the common practice is to produce an effective dose equivalent, SPARRC also provides a list of effective doses, binned in defined levels with corresponding maximum individual dose and number of people affected. However, the weighing factors are based on the updated values from ICRP-60 (1991) which provides a more complete list of recommended organ values. Only a slight difference is expected in effective dose when using the new values.

KSC Land and Population Database: The KSC data files on resident, worker, and spectator population and land surface types previously provided by NUS have been developed into a database that reformats the data at a resolution appropriate to the scenario being analyzed. An interfacing routine was produced and tested. It permits rapid access by the SATRAP dose conversion modules to the reformatted data. Testing showed that this new database and interface will permit efficient calculation of population dose by SATRAP.

A new receptor data base for the KSC area has been created with 40,000 cells of 1 km². This database covers a domain of 200 x 200 km around the launch site. The initial grid scale set up by NUS at 500 m has proven to be slightly finer than needed, so the data were consolidated to the 1 km grid. In addition, land features and population data (residential, worker, and spectator) had been stored in four different files. These files have been consolidated into one. Even though the final result is a large file of 3 Mbytes, access time is kept low by directly computing the offset location of the data rather than searching through the file for the desired grid location. Thus, almost all data items for the KSC site are now incorporated in the same record structure to save time. Each record contains:

- cell id	- spectator [pers]
- total population [pers]	- land fraction
- population density [pers/km ²]	- water fraction
- residential [pers]	- marsh fraction
- worker [pers]	- ocean fraction

Global Reference Atmosphere Model 1990

The original GEOTRAP global dispersion code used seasonal and zonal averaged 3D wind field. A new 3D wind field model has been implemented that gives winds at each point on the Earth's surface, not just a single average value for a whole zone of constant latitude. This model uses NASA's GRAM90 atmosphere database. GRAM90 is designed to calculate the wind vector, density, and other properties along the user-supplied trajectory of a launch. In the case of the Cassini FSAR nuclear analysis, this data is also required at all points of the globe up to 90 km altitude. A method for modifying the data to produce the definition needed has been designed and tested. It causes GRAM90 to make multiple runs at a single latitude-longitude coordinate, from 90 km down to zero in 2 km steps. The multiple runs are at latitude-longitude pairs covering the whole Earth. Because the wind components U, V, and W can be supplied on a global grid at a resolution as small as hundreds of kilometers, it is expected a very large database will be produced. For example, at a resolution grid of 5 degrees latitude by 5 degrees Longitude and 2 km in altitude, there are 2533 grid points, each with 45 points from z=90 km down to zero; for a total of 113490 points. The approach adopted is to retrieve wind data at a number of grid points adjacent to the advecting puff and to interpolate in time and space for each time step using groups of surrounding grid points. This technique will hasten the calculation process since the frequency of data retrieval is reduced. As an option, the user can select either GRAM90 or the current mean seasonal model which consists of wind components from combinations of zonal, long wave, and short wave.

New ICRP Lung Dose Model: The ICRP has approved a new lung dosimetry model documented in ICRP Publication 66. We have obtained a summary paper describing this model. It contains a time dependent rate of dissolution of inhaled particles specifically suited to the special case of Plutonium 238 oxide, which has a rate of dissolution that increases with time after inhalation. This effect is due to fragmentation of particles smaller than about 10 microns inside the lung, forming fragments that are much more mobile in vivo. The model also has a more realistic rate of uptake of particles that are deposited in the Nasal regions. This also is very important for Cassini since the typical source terms for launch accidents are very heavily weighted by particles at the very large sizes, over 10 microns, that predominantly deposit in the Nasal area. Overall, ICRP 66 is a more detailed model with more lung compartments and a wider variety of inter compartment transfer mechanisms. The LUDEP computer code which implements this model will be acquired for use in the project. ICRP intends to publish a revised ICRP 30 containing new inhalation dose values from this model at some time in the future.

Code Testing: Testing of GEOTRAP and of SATRAP was performed, aimed at key characteristics: database interfaces, running time, and the development of graphical output. For data interfaces, since the codes share common files such as isotope data, biotransfer coefficients, and dose conversion factor values, it is more logical to consolidate all duplicate files in one unique directory where changes, if needed, will affect all codes. Also, GEOTRAP/SATRAP needed improvement in running time because the deposition calculation produces thousands of geographic locations for which the surface level concentrations have been calculated, especially with SATRAP's nested grid system. The wide variation in grid scales, with scales varying between meters and kilometers, requires substantial computation. This and the combination of the many particle sizes result in calculations that may take several minutes. The current approach to reducing computation time is to determine a more efficient use of memory, while also simplifying the database search methods.

Graphical output of results represent the only way to verify large amount of data produced by the codes. Methods have been developed for producing two and three dimensional plots of geographically distributed output. For example, profiles of concentrations or contour lines of iso-deposition from GEOTRAP/SATRAP are post-processed using 3-D graphics software to verify that the results show the known symmetrical shape of the plume. These display techniques have also been used to verify that the complex logic of the nested geographic grid has been done correctly by displaying in 2-D the locations of the grid points at which calculations are made.

HIAD Code Revision: The output of the HIAD code was updated to have the same output dose distributions as GEOTRAP and SATRAP. In the original version, detailed dose values for each organ as well as collective dose for several exposure time intervals were computed; however, these results were not broken down according to numbers of persons exposed to each dose level. Thus, HIAD output was not presented in the same manner as GEOTRAP or SATRAP. This difference in the form of the output would create a difficult and time consuming task when consolidating the final result from outputs of different codes.

In addition to the revision of the output, the health effects computation methods in HIAD were made consistent with the other codes using BEIR IV and BEIR V, as described previously. These HIAD revisions were coded and tested. The constants used in various pathway dose calculations were updated consistent with other codes. The code will provide a list of effective doses binned into dose level intervals. It also provides: the corresponding maximum individual doses and number of persons affected; a list of detailed organ doses for each pathway; and a total health effects value per BEIR IV and BEIR V. If needed, HIAD will print the

uniform worldwide concentrations and the fractions of the released source deposited in each latitude band. Note that the code will now calculate either of two release scenarios at the user's discretion, 1) a reentry or launch accident injection at a single known latitude, or 2) an orbit inclination angle to simulate a random reentry from an orbit of known inclination but unknown reentry latitude.

Other: A presentation was made to the National Council on Radiation Protection and Measurements (NCRP) at their Bethesda headquarters on the radiological risk codes being developed for the Cassini mission by Martin Marietta Astro Space. The NCRP has been given a contract by DOE to review the techniques and models currently being used by industry for dispersion and uptake of radioactive material in the event of a nuclear accident. More specifically, the NCRP has been asked to review the analysis techniques that will be used for the Cassini safety reports and make a recommendation on the most appropriate biological uptake models and dose conversion factors. Halliburton NUS also gave a presentation on the techniques and model used in previous analyses for *Galileo* and *Ulysses*.

Safety Test Program

Analysis of Test Configurations: Fairchild Space performed some preliminary hydrocode analyses to determine the best scheme for the configuration and makeup of the dummy mass needed in the end-on RTG impact tests. Dummy fueled clad/graphite impact shell (GIS) combinations consisting of molybdenum powder (simulated fuel) encapsulated in molybdenum cladding were used in the FWPF aeroshell to be placed between the flight type test modules and the remaining bulk mass. However, even with the use of two intervening simulated modules, (one of FWPF and one of POCO graphite) the distortion in the clads of the third test module (i.e., the third module up the stack from the impact end) appeared to be appreciably large. The indication was that these simulated clad/GISs were still providing too hard an aftward impact point for the test clads.

Additional hydrocode analyses were performed by Fairchild to investigate alternative configurations. Table 3-1 presents the results for the various configurations, including those investigated in the preliminary analyses. Configurations A and B were the two configurations investigated in the preliminary analyses previously discussed. As described for these configurations, the GISs and fueled clads (FC) were not modeled separately, but a single moly shell containing moly powder was used to simulate both components. Configuration C consisted of the two trailing modules having flight type FWPF aeroshells and GISs containing a simulated FC having a moly clad with moly powder simulant for the fuel. The results show that the use of FWPF flight configuration modules in the two trailing positions of the stack do, in fact, give better distortion distributions than for other configurations studied. This is shown in

Table 3-2. It can be seen that either one POCO block or one FWPF followed by one POCO block (i.e., columns A and B of Table 2) produce much higher distortions in the third test module than does the stack with two FWPF follower modules. The two FWPF follower modules result in more representative distortions in the second and third test modules.

The recommendation was made to DOE that the test be conducted using FWPF flight configuration modules also in the two follower positions with flight FWPF GISs containing moly clads with powder to simulate the fueled clads. While there are enough FWPF aeroshells available, performing the tests in this manner will require eight additional GISs, which are not currently available.

Table 3-2. Comparison of Test Stack Configurations for End-on RTG Impact Test

Position of Module In Stack (from bottom)	FC Distortion - % (@ 55 m/s Impact Velocity)				
	Full Flight Configuration	Config. *	Simulated GIS/FC Combination		FWPF GIS Moly FC
			A	B	C
Mod 1	21.6		20.2	10.6	21.2
Mod 2	12.3		11.5	11.7	12.0
Mod 3	5.8		8.4	8.1	5.7
Mod 4	3.8		—	—	—
Mod 5	1.1		—	—	—
Type Aero-Shell					
Position 4			POCO	FWPF	FWPF
Position 5			—	POCO	FWPF

* All mass above given configuration consisted of bulk POCO (AXF5Q) graphite.

Hardware Design and Preparation: During this reporting period, detailed parts drawings and assembly drawings were initiated and are essentially complete for the converter hardware being prepared for the safety tests. In-house hardware was inventoried to determine what additional procurements were needed, and orders were placed for the required parts. The two flight discrepant converter shells needed for the tests were modified by Speedring, and they have been received in-house.

