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BI-MONTHLY PROGRESS REPORT
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MULTI-HUNDRED WATT RADIOISOTOPE
THERMOELECTRIC GENERATOR PROGRAM
LES 8/9 PROGRAM
MJS PROGRAM

Period from 1 May - 30 June 1975

prepared for:

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
ADVANCED NUCLEAR ENERGY SYSTEMS
WASHINGTON, D.C. 20545

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1 MAY 1975 TO 30 JUNE 1975

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INTRODUCTION/SUMMARY

This report covers significant events, activities and achievements on the MHW LES 8/9 and MJS Programs during the months of May and June 1975. Highlights for the report period are as follows:

A. Programmatic

- F2 and F3 RTG's were shipped to Lincoln Laboratory on 5/10 and were held in storage there under GE custodianship until 5/31, when they were removed from storage for integration and testing with the LES 8 spacecraft. Testing was completed on 6/9 and the units were returned to GE on 6/16 and 6/18.
- LES 8/9 Technical Management/Program Status Meeting was held on 5/21/75.

B. Safety

- The following meetings were held relative to the final safety review of the LES 8/9 mission:

Re-Entry Subpanel Meetings - 5/6/75, 5/16/75, and 6/16/75

Aerospace/GE Meeting to Review GE Reentry Stress Analysis - 5/20/75

INSRP Meeting on LES 8/9 FSAR - 6/17-19/75

MJS Reentry Subpanel Meeting - 6/19/75

- Tests were performed at AEDC to determine ablation characteristics of the T-50 emissivity sleeve material.
- Estimates of GE personnel radiation exposure for 1975 were found to be higher than limits set by ERDA. Corrective action was initiated to reduce exposures by changes in human factors, hardware design and in test procedures.

C. Systems

- Revised LL Source Control Drawing was reviewed by GE and comments were provided for consideration by LL in subsequent revisions.
- Preliminary working copies of the four top-level GE specifications for MJS were prepared for inhouse use. Final issue for ERDA review and approval is forthcoming.
- MJS Interface Meeting was held on 5/14-15/75 to review interface documentation.
- Lower-than-expected launch temperatures, newly-disclosed by TRW, have generated a potentially-serious problem within GE. The possible effects on RTG beryllium materials and on transient power and leakage rates are being explored.

D. Isotope Heat Source

- Analytical studies and comparisons to test data led to the conclusion that the PRD burst disk precludes outer clad rupture in the event the PRD lance fails to penetrate the burst disk.
- Successful impacts of PICS from "DOP-4" iridium, which are being phased into production for MJS, were performed.
- The C-12 outer clad was successfully assembled to the F-5 IHS.
- PISA vent testing continued at LASL. Fueled specimens are being tested at both LES 8/9 and MJS simulated conditions.
- Results of unfueled contamination tests showed very poor correlation between direct counting at surface contact and counting of smearable material wipes, and between initial direct counting levels and those following high temperature exposures.
- A single impact test at GE-VF using ThO₂ simulant and type WG Iridium resulted in failure.
- Thermal analyses were conducted for the highest MJS reentry velocity and path angle. Thermal stress analyses of the IHS end cap were also completed.

- Thermal analyses were conducted to determine the effects of outer clad elimination from the MJS design on storage and handling temperatures.
- Investigation of large-scale rejections in Ir filter vent piece parts led to the conclusion that furnace contamination was at fault, and action was taken to eliminate reoccurrence of the problem.

E. Converter

- Material analyses effort included studies of:
 - The effect of temperature on elongation properties of beryllium block.
 - Radiation vulnerability of thermoelectric silicon nitride coatings.
 - Acceptable hardness of "C"-seal silver coatings.
 - CO generation from astroquartz material.
- Analyses were performed to determine the effect of on-pad cooling on RTG internal pressure characteristics.
- A study was conducted to determine the feasibility of eliminating spool pieces from ETG's for the MJS program.
- New total and subsystem weight estimates were made for the MJS RTG configuration.
- Pressure-drop tests were conducted on the Q1A converter to evaluate flow characteristics of the insulation foil basket and the PRD.
- Converters F4 and F5 were completed at RCA and shipped to GE. Processing was completed on converter F13 and its pressure decay test was started. Thermopile assembly was completed for the Q2 converter.
- A review of thermopile-to-shell resistance data for 18-couple modules showed less than $\frac{1}{2}\%$ power loss after 5 years.

F. Product Assurance

- 148 AN's and 13 ECN's were processed.
- Quality Assurance activity centered on support of acceptance testing and the preparation for buyoff of flight RTG's F2, F3, F4 and F5.
- New Quality Plan for MJS was prepared and submitted to ERDA for review.
- The MHW Testing and Processing Operations Guidelines Policy document GEMS-420, was put into effect under preliminary ERDA approval.

G. Hardware Fabrication

- F13 converter hardware was delivered to RCA for assembly.
- Rigid-design PRD vent tube assemblies were fabricated for the first time.
- The first group of frit vents for MJS was fabricated and shipped to MRC.

H. Acceptance Testing

- Processing was completed on the F3 RTG and this unit together with the F2 RTG was shipped to LL for system integrated testing with the spacecraft.
- After testing was completed at LL, F2 and F3 RTG's were returned to GE-VF.
- F4 ETG was received from RCA and the following operations were performed on this unit: Receiving inspection and electrical checks, cold pressure decay testing, cable and flexible hose installation, ETG disassembly, reassembly with the IHS into the RTG configuration, IHS gas taps, RTG processing, IHS sampling and purging, weight and c.g. measurement, air performance and hot pressure decay testing, and preparations for vibration testing.
- F5 ETG was received from RCA, and after receiving inspection, cold pressure decay testing and electrical checks, was installed in the LAS for ETG disassembly operations.

I. Ground Support Equipment

- F4, F5 and F13 RTG Shipping Containers were completed. The F13 RTG-SC was shipped to JPL for walkthrough purposes.
- LAS #1 was utilized for processing of the F3 RTG, for conversion of the F4 ETG to the RTG configuration, and for processing of the F4 RTG.

1.0 PROGRAM MANAGEMENT

1.1 PROGRAM MANAGEMENT

1.1.1 PROGRAM PLANNING AND DIRECTION

1. F2 and F3 RTGs were shipped via ERDA van to Lincoln Laboratory at Hanscom AFB, Lexington, Mass. on 5/10/75 for integration with the LES 8/9 spacecraft and testing as part of an integrated spacecraft system. The units were held in storage under GE custodianship and monitoring of critical parameters until 5/31/75 when they were removed from storage. Stacking of the two units on the LL truss and integration with the spacecraft were completed by 6/5/75 and thermal vacuum testing was successfully conducted during the period 6/6 to 6/9/75. The units were destacked and returned to storage at LL until they were shipped back to GE-VF, F2 on 6/16/75 and F3 on 6/18/75.
2. A LES 8/9 Technical Management/Program Status Meeting was held on 5/21/75 with representatives from ERDA, LL, TRW, SAMSO, CCAFS, NRL, MMC and others. One outcome from the meeting was the indication that booster availability and launch load from other programs may impact the LES 8/9 launch schedule.
3. The MHW Testing and Processing Operations Guidelines policy document was reviewed with ERDA and resulting revisions were initiated.

1.1.2 CONTRACT MANAGEMENT AND COST CONTROL

1. MJS contract negotiations were completed, resulting in execution of the contract document by GE and ERDA.

1.1.3 CONTRACT PROCUREMENT

1. The F4 converter was received from RCA on 5/13/75.
2. The F4 IHS was received from Mound Laboratory on 5/20/75.
3. The F5 converter was received from RCA on 6/3/75.

1.1.4 PROGRAM DOCUMENTATION

The following documents were released during the reporting period:

1. MHW-RTG Systems Specification for LES 8/9, SS47A14603, Revision E.
2. Flight RTGs, ETGs and E-1 and E-2 Product Specification, CP47A14614, AN 11.
3. Isotope Heat Source Product Specification, CP47A14601, Revision F.
4. MHW-RTG Handling Sling Product Specification, CP47A14606, Revision E.
5. ETG Acceptance Test Procedure, SI249230, SIR Nos. 12 and 13.
6. RTG Acceptance Test Procedure, SI249239, SIR Nos. 4, 5, 6, 7 and 8.
7. IHS Receiving, Storage and Shipping Procedure, SI249234, SIR Nos. 10, 11 and 12.
8. RTG Storage, Shipping and Receiving Procedure, SI249238, SIR Nos. 5, 6 and 7.
9. RTG Assembly and Disassembly (in RTG-LAS), SI249235, Revision 5.
10. RTG Loading and Assembly Station Operating Manual, SI249241, SIR 2.
11. Portable Gas Service Cart Instructions, SI249229, SIR 6.
12. ROC and PSC System Setup and Checkout, SI249236, Revision 1.
13. RTG Receiving and Operating Procedures at LL, GESP-7115, Original Issue.

3.0 SAFETY

3.1 SAFETY ANALYSIS

Several meetings were held during the May - June period pertaining to the final safety review of the MHW/LES 8&9 mission. Each of these meetings is summarized briefly in the following paragraphs.

3.1.1 RE-ENTRY SUBPANEL MEETING

Place: Air Force Weapons Laboratory (AFWL)
Kirtland Air Force Base

Date: May 6, 1975

Purposes:

- 1) To review comments and questions of Subpanel on Appendix H (RTG/HSA Re-entry Response) of FSAR.
- 2) To review independent analyses.

Highlights of the discussion were as follows:

- Lack of properties on T-50 sleeve material, especially ablation characteristics, raises questions about the re-entry capability of the Heat Source. Ablation tests were urged by the Subpanel to be done prior to the FSAR review (scheduled for June 17).
- End-on re-entry needs to be analyzed in view of recent Viking FSAR review - Subpanel's position had previously been that end-on re-entry was not credible for MHW.
- APL/JHU reported results of a study to determine Heat Source stability as a function of tumble rate.
- Turbulent boundary layer heating is being investigated for steep angle, high velocity re-entries.

- AFWL reviewed a V, γ map based on the most recent trajectory. The most significant differences are that Case X (Spacecraft only @ 36,000 fps, -40°) is eliminated, and Case VI (Transtage plus Spacecraft @ 33,500 fps, -82°) disappears since the time available and the automatic dispensing sequence eliminates the Transtage from the configuration. In effect, Case VI reverts to Case VII (Spacecraft only @ 33,500 fps, -82°).
- Contact coefficients, minimum moduli, T-50 properties, and treatment of stress were discussed mainly in the review of Appendix H.
- Effects of water vapor erosion (cloud or rain encounter) on the Heat Source during re-entry were briefly discussed - no conclusion was reached and APL is to investigate.

Items to be addressed as a result of this meeting are as follows:

- 1) A meeting is to be set up between APL, Aerospace, and GE to review GE's stress models and analyses.
- 2) APL is to see if end-on re-entry can be analyzed prior to FSAR.
- 3) GE is to look at stresses in the GIS for free FSA re-entry (assuming aeroshell failure at peak heating).
- 4) GE is to check on the availability of a T-50 emissivity sleeve for ablation tests.
- 5) GE is to review and amend the material in Appendix H.
- 6) Aerospace is to check on the availability of facilities for ablation tests, and Air Force is to get the testing performed if a facility is available. These tests were to be independent of those planned by GE.

3.1.2 RE-ENTRY SUBPANEL MEETING

Place: ERDA/DANES, Germantown, Md.

Date: May 16, 1975

Purpose: Review GE Re-entry Analysis

This meeting was held to satisfy one of the items from the May 6 meeting. Aerospace, APL, and Fairchild Industries reviewed the GE analysis, which included the following items:

- Basis of T-50 sleeve properties
- Stress properties and analysis

3.1.3 AEROSPACE/GE MEETING

Place: GE Space Center, King of Prussia, Pa.

Date: May 20, 1975

Purpose: Review GE Re-entry Stress Analysis

This meeting essentially covered the material presented in the May 16 meeting.