Final delivery of the assembled converter test hardware to LANL/Sandia is now scheduled for the August-September period. The delay in this schedule has occurred because of several factors including other RTG program priorities arising that have taken precedence, long lead

times required on some of the converter hardware required, and the need for the heat source stack configuration analyses on which the design of the holding fixture for the modules depended. In addition, only toward the end of this reporting period was a test engineer designated at LANL to plan and coordinate the test effort between that laboratory and Sandia. It has been necessary for consultation and agreement between Martin Marietta and LANL for some details of the safety test hardware

Test Planning: A meeting called by DOE was held at Fairchild on March 24, 1994, for purposes of meeting the recently appointed test engineer/director from LANL and to discuss details of the safety tests. The meeting was attended by representatives from DOE/NE-53, Martin Marietta Astro Space, Fairchild Space, LANL, and Lamb Associates (consultant to LANL). Fairchild presented the results of their hydrocode analyses on the test stack configurations for the end-on impact tests. Additional configurations recently analyzed were presented that involved other combinations of FWPF and POCO aeroshells and GISs (including some without individual GISs). These results, however, did not alter the choice of the configuration previously recommended to DOE for use in the tests (i.e., both follower modules of FWPF aeroshells, FWPF GISs, and moly simulants for the fueled clads). As a result of the discussion held on these configurations, the decision was made not only to use FWPF aeroshells and FWPF GISs in the two follower modules but also to use flight type iridium shells with depleted urania simulant for the fueled clads in these modules. DOE indicated that there was enough iridium hardware available for these tests. During the meeting, LANL was requested by Martin Marietta to review the drawings prepared for the converter test hardware and to decide whether they (LANL) would provide the parts for the heat source support fixtures as they did on the *Galileo/Ulysses* test program.

Task 4

Qualified Uncouple Production

TASK 4 QUALIFIED UNICOUPLE FABRICATION

Qualification lot unicumple production was completed in May 1993. Production of flight unicouples is addressed in Task 5. The remaining efforts in Task 4 are associated with the fabrication and testing of 18 couple modules.

18 Couple Module: 18-10

Module 18-10 reached the 2000 hour acceptance test milestone on 28 October 1993. As of 31 March 1994, the module has achieved 5700 hours at the accelerated hot shoe temperature of 1135°C, and will reach the 6000 hour qualification milestone on 12 April 1994. During this reporting period, the module performance continued to fall within the database established by MHW and GPHS 18 couple modules.

The thermoelectric performance is evaluated primarily by the trends of the internal resistance and power factor (open circuit voltage/delta temperature/internal resistance). Figures 4-1 and 4-2 show these trends in comparison to GPHS module 18-8, the last module built during the program. Agreement is excellent and provides a high degree of confidence that the GPHS unicumple manufacturing processes have been successfully replicated. Table 4-1 summarizes initial and 5700 hour performance.

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 trend continues to fall within the database confirming the re-establishment of the GPHS silicon nitride coating processes. To make a more direct comparison of the 18-10 and 18-8 trends, differences in hot shoe operating temperature as shown in Figure 4-4 must be taken into account. The rate at which materials sublime from the hot shoe and hot junction region has an exponential temperature dependence. A 15°C increase in temperature raises the sublimation rate by 50%. Analyses were performed to correct the 18-10 data to the same temperature level as 18-8. The 18-10 test times are shifted to the right by an amount proportionate to the difference in sublimation rates at the two temperatures. Results are shown in Figure 4-5. This normalization results in a convergence of the data at a normalized time of 7500 hours. The normalization was made using the same rate equation for both modules over the total test time. In reality, 18-10 with its higher operating temperature may have lost the full effectiveness of the silicon nitride coating earlier at which time a higher sublimation rate equation should be introduced. If this correction were made, the 18-10 data would be shifted even farther to the right.

Figure 4-1. Internal Resistance Ratio (18-10, 18-11, and GPHS 18-8 Modules)

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

**Table 4-1. Comparison of Initial and 5702 Hour Performance of
 Module 18-10 at 1135°C**

	Initial 8/4/93	t = 5702 hours 3/31/94
Heat Input, Watts	191	192.1
Hot Shoe, C Average	1136.2	1130
Hot Shoe Range C	3.9	5.7
Cold Strap, C Average (8 T/Cs)	309.5	308.8
Cold Strap Range (8T/Cs)	10.8	12.9
Cold Strap Average (12 T/Cs)	304.6	303.4
Cold Strap Range (12 T/Cs)	22.3	22.6
Load Voltage, Volts	3.501	3.507
Link Voltage, Volts	0.189	0.179
Current, Amps	3.168	2.989
Open Circuit Voltage, Volts	7.151	7.488
Normalized Open Circuits (8T/Cs)	6.324	6.667
Normalized Open Circuits (12 T/Cs)	6.284	6.622
Average Couple Seebeck Coefficient (12)	499×10^{-6}	525.5×10^{-6}
Internal Resistance, Ohms	1.093	1.272
Internal Resistance Per Couple (Avg.)	0.0607	0.0707
Power Measured, Watts (Load + Link)	11.691	11.02
Power Normalized, Watts (8 T/Cs)	9.143	8.735
Power Normalized, Watts (12 T/Cs)	9.028	8.617
Power Factor	40.987×10^{-5}	39.09×10^{-5}
Isolation		
Circuit to Foll, Volts	-1.676	-1.237
Circuit to Foll, Ohms	5.22K	2.04K

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

Figure 4-4. Hot Shoe Temperature - Modules 18-10, 18-11 and GPHS 18-8

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

**Figure 4-5. Isolation Resistance Versus Normalized Time
for Modules 18-8 and 18-10**

Individual Unicouple Performance: Observations have been made of the performance of certain individual couples to help answer a question that arose during unicouple fabrication. After the preassembly operation (copper pedestal is brazed to the tungsten cold shoe of the second bond assembly), it had been observed that room temperature internal resistance for Cassini couples typically decreased, whereas during the GPHS program it typically increased. When the unicouples were selected for 18-10, two that had the largest and smallest resistance changes were chosen. These were positioned in heavily instrumented locations in the module so that their individual performance could be measured. Table 4-2 shows the room temperature resistance changes and the internal resistance changes observed during operation for each of the six rows and for individual couples in rows 2 and 5. Unicouple H0290 (row 5, position 14) had shown a 0.9 milliohm decrease after preassembly. Unicouple H0172 (row 2, position 6) had shown no change. During operation, both couples have shown a normal 16.7% increase in resistance.

Table 4-2. Module 18-10 Internal Resistance Changes

Position	Serial #	2nd Bond Milliohm	Preassy Milliohm	Deltari Milliohm	T = 0 Milliohm	T=1500 Hours	Deltari Milliohm	Percent Increase	T=5702 Hours	Deltari Milliohm	Percent Increase
1.0	H0148	22.9	22.6	-0.3							
2.0	H0149	22.9	22.7	-0.2							
3.0	H0150	22.8	22.5	-0.3							
					183.0	198.7	15.7	8.6	212.5	29.5	16.1
4.0	H0250	23.2	22.8	-0.4	61.6	66.8	5.2	8.4	71.3	9.7	15.7
5.0	H0256	23.1	22.7	-0.4	61.6	67.0	5.4	8.8	71.5	9.9	16.1
6.0	H0172	22.8	22.8	0.0	61.2	66.9	5.7	9.3	71.4	10.2	16.7
					184.0	200.0	16.0	8.7	213.6	29.6	16.1
7.0	H0044	23.0	22.3	-0.7							
8.0	H0145	22.5	22.2	-0.3							
9.0	H0113	22.5	22.3	-0.2							
					181.0	197.6	16.6	9.2	211.0	30.0	16.6
10.0	H0103	22.6	22.4	-0.2							
11.0	H0184	22.8	22.4	-0.4							
12.0	H0146	22.7	22.4	-0.3							
					183.0	198.6	15.6	8.5	212.1	29.1	15.9
13.0	H0125	22.3	22.0	-0.3	60.0	65.8	5.8	9.7	70.4	10.4	17.3
14.0	H0290	23.1	22.2	-0.9	61.2	66.8	5.6	9.2	71.4	10.2	16.7
15.0	H0201	22.5	22.1	-0.4	60.9	66.7	5.8	9.5	71.2	10.3	16.9
					182.0	198.7	16.7	9.2	212.5	30.5	16.8
16.0	H0176	22.6	22.1	-0.5							
17.0	H0129	22.5	22.2	-0.3							
18.0	H0215	22.6	22.0	-0.6							
					182.0	198.6	16.6	9.1	212.3	30.3	16.6

18 Couple Module: 18-11

Assembly of module 18-11 was completed in December 1993. This module contains uncouples selected from the qualification lot of uncouples, built prior to the E-6 production lot.

All 18 couple modules had been inserted into the foil insulation assembly during the previous reporting period. One of these assemblies, H0641, experienced a large resistance increase (from 23.2 to 64.2 milliohms) after connector forming operations. This unit was replaced and evaluated by Engineering to determine the cause of failure. The second bond interface between the tungsten cold shoe and the N-type 63.5% SiGe segment was found to be cracked, similar to failures observed during assembly of module 18-10.

Assembly operations proceeded through yarn wrapping and riveting operations without difficulty. Following qualification testing, a new pneumatic rivet gun was used for all rivet installations. Together with several changes to operating procedures, this enabled riveting of all assemblies without damage. Hot side thermocouples were installed into the hot shoes of six selected uncouples, with one thermocouple found to be open. At MRB direction, the opened thermocouple was not replaced as the remaining five provided adequate measurement redundancy. Instrumentation leads were potted with RTV-566 into two 50-pin connectors using newly designed potting molds. The new molds provided more

uniform filling than did the previous design used for module 18-10, however, one of three voltage sensing leads in one of the two connectors was damaged during the potting operation. A jumper was installed in the vacuum test station to provide the necessary connections for the test rack. The module was delivered for performance testing in December 1993.

The module was put on test in January 1994. Table 4-3 summarizes the room temperature resistance measurements and silicon nitride coating weight gains for the couples selected for 18-11. The module was brought up to a 1035°C hot shoe temperature on 26 January 1994 following a heat-up schedule similar to 18-10. Comparison of 1035°C data with modules 18-7 and 18-10 is shown in Table 4-4. All module performance parameters looked normal and after 140 hours at 1035°C, the hot shoe temperature was increased to the accelerated temperature of 1135°C on 2 February 1994. As of 31 March, the module had achieved 1362 hours. It will reach the 2000 hour acceptance test milestone on 27 April 1994. Internal resistance and power factor trends are normal and are shown in Figures 4-1 and 4-2, along with modules 18-8 and 18-10. Table 4-5 summarizes performance initially and at 1362 hours. The isolation resistance is also showing the normal trend and is still in the increase mode. The trend is shown in Figure 4-3, along with 18-10 and the MHW and GPHS database.

Table 4-3. Internal Resistance and Si₃N₄ Coating Weight of Couples Selected for Module 18-11

Position	Serial #	2nd Bond Milliohm	Preassy Milliohm	Unicouple Milliohm	Wrap Milliohm	Av. of 4 Milliohm	Weight Gain Milliohm	Coat Run No.
1.0	H2006	22.50	22.10	22.30	22.60	22.38	7.17	104.00
2.0	H0507	22.40	21.90	22.40	22.30	22.25	7.24	21.00
3.0	H0512	22.70	22.20	22.70	22.60	22.55	7.28	21.00
4.0	H0439	23.20	22.70	22.40	22.20	22.38	7.65	31.00
5.0	H0587	22.50	22.40	22.70	22.70	22.58	7.41	24.00
6.0	H0657	22.70	22.50	22.60	22.80	22.65	7.49	32.00
7.0	H0585	22.90	22.70	22.60	22.70	22.68	7.48	24.00
8.0	H0459	22.50	22.10	22.50	22.70	22.45	7.53	27.00
9.0	H0562	22.70	22.30	22.60	23.00	22.65	7.57	23.00
10.0	H0248	22.70	22.30	22.80	22.70	22.63	7.78	15.00
11.0	H0163	22.90	22.40	23.00	22.90	22.80	7.96	8.00
12.0	H0282	22.70	22.40	22.70	22.40	22.55	8.07	14.00
13.0	H0328	22.90	22.30	22.90	22.80	22.73	7.48	18.00
14.0	H0326	22.60	22.00	22.60	22.70	22.48	7.57	18.00
15.0	H0232	22.50	22.00	22.60	22.30	22.38	7.82	17.00
16.0	H0590	22.60	22.40	22.60	22.70	22.58	7.73	24.00
17.0	H0393	22.60	22.10	22.40	22.70	22.45	7.71	102.00
18.0	H0496	22.50	22.30	22.50	22.70	22.55	7.67	22.00

Statistics

Mean	22.68	22.28	22.61	22.64	22.54	7.59
Std Dev	0.20	0.23	0.18	0.21	0.14	0.24
Std Err	0.05	0.05	0.04	0.05	0.03	0.06
95% Conf	0.10	0.11	0.09	0.11	0.07	0.12
99% Conf	0.13	0.15	0.12	0.14	0.10	0.16
Sum	408.20	401.10	406.90	407.50	405.68	136.61
Max	23.20	22.70	23.00	23.00	22.80	8.07
Min	22.40	21.90	22.30	22.20	22.25	7.17

Table 4-4. Comparison of Initial Performance at 1035°C of Modules 18-7, 18-10, and 18-11

	Module 18-7	Module 18-10	Module 18-11
Heat Input, Watts	162	163.6	163.4
Hot Shoe, C Average	1035.6	1033.4	1034.6
Hot Shoe Range C	12	7.5	5.7
Cold Strap, C Average (8 T/Cs)	293.9	285.4	291.5
Cold Strap Range (8T/Cs)	9.7	9.0	1.6
Cold Strap Average (12 T/Cs)	290.0	280.8	286.9
Cold Strap Range (12 T/Cs)	21.3	19.8	19.1
Load Voltage, Volts	3.504	3.501	3.504
Link Voltage, Volts	0.164	0.163	0.096
Current, Amps	2.520	2.596	2.586
Open Circuit Voltage, Volts	6.353	6.355	6.381
Normalized Open Circuits (8T/Cs)	6.293	6.239	6.308
Normalized Open Circuits (12 T/Cs)	6.258	6.199	6.297
Average Couple Seebeck Coefficient (12)	497×10^{-6}	492×10^{-6}	497×10^{-6}
Internal Resistance, Ohms	1.065	1.041	1.075
Internal Resistance Per Couple (Avg)	0.0592	0.0578	0.0597
Power Measured, Watts (Load + Link)	9.246	9.485	9.311
Power Normalized, Watts (8 T/Cs)	9.072	9.142	9.099
Power Normalized, Watts (12 T/Cs)	8.970	9.027	8.981
Power Factor	41.67×10^{-5}	41.88×10^{-5}	41.42×10^{-5}
Isolation			
Circuit to Foil, Volts	-1.55	-1.86	-1.66
Circuit to Foil, Ohms	9.2K	18K	24.5K

Individual Unicouple Performance: Module 18-11 is instrumented identically to 18-10. The Performance trends of the six individual rows and six individual couples are being monitored with results shown in Table 4-6. All individual rows and couples are performing within a narrow band.

**Table 4-5. Comparison of Initial and 1362 Hour Performance of
 Module 18-11 at 1135°C**

	Initial 2/2/94	t = 52 hours V_L = 3.5V 2/4/94	t = 1362 hours 3/31/94
Heat Input, Watts	190	192.9	192.8
Hot Shoe, C Average	1137.8	1137.5	1132.1
Hot Shoe Range C	5.4	5.2	5.5
Cold Strap, C Average (8 T/Cs)	311.9	314.3	311.4
Cold Strap Range (8T/Cs)	2.6	2.5	2.1
Cold Strap Average (12 T/Cs)	306.5	308.9	306.1
Cold Strap Range (12 T/Cs)	20.1	20.3	20.3
Load Voltage, Volts	3.895	3.499	3.522
Link Voltage, Volts	0.108	0.121	0.113
Current, Amps	2.842	3.174	3.094
Open Circuit Voltage, Volts	7.140	7.160	7.356
Normalized Open Circuits (8T/Cs)	6.319	6.359	6.553
Normalized Open Circuits (12 T/Cs)	6.276	6.316	6.509
Average Couple Seebeck Coefficient (12)	498 X 10 ⁻⁶	501 X 10 ⁻⁶	516.6 X 10 ⁻⁶
Internal Resistance, Ohms	1.104	1.115	1.203
Internal Resistance Per Couple (Avg.)	0.0613	0.0620	0.0668
Power Measured, Watts (Load + Link)	11.375	11.492	11.244
Power Normalized, Watts (8 T/Cs)	8.909	9.065	8.923
Power Normalized, Watts (12 T/Cs)	8.789	8.942	8.804
Power Factor	40.452 X 10 ⁻⁵	40.557 X 10 ⁻⁵	39.93 X 10 ⁻⁵
Isolation			
Circuit to Foil, Volts	-1.68	-1.36	-1.27
Circuit to Foil, Ohms	6.29K	5.95K	14.1K

Table 4-6. Module 18-11 Internal Resistance Changes

Position	Serial #	2nd Bond Milliohm	Preassy Milliohm	Delta1 Milliohm	T = 0 Milliohm	T=1362 Hours	Delta1 Milliohm	Percent Increase
1.0	H2006	22.5	22.1	-0.4				
2.0	H0507	22.4	21.9	-0.5				
3.0	H0512	22.7	22.2	-0.5				
					182.3	198.9	16.6	9.1
4.0	H0439	23.2	22.7	-0.5	62.3	67.7	5.4	8.7
5.0	H0587	22.5	22.4	-0.1	61.0	66.2	5.2	8.5
6.0	H0657	22.7	22.5	-0.2	61.4	67.1	5.7	9.3
					184.1	200.4	16.3	8.9
7.0	H0585	22.9	22.5	-0.4				
8.0	H0459	22.5	22.1	-0.4				
9.0	H0562	22.7	22.3	-0.4				
					185.7	202.4	16.7	9.0
10.0	H0248	22.7	22.3	-0.4				
11.0	H0163	22.9	22.4	-0.5				
12.0	H0282	22.7	22.4	-0.3				
					184.9	201.0	16.1	8.7
13.0	H0428	23.1	22.7	-0.4	62.1	67.6	5.5	8.9
14.0	H0326	22.6	22.0	-0.6	62.2	68.0	5.8	9.3
15.0	H0232	22.6	22.0	-0.6	60.9	66.4	5.5	9.0
					184.7	201.5	16.8	9.1
16.0	H0590	22.6	22.4	-0.2				
17.0	H0393	22.6	22.1	-0.5				
18.0	H0215	22.5	22.3	-0.2				
					184.2	200.7	16.5	9.0

18 Couple Module: 18-12

Assembly of module 18-12 was initiated in February 1993. This module contains unicouples selected from the remaining unicouples of the E-6 production lot (i.e., assemblies not installed into the E-6 flight converter). Assembly operations were preceded by a series of drawing and assembly procedure changes to correct errors encountered during the fabrication of modules 18-10 and 18-11.

During February and March, unicouples were inserted into the foil insulation assembly, including six pre-drilled assemblies for standard hot side thermocouple instrumentation. One drilled uncouple was replaced due to excessive voiding in a cold stack braze joint discovered during post-drilling inspection. Forming, riveting, and rivet setting (swaging) were completed. Electrical measurements indicate no damage was introduced during these operations. Assembly operations will continue through April, with delivery to the Building B test facility scheduled for early May.

Task 5

ETG Fabrication, Assembly, and Test

TASK 5 ETG FABRICATION, ASSEMBLY, AND TEST

Uncouple Production

As a significant milestone during this six month reporting period, the production of E-6 uncouples was completed mid-October 1993. Substantial progress has also been made on E-7 uncouple production with its completion expected by the end of April 1994. An overall status of flight uncouple production is shown in Table 5-1. Significant issues related to the production of flight uncouples during this reporting period are discussed in the following paragraphs.

Second Bond – Static Load Fixture

At the start of this reporting period, efforts focused on qualifying the graphite frame static load fixture as an alternate to tungsten clips for the second bond assembly operation. During the October reporting period demonstration runs were completed which showed that the static load fixture was acceptable for second bond fixturing. A detailed accounting of the development work and demonstration runs is provided in Cassini Memo No. 240. At the start of November, operator certification runs were successfully conducted. DOE approval to proceed with the use of the static load fixture was obtained at the 5 November 1993 production readiness meeting. Following this, the process specification was revised to incorporate the static load fixture. Actual use of the static load fixture was initiated early in December 1993 with the tungsten clips and the static load fixture being used in parallel. Based on the excellent results (yield ~97%) that have been achieved with the tungsten clips over the past six months, the approach to employ the clips for the majority (~85%) of production continues to be implemented. Bonding results with the static load fixture are, however, gradually being accumulated. These inspection data can later be employed to guide the selection of the most desirable fixture. It should be realized that the variation of available segment lots will be a key factor in this selection. Results for the static load fixture through the end of March 1994 are summarized in Table 5-2. Based on the positive results of the trial runs (conducted in January) a second operator was certified for second bond production with the static load fixture.