3.1.4 RE-ENTRY SUBPANEL MEETING

Place: AFWL, Kirtland AFB

Date: June 16, 1975

Purposes:

- 1) To review preliminary results of the T-50 sleeve ablation tests.
- 2) To review updated re-entry analysis for LES 8,9/MHW safety review.

Highlights of the discussion were as follows:

- The FSA was shown to have adequate ablation and structural capability with a margin of safety greater than 3.0 in stress.

- Effects of sleeve surface roughness on transition heating were presented. Aeroshell stress margin of safety was given as -0.04 (elastic analysis) for turbulent heating being included in the steep angle, high velocity re-entry. Plastic analysis is expected to yield a positive value.
- Effects of axial temperature gradients in the sleeve were shown to be negligible.
- The effect of contact coefficient (sleeve-to-aeroshell) on stress levels in the aeroshell was discussed by GE and APL.
- Billet data on individual aeroshells give higher margins of safety for re-entry stress than does analysis using a modulus based on minimum strength data of all billets as presented in FSAR.
- End-on re-entry of the Heat Source for Earth orbital decay was shown to be no problem (APL analysis).

3.1.5 INSRP MEETING ON LES 8/9 FSAR

Place: AFWL, Kirtland AFB

Dates: June 17-19, 1975

This was the last meeting of the Interagency Nuclear Safety Review Panel (INSRP) to review the Final Safety Analysis Report (FSAR) for the MHW/LES 8&9 Mission. As a result of the previous reviews of the re-entry analysis, the Re-entry Subpanel elected to assume failure of the aeroshell for all steep angle, high velocity re-entries. This assumption was made pending the final results of the ablation tests on the T-50 sleeve.

3.1.6 MJS RE-ENTRY SUBPANEL MEETING

Place: AFWL, Kirtland AFB

Date: June 19, 1975

The purpose of this meeting was twofold:

- 1) To discuss the launch vehicle failure assumptions inherent in the V- γ maps provided to date by Convair/General Dynamics in order to establish whether there are re-entries more severe than those that have been defined.
- 2) To have JPL provide a summary of the available break-up analysis results.

The principal points discussed relating to the V- γ maps are:

- 1) The preliminary V- γ map prepared by General Dynamics included an assumption that the TE-364-4 stage fires with the same orientation as the Centaur. Since the MJS launch will use a guided version of the TE-364-4, rather than the spin-stabilized version used for earlier launches, the possibility exists that the TE-364-4 could have a misoriented burn, much as has been assumed for the LES 8/9 mission.

NASA-Lewis responded that, as related to the trajectory, the velocity in excess of escape speed at the end of the Centaur burn is sufficient so that even a misorientation of the TE-364-4 by 180 degrees would probably not result in a return trajectory. This condition generally would apply only to the normal 2nd burn of the Centaur.

- 2) The question of whether the Centaur misorientations occur in totally random fashion or whether there is a preferential direction around the nominal was raised. This point is being addressed by General Dynamics/Convair under the direction of NASA Lewis.
- 3) The question of whether early burns can occur was addressed by noting that the Centaur first burn occurs only 10 seconds after separation from the Titan. The Centaur second burn occurs while in a circular orbit and the Centaur attitude is held in a tangential direction; thus, an early burn would produce the same consequences as an on-time burn.

- 4) The possibility of late burns was addressed by noting that the nominal launch sequence involves achieving a 90 n.mi. parking orbit after the first burn of the Centaur. The sequence involves a second burn about 45 minutes later. If the burn should not occur, a shutdown sequence will occur, MECO (main engine cut off) will be issued, and the TE-364-4 stage will be fired (in a tangential direction).
- 5) Should a short burn occur, the separation sequence will be followed. The consequence will be identified by NASA.
- 6) A long burn (burn to depletion) of the Centaur would add 200 to 300 feet per second velocity, which would increase the velocity to a value such that reentry couldn't occur regardless of what happened subsequent to the TE-364-4 stage. Again, this would apply only if the Centaur were oriented correctly for the burn.
- 7) A timing sequence separates the spacecraft from the TE-364-4 and deploys the booms.
- 8) The probabilities associated with the various failure modes will be supplied by General Dynamics.

The reentry configurations expected are:

- 1) For orbital decay, the principal reentry configuration will be the spacecraft with booms deployed.

As a lower probability configuration, resulting from a battery failure, the Centaur stage (tanks empty), TE-364-4, and spacecraft (booms stowed) could be the reentry configuration.

- 2) For powered reentries, the configuration will be the Centaur, TE-364-4, and spacecraft.

In almost all cases where the spacecraft is released before reentry, there is adequate time for the booms to deploy.

A summary of the results from the first three break-up trajectories was provided by JPL. The initial re-entry conditions for these cases are presented in Table 3-1. Table 3-2 lists the conditions at RTG release. The most significant result from the analyses completed to date is that the break-up sequence places the stack of three RTG's into an end-on attitude, and (after release from the spacecraft) the remnants of the mounting boom and RTG cable act to maintain the end-on attitude.

TABLE 3-1
INITIAL CONDITIONS FOR BREAKUP CASES

Case I	Cruise configuration/fully deployed SC $V_e = 36,000$ fps $\gamma_e = -5.07$ deg. Trim angle = 173 deg. (min. γ re-entry)
Case II	Cruise configuration/fully deployed SC $V_e = 36,000$ fps $\gamma_e = -46$ deg. Trim angle = 173 deg. (steep angle/max. stress re-entry)
Case III	Cruise configuration/fully deployed SC $V_e = 25,700$ fps $\gamma_e = -0.2$ deg. Trim angle = 173 deg. (orbital decay re-entry)

TABLE 3-2
CONDITIONS AT RTG RELEASE

Case I	Time: 45 sec. Altitude: 287 Kft. V_i : 36,100 fps γ_i : -2.86 deg.
Case II	Time: 5.3 sec. Altitude: 263 Kft. V_i : 36,200 fps γ_i : -45.6 deg.
Case III	Time: 480 sec. Altitude: 306 Kft V_i : 25,740 fps γ_i : -0.6 deg.

An additional point raised in the summary was the possibility of a hydrazine tank explosion, resulting in a 4-pound piece of shrapnel with a velocity of 650 ft./second. Subsequent to the release of the preliminary break-up report, it was established that the piping leading to the tank may fail prior to the tank failure, leading to a reduction in tank pressure and eliminating the shrapnel. GE pointed out that information available for the SNAP-27 safety report indicated that a titanium tank may split rather than shatter.

The following items were to be addressed as a result of the meeting:

- 1) General Dynamics (under NASA Lewis direction) will investigate whether Centaur misorientation failures are random in direction as opposed to being biased around some nominal heading.
- 2) NASA Lewis will investigate the consequences of a 180° misorientation of the TE-364-4 stage after a successful Centaur second burn.
- 3) NASA Lewis will establish the attitude after a short second burn of the Centaur and the consequence of the subsequent TE-364-4 burn.
- 4) General Electric will supply the SNAP-27 data on titanium tank rupture if the data are still available in the files.
- 5) JPL will check the timing sequence for release of the spacecraft to establish whether for downward pointing misorientations the reentering configuration is the spacecraft with booms deployed.
- 6) JPL will give reference to the NOL report on tank rupture that was used as a basis for estimating the shrapnel size and velocity.

3.2 TESTING

A series of tests was performed on June 12 & 13 in the AEDC (Arnold Engineering Development Center) 5MW arc facility to determine the ablation characteristics of the emissivity sleeve material (T-50) for the MHW/LES 8 & 9 Heat Source. The objective of the tests was to simulate as closely as possible trajectory conditions for a steep

angle, high velocity re-entry such as that for Case VI (33,500 fps, -82°) in the FSAR. The simulation was to include comparable stagnation pressures and best attainable values of heat transfer and stream enthalpy. As part of the tests, the ablation performance of the T-50 carbon-carbon material was to be compared with that of ATJ graphite, and the test results were to be compared with analytical predictions.

Material specimens of the T-50 used in the test were cut directly from an emissivity sleeve; these were 2 x 3 inches in size with the long dimension running in the circumferential direction of the sleeve. The ATJ-S comparison specimens were machined to have the same dimensions and surface curvature. In addition to the T-50 and ATJ-S specimens, stagnation pressure gages and copper block calorimeters having the same external dimensions and shape were prepared for measurement of the (arc) stream conditions. The test specimens and gages were mounted according to the matrix shown in Table 3-3, each being oriented so that it would be normal to the arc stream. The 5 MW arc facility uses a rotating and indexing head that has seven sting (specimen) positions. Each sting is rotated (rotation being normal to stream velocity) into the arc stream and allowed to remain for the time desired. As shown in the table, two different runs were made, each corresponding to a different stagnation pressure.

Prior to the two test runs, a calibration run was made to characterize the pressure distribution (axially) in order to determine where to position the stings and indexing head. Arc operating conditions were selected to give as near maximum stream enthalpy as possible within the capability of the facility for the lower stream pressure. This enthalpy level (approximately 2100 BTU/LB) was duplicated at the higher stream pressure for comparison of test results. The integrated transfer during the test was selected to approximate that for the Case VI re-entry (33,500 fps, -82°) as shown in Figure 3-1. Test times were selected accordingly as well as at a lower integrated heat.

Table 3-4 presents the data obtained in the test runs. The high pressure run is seen to be around 57% higher than desired, while the low pressure run is about 21% low.

TABLE 3-3
SPECIMEN AND GAGE MATRIX
(BY TEST RUN)

Sting		1	2	3	4	5	6	7
Model or Gage	Run #1	T-50	T-50	T-50	ATJ-S	cal.	pres.	cal.
	Run #2	T-50	T-50	T-50	ATJ-S	cal.	pres.	cal.
Model Pressure, atm. (desired)	Run #1	←————— 11.5 —————→						
	Run #2	←————— 8.0 —————→						
Test Time, sec. (desired)	Run #1	3.0	3.0	5.0*	5.0*	←———— sweep —————→		
	Run #2	5.0	5.0	7.5*	7.5*	←———— sweep —————→		
$\dot{q}$ (desired), BTU/Ft ² -sec.	Run #1	←————— 1370 —————→						
	Run #2	←————— 920 —————→						
$\int \dot{q} dt$, BTU/Ft ² (desired)	Run #1	4100	4100	6900*	6900*			
	Run #2	4600	4600	6900*	6900*			

*Based on integrated heating in 33,500 fps, -82° re-entry

Stream enthalpy for both runs targeted for ~2100 BTU/Lb.

FIGURE 3-1

COMBINED CONVECTIVE & RADIATIVE HEATING

CASE VI

TABLE 3-4
SUMMARY OF TEST RUNS

RUN	STING	MATERIAL	TEST TIME (SEC)	PRESSURE (ATM)	ϕ HEAT TRANSFER BTU/FT ² -SEC	ENTHALPY BTU/LB	$\int \dot{q} dt$ BTU/LB	$\int \dot{q} dt$ TEST/EST.
1	1	T-50	3.09	18.0	1800	2089	5560	0.81
	2	T-50	3.20	↓	↓	↓	5760	0.83
	3	T-50	5.73*	↓	↓	↓	10300	1.49
	4	ATJ-S	5.40	↓	↓	↓	9720	1.41
2	1	T-50	4.83	6.35	1130	2113	5460	0.79
	2	T-50	5.38	↓	↓	↓	6080	0.88
	3	T-50	8.26	↓	↓	↓	9340	1.35
	4	ATJ-S	8.15	↓	↓	↓	9210	1.34

*Specimen broke up at $t = 3.32$ sec. with a $\int \dot{q} dt$ (TEST/EST.) = 0.82

A post test inspection of the T-50 specimens and a review of the high speed motion pictures taken during the test runs revealed that selective ablation of the woven structure occurred. Localized attack along the juncture of thread plies was severe enough to channel through the total thickness (0.100 inch) in some of the specimens. This channeling or undercutting appeared to be monodirectional, depending on the direction of the thread overlay. There was gross mechanical removal of fibers and spallation of wrap layers in some of the specimens. As seen from Table 3-2, the No. 3 T-50 specimen in Run No. 1 broke up completely prior to the end of the run. However, the pressure for this run was 57% higher than is predicted for the re-entry condition. If the stagnation line (of the arc) recession of the specimens is taken as representative of the general ablation characteristic of the sleeve material, the ablation rates for the T-50 are estimated to average three (3) times the rate of ATJ-S. This can be seen in Figure 3-2 which presents the reduced data from the tests. The solid curves are based on the diffusion limited Scala-Gilbert recession. Test temperatures of the specimens did not exceed 5200°R on the ATJ-S or 5400°R on the T-50 in the low pressure run.