**Table 5-1. Cassini RTG Program Unicouple Hardware Production Status
(Through 23 March 1994)**

	Qual Lot			E-6				
	Total Accepted	Actual Yield *	Planned Yield	Cumulative ITD			Total Planned Starts	Planned Yield
				Total Starts	Total Accepted	Actual Yield *		
Vacuum Castings	90	98.9%	92.9%	54	54	100%	54	95.0%
Powder Blends	42	93.3%	94.3%	26	26	100%	26	96.0%
Hot Pressing	165	95.9%	85.7%	149	143	96.0%	149	90.0%
N-P Bonds	34	85.0%	85.7%	40	35	87.5%	40	90.0%
Pellets	1636	87.0%	78.6%	3020	2444	80.9%	3020	85.0%
Segments	2739	89.1%	78.6%	3921	3629	92.6%	3921	85.0%
Hot Shoes	1235	86.6%	78.6%	1541	1358	88.1%	1541	85.0%
First Bonds	736	93.2%	74.3%	1245	1172	94.1%	1245	82.0%
Coated First Bonds	591	85.9%	85.7%	1168	1086	93.0%	1168	90.0%
Second Bonds	411	91.3%	85.7%	1012	846	83.6%	1012	90.0%
Nickel Plating	2300	96.1%	90.0%	8568	8503	99.2%	8568	93.0%
Couple Preassembly	367	92.4%	85.7%	835	733	88.0%	835	90.0%
Brazed Radiator Assembly	455	91.9%	90.0%	1103	955	86.6%	1103	93.0%
Machined Radiator Assembly	351	98.0%	88.6%	961	825	85.8%	961	92.0%
Cold Stack	290	85.5%	90.0%	817	749	91.7%	817	93.0%
Coated Spacers	405	92.0%	85.7%	840	742	88.3%	840	90.0%
Unicouple Assembly	234	84.2%	87.1%	750	662	88.3%	750	91.0%
Wrapped Unicouple Assembly	225	97.0%	95.8%	652	647	99.2%	652	97.0%

	E-7							E-8						
	Started This Week	Accepted This Week	Cumulative ITD			Total Planned Starts	Planned Yield	Started This Week	Accepted This Week	Cumulative ITD			Total Planned Starts	Planned Yield
			Total Starts	Total Accepted	Actual Yield *					Total Starts	Total Accepted	Actual Yield *		
Vacuum Castings	♦	♦	59	58	98.3%	59	96.0%	♦	♦	82	78	95.1%	82	96.8%
Powder Blends	♦	♦	26	27	96.4%	26	96.8%	♦	♦	35	33	94.3%	35	97.4%
Hot Pressing	♦	♦	141	139	98.6%	141	92.0%	0	0	169	166	98.2%	175	93.6%
N-P Bonds	♦	0	39	35	94.6%	39	92.0%	0	0	12	10	100%	49	93.6%
Pellets	♦	0	3896	3322	87.5%	3896	86.5%	0	97	2160	1096	92.6%	3981	87.9%
Segments	♦	0	3624	2937	91.0%	3624	86.5%	0	0	4189	2270	87.4%	4189	87.9%
Hot Shoes	♦	44	1736	1325	89.1%	1736	86.5%	91		506			1809	87.9%
First Bonds	♦	0	1201	1131	94.3%	1201	85.6%	57	44	239	160	96.4%	1516	88.5%
Coated First Bonds	♦	♦	1008	948	94.0%	1008	92.0%	32	45	256	186	96.9%	1256	93.6%
Second Bonds	♦	8	970	905	97.0%	970	92.0%	43	0	176	13	92.9%	1122	93.6%
Nickel Plating	♦	0	9954	9816	98.6%	9954	94.4%	252	308	1050	560	95.2%	10836	95.5%
Couple Preassembly	8	0	807	676	94.7%	807	92.0%	35		35			1014	93.6%
Brazed Radiator Assembly	♦	♦	1071	984	91.9%	1071	94.4%	39	20	123	57	90.5%	1140	95.5%
Machined Radiator Assembly	♦	0	946	872	92.2%	946	93.6%	0		16			1060	94.9%
Cold Stack	0	34	872	729	84.4%	872	94.1%						976	94.9%
Coated Spacers	♦	♦	840	817	97.3%	840	92.0%	0	0	160	155	96.9%	1024	93.6%
Unicouple Assembly	35	51	698	592	91.1%	726	92.8%						908	94.2%
Wrapped Unicouple Assembly	34	0	572	342	96.3%	650	97.6%						610	96.0%

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

♦ Production complete.

Table 5-2. Results for the Static Load Fixture through the End of March 1994

Time Period	Bonds Made with the Static Load Fixture	Quantity Inspected	Quantity Accepted
Dec 93	39	33	31
Jan 94	15 *	15 *	13 *
Feb 94	12 **	-	-
Mar 94	12	-	-
	Total	33	31

* Engineering Hardware for Operator Certification Not Counted in Prime Yields

(Yield = 94%)

** Quantity of 12 Listed for February Corrects Previously Reported Quantity of 24

Machining of Radiator Attachment Assemblies

As discussed in prior monthly reports, repeated difficulties were experienced with the vendor machining of the radiator attachment assemblies. As a result of these problems, the decision was made to move this machining task in-house. Following a readiness review in late September 1993, actual in-house machining was initiated. During this six month reporting period, in-house machining results, with respect to part dimensional requirements, were generally satisfactory. The switch to in-house machining was not, however, without problems. At the start of the in-house machining task, an increased number of machined assemblies had to be reworked for burrs. Retraining of operators for burr removal was necessary since the smaller burrs generated by in-house machining differed in size and location from those previously produced by vendor processing. As operator training progressed the need to rework decreased. Also, as will be discussed in the subsequent Cold Stack Assembly section, a flatness problem originating with the machining of the radiator attachment assembly had to be corrected to resolve a cold stack braze voiding problem.

Despite the difficulties encountered, the decision to machine radiator attachment assemblies in-house has proved to be beneficial. In-house machining yields represent an improvement over prior vendor results. Furthermore, in-house processing has provided increased control over the machining schedule, thus eliminating downstream delays in brazing production. This additional control has also permitted more direct feedback for the correction of process problems.

Electrical Insulators (New)

The shipment of the first portion of the new electrical insulator replacement order (quantity ~ 940, Lot # M0907) was received from WESGO early October 1993. Quality acceptance testing was completed satisfactorily during the first week in November 1993. The metallized thickness was at the desired 0.5 mil nominal value and the Modulus of Rupture (MOR) strength results were excellent: 66.7 ksi average with 59.2 ksi minimum, 76.9 ksi maximum, and standard deviation of 4.9 ksi. This was a significant event, since insulators were the last new part needed for Cassini production. WESGO was authorized to complete the balance of the order. At the end of February 1994, the final portion of the replacement order (~2800 pieces, Lot #M0116) was received. QA testing was completed by mid-March with acceptable results. Once again the MOR results were good with 63.0 ksi average, 47.8 ksi minimum, 66.9 ksi maximum, and 7.9 ksi standard deviation

Machining of Electrical Insulators

During this six month reporting period, two problems related to the vendor (Sheffield) machining of the electrical insulator were addressed - foreign material/contamination and cracking. During the last week in October 1993, two lots of machined insulators were placed on non-conformance report for foreign material (isolated black particles ~0.5 to 1.0 mil in diameter) and metallic particles on the ground alumina surfaces. During November 1993, efforts were expended to resolve this contamination problem, and multiple vendor visits were made. Vendor deburring of the parts with silicon carbide paper followed by inadequate cleaning was identified as the source of contamination. To rectify this situation and ensure proper cleanliness in the future, the vendor processing instructions were modified. The parts are to be kept wet during deburring and a final ultrasonic cleaning (in water) followed by a methanol rinse was added. Machined parts received late November showed that these cleaning steps were effective in eliminating the contamination problem. With regard to the machined insulator lots placed on nonconformance report, recleaning prior to cold stack assembly or the normal grit blasting after the cold stack assembly braze removed the foreign material.

During December 1993, a cracking problem was identified with the machining of electrical insulators. Machining Lots 24 and 25 (with ~100 parts per lot) each had a ~15% rejection rate for cracking. Cracks were typically observed on both edges of a part corner. Prior experience showed cracking rates to be only 2 to 5 %. In what later was deemed a coincidence, Lot 24 insulators were the first set of parts to be machined from the new insulator replacement lot (M0907). Metallographic and SEM examinations of cracked parts, that were completed in December 1993, found no deficiencies with the alumina substrate from body lot M0907.

In January 1994, machining of Lot 26 was witnessed by Martin Marietta to further evaluate the cause of cracking. Due to the nature and location of the cracks, attention was focused on the corner machining operations. During the first visit for machining of Lot 26 (quantity 126), one plating lot (quantity 21) was monitored through edge and corner machining. No cracks were observed on these machined parts. Also during the visit, it was identified that the grinding wheel grit size had not been properly controlled, and was inconsistent on previous machining lots. It was learned that during Lot 25 machining the wheel was worn to the bottom and had to be replaced. The evidence of these control problems at Sheffield further supported the conclusion that the cracking problem was attributable to an anomaly in the machining operations, not a material deficiency with the replacement body lot M0907. The balance of Lot 26 was processed through edge and corner machining without Martin Marietta supervision. (Severe winter weather prevented timely vendor oversight.) Post machining examination of this balance of 105 parts showed 11 cracked parts. At this point witnessing the machining of the next Lot 27 was deemed necessary in order to continue efforts for resolution of the cracking problem. Prior to the machining of Lot 27, the corner machining fixture was modified to provide additional support to the corner being machined.

Under full Martin Marietta supervision, grinding of Lot 27 (103 parts) was completed toward the end of February 1994. The post machining inspection results were excellent, with only one cracked part. The high level of Martin Marietta involvement is indicative of the special care needed in the machining of the insulator. Early in March 1994, insulator machining Lot 28 (104 parts) was completed at Sheffield. Martin Marietta witnessed the corner machining in the processing of this lot. No cracks were generated during the cornering operation. Data from machining Lots 27 and 28 show only one cracked part from a total of 209 machined parts (cracking rate less than 1%). These results show the cracking problem has been placed under control.

As a formal close-out to this cracking problem, Engineering completed a cause and corrective action report (Ref. Cassini Memo No. 269) late March 1994. In summary, the report concludes that the improvement in Sheffield's workmanship, as a direct result of Martin Marietta supervision, is the most substantial reason for elimination of the cracking problem. The report also details the other beneficial changes – utilization of the original type of 320 grit wheel; modification of the corner fixture for improved support; insertion of front and back dummy insulators in the corner fixture set-up; reduction of material removal rates; and control of the grinding direction. The vendor process sheets have been updated to formally include these refinements.

Due to the reliability problems encountered at Sheffield, efforts were initiated in February 1994 to develop an alternate vendor for the insulator machining. During the third week of February, a visit was made to Insaco to review the insulator machining requirements and evaluate the vendor's capabilities. Overall assessment from the visit was that Insaco had the facilities and experience to perform the insulator machining task. Additional progress on this effort was slowed due to Insaco's request for a proprietary/non disclosure agreement. At the end of March 1994, the Martin Marietta legal department was still evaluating the risks associated with such an agreement. It is hoped that a signed agreement can be in place by the end of April. Once an agreement is reached, technical and procurement issues will be worked to bring Insaco on-line. It is planned to first have a development phase in which the vendor's fixturing and process will be defined. During this first phase the vendor will be required to demonstrate satisfactory machining of the parts. Based on the results of the development phase, a decision can then be made to proceed with Insaco machining of prime (flight) insulators.

Cold Stack Assembly

At the end of October 1993, difficulties in the cold stack assembly were being experienced with voiding and deep negative fillets in the braze joint between the machined radiator attachment assembly and the electrical insulator. While the magnitude of this problem did not threaten the E-7 converter assembly schedule, it did cause the October and November monthly yields to be ~15% lower than desired. EMQ efforts continued throughout November 1993 to remedy this situation. Metallographic and SEM evaluations were performed on several samples which showed that the Cusil braze alloy wet both the machined radiator and insulator surfaces. These results indicated that 1) the braze temperature was correct and 2) the surface preparation steps prior to brazing were performed satisfactorily. An area of alumina contamination from grit blasting was found on one sample. This contamination was not responsible for the voiding problem, but its presence necessitated cautioning of the operators to protect the machined surfaces of the radiator during deburring/grit blasting.

To assess the severity of the voiding problem, cold stack cold beam deflection tests (per RQ28B1) were conducted on rejected assemblies that exhibited substantial braze voids at the machined radiator to insulator joint. Failures of these samples occurred in the insulator, not the braze joint with failure loads comparable to loads typically achieved with accepted cold stack assemblies. These results indicated that the braze void problem was a visual acceptance issue rather than a structural defect.

As the evaluation progressed, inadequate flatness of the machined radiator (causing poor contact between the insulator and machined radiator) was attributed as the cause for the voiding problem. Flatness checks on machined assemblies revealed that a portion (10% to 20%) of the machined lots became slightly distorted during machining resulting in flatness deviations of 1 to 2 mils. Also, on several assemblies it was detected that sanding of the parts during deburring operations caused a shallow but an unacceptably deep chamfered edge which could not be filled by the braze material. Processing of the machined radiator was subsequently modified to improve flatness. The key corrective actions taken were: 1) Resequencing the machining operations to drill the hole, then mill the parallel surfaces; 2) Instituting in-process checks for flatness by the machinist; 3) Cautioning the machinist on preventing distortion of the assembly during fixturing (set-up/removal); and 4) Eliminating the routine hand sanding of the radiator brazing surface (sanding is permitted only to remove a burr). An Engineering Report (Cassini Memo No. 261) provides an in-depth discussion of the flatness problem and the basis for the corrective actions. These improved practices were instituted in December 1993. At the end of January 1994, data from the last 230 cold stacks inspected showed that the braze voiding problem was under control with only 11 rejects (~5%) for braze related problems. Overall, for the period of January through March, the cold stack assembly yield has continued to improve with 407 assemblies accepted at a 90% yield. (The E-7 cold stack production cumulative yield has risen to 84%.)

As an issue related to the voiding problem, the addition of a flatness requirement to the machined radiator drawing had been considered. Parallelism of the machined radiator attachment assembly surfaces within 1.5 mils is specified by the drawing, however this does not relate directly to a flatness requirement. During the past several months, data on radiator flatness was measured and compared with braze results. Factoring in the accuracy of the measurement technique, no correlations between measured flatness and braze results were established. As a consequence, it was decided not to incorporate a flatness requirement on the machined radiator.

Procurement of Additional Unicouple Parts

During January 1994, an effort was initiated to procure four additional unicouple parts:

- Tungsten Cold Shoes (3803P1)
- Amzirc Heat Shunts (3847P2)
- Tungsten Compensators (3805P1)
- Alumina Hot Shoe Spacers (3922P1)

An additional lot of tungsten cold shoes will be necessary to complete E-8 production. Rough estimates show the need for additional cold shoes in the April 1994 (worst case) to June 1994 (best case) time range. The procurement of the remaining three unicouple parts is being done to provide part quantity margins in the event that production yields do not meet planned yields. A status of the procurement activities for each of these parts is provided below.

Tungsten Cold Shoes: The supplier on the original order of Cassini program cold shoes, Osram (formally GTE) Sylvania, responded with an unsuitably long lead time of 16 weeks. Attempts to improve this lead time were not successful. As a result, a purchase order was placed with Schwarzkopf Technologies (Holliston, MA). Schwarzkopf quoted an 8 week delivery cycle. Prior to placing the order, Martin Marietta personnel visited the Schwarzkopf facilities to verify their capabilities. During this visit samples of the tungsten body lot material for both the cold shoes and tungsten compensators was obtained for Martin Marietta approval. Chemical purity and metallographic evaluations on these samples determined that they were satisfactory.

Schwarzkopf plans to use wire EDM to machine the thickness of the cold shoe oversized and then achieve final thickness by lapping. An Engineering review has concluded that, if the material lapped-off is sufficiently deep (1 to 2 mils per side) to remove the wire EDM recast layer, then wire EDM is a satisfactory process. The Schwarzkopf promised delivery date is the end of April 1994. To monitor the progress on this order and verify the use of wire EDM, plans are underway to obtain machined samples from Schwarzkopf at various stages in their process.

Amzirc Heat Shunts: As discussed in the January 1994 Monthly Technical Report, the schedule limitations on obtaining new Amzirc body lot material will cause this new procurement to follow the same path as the original heat shunt order. (Note: The original order of parts required machining to size and chemical etching as rework prior to plating.). In February 1994, Martin Marietta personnel visited CARR, the supplier for the first Cassini program order, to address procurement details. At this visit, plans were made to have Martin Marietta representatives present when the parts are fabricated. A tentative time of mid-May 1994 is scheduled for part production.

Tungsten Compensators: Both Osram Sylvania and Schwarzkopf have responded with quotes on this part. Sylvania supplied the parts on the first Cassini program order. This order is not on the critical path and time is therefore available to work the procurement details with these two vendors. The Martin Marietta purchasing organization is contacting Osram Sylvania to achieve an improvement in delivery time. (Similar to the tungsten cold shoes, Sylvania has quoted an unacceptable lead time for tungsten compensators.) Before Schwarzkopf is considered for this part order, the results of the cold shoe part fabrication will be evaluated. If satisfactory, this will confirm Schwarzkopf's technical capability to produce this part.

Hot Shoe Spacers: Plans are to procure the hot shoe spacers from the supplier, AlSiMag, of the original Cassini program order. The spacers will be made from the same green tape material used for the first order.

Unicouple Mapping Code

During October 1993, the original unicouple mapping code used for previous RTGs was successfully recovered and adapted to run on the SUN workstation. Sample checkout runs using F-5 data have demonstrated that the program is functioning properly. As an added productivity feature, a plotting program that interfaces with the mapping code was developed. This plotting code will provide automatic generation of the unicouple map drawing. A PIR of the mapping code has been prepared. The code listing is designated as document 23009074.

E-6 Unicouple Map

In November 1993, the E-6 unicouple map was formally released following Engineering and Quality review.

E-6 Foil Insulation Assembly

During September 1993, improper fit of the foil panels over the alignment pins was experienced at the start of level 4. Several causes were identified, including both tolerance stack-up and a drawing error in panel dimensions for the first layer of level 4. In mid-October 1993, level 4 panel misfit was remedied per MRB direction by several modifications. Cloth panel type for layers 1, 2, and 3 was changed from 8 mil M9A3 to 4 mil M9A2. The fold-line to center-line of punched hole (Dimension C) for the cloth and foil panels in layer 1 was modified from 1.417" to 1.420". The cloth type specified for layer 1 of level 4 in the design was subsequently changed to M9A2 by a formal Engineering Change Notice (ECN No. 332).

At the start of level 5 a misfit, similar to that found at level 4, was experienced in the first foil layer. Several foil panels were severely torn at alignment pin corners requiring replacement. In order to mitigate the fit problem the cloth for layers 1 and 2 were changed from M9A3 to the thinner M9A2 type. In addition, the first cloth layer was installed without the 45° offset (shift) from the underlying level 4 as specified on the assembly drawing. Both the use of M9A2 cloth and the change of the first cloth layer offset were approved by MRB before proceeding. The remainder of level 5 was assembled without defects.