FIGURE 3-2

T-50 CARBON/CARBON ABLATION RATE

AEDC 5MW ARC FACILITY

3.3 OPERATIONAL SAFETY

3.3.1 PERSONNEL RADIATION EXPOSURE REQUIREMENTS

A new ERDA Regulation, Manual Chapter 0524, "Standards for Radiation Protection", dated April 8, 1975, lowers the whole body dose rate limit to 5 rem per year. In addition, ERDA contractors must conduct operations in such a manner to assure that radiation exposures to test personnel are limited to levels technically and economically practicable.

3.3.2 GE PERSONNEL EXPOSURE EXPERIENCE

An estimate of the total radiation exposure to GE personnel for 1975 was determined. The estimate is based on:

- 1) System test schedules issued 5 June 1975 on LES 8/9 IHS and RTG activities.
- 2) Program Office MJS Q-2 and F-6 schedules.
- 3) F-2 and F-3 measured personnel exposures for operations from IHS receipt through RTG mass property testing.
- 4) Q-1 measured personnel exposures for vibration and thermal vacuum testing.
- 5) Lincoln Laboratory and CCAFS operations.

The total estimated whole body exposures (neutron and gamma) for MHW personnel for each calendar quarter are summarized in Table 3-5.

TABLE 3-5 - TOTAL 1975 WHOLE BODY EXPOSURES (REM)

<u>QUARTER</u>	<u>TECHNICIANS</u>	<u>TEST CONDUCTORS</u>	<u>QUALITY CONTROL</u>	<u>HEALTH PHYSICS</u>
● First (Jan - Mar)	1.3	0.6	0.8	0.6
● Second (Apr - June)	15.3	7.1	5.1	2.9
● Third (July - Sept)	20.3	7.8	6.8	4.2
● Fourth (Oct - Dec)	13.1	6.3	4.1	2.5
TOTAL	50.0	21.8	16.8	10.2

The GE administrative goal at the present time is to limit exposures to 2.0 Rem per quarter. In view of the revised regulation, which is contractually imposed on the MHW Program, a GE Space Division administrative goal of 1.25 Rem per quarter is being considered.

3.3.3 CONCLUSIONS AND CORRECTIVE ACTION

The estimated personnel radiation exposures in Table 3-5 are too high and corrective action has been initiated to satisfy the intent of the new ERDA regulations. Positive steps are being taken to reduce radiation exposures via improvements in the human factors design aspects of the RTG Handling Sling and RTG Shipping Container. Test procedures are being reviewed to simplify operations and thus, to reduce total exposure during the overall hardware flow.

4.0 SYSTEMS

1. F2 and F3 flight RTG's and supporting GSE were shipped via ERDA van to Lincoln Laboratory on Saturday, May 10th, arriving Sunday morning, May 11th. Stacking operations by the GE field team were performed during the week of June 2nd. In the intervening period, GE provided custodianship for the stored RTG's, monitored critical RTG storage parameters, performed necessary RTG pressure maintenance functions and participated with Lincoln Laboratory in a talk-through of RTG stacking and installation procedures. Stacking operations took longer than planned due to three major problems:

- (1) The LL squib-controlled vent line was inadvertently left open by a LL technician.
- (2) A LL vent tube installation had leakage problems, basically related to MS fittings.
- (3) A wrong shorting plug was discovered in the LL junction box.

During the Lincoln Laboratory operations, a variety of handling and installation problems were identified which caused higher than anticipated radiation exposure rates to GE personnel. The source of each of these problems is being carefully reviewed by GE to identify design modifications which will lead to a reduction of these rates at the Cape and on the MJS program.

Spacecraft integration tests were successfully completed by the week of June 9th and the RTG's were destacked by the GE field team and returned to the RTG shipping containers. During installation of the shipping container flex line, it was found that the threads on the F2 Gas Management Valve had been partially stripped. The units were returned singly to GE (F2 on 6/16 and F3 on 6/18) to avoid the transport van air conditioning problems encountered during the two-unit shipment from GE to LL on May 10th. The units have been temporarily placed in storage at GE awaiting completion of ongoing tests with F4 and F5.

2. The revised Lincoln Laboratory Source Control drawing was received by GE on May 5th and subjected to a review. A red-lined copy of the drawing and comments were returned to Lincoln Laboratory on May 10th. A second revision was received on June 18th and comments were provided by June 25th. A third revision, necessitated primarily by unresolved problems on cable routing, clamps, insulation, etc. in the stacked configuration will still be required. Since this is an area of high radiation exposure rate, it is important that the interfaces be clearly resolved before operations at the Cape.
3. A preliminary issue of the four top-level GE specifications for MJS were distributed for internal GE review during the month of May. By the end of June, comments had been incorporated, revisions completed and a working copy reissued for GE internal use. Final issue for ERDA review and approval is expected by mid August. Specification designations are as follows:

SS47A14617	System Specification for the MHW-RTG, MJS Spacecraft
NS-0020-05-03	Environmental Criteria and Test Requirements for the MJS MHW-RTG Program
CP47A14618	Product Specification for the MHW-ETG, MJS
CP47A14619	Product Specification for the MHW-RTG, MJS

4. A letter proposal summarizing GE's position on magnetic testing for MJS was prepared and forwarded to ERDA on June 30th (ref: 1K00-RJK-480).
5. GE was represented at the LES 8/9 Technical Management/Program Status meeting at CCAFS on May 21st. Schedules were a prime topic of discussion with 11/26/75 given as the earliest possible launch date.
6. The INSRP review of the LES 8/9 Final Safety Analysis Report was held in Albuquerque on June 17, 18 and 19, after a meeting of the re-entry subpanel group on the 16th. GE's analysis and prediction of source terms were presented. Flight approval is anticipated without significant additional effort by GE.

7. An MJS interface meeting was held at GE on May 14-15 to review the status of interface documentation. A second version of ES509289-4, Revision A, was reviewed in detail as well as an updated version of the JPL/ERDA interface specification, ES509290. With minor exceptions, general agreement was obtained on both documents. RTG constraints on the spacecraft system were forwarded to JPL on 28 May for incorporation in ES509290. The JPL specification ES509289-1, Detail Specification for RTG Requirements, was not discussed. ERDA and JPL will separately review the GE comments provided on 18 April in light of separate JPL/ERDA management agreements.
8. GE surfaced a potentially serious RTG launch temperature problem on LES 8/9 in letter 1K00-RJK-445 dated May 27, 1975. As a result of continued air conditioning changes, what was originally a high RTG launch temperature problem has become a low temperature problem with regard to the following:
 - Reduction in ductility of RTG beryllium cases and stacking hardware opens up the question of RTG qualification status (all qual. testing was done at an average RTG case temperature of approximately 350°F as opposed to the currently expected launch temperature of 120°F).
 - RTG transient power and leakage rate requirements are impacted by the lower launch temperature.

These and related concerns are being actively explored by both Lincoln Laboratory and GE. A thermal working group meeting, scheduled for July 8-9 at TRW, will explore the overall system implications of the problem.

5.0 ISOTOPE HEAT SOURCE (IHS)

During this reporting period, May/June 1975, the design and development effort continued with emphasis in the following areas:

- Recalculation of IHS temperatures for the MJS storage and operational conditions
- Characterization of gas release from carbon components
- Sources of Pu contamination in the FSA

5.1 GENERAL

5.1.1 DESIGN

A minor design change affecting the EPC vent valve handle was made. A self-locking insert was added to minimize the probability of loosening which had occurred on LES 8&9.

5.1.2 ABLATION SLEEVE

5.1.2.1 LES 8&9

During May/June 1975, three additional T-50 composite ablation sleeves were successfully baked-out in the GE-Evendale facility and shipped to GE-VF in the transportation container. The bake-out schedule for aeroshells and the POCO IHS end supports is shown in Table 5.1-1.

5.1.2.2 MJS

Some difficulty has been encountered in the fabrication of the MJS Pyrocarb-406 ablation sleeve. A dummy sleeve was used for the MJS walk-through at ML/MRC. It is anticipated that the current difficulties will be resolved without significant impact on the assembly schedule for the Q-2 IHS.

Table 5.1-1

BAKEOUT SCHEDULES FOR IHS CARBON

PART	CARBON TYPE	BAKEOUT SCHEDULE	
		TIME - Hrs	TEMP. - °C
Aeroshell	POCO	24	1500
Internal structures	Pyrocarb-508	24	1500
Compliance pads	Graphite cloth	24	1500
Ablation sleeve Heat source supports	T-50 composite (LES) Pyrocarb-406 (MJS) POCO	{ 24 12 12	1500 1000 1500
Graphite impact shells	T-50 composite	24	1350

5.1.3 Ir OUTER CLAD

The C-12 clad was successfully assembled to the F-5 IHS. Closure was effected on 8 May 1975.

5.1.4 GAS MANAGEMENT SYSTEM

5.1.4.1 Review of PMD/PRD Operation

The PMD/PRD for LES 8&9 was designed to permit release of the He generated by the $^{238}\text{PuO}_2$ fuel while maintaining an IHS pressure of ~ 2 PSIA. Some concern existed that failure of the barometrically-actuated spring/bellows to force the lance through the aluminum diaphragm could produce excessive pressure in the Ir clad. The assembly, shown in Figure 5.1-1, incorporates a coil spring, lance, hermetically-sealed stainless steel bellows, aluminum burst disk, aluminum housing, 50 ft. of coiled tubing and filter connected to the IHS vent feed-through. The burst disk is mechanically sealed into the one-half of the PMD/PRD housing, therefore containing fuel-generated helium inboard of the burst disk. The other half of the PMD/PRD housing contains an evacuated bellows. Inside the bellows is a compressed coil spring with a potential force of about 24 pounds prior-to-launch resulting from ambient atmospheric pressure on the bellows. A lance is mounted on the bellows opposite end about 1/4 inch from the burst disk.

This PMD/PRD is assembled on the RTG during launch pad readiness. Therefore, component lifetime requirements are very short, i.e., the evacuated bellows is only required to be leak tight for the anticipated maximum launch pad period.

During launch, the atmospheric pressure reduction will unbalance the bellows force equilibrium and thus cause the lance to advance towards the burst disk. Above 40,000 ft., the lance will be driven through the burst disk by the net spring force. The lance is helically fluted to eliminate possible sealing of burst disk and lance. The IHS is hence permanently vented; however, the 50 ft. of coiled tubing will maintain a positive pressure differential between the IHS and environment due to molecular conduction.

FIGURE 5.1-1
IHS PMD/PRD DESIGN CONCEPT

In the unlikely event the lance does not penetrate the burst disk, the ever-increasing helium pressure within the IHS (at a rate of 3 psi/month) will stress the aluminum burst disk, and cause creep failure in approximately two months after launch. The rupture life of the burst disk is significantly affected by the length of time spent on pad, as pad hold time contributes to the helium inventory and pressure value at the time of launch.

The burst disk rupture pressure is significantly less than the iridium clad burst pressure; this has been verified through comparison of the analytically-derived iridium outer clad burst point and the data from the PRD burst disk creep test.

The burst disk is therefore a redundant feature of the PRD to preclude iridium outer clad pressure rupture in the event the PRD lance does not penetrate the burst disk. No mission objectives are thereby affected.

5.1.4.2 Testing

The operability of the PRD under static and launch dynamic (shock and vibration) conditions has been demonstrated. Testing is planned for demonstration of the assembled PMD/PRD system after sequential environmental exposures during subsequent reporting periods.