Assembly of level 6 experienced foil misfit problems comparable to those of Levels 4 and 5. Test fits indicated that the molybdenum foil panels would tear at alignment pin corners. The panel misfit was remedied by a method similar to that used at level 5. The cloth for all of layers 1, 2, and the end sections only of layer 3 were changed from 8 mil M9A3 material to the thinner 4 mil M9A2 material. Also, cloth panels at layer 1 were not offset 45° from the underlying level 5 panels. The 45° offset was instead introduced at the subsequent foil panel of the layer 1. These modifications were performed at MRB direction. Lay-up of the E-6 foil insulation assembly then proceeded without difficulty. Level 7 panels did not experience misfit problems. This was attributed to a reduction in overall assembly dimensions to below nominal values and gradual modifications in the assembly techniques. Engineering analysis of the modifications introduced during assembly determined that, on a conservative basis, the maximum possible impact to RTG performance would be less than 0.35 watts (well below 0.5% of total power output). This analysis and a summary of the E-6 foil insulation fabrication history is detailed in Cassini Memo No. 251.

To seek corrective action for the problem encountered during the E-6 layup, a study of the foil misfit situation was conducted. The two principal recommendations from this study were (1) hold the assembly at its nominal, rather than maximum allowed, dimensions when setting-up for retaining band welding, and (2) offset each foil/cloth panel 45° with respect to the previous foil/cloth panel. Maintaining nominal flat to flat dimensions on the octagonal cross-section will prevent the need to increase the fold line to hole center line dimension of the foil panels. Offsetting will reduce the "bunching" effect at the corners and will subsequently prevent tearing of the panels due to stretching the foil over the alignment pins. Both of these changes were incorporated into the foil lay-up drawing in preparation for the E-7 foil lay-up activities.

E-6 Thermopile Assembly

Upon completion of the foil lay-up, the E-6 foil insulation assembly was transferred to the thermopile assembly tooling.

A process readiness review for uncouple insertion activities was held with DOE on 22 November 1993. Training results for insertion, base wrapping, and uncouple removal were reviewed, along with the results of tooling check-out activities. Approval was granted to proceed with uncouple insertion for E-6.

In parallel with the insertion work, training for the next thermopile assembly process readiness activity, connector forming and riveting, was conducted. A simulated section of a foil insulation assembly was installed onto a duplicate thermopile assembly fixture for this purpose. Operator training included connector forming, rivet popping, rivet setting (swaging), and rivet removal. Inspector training included inspection of the above operations, along with borescope use for the measurement of hot shoe clearances between uncouples and inner moly frame bulkheads.

All of the 572 uncouples were successfully inserted, wrapped with quartz yarn (base wrapping), and aligned to riveting tooling. Figure 5-1 illustrates the uncouples subsequent to insertion and prior to forming and riveting of the electrical connectors.

Several uncouples were replaced (prior to insertion) from the group of 572 initially selected for the E-6 thermopile during pre-insertion electrical inspections. A total of four uncouples were replaced due to resistance increases of more than 0.4 milliohms from measurements taken during previous uncouple assembly operations. This number of replacements is consistent with previous GPHS-RTG experience. Figure 5-2 depicts the inside of the thermopile subsequent to uncouple insertion.

Process readiness for the uncouple forming and riveting operations, including rivet removal and borescope operations, was approved in early January. Final alignment checks were performed and forming and riveting of the eight double rows was successfully completed in the first week in March. Figure 5-3 shows a close-up of the riveted interface including parallel strap, and Figure 5-4 illustrates the completed thermopile assembly subsequent to forming and riveting operations. Figure 5-5 depicts the borescope which is utilized for internal inspections of the thermopile.

Figure 5.1. Detailed View of Thermopile Exterior After Unicouple Insertion

Figure 5-2. Internal View of E-6 Thermopile After Unicouple Insertion

Figure 5.3. Close-Up of Riveted Electrical Connectors

Figure 5-4. E-6 Thermopile Assembly Prior to Connector Wrapping

Figure 5.5. Borescope Inspection Set-Up

Following the forming and riveting operations, electrical resistance measurements of the thermopile assembly were taken. All measurements were within specification, however, several rivet joints exhibited higher than normal electrical resistance. During diagnostic checks to understand this occurrence, it was found that the resistance of these joints had increased. This finding was documented on Defect Report No. DR84417. In each case, measurements indicated that the additional resistance was in the parallel interconnect path and not the primary current path. In accordance with the direction of the DR, the rivet joints exhibiting abnormally high resistances were reswaged. A full set of electrical checks were then repeated. Four uncouple pairs (positions 3, 4, 32, and 33 on double row E-F) were found to exceed the 0.4 milliohm engineering flag for comparison of calculated versus measured resistance.. This finding was noted on DR84417. All data has been forwarded to Engineering for review.

In order to maintain schedule, it was decided to temporarily keep this DR item open and proceed with connector (Katucki) wrapping efforts. Training for wrapping of the uncouple electrical connectors was completed and the planning was updated to better describe the wrapping operation. Process readiness for connector wrapping was achieved 21 March

1994. Actual wrapping work is planned to start the first week of April 1994. An electrical measurement plan has been developed to monitor uncouple resistance (especially the high resistance rivet joints) during the course of connector wrapping. This resistance data will be used in the ongoing Engineering evaluations. Double row E-F will not be wrapped until the resistance deviation on DR84417 is closed out.

Converter Hardware

Radifrax Coating: Completion of all Cassini plasma arc spraying of radifrax coating on the heat source supports has been accomplished. All emissivity and bend tests were satisfactorily completed and the parts were accepted.

E-6 Converter Shell Subassembly: The outboard heat source support assembly, less foil insulation or yarn wrapping, was assembled in preparation for preloading/alignment. The installation of the inboard and outboard latches and the outboard heat source support to the E-6 shell was completed. Preloading of the outboard heat source support assembly was then performed. Measurements of alignment were taken and the necessary shimming of the outboard heat source support was completed. The alignment was rechecked and found to be acceptable after shimming. Alignment of the inboard latches required an ECN which permitted increasing the latch hole diameters in order to meet the parallelism requirements. The hole diameters in the latches were then enlarged and inspected. The latches were reinstalled and the parallelism check was found to be acceptable. Assembly of the electrical receptacle, PRD diaphragm, and the gas management system to the E-6 converter shell assembly will be initiated in early April 1994.

Qualification Electrical Receptacle Connectors: Electron beam weld samples for welding certification of the electrical leads on the electrical receptacle assembly were completed. In accordance with the Engineering direction to update the welding definition from the MHW vintage requirements to current industry standards, welding on the samples was performed per AMS 2681 with certification per MIL-STD-1595. This change was incorporated into the receptacle assembly drawing via an ECN. Metallographic and radiographic examinations on the samples were completed with satisfactory results and a process certification was issued. The qualification electrical receptacle assembly was then electron beam welded to attach the five cable (test configuration) assemblies. Radiographic and metallographic tests have been completed and the assembly was accepted. The electrical receptacle assembly has been forwarded to the vendor (Gulton) for completion of qualification testing.

RTD Cable Assembly: Fabrication and acceptance testing of the 23008080G1 cables have been completed. Four of these cables are used in the assembly of each RTD cable and a sufficient number of cables have been fabricated for F-2, F-5, E-6, E-7, E-8, as well as the qualification RTD cable assembly. Procurement of the Cannon connectors was completed with delivery of the connectors occurring the end of March 1994. Spare connector contacts were also obtained for crimp tool verification. The procurement of the back-up Gulton connector was canceled since the Cannon delivery was on schedule and delivery delays were anticipated for the back-up connectors. Attachment of the connector and RTD sensors are scheduled to begin in April. The RTD cable assembly fabrication schedule is shown in Figure 5-6.

The design of the dynamic test fixture to qualify the new RTD cable assembly design has been completed and fabrication has begun. Fixture fabrication is expected to be completed in May 1994.

Figure 5-6. RTD Cable Assembly Fabrication Schedule

Midspan Can Assemblies: The progress of Engelhard on the fabrication of the E-7 Iridium midspan can assemblies continues to be monitored. During this six month period, Engelhard had successfully fabricated cans and tabs. The third welding demonstration for certification was completed at the end of March. Martin Marietta personnel witnessing the operation have reported favorable results. Formal evaluation of the weld joint will be completed before certification is granted.

E-8 Fin/Tube Assemblies: All eight fin tube assemblies were x-rayed and excess tube penetration at the mid-span crossover tube locations was detected. New assemblies were started after drawing and planning changes were made to prevent the tube penetration problem from reoccurring.

Task 6

Ground Support Equipment

TASK 6 GROUND SUPPORT EQUIPMENT (GSE)

Read Out Console (ROC)

All three ROC data acquisition system upgrades have been completed. A drawing ECN to document refurbishment changes has been prepared and will be issued after the checkout of the system. Software preparation for the system is almost complete. The first ROC is ready to be moved to Building 800 for checkout where it will be interfaced with the Loading and Assembly Station (LAS) and the qualification ETG. After checkout the ROC will be used for operator training.

Task 7

RTG Shipping and Launch Support

TASK 7 RTG SHIPPING AND LAUNCH SUPPORT

Support for the development of the new RTG shipping container continued during this report period. Procedures and preparations were reviewed for the thermal qualification test conducted at Mound in November 1993 and on-site representation was provided during the test. In addition, various specifications and requirements documents were reviewed. The effect that the use of the new container may have on RTG shipping and receiving operations at the Kennedy Space Center was also reviewed.

Launch support activity in this report period focused on planning the handling operations and the route the RTGs will follow at the launch facility (Pad 40). Under review is the routing of the RTGs from ground level at the pad to level 14, where they will be joined to the spacecraft. Two routes are presently receiving attention: (1) use of an elevator to raise the RTGs from ground level directly to level 14, and (2) utilizing two crane lifts – one from the ground to intermediate level 6, where the RTGs would be transferred to a second crane for the lift from level 6 to level 14. A number of considerations are involved and several organizations are participating in discussions. Additional information gathering and evaluations are in progress and are expected to be the subject of further discussion before a preferred routing is adopted.

Task 8

Designs, Review, and Mission Applications

TASK 8 DESIGNS, REVIEWS, AND MISSION APPLICATIONS

8.1 Galileo/Ulysses Flight Performance Analysis

Galileo: Attached are the power trends for the two RTGs (F-1 and F-4) on the Galileo spacecraft. Available data from JPL extends to 29 November 1993 when the mission time reached 36,072 hours (4.1 years). Figures 8-1 and 8-2 show the individual RTG power profiles. Figure 8-3 is the total RTG power for Galileo. Power trends continue to closely follow the TEG model predictions and the available power continues to exceed spacecraft requirements as shown in Figure 8-4.

RTD temperatures are shown in Figure 8-5. Three of the four RTDs continue to operate. The spacecraft is 3.54 A.U. (328 million miles) from the sun and RTD temperatures continue to agree well with the model predictions.

Figure 8-1. Galileo RTG F-1 Power

Figure 8-2. Galileo RTG F-4 Power

Figure 8-3. Galileo RTG Power (F-1 and F-4)

Figure 8-4. RTG Power and Spacecraft Required Power

Figure 8-5. Galileo Outer Shell Temperature

Ulysses: The spacecraft is three years into its mission, 365 million miles from the sun, 39 degrees below the planetary orbital plane and heading for a summer 1994 pass of the south pole of the sun. As previously discussed, the RTG current is not measured and RTG power is inferred from a number of spacecraft measurements and conditions. Results from the latest power algorithm (#2) are shown in Figure 8-6, where minimum and maximum power estimates are given. Agreement with TEG model predictions is only fair which is not surprising given the limited but unknown accuracy of the power algorithm.

Figure 8-6. Ulysses RTG F-3 Power

8.2 Individual and Module Multicouple Testing

Multicouple life testing continued during this reporting period. Three multicouples are currently on life test in Station #3 and two multicouples in Station #5, as shown in Table 8-1.

Table 8-1. Multicouple Life Test Summary

Multicouple	Test Station	Accumulated Test Hours
Build 3 - M/C 1026-8	#3	21,654
Build 5 - M/C M042-G4	#3	5,712
Build 5 - M/C M043-18	#3	3,903
Build 5 - M/C N042-5 (No GaP)	#5	12,688
Build 5 - M/C M043-19	#5	13,141

All multicouples except M043-19 are operating at normal RTG operating temperatures and with a -6 volt bias applied between the negative multicouple terminal and ground. Multicouple M043-19 is operating at reduced hot side temperatures but previously operated at normal and accelerated hot side temperatures as shown in Table 8-2. The multicouple performance trends are shown in Figures 8-7 and 8-8.

Table 8-2. Multicouple M043-19 Test History

Hot Junction Operating Temp (°C) .	Time at Operating Temp (hours.)
1000	1838
1050	3753
950	7550
Total	13,141

Figure 8-7. Performance Trend for Build 3 Multicouple

Figure 8-8. Performance Trends for Build 5 Multicouples

One unplanned test shutdown occurred during this reporting period. A power outage occurred in the Building B facility on 21 December 1993. Vacuum Station #5 temporarily lost heater power. The multicouples cooled to approximately 800°C before power was reapplied. Vacuum Station #3 also temporarily lost heater power and subsequently lost vacuum due to a shutdown of the cryopump. The shutdowns occurred because of a fluctuating output voltage from the emergency power generator which was activated when house power was lost. A faulty speed controller in the emergency power generator was found and repaired. Build 4 multicouple M042-8, which was exhibiting evidence of cold end debonding, was removed from test Station #3, since the station had cooled to ambient as a result of the shutdown. A test readiness review was conducted on 23 December 1993 after repair of the emergency generator was completed. Testing was resumed in Vacuum station #3 immediately thereafter.

Two multicouples were removed from life testing in October and December of this reporting period because of excessive performance degradation. The multicouples removed were Build 3 multicouple 1026-3 and Build 4 multicouple M042-8. Build 3 multicouple 1026-3 had accumulated ~18,700 hours of operation and was removed because of uncharacteristic increases in internal resistance after restarting life testing on 29 September 1993. Build 4 multicouple M042-8 was removed from testing after operating for 19,976 hours. It was exhibiting evidence of cold end debonding, similar to Build 4 multicouple M042-10, which was previously removed from life testing after operating for ~18,000 hours.

Post test examination of Build 4 multicouple M042-10 was completed in November of this reporting period. Metallographic examination revealed debonding of the cold end glass (~90%) between the GS-526 glass and graphite cold cushion. This is believed to be the cause of the observed power degradation. The debond was likely initiated by the thermal shock which occurred after ~11,000 hours, and which was due to an unplanned, uncontrolled automatic shutdown of the life test. The use of SiC has been shown to improve the performance of the bond between the GS-526 glass and the graphite heat collector at the hot end. It is planned to incorporate the same SiC coating on the graphite cold cushion to improve the strength of the cold end bond for future multicouples.

The low temperature glass (CV-635) on the cold end was found to be friable on the more negatively biased side of the thermopile. It is not clear whether this contributed to the debonding of the GS-526 glass from the cold cushion. No alkali contamination was found in the cold end glasses which could cause this friable condition. A small concentration of CaO (0.8%) was found in the CV-635 glass but it has not been established whether this could have caused the friable condition.

The condition of the hot end glass bond between heat collector and thermopile was quite good with only minor debonding found (~20 mils and 5 mils in from the edge of the squeeze out glass). A report summarizing the detailed findings was issued in December 1993 (Ref. CON No. 808). .

Post mortem examination of Build 3 multicouple 1026-3 was also completed in December 1993. Examination of the multicouple revealed an apparent crack in the perimeter glass on three sides of the thermopile. Acoustic imaging of the thermopile was performed at Martin Marietta Laboratories (Baltimore, MD) to verify and determine the depth of the crack. The acoustic images clearly indicated the presence of a crack through the thermopile. It is believed this crack was initiated during an unplanned, uncontrolled shutdown of the life test which resulted in a rapid thermal excursion to the multicouple. A report summarizing the detailed findings from the acoustic imaging examination will be issued in April.

Task 8.2 also includes providing support to DOE by participating in meetings of the thermoelectric community to discuss and assess (1) progress and improvements in the development of thermoelectric materials, and devices, and (2) by reviewing contemporary reports and literature. A Thermoelectric Materials Review Meeting was hosted by Martin Marietta on 3 November 1993. The purpose of the meeting was to review current advances in thermoelectric materials and test results on thermoelectric devices. DOE, Ames Laboratory, Fairchild Space, JPL, ThermoTrex , and Martin Marietta participated in the review. The results of the review were summarized in CON No. 815 which was issued in December 1993.

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

This task has been successfully completed.

8.4 Technical Conference Support

No significant activity this reporting period.

8.5 Evaluation of an Improved Performance Unicouple

This task was authorized on 18 January 1994. The objective of this task is to fabricate an improved performance unicouple and to evaluate its performance in an 18 couple test module. The planning for this task has been completed. The development flow plan is shown in Figure 8-9 and the overall task summary schedule is shown in Figure 8-10.

TASK 8E
IMPROVED UNICUPLE

8.5 Evaluation of an Improved Performance Unicouple (Cont'd)

Three compacts of an improved SiGe P material (Si 0.796, Ge 0.199, B 0.005) and three compacts of an improved SiGe N material (Si 0.7712, Ge 0.1928, Ga 0.0072, P 0.0288) were fabricated at Martin Marietta in March 1994. The compacts were fabricated by the vacuum chill cast – hot press method. The P compacts were double pressed and the N compacts triple pressed to ensure compositional homogeneity. Residual SiGe N material (crushed) from the MOD-RTG Program was used for the fabrication of the improved N material.

Ames Laboratory has developed an improved SiGe-GaP N type material which is fabricated by mechanical alloying and hot isostatic pressing. This effort was conducted in parallel with the Martin Marietta effort. Ames has completed fabrication of three improved SiGe N compacts in March. Two of the compacts have been sent to Martin Marietta for use in unicouple bonding studies and the third compact will be characterized at Ames. The properties of the Ames improved material will be compared to the standard Cassini unicouple material and Martin Marietta's improved N material. The preferred N material for the improved unicouple will be selected on the basis of the property measurement data and its availability for unicouple production.

Samples of the Martin Marietta improved N and P materials were sent (without heat treatment) at the end of March to Ames Laboratory for RT Hall Effect measurements and high temperature property measurements. These measurements will determine if further processing (heat treatment) is required. Samples of standard Cassini unicouple production material (N and P) were sent to Ames in February for high temperature property measurements to establish a baseline for evaluating the improvement of the new materials. An integrated average figure of merit (300-1000°C) of 0.76 and $0.55 \times 10^{-3} \text{ } ^\circ\text{C}^{-1}$ were measured for the Cassini N and P materials, respectively. Property measurements of the improved N and P materials are expected to be completed in April.

It is planned to diffusion bond the unicouple pellets and segments. A two-step bonding process for pellet bonding is anticipated (i.e., bonding the N SiGe-GaP in the first cycle and the P SiGe in the second cycle) because of the disparity in the melting points of the improved N and P materials. Bond scoping trials were successfully performed in March which verified the feasibility of diffusion bonding the improved SiGe/GaP N material. Several pre-production improved unicouples will be fabricated for testing to verify the strength of the bonds using this new material.

Unicouple production will be initiated following confirmation that the thermoelectric material properties have been enhanced and adequate unicouple bond strength has been demonstrated. It is planned to fabricate 25 improved uncouples, 18 of which will be installed in a newly fabricated 18 couple test module. Module heat up is scheduled to begin in November, and several weeks of performance testing will be completed by the end of the year. A recommendation regarding further testing will be made to DOE following analysis of the performance data.

Task 9

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

TASK 9 PROJECT MANAGEMENT, QUALITY ASSURANCE, AND RELIABILITY

9.1 Project Management

Contract required weekly reports, monthly reports, quarterly reports and data submissions were delivered on schedule. Cassini Monthly Status Reviews were held in October and January. Cassini Quarterly Reviews were supported in December and March.

The following DOE directions to perform work were received this period:

DOE Letter Ser RTG-035 (Incorporated into Contract Change M026 proposal) -- Acquire DC power supply and Primavera training.

DOE Letter Ser RTG-039 (Task 8 Subtask definition) -- Extends multicouple long-life testing and authorizes technical conference paper preparation and participation.

DOE Letter Ser RTG-041 (Task 8 Subtask definition) -- Fabricate and test an 18 couple module using improved thermoelectric material.

The proposal for Contract Change M026 was submitted and definitized this period. Other changes definitized were M013, M022, and M023. At this time all contract changes are definitized.

The annual update to the Milestone Plan was completed this period and submitted to DOE.

The Primavera software to be used for the schedule portion of the Program PMS activity was installed and checked out. The Cassini Schedule Specialist completed the planned training and program data input was initiated with the objective of using the Primavera system for schedule status reporting and the management status report for April.