5.1.5 FUEL SPHERE ASSEMBLY (FSA)

5.1.5.1 Graphite Impact Shell (GIS)

No changes in design or fabrication of the GIS were made during the May/June 1975 reporting period. No decision has yet been reached regarding the test program directed to investigate means of sealing the plug in the GIS.

The total activity in the MHF-13 GIS after removal of the fueled PICS (see Bi-Monthly Reports for January/February 1975 and March/April 1975) was measured by ML/MRC. The ML/MRC whole body counter was used to detect the 17 Kev ^{238}Pu x-ray. The total ^{238}Pu content of the GIS is estimated to be ~ 24 microcuries $\pm 20\%$. The destructive examination of the MHF-13 GIS will be carried out by LASL on a small segment $\sim 16\%$ of the total shell. The remaining material from this specimen was lost in an accident which occurred during digestion of the non-combustible residues from the GIS.

Autoradiography on a segment of the GIS, including a portion of the plug, showed ^{238}Pu had migrated into the internal GIS surfaces to a depth $\leq 1 \text{ mm}$ ($\leq 0.004 \text{ inch}$). There was no indication from this test of ^{238}Pu migration along the threads of the GIS plug.

5.1.5.2 Post Impact Containment Shell - PICS

5.1.5.2.1 Fabrication

- A. Details of the production of Ir sheet and of Ir hollow hemispheres are given, respectively, in the reports of the HNL Metallurgy and Ceramics Division and in the Monthly Newsletters of ML/MRC.
- B. The HNL "DOP-4" material is being phased into production of sheets (at HNL) and hemispheres (at ML/MRC). After the successful impacts of three specimens of 'DOP-4' Iridium at GE (see Bi-Monthly Report for March/April 1975) GE has recommended an investigation to evaluate the factors causing the improved impact performance.

One impact of the current HNL-ML/MRC Ir PICS was carried out; the specimen failed. See Section 5.2.

5.1.5.3 PISA Venting

5.1.5.3.1 He Release

PISA vent testing continued at LASL with fueled specimens operating at temperatures simulating conditions in LES 8&9 (on MHFT-44 in He) and in MJS (on MHFT-37 and MHF-30 in vacuum).

- A. The erratic behavior of MHFT-37 continued through this reporting period. The He release was observed to drop below the detection limit and remained in this condition for 10-20 days after which a large burst of He was observed, followed by a period of 10-20 days during which the release was at the nominal generation rate. MHFT-37 is being operated in vacuum with the fuel/Ir PICS interface temperature at $\sim 1335^\circ\text{C}$.

- B. MHFT-44 is operated in He with the Fuel/Ir PICS interface at $\sim 1220^{\circ}\text{C}$. This unit was placed on test in June 1974, and is being checked once a month for He release, since continuous measurements are precluded by the He atmosphere. The He release signal was measured on 27 June 1975, and was found to be erratic, varying from 0.1 to 1.5 times the He generation rate. This was the first time since the specimen was placed on test that the release rate was not found to be equal to the generation rate.
- C. MHF-30, one of the FSAs removed from the Q-1 IHS, has been on test since November 1974 in vacuum with the fuel/PICS interface temperature at 1335°C . The He release was initially erratic, but the release has remained constant at the generation rate since April 1975.
- D. Tables 5.1-2a and 2b show the status of the vent tests. The vent designs are shown in Figure 5.1-2.

5.1.5.3.2 Pu Release

- A. An accurate model to describe the release of Pu materials under He flow through the vents at pressure conditions has not been found. The release under free molecular flow conditions is shown in Figure 5.1-3.
- B. The activity levels found in the GISs analyzed destructively or otherwise measured at ML/MRC and LASL are shown in Table 5.1-3. The very large difference in contained Pu between MHF-27 (found at LASL to contain $\sim 38\mu\text{g}$) and MHF-29 (found at ML/MRC to contain $0.046\mu\text{g}$) remains unexplained. The Pu content determined at ML/MRC in the 'whole-body' counter for MHF-13 was $28\mu\text{g}$, a value in reasonably good agreement with the LASL findings on MHF-27. Both these units had the same mechanical and thermal history as parts of the Q-1 IHS assembly.

Table 5.1-2a
MHW PICS VENT TEST DATA
(INDIVIDUAL SPHERES)

SPECIMEN NUMBER	STATUS	TEST CONDITIONS			DIMENSIONAL CHANGE	VENT CONDITIONS				TESTING ORGANIZATION	METALLOGRAPHY/ COMMENTS
		TEMPERATURE - °C	EXPOSURE TIME - HOURS	EXPOSURE ENVIRONMENT		He MASS SPEC.		BUBBLE CHECK			
						IN FURNACE (1)	IN LAB (2)	NO. 1	NO. 2		
* MHFT-37	On test	1335	11100 30 JUN.	vacuum	nyr	erratic	n/a	nyr	nyr	LASL	nyr; test continuing
MHFT-39	C&E	1335	2000	vacuum	None	n/a	open	nyr	nyr	LASL	Vapor deposited ceramic in vent filter: Si, Pu, Ca, O + (Mg, Al, Fe) - impacted
MHFT-40	C&E	1335	2000	vacuum	none	n/a	open	open	open	LASL	Vapor deposited ceramic in vent filter: Si, Pu, Ca, O + (Mg, Al, Fe) - impacted
MHFT-41	C&E	1335	2000	vacuum	none	n/a	closed	closed	closed	LASL	NOT impacted; same as MHFT-40
* MHFT-42	C&E	1335	5400	vacuum	none	erratic	n/a	n/a	n/a	LASL	Vapor deposited ceramic in vent filter: O Pu, Ca, Si, (Mg, Al, Fe) -
* MHFT-44	On test	1220	8700 30 JUN.	Helium	nyr	n/a	open	n/a	n/a	LASL	nyr; test continuing
MHFT-45	C&E	1335	720	vacuum	none	n/a	open	open	closed	LASL	Vapor deposited ceramic in vent filter: Pu, Ca, Si, O, + (Mg, Al, Fe) - impacted
MHFT-47	C&E	1335	720	vacuum	none	n/a	open	nyr	nyr	LASL	Same as MHFT-45 - impacted
MHFT-48	C&E	1335	720	vacuum	none	n/a	open	nyr	nyr	LASL	Same as MHFT-45 - impacted
MHFT-49	C&E	1335	720	vacuum	none	n/a	open	open	closed	LASL	Same as MHFT-45 - impacted
MHFT-50	C&E	1335	720	vacuum	none	n/a	open	nyr	nyr	LASL	Same as MHFT-45 - impacted

n/a = not applicable
nyr = not yet reported

* special vent test specimens
C&E = Test complete and specimen examined

(1) Mass spec. measurement in furnace at test temp.
(2) Mass spec. measurement in lab. vac. chamber
@ self-heat temp. 5 900 C

Table 5.1-2b
MHW PICS VENT TEST DATA
(SPHERES FROM Q-1)

SPECIMEN NUMBER	STATUS	TEST CONDITIONS			DIMENSIONAL CHANGE	VENT CONDITIONS				TESTING ORGANIZATION	METALLOGRAPHY/ COMMENTS
		TEMPERATURE - °C	EXPOSURE TIME - HOURS	EXPOSURE ENVIRONMENT		He MASS SPEC.		BUBBLE CHECK			
						IN FURNACE (1)	IN LAB (2)	NO. 1	NO. 2		
MHF-27	C&E	1220 ?	200	He	none	n/a	open	open	open	LASL	Frit generally clean but some Pu, Ca, Si ceramic material vapor deposited
MHF-28	C&E	1220 ?	200	He	none	n/a	n/a	open	open	ML	Same as MHF-27
MHF-29	C&E	1220 ?	200	He	none	n/a	n/a	open	open	ML	Same as MHF-27
MHF-30	On test	1220 ? 1335	200 5000	He vacuum	nyr nyr	erratic	n/a	n/a	n/a	LASL	nyr (3)
MHF-13	C&E	1220 ?	200	He	nyr	n/a	n/a	open	open	ML	Same as MHF-27 Used old type vent filter

n/a = not applicable
nyr = not yet reported

C&E = Test Complete and specimen Examined
(3) As of 30 June 1975

(1) Mass spec. measurement in furnace @ test' temp.
(2) Mass spec. Measurement in lab vac.chamber @ self-heat temp. = 900 C.

MHV PISA VENT FILTER - PRE-FLIGHT DESIGN

MHV PISA VENT FILTER - FLIGHT DESIGN

FIGURE 5.1-2

VAPOR PHASE RELEASE OF $\text{PuO}_2(\text{g})$ vs. TIME
 FROM 48 VENTS, 24 FSAs, MHW-IHS AT 1327°C (1600 K, 2420 F)

FIGURE 5.1-3

Table 5.1-3

TOTAL Pu FOUND IN ANALYSES OF MHW GISS

SPECIMEN NUMBER	THERMAL EXPOSURE		QUANTITY OF Pu -micrograms (grams x 10 ⁻⁶)	VENT FILTER
	TEMP - °C	TIME -hours		
MHFT-15	1440	7395	19.0	} ALL-OLD FILTER DESIGN
MHFT-18	1250	1332	17.0	
MHFT-19	1440	1105	56.0	
MHFT-22	1440	3300	625.0 (1)	
MHFT-39	1335	2016	8.0	} ALL-NEW FILTER DESIGN
MHFT-42	1335	5440	1600.0	
MHFT-50	1335	730	1250.0 (2)	
MHF-27	1250	200	38.0 (3)	
MHF-29	1250	200	0.046 (3)	

(1) PICS cracked while on test

(2) Determination made after impact which cracked PICS

(3) Both units identical; removed from Q-1/IHS

- C. The unfueled contamination test capsule MHD-26 was exposed at 1350°C for periods of 100 hours and 200 hours with the decontamination steps following each exposure. The results of direct measurements are shown in Table 5.1-4. The smearable contamination after the 100-Hr. exposure was 1300 DPM; the level after 200 hours was not reported. The decontaminating solution used after the second exposure contained ~ 80 ng $\sim 1 \mu$ Ci of ^{238}Pu . The initial decontaminating solution and that following the first 100 hours exposure were not measured.

The test results indicate very poor correlation between:

- Direct counting at surface contact and counting of wipes of smearable material.
- Initial direct counting levels and those following high temperature exposures.

The specimen will be exposed for an additional 400 hours at 1350°C and measurements will again be made.

5.1.6 GAS ANALYSES ON MHW - IHS

5.1.6.1 Gas Sampling Results

Gas samples were taken on F-4 IHS at GE-VF and on F-5 IHS at ML/MRC. The results of the analyses are shown in Table 5.1-5.

5.1.6.2 Outgassing of the F-4 IHS

A very large number of additional gas samples were taken on the F-4 IHS, as this unit was processed in the GE-VF LAS. The calculated quantity of CO in the F-4 IHS, as reflected by the specimens analyzed, is given in Table 5.1-6. After ~ 360 hours of exposure with calculated temperatures ranging from $\sim 1100^\circ\text{C}$ on the aeroshell to $\sim 1220^\circ\text{C}$ on the GIS, the calculated quantity of CO in the IHS was reduced to ≤ 1 milligram.

TABLE 5.1-4

IRIDIUM SPHERE MHD-26 DIRECT READINGS

AREA	INITIAL C/M (05/02/75)	AFTER FIRST HEAT (05/20/75)		AFTER SECOND HEAT (05/17/75)	
		C/M DIRECT	5.4-5.5 MEV	C/M DIRECT	5.4-5.5 MEV
POLE 1	20	24700	91%	137000	61%
POLE 2	2	14700	38%	72700	55%
WELD A	15100	27600	47%	70500	51%
WELD B	4700	6000	50%	18700	47%
WELD C	6300	9800	45%	49200	55%
WELD D	47100	59300	48%	119800	53%
45° LEFT	1500	23100	68%	134000	59%
45° RIGHT	500	14900	62%	81300	53%

WASH SOLUTION:

 2.00×10^6 DPM
 $\approx 1 \mu\text{Ci}$
 $\approx 0.080 \mu\text{g}$

TABLE 5.1.5 GAS ANALYSES RESULTS

MFW-IHS

CONSTITUENT	VOLUME PERCENT								SAMPLING DATE	ANALYSIS BY
	CO	CO ₂	H ₂	H ₂ O	N ₂	C ₂	Ar	He		
F-1/IHS										
SAMPLE NO.1	22.45	3.95	0.15	--	--	T	--	73.45	2 Jul.1974	ML/MRC
2	16.90	2.33	0.11	--	0.47	0.02	0.01	80.16	8 Aug.1974	ML/MRC
3	6.13	0.23	0.10	0.07	0.14	--	0.04	93.29	6 Sep.1974	ML/MRC
4	3.57	0.10	0.08	0.03	0.12	0.03	0.03	96.05	21 Nov.1974	ML/MRC
5	0.98	0.02	--	0.02	0.83	0.22	0.05	97.87	13 Dec.1974	ML/MRC
6	4.84	0.05	0.18	0.03	8.5	2.49	6.15	77.76	22 Jan.1975	GE
6	4.1	0.05	0.09	--	12.5	3.2	6.1	73.96	22 Jan.1975	GE/GAS (check)
7	2.1	0.02	0.09	--	0.13	0.003	8.1	89.56	22 Feb.1975	GAS
7	2.02	0.02	0.13	0.03	0.79	0.18	8.4	88.4	22 Feb.1975	ML/MRC (check)
F-2/IHS										
Sample No.1	32.60	3.46	0.06	0.01	0.39	0.01	--	63.47	25 Jul.1974	ML/MRC
2	34.42	2.86	0.07	--	0.58	0.01	--	61.96	12 Aug.1974	ML/MRC
3	6.14	0.17	--	0.03	0.24	--	--	93.42	10 Sep.1974	ML/MRC
4	3.15	0.10	0.06	--	0.34	--	--	96.35	22 Oct.1974	ML/MRC
5	2.09	0.11	0.06	0.01	0.35	0.01	--	97.37	19 Dec.1974	ML/MRC
(*) 6	0.93	--	0.01	--	25.4	7.0	0.32	66.4	13 Feb.1975	GAS
(*) 6	2.38	0.04	0.01	0.05	36.6	10.5	0.48	49.82	13 Feb.1975	ML/MRC(check)
F-3/IHS										
Sample No.1	6.47	3.40	0.07	--	1.76	--	--	88.3	12 Sep.1974	ML/MRC
2	10.24	1.31	0.06	0.07	0.16	0.01	1.21	86.94	15 Oct.1974	ML/MRC
3	4.41	0.21	0.09	--	0.97	0.02	0.09	94.21	29 Oct.1974	ML/MRC
4	3.29	0.12	0.06	--	0.24	0.01	--	96.28	17 Dec.1974	ML/MRC
5	2.5	0.03	0.02	--	0.34	--	--	97.15	6 Feb.1975	GAS
5	2.57	0.03	0.04	--	0.22	0.03	--	97.06	6 Feb.1975	ML/MRC
F-4 IHS										
Sample No.1	25.10	11.57	0.10	--	0.07	0.01	--	63.13	1 Apr. 1975	ML/MRC
2	16.87	1.23	0.02	0.01	0.22	--	0.01	81.63	30 Apr.1975	ML/MRC
(a)2	2.18	0.08	0.03	0.03	3.25	--	0.03	94.38	30 Apr.1975	ML/MRC
F-5 IHS										
Sample No.1	12.42	16.75	0.09	0.01	0.12	0.01	0.01	70.61	13 May 1975	ML/MRC
(a)1	1.19	0.13	0.19	--	0.02	--	--	98.47	13 May 1975	ML/MRC
2	6.25	3.46	0.06	0.01	--	--	--	90.17	20 May 1975	ML/MRC
(a)2	0.05	0.02	0.08	0.01	0.05	--	0.01	99.31	20 May 1975	ML/MRC
3	14.05	1.70	0.03	--	0.05	--	--	84.15	10 Jun.1975	ML/MRC
(a)3	2.06	0.11	0.06	--	0.01	--	--	97.75	10 Jun.1975	ML/MRC

TABLE 5.1-6

SUMMARY OF CO CONTENT OF F-4 IHS

SAMPLE NUMBER	ELAPSED TIME - t_0 +Hrs	QUANTITY OF CO IN F-4 IHS (CALCULATED) -milligrams	IHS CONDITIONS
1	0 1 Jun.75 05:12	120.0	FLUSHING EVERY 2 HOURS BACKFILL WITH He TO 760 TORR
2	+ 6	248.0	
3	+12	39.0	
4	+18	6.9	
5	+24	3.1	
6	+31	2.8	
7	+55	0.5	
8	+79	0.4	
9	+103	383.0	STATIC - 24 HOURS BETWEEN SAMPLES - BACKFILL TO 120 TORR
10	+126	453.0	
11	+151	341.0	
12	+175	196.0	
13	+198	143.0	
14	+227	16.0	RESUME FLUSHING EVERY 2 HOURS BACKFILL TO 760 TORR MINIMUM
15	+232	4.7	
16	+266	0.14	
17	+284	0.54	
18	+308	0.31	
19	+332	8.8	STATIC - 24 HOURS BETWEEN SAMPLES - BACKFILL TO 120 TORR
20	+353	3.0	
21	+364	0.64	

1970.83 milligrams total

5.1.7 BAKE-OUT OF MHW-IHS CARBON COMPONENTS

During the reporting period May/June 1975, the ablation sleeve and POCO end supports for F-5 IHS were heat-treated at GE-Evendale. See the Bi-Monthly Reports for January/February 1975 and March/April 1975 for a discussion of the bake-out facility and previous bake-out operations.

5.2 IMPACT TESTING

5.2.1 IMPACT TESTING AT GE-VF

A single impact test was done using the HNL-ML/MRC type WG Iridium and ThO₂ simulant. The specimen failed with hoop stress cracks in the weld and a very deep fingerprint on the impact face. Deformation was $\cong$ 6.9%. Details are summarized in Table 5.2-1.

5.2.2 IMPACT TESTING AT LASL

No impact tests with fuel or simulant were done at LASL during the reporting period.

5.2.3 MULTI-SPHERE TESTS

No multi-sphere tests were performed during the reporting period.

TABLE 5.2-1

FSA TEST SUMMARIES - IMPACTED AT -GE-VF

DATE AND TEST NUMBER	IMPACT SPECIMEN DATA			IMPACT CONDITIONS				RESULTS
	GRAPHITE IMPACT SHELL No. Density = ρ - g-cm ⁻³ Thickness = t_c - inch Type	IRIDIUM CONTAINMENT: No. Thickness Heat treatment + date Other; Welded by:	SPHERE MATERIAL: Fuel: <chem>FuO2</chem> Simulant: <chem>ThO2</chem> No.; Dia.; Z TD; Heat treat.; other	Specimen weight total - grams	Velocity - fps	Energy - ft-lbs	Temperature - °C (°F)	
26 Jun 75 MHT-93	903744-1 ρ = 1.20 t_c = 0.46	WG-218-1 WG-217-4 0.026 in H/T 18 Hrs. @ 1500°C before butt weld by ML/MRC	<chem>ThO2</chem> No. 624-1 76% TD Not H/T with Ir		303.2		1370 (2500)	Failed: H/D = 1.225/1.713 S(%) = 6.9 GIS Rotation = 5° Tensile cracks in weld. Extensive fingerprint on impact face.

5.3 AEROTHERMAL AND MISCELLANEOUS ANALYSES AND TESTING

5.3.1 REENTRY

In the preliminary MJS spacecraft breakup analysis JPL determined that the RTG three-unit array would be released from the spacecraft intact. The JPL study also indicated that a slight axial C.G. offset would cause the RTG array to trim in a near end-on attitude. In the LES 8/9 configuration (two-unit array), the IHS would "fall out" of the converter and assume a side-on orientation. However, the ballistic coefficient for the MJS three-unit array end-on is too high to allow the leading IHS to separate. As a result, the array could maintain the leading IHS end-on into the air stream until the leading converter has been destroyed by the reentry environment. Since an individual IHS was not designed to survive an end-on reentry, it could not be expected to survive for very long with the RTG array pushing it.

A thermal analysis has been conducted for this reentry situation for the extreme "worst case" corner of the V- γ map, i.e. the highest reentry velocity and highest path angle. The accompanying thermal stress analysis of the IHS end cap was also completed and is reported in Paragraph 5.3.2.

The results of this analysis indicate that unless there is substantial heating augmentation on the RTG case due to cylinder/fin corner effects, survival of the IHS is unlikely for a steep angle, superorbital reentry if the RTG three-unit array reenters end-on. Determination of case heating augmentation levels would require heating rate testing of the correct geometry. Analytical resolution of the heating level is not feasible.

5.3.2 STRESS ANALYSES

Stress analyses of the MJS-IHS end cap were performed to assess the structural integrity of the IHS for the extreme "worst case" end-on reentry at the heating rates and aerodynamic loadings discussed in Paragraph 5.3.1.

Based on the analyses performed, it was concluded that the end cap will not survive this end-on reentry condition. Since the design was not based on this condition, the failure of the cap to survive should not be unexpected.

The analyses were performed for a no-interference case (simple support) and for an interference case (edge fixity). Since the cap will fail under both conditions, changes in the clearance between the end cap and aeroshell should have negligible effect.

Other changes, such as local increases in thickness, do not appear particularly promising. For example, a thickness change could result in a higher thermal gradient and thus aggravate the stress problem.

5.3.3 THERMAL ANALYSES

5.3.3.1 Storage and Handling Temperatures with IHS in the SPC

The elimination of the iridium can for the MJS-IHS design has required the incorporation of a stainless steel EPC (Environmental Protection Can) to protect the graphite heat source during various stages of IHS assembly, shipment and storage. The emissivity of the oxidized EPC was measured as 0.245. Because the I.D. of the iridium can had a high emissivity coating and the EPC does not, the resulting internal IHS temperatures were in question. Also of concern was the temperature of the IHS vent valve and associated hardware which is mounted to the top of the EPC.

Based on the experimental data obtained in tests of the SPC in the Isotope Heat Source Shipping Container (IHS-SC) with the EHS providing 2480 W_t input, the temperatures shown in Table 5.3-1 were measured or calculated. The calculations assume He in the EPC, SPC, and IHS-SC.

TABLE 5.3-1

MHW-IHS TEMPERATURES IN SPC
(WITH He IN EPC, SPC, AND IHS-SC)

TEMPERATURE - °C (°F)

	LES 8 & 9		MJS	
Sleeve	N/A			
Ir Clad/EPC	538	(1000)*	482	(900)
Aeroshell	580	(1075)	605	(1125)
Retainer Ring	605	(1120)	632	(1170)
GIS (AVG)	705	(1300)	732	(1350)
PICS (AVG)	816	(1500)	843	(1550)
Fuel (AVG)	927	(1700)	955	(1750)

*Measured, all others calculated

5.3.3.2 Steady State MJS-IHS Operational Temperature

A complete examination was made of the 1/4 Sphere Model used to determine IHS operational temperatures. The model was updated to include the following changes:

- (1) Fuel emissivity was updated to LASL values⁽¹⁾
- (2) GIS thermal conductivity in circumferential direction was changed to 8 times the radial conductivity
- (3) Minor changes in the model dimensions
- (4) Retainer ring material was changed from T50 to Pyrocarb 508.

The new HSA Operational Temperatures are presented in Figure 5.3-1.

5.4 MATERIAL DEVELOPMENT AND TESTING

5.4.1 COMPATIBILITY TESTS

5.4.1.1 Unfueled Ir Tests

No change in the status of the formal unfueled Ir tests occurred during this reporting period.

5.4.1.2 Tests with Fuel - LASL

Details of the LASL compatibility tests on capsules and spheres are given in the LASL monthly reports.

All the capsule-type compatibility tests have been terminated. The detailed examination and reports are still in progress. No Ir/PuO₂ interactions have been observed with any of the specimens examined to date.