No significant Environmental, Health, and Safety incidents occurred this period. No significant adverse findings/observations resulted from two audits which included EH&S. A 16 person Martin Marietta team conducted an EH&S audit in February 1994 and EH&S was included in the DOE Quality Assurance Audit in March 1994.

Attached are the updated Cassini RTG Program calendars for 4Q93, 1Q94 and 2Q94 showing program meetings and important program-related events.

9.2 Quality Assurance

Process Readiness and Production Readiness Reviews

Approval was given for the production of second bonds using the static load fixture.

Process readiness reviews were held for the following thermopile fabrication processes:

- Insertion of unicouples in the converter
- Forming and riveting unicouples
- Borescope inspection of the converter
- Rivet removal
- Wrapping uncouple connectors (Katucki wrap)

Quality Plans and Documents

No new plans or documents were prepared during this period.

Quality Control of Fabrication

18 Couple Module: Inspection support was provided for the fabrication of module 18-11, which was completed and placed on test. Inspection support is being provided for the fabrication of module 18-12, which is scheduled to be completed at the end of April. The test facility has been checked out and is ready for the module.

Converter Hardware: Inspection support continues to be provided for fabrication of the E-6 thermopile, which has completed forming and riveting. As discussed in the Task 5 section of this report, due to shifts in resistance data of several riveted joints, rework (reswaging) has been performed and studies are currently underway to assure that the joints are acceptable.

Effort in the receiving area was applied to receiving converter procured materials, such as: spring washers, screws, C-seals, PRD housing, radifrax coated parts, PRD bellows, molybdenum foil, etc. Some delays are occurring because of the lack of proper certifications at the time of delivery of many lots.

Inspection of the E-7 outer shell assembly has been completed and the unit is being prepared for PD224 coating. Welding of the qualification unit electrical receptacle was witnessed by QA and the welds were found to be visually acceptable. Final evaluation of the welded assembly was completed in-house and the assembly was formally accepted. The receptacle has been forwarded to Gulton Industries for the completion of qualification testing.

Unicouple Production: Yields in the production of unicouples have improved through this past 6 months. Most of the persistent process problems have been addressed, with corresponding yield improvements. A defect reduction program has been initiated to address processes which are experiencing yields below goal levels. Weekly reports are prepared which, using the Nonconformance Log, provide an analysis of data of initial inspection results. Using this report as a basis, weekly meetings are held, with all disciplines present, to discuss the analyses and identify corrective actions. Thus far, the approach has had a positive affect on the unicouple processes.

Material Review Board: The Class I NR, which addressed the high flow pressure drop on the E-7 outer shell assembly, was closed with acceptance of the assembly. No new Class I NRs were issued this reporting period.

Quality Assurance Audits

The 1993 audit program was completed, as scheduled, with the exception of the QA systems audit of the purchasing system. This audit could not be performed because of the transition to a new system, which obsoleted the existing procedures. This audit has been rescheduled for early 1994.

The 1994 audit schedule has been developed and includes six QA systems audits, six unicouple process audits, and six converter process audits. To date, audits have been performed of the stockroom, unicouple cold stack process, and converter assembly area tooling.

Quality Assurance Status Meeting

Three DOE QA Status Meetings were held during this period. All action items, except for two issued at the 26 January meeting were closed. The two open items are near completion and will be closed shortly. The next meeting is scheduled for 20 April 1994.

Task H

CAGO Acquisition (Capital Funds)

TASK H CONTRACTOR ACQUIRED GOVERNMENT OWNED PROPERTY (CAGO) ACQUISITION

H.1 CAGO - Unicouple Equipment

Hot Press #3 Refurbishment and Qualification: Refurbishment of Hot Press #3 (HP-3) is complete and the unit is operational. Qualification of HP-3 for use in prime hardware was initiated and is continuing. Completion of the qualification effort has been partially delayed by the use of HP-3 to produce compacts (engineering hardware) for Subtask 8.5. Maintenance related events which caused delays during installation and checkout phase were:

- Replaced failed Micricon temperature controller unit.
- Repaired water leak in bottom ram.
- Replaced flow switch in safety shutoff system to reduce "false" shutdowns.

These maintenance efforts generally involved systems that were not part of the earlier refurbishment.

During the qualification phase, a cracked 63.5% SiGe-P compact resulted in additional delays. The problem was corrected by reworking the mold collar, the mold stool support, and the spacer rams to eliminate misalignment. At the end of March, the only remaining task to complete qualification was the pressing of a 63.5% P-SiGe compact to meet specific density requirements. Presently, process parameters (temperature) are being adjusted to meet the density goals.

Second CVD Silicon Nitride Coating Furnace: Installation and operational checkout of the second Silicon Nitride Coating Furnace was completed this period. Qualification for use in prime hardware production involves demonstration of processing to prime standards. This was initiated and is continuing. The furnace has been profiled and a silicon wafer calibration was accomplished. Events during installation, checkout, and qualification include:

- Replacement of components and parts removed to keep Unit No. 1 operating.
- Vendor replacement of parts not meeting specifications.
- Vendor correction of wiring errors and replacement of damaged components.
- Repair of failed computer from Unit #1 (computers interchanged to keep furnace #1 in production).

H.2 CAGO - ETG Equipment

No significant activity this reporting period.

H.3 CAGO - MIS

The authorized computer and associated general purpose and Primavera Project Management software were acquired, set up, and checked out. Implementation of productivity features (FAX , network connections, data interchange, and main frame access) and resolution of minor software anomalies involving auxiliary programs remain and will be worked when both the computer and personnel are free of higher priority use.

H.4 CAGO - Building 800 Equipment Refurbishment/Upgrade

The accomplishments related to the acquisition or refurbishment of capital equipment are found in this report section. The Generator Processing Facility (Building 800) has been completed to the point that test operator training can be initiated in early April. Key events related to CAGO acquisition include:

- Subcontractor selection and negotiation and placement of subcontracts.
- Installation and checkout of the new Gas Management System (GMS).
- Acquisition and Installation of Components/Equipment to refurbish the Read Out Consoles (ROC).
- Completion of identified Building 800 equipment refurbishment, repair, and upgrade.

During checkout and operation to date the following additional needs have been identified:

- Overhaul/refurbish/replace turbo-molecular pump (backup unit).
- Flow cleaning of sections of the system to eliminate contamination.

Program Calendars

Cassini RTG Program Calendar

As of 30 March 1994

1st QTR 1994

	M	T	W	T	F	S	S	FW
J A N U A R Y						1	2	
	3	4	5 Fuel Chemical Analysis Meeting - Germantown - Reinstrom	6 Monthly Program Status Review - Valley Forge - Process Readiness Review Forming, Riveting, Wrapping for Thermopile Assembly	7	8	9	01
	10	11	12	13	14	15	16	02
	17	18	19	20	21	22	23	03
	24 Monthly Reports Due to DOE	25	26 QA Status Meeting - Valley Forge -	27 Engelhard Visit Braun/Dower/ Sayell/Sardaro	28	29	30	04
F E B R U A R Y	31	1 CVS Working Group - Atlanta - Reinstrom	2	3	4 Sheffield Visit Boyton/Braun	5	6	05
	7 Sheffield Visit Boyton/Hofmeister	8 Gauritis Exec Status Review East Windsor - Hemler Thermal Conductivity Characterization Studies Meeting - Fairchild - Bradshaw/Tobery	9 Process Readiness Review Rivet Removal for Thermopile Assembly	10	11	12	13	06
	14	15	16 Insaco, Inc. Visit Boyton/Braun/ Dower	17	18 RTG Handling Meeting - KSC - Reinstrom	19	20	07
	21	22	23	24 Monthly Reports Due to DOE	25	26	27	08
	28	1 Schwarzkopf Visit Dadd, Dower, Hofmeister	2 Quality Assurance Audit Cassini RTG Program - Building B - Raczynski/Guitorinao/Simkins/Smith/Zula	3	4	5	6	09
M A R C H	7	8 Gauritis Exec Status Review East Windsor - Hemler	9	10	11	12	13	10
	14	15 Cassini Quarterly Review - Mound - Hemler/Reinstrom/ Braun	16	17	18	19	20	11
	21	22 Process Readiness Review "Katuck" Wrap for Thermopile Assembly	23	24 Monthly Reports Due to DOE RTG Safety Testing for the Cassini Program - Fairchild, Germantown - Hemler/Hartman/Cockfield	25	26	27	12

Cassini RTG Program Calendar

As of 20 April 1994

2nd Qtr 1994

2nd Qtr 1994									
	M	T	W	T	F	S	S	FW	
A P R I L	28	29	30 Baseline Recertification Meeting JPL - Pasadena, CA Hemler	31	1	2	3	13	
	4	5 Design Review Subsystem 180 - Hanford - Retnstrom/Cockfield	6	7	8	9	10	14	
	11	12 Gauritis Exec Status Review East Windsor - Hemler	13	14	15	16	17	15	
	18	19	20 QA Status Meeting - Valley Forge - Saydah, et al	21	22 Monthly/Quarterly/ Semi-Annual Reports Due to DOE	23	24	16	
	25 INSRP Review of Risk Code - DOE-HQ - Damon/Ha/ Bradshaw/Hemler/ Cockfield	26	27 Cassini RTG Program Review - Fairchild Space - Hemler/Braun Retnstrom/Cockfield	28	29	30	1	17	
M A Y	2	3	4 Launch Planning Meeting - Kennedy Space Center - Retnstrom	5	6	7	8	18	
	9	10	11 Titan IV A Final Sequence Review - Martin Marietta, Denver - Hemler/Bradshaw / Rosko	12	13	14	15	19	
	16	17 Gauritis Exec Status Review East Windsor - Hemler	18 DOE Program Review - Valley Forge - Hemler, et al	19	20	21	22	20	
	23	24 Monthly & Semi Annual Reports Due to DOE	25	26	27	28	29	21	
	30 Holiday	31	1	2	3	4	5	22	
J U N E	6	7	8	9	10	11	12	23	
	13	14	15	16	17	18	19	24	
	20	21 Gauritis Exec Status Review East Windsor - Hemler	22	23	24 Monthly Reports Due to DOE	25	26	25	

**DATE
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5/18/94

END