The status of the FSA compatibility tests is shown in Table 5.4-1; see Figure 5.4-1 for test configuration. As noted in Paragraph 5.1.5.3, the only currently observable behavior is He venting for those units continuing on test. See also Tables 5.1-2a and b.

(1) CMB-1904, Los Alamos Scientific Laboratory Monthly Report for August, 1972.

MJS-IHS OPERATIONAL TEMPERATURES

VOLUME AVERAGE TEMPERATURE

PART	°C	°F
SLEEVE	1050	1928
AEROSHELL	1090	1995
RETAINER	1120	2052
GIS	1185	2162
PICS	1295	2368
FUEL	1365	2487

FIGURE 5.3-1

TABLE 5.4-1

MHV FUEL SPHERE ASSEMBLY COMPATIBILITY TESTS AT LASL

SPECIMEN NUMBER	MHV OPERATIONAL MODE - GAS IN Ir/FUEL CAP	HELIUM VENT HOLE DIAMETER - INCH	EXPOSURE TEMPERATURE - DEGREES CELSIUS		TEST START - DATE	EXPOSURE TIME - HOURS		STATUS AS OF 30 JUNE 1975
			O.D.GIS -MEASURED	Ir/FUEL CALCULATED		PLANNED	ACTUAL	
MHFT-1	vacuum	0.0008	1340	-1440	Aug. 1972	2150	2150	Exposure complete; data reported
MHFT-15	"	0.0015	"	"	25 May 1973	3300	7395	" " " "
MHFT-19	"	0.005	"	"	18 May 1973	1480	1105	" " " "
MHFT-20	"	0.005	"	"	May 1973	8760	14000	In storage; not yet examined
MHFT-22	"	0.005	"	"	15 Jun 1973	3300	3300	Exposure completed; data reported
MHFT-14	helium	0.0008	1180	1250	Mar. 1973	2150	1248	Exposure complete; data reported
MHFT-18	"	0.005	"	"	21 May 1973	1460	1365	" " " "
MHFT-21	"	0.005	"	"	1 Jun. 1973	8760	4500	" " " "
MHFT-10	helium	0.0008	1018	1150	Mar. 1973	4380	1244	Exposure complete; data reported
MHFT-16	"	0.0015	"	"	6 Jun. 1973	3300	14000	In storage; not yet examined
MHFT-17	"	0.005	"	"	7 May 1973	3300	14400	" " " "
MHFT-23	"	0.005	"	"	Test not begun	--	--	Transferred to environmental test
MHFT-37	vacuum	0.005	1210	1335	24 Feb. 1974	3000	11100	Test continuing
MHFT-42	"	0.005	"	"	21 Feb. 1974	3000	5440	Exposure complete; data reported
MHF-30	"	0.005	"	"	Nov. 1974	73300	5000	Test continuing
MHFT-44	helium	0.005	1180	1250	3 Jun. 1974	1500	8700	Test continuing

5-25

FIGURE 5.4-1 LASL FSA COMPATIBILITY CONFIGURATION

5.4.2 IRIDIUM

As a result of preliminary firing operations (1500°C in hydrogen), 25 out of 38 Ir weld discs and 23 out of 72 Ir-powder-coated Ir vent covers were rejected due to localized melting and associated (exaggerated) grain growth. This situation occurred after 129 out of 132 frit vent assemblies (fabricated to completion) were determined to meet all drawing and specification requirements. The high yield experienced with the initial vent assemblies indicated that materials and processes were in control; late large-scale piece part rejections attest to the fact that control was lost somewhere in the process.

A. Weld Discs

An exaggerated large-grain condition was detected along the edge of the majority of specimens processed for 15 minutes at 1500°C (hydrogen). The large-grain regions exist over arc lengths varying between 30 and 90 degrees; approximately 270 degrees of each disc appear to be unaffected by the treatment.

The flat Ir weld discs were attacked more severely on the side opposite the floor of the tungsten boat (supporting structure during heat treatment). In the region of attack, melting is complete through grain boundaries and intermittent through the bulk of the grains facing away from the floor of the tungsten boat. The affected regions were generally coated with a thin, glass-appearing film.

Selected specimens were subjected to electron-probe examination. The surfaces of the melted material were found to be rich in aluminum and silicon while the only grain boundary contaminant was identified as aluminum. Some local pockets containing high concentrations of calcium were also in evidence.

B. Ir Coated Cover Discs

Only 2 specimens examined showed a glassy film of the type detected on the weld discs. In the case of the cover discs, the melting and large-grain condition is not confined to the edges of the component, but is localized between edge and pole.

The sources of contamination might have been:

1. The Ir material itself.
2. The Ir powder used to make the filter frit.
3. Material on work benches, pipes, tables, etc. in the room being used to heat treat parts (a refractory laboratory is used to produce glass and ceramic materials for SSL programs).
4. Material transferred to the tungsten boats prior to, or after, loading of MJS vent parts.
5. Moly-wire-wound alumina tube used to house the vent parts during hydrogen heat treatment.
6. Material that might flow through the tube due to pressure changes during the heat treat cycle.

After a thorough investigation, it was concluded that the Ir sheet and powder were clean. Action was taken to preclude further contamination from the other possible sources noted.

5.4.3 CARBON

To verify the adequacy of the bake-out used for F-4 and F-5 IHS's and proposed for use on the MJS units, a series of tests has been planned.

A. Test Objectives

- 1) To quantitatively determine the gaseous species evolved from MJS graphitics at operating temperature after implementing the proposed MJS bake-out procedures
- 2) To determine if additional quantities of CO will be released from MJS graphitics after undergoing bakeout and being stored in typical MRC glove box environments.

B. Test Specimens

The following graphitics will be tested:

- 1) POCO - aeroshell
- 2) T-50 Composite - GIS
- 3) Pyrocarb 406 - ablation sleeve
- 4) Pyrocarb 508 - internal parts
- 5) Cloth - compliance pads

Test specimens of each type material will be the actual thickness used in the heat source design. The specimens will be $\frac{1}{4}$ " lg. x $\frac{1}{4}$ " wide.

C. Testing Procedures

Coupon testing will be performed in the same GE-Evendale Facility used to bake out and handle the LES 8&9 parts. After exposure to the thermal process schedule shown in Table 5.1-1, one group of specimens will be examined immediately to determine the extent of CO removal and other groups of specimens will be exposed in the controlled atmosphere of the glove box for varying periods to simulate exposure in the ML/MRC "F" line. The ML/MRC Facility is not being used because of potential contamination problems and possible schedule impact. The GE-Evendale and ML/MRC O₂ and H₂O permissible levels are comparable. Test results are anticipated during July-August, 1975.

5.4.4 PLUTONIUM DIOXIDE FUEL

5.4.4.1 Fuel Fabrication

The LASL and ML/MRC monthly reports discuss, respectively, the development and production fuel fabrication work.

5.4.4.2 Feed Material

Development work on the feed materials is given in the SRL monthly reports.

5.4.4.3 Fuel Characterization

The status of fuel characterization is shown in Tables 5.4-2 and 5.4-3. During the reporting period May/June 1975, LASL initiated studies on the effects of He ingrowth. There is special interest in the He retention during storage when temperatures are low and the release rate is perhaps a decade lower than the generation rate. Preliminary data indicate that formation of bubbles in grain boundaries and in the grain juncture points may greatly affect the mechanical behavior of $^{238}\text{Pu O}_2$ as contrasted to $^{239}\text{Pu O}_2$ or UO_2 .

TABLE 5.4-2
MHW FUELS CHARACTERIZATION - 1

1.0 FUEL PROPERTIES

(STATUS - as of 30 June 1975)

CATEGORY	STATUS	RESULTS/COMMENTS
1.1 DENSITY	CONTINUING	DIAMETRAL SECTIONING IN PROGRESS TO DEFINE POROSITY DISTRIBUTION; RANGE FOR SPHERES: 80% TD. to 90% TD; NOMINAL MRC/ML 82 % TD DENSITY VARIATION WITHIN SPHERES = 15%: CENTER-TO-SURFACE
1.2 MECHANICAL	IN PROCESS	ROOM TEMP. DATA ON LASL AND ML/MRC MATERIAL COMPLETED; HIGH TEMP. DATA IN PROCESS; CONTINUED TESTING SHOWS NO PLASTICITY; He INGROWTH EFFECT BEING CHECKED; TESTS WITH ²³⁹ Pu PLANNED
o COMPRESSIVE	CONTINUING	
o 4-POINT BEND	" "	
o YOUNG'S MODULUS	" "	
o POISSON'S RATIO	" "	
o SHEAR	CANCELLED	NO WORK PLANNED
o HARDNESS	CANCELLED	NO WORK PLANNED
1.3 THERMAL CONDUCTIVITY	PARTIAL DATA	COMPLETE TO 1350 C; HIGH TEMPERATURE DATA, TO 2200 C, WAITING ON INSTALLATION AND CHECKOUT OF APPARATUS : DATA NEEDED NO WORK PLANNED
1.4 SPECIFIC HEAT	COMPLETE	DATA AVAILABLE FROM STUDIES ON Pu REACTOR FUELS ²³⁹ Pu
1.5 MELTING POINT	COMPLETE	DATA ON PRODUCTION FUEL SHOWS EFFECTS OF IMPURITIES NEEDED TO DETERMINE SYNERGISTIC MP DEPRESSION, NO ENHANCED REACTION BELOW Ir+C EUTECTIC @ 2200 C. (DATA BY LASL)
o PURE FUEL	COMPLETE	
o FUEL+Ir+CARBON		
1.6 THERMAL EXPANSION	PARTIAL DATA	COMPLETE TO 1400 C; VERIFIES PREVIOUS WORK; REQUIRES HIGH TEMPERATURE APPARATUS: DATA NEEDED NO WORK PLANNED
1.7 EMITTANCE	PARTIAL DATA CANCELLED	LASL REPORTED DATA THROUGH 1400 C; TO 2000 C LATER; NO WORK PLANNED
1.8 SOLUBILITY	CONTINUING	SOLUBILITY IN FRESH AND SALT WATER CONTINUING UNDER STUDY; ENCAPSULATED SPHERE TEST STARTED MAR 73 (MHET-13) SEA WATER
1.9 VAPOR PRESSURE	AVAILABLE	DATA ARE FOR "PURE" ²³⁹ PuO ₂ ; DATA CHECKS ON PRODUCTION MATERIAL ARE REQUIRED; Ca, Si, Al, Fe, Mg OXIDES FOUND IN VENT FILTERS
1.10 RADIATION	CONTINUING	DATA TO BE CHECKED ON PRODUCTION SPHERES; NEUTRON LEVELS DEPENDENT ON LIGHT ELEMENT IMPURITIES CONTENT AND EFFECTIVENESS OF ¹⁶ O EXCHANGE.
1.11 SINTERABILITY	IN PROCESS	SEE LASL REPORTS FOR FUEL DEVELOPMENT STUDIES; 10000 HOURS DATA REQUIRED AT OPERATIONAL TEMPERATURE

TABLE 5.4-3

MINI FUELS CHARACTERIZATION - 22.0 FUEL BEHAVIOR/RESPONSE

(STATUS as of 30 June 1975)

CATEGORY	STATUS	RESULTS/COMMENTS
2.1 VIBRATION		
o FSA @ MRC/ML	IN PROCESS	MMFT-11 VIBRATED; EXAMINED @ LASL; SPHERE BROKEN IN 5 PIECES; FINES = 0.6% TOTAL FUEL, 7 ADDITIONAL TESTS = & BROKEN SPHERES
o HSA @ GE-ISAO	IN PROCESS	EXPOSURE OF 2-11 COMPLETE; POST-MORTEM COMP'D OCT. 74; NO Pu FOUND
2.2 IMPACT		
o PELLETS @ LASL	PARTIAL	LOW TEMPERATURE PELLET IMPACT DATA; NEED HIGH TEMPERATURE DATA
o HOT BARE SPHERES @ ML	COMPLETE	TWO SPHERES DROPPED @ 1000 C; BROKE IN LARGE PIECES
o FSA @ LASL	IN PROCESS	10 FUELED FSAs IMPACTED; SEE IMPACT TEST Sect. 5.2) 3 WITH ORNL/ML Ir
o HSA @ SANDIA	IN PROCESS	12-PACK IMPACT No.1 GOOD RESULTS; No.2 WITH SHAVED GIS AND "BAD" Ir POOR RESULTS; 24-PACK IMPACTED; ALL Ir FSAs CRACKED; THREE BADLY
2.3 AGING EFFECTS		
2.3.1 He RETENTION/RELEASE		
o SMALL PELLETS @ LASL	COMPLETE	DATA AVAILABLE INDICATE NO PROBLEM AT 1300 C FOR SMALL PIECES
o LARGE SAMPLES @ LASL	IN PROCESS	QUANTITATIVE RETENTION DATA @ 900, 1150, 1250, 1370, & 1450 OBTAINED
o STORED SPHERES @ LASL	IN PROCESS	ON TEST (COMPATIBILITY TEST SPHERES) SEE TABLE 5.4-1
2.3.2 RADIATION DAMAGE + He INGROWTH	IN PROCESS	CHANGE IN MECHANICAL PROPERTIES AND MICROSTRUCTURE MAY RESULT FROM He BUBBLE CONCENTRATION ALONG GRAIN BOUNDARIES; NEW SPECIMENS BEING MADE; TESTS WITH 239 Pu PLANNED
2.3.3 DEOXYGENATION @ LASL	IN PROCESS	LONG TERM SPHERE TESTS WITH CHANGE IN O/Pu; DIMENSIONAL CHANGES REDUCING ACTION OF CO UNDER STUDY
2.4 OXIDATION: @LASL & ML	IN PROCESS	REDUCTION AND REOXIDATION? SHOWED? SMALL DIMENSIONAL CHANGES; APPARENT REDUCTION OF FUEL IDENTIFIED AS AN ARTIFACT
2.5 Pu RELEASE		
o VAPOR	IN PROCESS	VAPOR TRANSPORT OF PuO ₂ CAL'D FOR KNUDSEN FLOW; NEED ADDITIONAL CALC'S AT PRESSURES REACHED IN FSAs WITH INTERMITTENT VENTING
o ALPHA KNOCK-ON	CALCULATED	
o PARTICULATES	CONTINUING	LASL MAKES FINES MEASUREMENTS ON ALL IMPACTED SPHERES
2.6 ABLATION/VAPORIZATION	CANCELLED	FACILITIES PROBLEMS IN THE USE OF LIVE FUEL
2.7 COMPATIBILITY @ LASL	IN PROCESS	SEE DETAILED BREAKDOWN ON COMPLETED AND PLANNED TESTS - Sect. 5.4.1.2
@ DWDL	TEST COMPLETE	TESTS ON FULL-UP FSAs STARTED APR. 73 5000 HR. IN GRADIENT, ISOTHERMAL EXAMINED; TENSILE TESTS REPORTED
2.8 THERMAL RESPONSE		
o REENTRY THERMAL RAMP	COMPLETE	INCLUDED IN THE SSST
o ASYMMETRICAL THERMAL RAMP	COMPLETE	SPHERES CRACKED BUT REMAINED INTEGRAL; LASL & MRC/ML SPHERES RUN
o SYMMETRICAL RAMP TO OPERATIONAL - 1450 C	COMPLETE	LASL SPHERES CHECKED AFTER 1 YEAR SHOWED NO DAMAGE OR CHANGE WHEN HEATED TO 1450 C @ MRC/ML: 1 SPHERE AFTER 6 mos STORAGE TO 1250 C OK

6.0 CONVERTER

6.1 MODULE ANALYSIS

Module analysis activities for this reporting period are covered in Section 6.5.

6.2 MATERIAL ANALYSES

6.2.1 LONGITUDINAL ELONGATION PROPERTIES OF BERYLLIUM BLOCK HP-10 USED IN THE LES 8/9

The effect of temperature on the longitudinal elongation properties of beryllium block HP-10 was investigated by plotting the results of the manufacturer's quality control material test reports. Using the lowest curve of all the billets used for LES 8/9 program hardware, the ductility expressed as elongation at 350°F is about 300% greater than at room temperature. Figure 6.2-1 shows a plot of the longitudinal elongation in % versus temperature in °F. The test samples are taken from the rim of the mid-section of the billet, which yields the lowest values because of the slightly reduced pressure in this section during fabrication. The increased values at 550°F are due to the improvement of the powder production technique and the processing improvement as stated by the manufacturer. Two transverse elongation properties are taken, one from each end of the billets. They yielded all higher values and are therefore not plotted. All the mechanical properties tested were within the specification NS 0060-07-08. The chemical composition given in the test reports met the specification requirements.

6.2.2 RADIATION VULNERABILITY ASSESSMENT OF SILICON NITRIDE COATING ON THERMOELECTRICS FOR LES-8/9 MISSION

An assessment was made of the subject coating as a supplement to Reference 1. This coating appears on the silicon-germanium alloy (SiGe) in the thermoelectric unicouples and acts as a sealant to prevent sublimation of the alloy at the relatively high operational temperatures. The following components of the radiation environment were considered in order to determine the total mission ionization dose absorbed by the coating.

6.2.2.1 Gamma Rays

The ionization dose in the coating due to gamma rays emitted by the heat source was calculated in the following way: The specific activity of

FIGURE 6.2-1

^{238}Pu for several energy groups was obtained from an applicable Savannah River Lab. report (Ref. 2). This data was given for 30 days, 1 year and 5 years after purification. The 1-year data was used in the calculation although the results would not have been appreciably different had either of the other two data sets been used. The Savannah River data was measured in absence of the 0.020" iridium jacket on the fuel spheres and in absence of the 0.010" iridium layer external to the spheres. Therefore, account was taken in the calculations of the attenuation due to 0.030" of iridium. The gamma fluence at the thermoelectric elements was calculated by assuming all of the gammas that are not attenuated by the iridium escape uniformly through the area of a cylinder defined radially by the retaining tray ($r \approx 9$ cm) and axially by the sphere seat plates ($h \approx 30$ cm). Such a cylinder has total surface area $A \approx 2000 \text{ cm}^2$. The total fluence on the SiGe alloy after 6 years (5 year mission after launch and 1 year pre-launch storage) is assumed to be given by $F = Nf/A$ where N is the number of photons in 6 years and f is a factor that represents the attenuation of the 0.030" of iridium. The source N is equal to the specific activity (photons per second per gram) from Ref. 2 times the number of grams of ^{238}Pu in 24 spheres times the number of seconds in 6 years ($6 \times 3.15 \text{ E}7 \text{ sec.}$). The total mass was taken to be 24 times the average ^{238}Pu mass as measured by Mound Laboratories (Ref. 3). Thus

$$N = f(E) \times 24 \times 177\text{g} \times 6 \times 3.15 \text{ E}7 = 8.0 \text{ E}11 f(E)$$

where $f(E)$ is the number of photons in an energy group as given by Ref. 2. This expression for N amounts to the worst-case assumption that the energy dependence of the fluence within a group is flat. The mission ionization dose produced by gamma rays is then

$$D = \frac{N \cdot K}{A} \int_E f(E) E \exp(-\mu_1^{\text{att}}(E) \cdot X) \frac{\mu_2^{\text{abs}}(E)}{\rho} dE \text{ rads} \quad (1)$$

where

$$K = 1.6 \text{ E-}8 \text{ rads/MeV/g}$$

$$\mu_1^{\text{att}} = \text{iridium attenuation coefficient (cm}^2/\text{gm)}$$

$$\mu_2^{\text{att}} / \rho = \text{Si}_3\text{N}_4 \text{ absorption coefficient (cm}^2/\text{gm)}$$

$$X = \text{thickness in gm/cm}^2 \text{ corresponding to 0.030" iridium}$$

The result after integrating overall energy groups was $D = 2\text{E}4 \text{ rads}$.

6.2.2.2 Trapped Electrons

The trapped electron environment is described in Ref. 1. To compute the mission ionization dose in the coating, allowance is made for the 0.080" beryllium outer case. In the calculation, use was made of the energy deposition function of Watts and Burrell (Ref. 4) for isotropic incidence. This function has units of MeV/gm/unit current. The dose in the coating is given by

$$D(Z) = K \int_E \rho_{iso} \left[E, Z/r_o(E) \right] \Phi(E) dE \text{ rads} \quad (2)$$

where

$$K = 1.6 \text{ E-8 rads/MeV/gm}$$

$$\rho_{iso} = \text{Burrell's dose function for isotropic incidence} \\ (\text{MeV-cm}^2/\text{gm})$$

$$Z = \text{shield thickness (gm/cm}^2\text{) corresponding to 0.080" Be}$$

$$r_o = \text{electron path length at energy E}$$

$$\Phi = \text{mission fluence (electrons/cm}^2\text{)}$$

The result was 2.5 E5 rads.

6.2.2.3 Trapped Protons

The 0.080" beryllium outer case corresponds to a proton cutoff energy of about 16 MeV. The trapped proton environment above this energy is completely negligible.

6.2.2.4 Total Mission Ionization Dose

Summing the trapped electron and the heat source gamma contributions results in a mission ionization dose of 2.7 E5 rads.

6.2.2.5 Comparison to Data and Conclusions

According to W. J. Patterson (Ref. 5), silicon nitride films have been exposed to 1E7 rads and have suffered no change in mechanical or electrical properties. Inasmuch as the test levels are over an order of magnitude larger than mission levels, it is judged that there should

be no problems with the coating during the mission. There is also a one order of magnitude safety margin between the mission dose ($3E5$ rads) and the referenced no-effect data point ($1E7$ rads).

REFERENCES

1. L. T. Smith, "Radiation Vulnerability Assessment of MHW-RTG for LES Mission", PIR 1H-71-185, 4/17/75.
2. D. H. Stoddard and E. L. Albenesius, "Radiation Properties of ^{238}Pu Production for Isotropic Power Generators", AEC Report No. DP 984, July 1965 (Amended 1968).
3. Letter from Dr. Johnson, Mound Laboratories, to Dr. P. E. Brown, GE-SD.
4. J. W. Watts and M. O. Burrell, "Electron and Bremsstrahlung Penetration and Dose Calculation" in Proc. Natl. Symposium on Natural and Man-made Radiations in Space", NASA TM X-2440, January 1972.
5. Personal Communication from W. J. Patterson, GE Aerospace Electronics Division.

6.2.3 ACCEPTABLE HARDNESS OF SILVER COATING ON MHW CONVERTER "C" SEALS

6.2.3.1 Background

In the past, the hardness of the silver coating on "C" seals (Part Nos. 47C302638P1 thru P8) has never been measured, or used, as part of the acceptance criteria in the controlling specification (NS0060-05-21). In April, 1975, the specification was revised to require a hardness determination (KNOOP-75 max.) on 2 specimens per lot. This requirement became effective for all "C" seals ordered after September, 1974.

In addition, during this same time frame, the practice of hanging individual "C" seals by wire (during plating) was changed to barrel tumbling plating; hundreds of "C" seals can be plated at one time with the latest technique, and actual "C" seals, rather than flat sheet specimens, are used for coating evaluation.

Until recently no hardness measurement has been recorded of silver on "C" seals. The hardness number (75 max. KHN) was established on a "best guess" basis; the plating facility (Pressure Sciences, Inc.) believed they would make no coating having higher hardness. Pressure Sciences arrived at this number by preliminary work indicating the barrel coatings should have a range of hardnesses varying between 37 and 43 KHN.

It appears that silver coating hardness will be 120 KHN, or greater, if brighteners are added to the plating bath, or the metal is cold worked. It is to the advantage of the design to maintain as soft a coating as possible, since sealing is assisted by increased ease of metal flow. GE, therefore, would prefer a coating to approach the softness of pure ductile virgin metal (35 to 45 KHN). Since the plating vendor agreed that the coating would not exceed 75 KHN, GE agreed to implement that number in the controlling specification.

6.2.3.2 Recent Testing Experience

Recently, the product of a 590-piece plating run was tested, for hardness, at GE and at SELREX (mechanical testing facility selected by Pressure Sciences). Two P-1 type "C" seals were forwarded to GE and one was forwarded to SELREX. Table 6.2-1 lists the data obtained from all testing.

TABLE 6.2-1 HARDNESS (KNOOP-25 GR. LOAD) OF P1-"C" SEAL SILVER PLATE

	(2) G. Smith GE	(3) G. Smith GE	(4) SELREX (Pressure Sciences)	(5) SELREX (Pressure Sciences)	(6) E. Feingold (GE)
(1) Sample No. 1	75.8 73.6 73.6 <u>69.6</u> 73.2 Av.	98 <u>98.8</u> 98.4 Av.	102 <u>97</u> 99.5 Av.	98 <u>92</u> 95. Av.	99 } One Leg 100 } of 97.7 Av. <u>94</u> } Seal 87 } Remaining 70 } Leg of 73.7 Av. <u>64</u> } Seal
(7) Sample No. 2	79.3 72.5 83.0 <u>92.5</u> 81.8 Av.	No Data	102.0 <u>101.0</u> 101.5 Av.	98.0 111.0 <u>100.0</u> 103.0 Av.	No Data
(8) Sample No. 3		54.0 <u>44.0</u> 49.0	No Data	56.0 51.0 <u>48.0</u> 51.7 Av.	51.7 <u>60.5</u> 56.1 Av.

NOTES:

- 1 & 7 (P1-"C" Seal Specimens forwarded directly to GE (from Pressure Sciences) for hardness evaluation.
- (2) Sample mounted on a flat stationary stage.
- (3) Sample mounted on an adjustable stage.
- (4) SELREX hardness measurements on GE specimens.
- (5) GE specimens repolished and etched at SELREX and new hardness no.'s established.
- (6) Hardness evaluations by Dr. Feingold (Space Sciences).
- (8) P1-"C" Seal Specimens forwarded directly to SELREX (from Pressure Sciences) for hardness evaluation.

In the original testing of two separate samples, GE had determined that the average hardness of the coatings was 73.2 and 81.8 KHN. Single hardness readings, on each coating, exceeded the acceptance limit of 75 KHN.

The original testing of the sample by SELREX resulted in an average hardness number of 51.7, with no individual hardness exceeding 56 KHN.

Obviously, there was a contradiction in data, or, 2 of the 3 specimens were appreciably harder than the other. This meant that either the plating procedure was capable of producing a product having a wide range of hardness numbers, or the techniques employed in measurement were at fault.

As a result, the GE specimens were taken to SELREX for evaluation, and the SELREX specimen was measured by GE.

SELREX determined that hardness of the specimen having a GE-determined hardness of 73.2 was 98.4 and the other specimen having a GE-determined hardness of 81.8 was 101.5.

At this point, GE decided that a flat stage might be producing erroneous readings and employed an adjustable stage to take the reading on the SELREX specimen (51.7 KHN). GE determined the hardness to be 49.0 KHN). This was the first time agreement had been obtained between the two testing facilities.

GE then remeasured the hardness of the original specimens forwarded to GE for evaluation, using the adjustable stage. The specimen having an original GE hardness of 73.2 (flat stage) now was found to average 98.4. The second specimen was not measured on the adjustable stage.

Dr. E. Feingold (GE-Space Sciences Laboratory) was asked to evaluate the specimens and his findings agree with those established by Smith (GE) and SELREX.

6.2.3.3 Conclusions

- GE has now established three hardness-measuring facilities that are capable of providing reproducible results.
- The barrel plating process produces coatings having a wide range of hardnesses in a single run (batch, lot).

- On the basis of only 3 specimens tested out of 590 pieces run, a total of about 400 would not meet the 75 KHN hardness limit in the controlling specification.
- One would have difficulty sorting the hard and soft specimens from a given lot or run (visually).

6.2.3.4 Recommendations for Future Procurements

1. Keep the hardness requirement in the specification.
2. Change the maximum hardness limit from 75 KHN maximum to some higher number which has yet to be established.
3. Accept the SELREX hardness number; GE verification is not required. GE's option to test, if desired, should remain.
4. Change the required number of specimens to be tested from 2 specimens per lot to: 2 specimens chosen at random from every 100 specimens coated per lot. If any one specimen exceeds the specified hardness limit the entire lot shall be rejected.
5. Establish the highest hardness number that is practical when rewriting the specification. This number should be established by test rather than by "best guess."
6. The plating vendor (Pressure Sciences) should be appraised of the information contained herein, and be requested to revise his procedures (if possible) to provide softer silver coatings (future orders).

6.2.4 CARBON MONOXIDE GENERATION DUE TO ASTROQUARTZ OUTGASSING

6.2.4.1 Introduction

A major contributor to the production of carbon monoxide (CO) within the RTG converter is due to the outgassing of water vapor from the quartz material within the converter assembly. This water vapor reacts with the graphitic material of the ablation sleeve to produce CO. The reaction takes place when the graphite is above 800°C according to the following:

An attempt was made to determine if CO production could be quantitatively predicted as a function of pressure-temperature relationships seen by the converter during processing. The problem was studied in two phases: 1) converter preparation and 2) quartz outgassing properties. For purposes of this investigation, it was assumed that all material outgassed by the quartz insulation was water vapor, and that above the temperature of 800°C all water produced combined with carbon to produce CO.

Unfortunately, due to a lack of data, it was not possible to construct a model to predict CO formation relative to converter pressure-temperature relationships.

6.2.4.2 Converter Preparation

An examination of the converter pressure-temperature relationships during processing was made. It was felt that a comparison of these relationships for a number of converters would indicate if a model to predict CO generation were feasible. If the pressure-temperature relationships approximate each other it is felt that a generalized, if not a somewhat cumbersome, model based on these parameters could be constructed.

The only data available at the time of this study was from the Q-1A converter processing (see Figures 6.2-2 through 6.2-4). For this reason, it was not possible to establish the required processing relationships. Additionally, sufficient data concerning processing station outgassing/pumping characteristics was not available. This information is necessary in order to assure the validity of the converter outgassing data.

If this approach is to be successful, additional input is needed.

6.2.4.3 Quartz Outgassing

The outgassing characteristics of quartz were examined as an alternative means of predicting CO production with the converter. It was felt that by establishing these properties it would be possible to scale them to an "equivalent converter" which would then allow the construction of a general model to predict CO formation. Data from several sources was available for this effort.

Q-1A CONVERTER

11

FIGURE 6.2-2

Q-1A CONVERTER

11

6-12
TEMPERATURE - °C

TIME - HOURS

FIGURE 6.2-3

Q-1A CONVERTER

11

FIGURE 6.2-4

The major difficulty encountered was the lack of correlation between the individual sets of data. It was expected that the quantity of water vapor generated as a function of temperature would vary only in magnitude for the various samples. This was not the case (see Figure 6.2-5). The most likely explanation for this scatter is to be found in the pre-testing handling of these specimens. It is evident that if this approach is to succeed, all test data must be generated from quartz samples which are prepared in the same manner as that used for material installed in the converter.

Another difficulty encountered with this method is that the test samples were heated isothermally, whereas the quartz insulation in the converter is not so treated, thus greatly increasing the complexity of the task of comparing characteristics.

Again, as with the previous case, it is felt that additional data is necessary, before it will be possible to generate a model of CO production in the RTG converter.

6.2.5 SUMMARY OF MJS-RTG MATERIALS

Table 6.2-2 is a list compiled during the reporting period of all materials used in the fabrication of the RTG for the MJS Program.

6.3 CONVERTER SYSTEMS AND DESIGN

6.3.1 RTG PRESSURE DECAY RESPONSE TO ON-PAD COOLING

6.3.1.1 Introduction

An analysis was performed to determine the effect of on-pad cooling with respect to RTG internal pressure characteristics. Of specific interest is the impact of such cooling on the requirement that the RTG be capable of maintaining a minimum positive pressure differential of 0.5 PSI with respect to the atmosphere at the end of an unattended 30-day hold period.

Two general cases of RTG cooling were analyzed :

1. Continuous cooling at specific RTG case temperatures.
2. Continuous cooling at a RTG case temperature of 350°F for a definite period with a drop in RTG case temperature to 100°F prior to launch.

TOTAL OUT GASSING - MICRON LITERS

FIGURE 6.2-5
6-15

TABLE 6.2-2 RTG COMPONENTS AND MATERIAL SUMMARY

COMPONENT	MATERIAL	MATERIAL FORM	MATERIAL SPECIFICATION
Outer Shell	Beryllium	HPB (Hot Pressed Block)	NS0060-07-08 (GE)
Pressure Dome	Solar SP40 Thermal Coating	Paint Spray Sintered	RPS 230-20 (Solar)
End Enclosure - Fwd End Enclosure - Aft	6-2-4-2 Titanium	Plate	AMS 4976
Mounting Bkts - Fwd Mounting Bkts - Aft Bushing	RC 356 Thermal Coating	Plasma Arc Spray	NS0060-02-03 (GE)
T/E Sealing Screw T/E Nut Plate	6 Al-4V Titanium	Rod	MIL-T-9047F
Preload Screw	Inconel X-750	Bar	AMS 5668D
C Seal-Unicouple C Seal-P.O. Conn. C Seal-Gas Mgt. C Seal-Vent Line C Seal-Press. Dome P.O. Conn Shell Retainer Screw-Press. Dome Screw-Mtg. Bkt.	Inconel X-750	Bar	AMS 5667
C Seal Plating	Soft Silver	Plating	NS0060-07-08 (GE)
Self Aligning Bearing	Inconel X-750	Race & Nut	AMS 5667
	440C Stainless Steel	Ball	QQS763d
Valve-Gas Mgt. Tubing-Valve Feedthru Fitting Gas Adapter Mgt. Feedthru-Vent	304 Stainless Steel	Bar Rod Tube	QQS763d
Screw-End Encl. Nut-End Encl.	A286 Stainless Steel	NAS Screw and Nut	MIL-H-6875
Barrier	Tungsten	Wrought Sheet	AMS 7898
Wafer Retention Washer	Iridium	Wrought Sheet	NS0060-01-02 (GE)
Bearing Disk	Zirconia (ZrO ₂)	Hot Pressed & Sintered Y ₂ O ₃ Stabilized	NS0060-01-05 (GE)

RTG COMPONENTS AND MATERIAL SUMMARY
(Cont'd)

COMPONENT	MATERIAL	MATERIAL FORM	MATERIAL SPECIFICATION
Heat Source Support-Fwd Heat Source Support-Aft	POCO Graphite AXF-5Q	Flat Plate Type II Class II	NS0060-02-63 (GE)
Insulation Thermopile	Astroquartz	Cloth	M9A (RCA)
Insulation End Caps	Molybdenum	Foil	M8A1 (RCA)
Inner Frame	Molybdenum	Sheet	M8C1 (RCA)
Miscellaneous Insulation	Astroquartz	Yarn	M9D1 (RCA)
	Microquartz	Fibrous	M9A1 (RCA)
Thermoelectrics	Silicon Germanium 63.5 A/O & 78 A/O and Silicon Molybdenum 85 W/O	Hot Pressed	M28A (RCA)
Hot Shoe Spacer	Alumina Al ₂ O ₃	Fired Sheet	NS0060-01-06 (GE)
Electrical Straps	Copper	Wire Strip	M1A1 (RCA)
Ni Plating	.0002 Thk	Sheet	
Cold Stack			
Heat Shunt	AMZ1RC	Sheet	M1B1
Pressure Pad	SST 303	Sheet	M5A2
Compensator	Mo	Sheet	M8B1
Electrical Insulator	Al ₂ O ₃	↓	M4C2
Electrical Conductor	Cu		M1A1
Compensator	W		M2A1
Pedestal	Cu		M1A1
Cold Shoe	W		M2A1
Braze Shims	NICUSIL		
" "	CUSIL		
" "	INCUSIL		
Cold Stack Plating	Ni	.0005 Thk	

RTG COMPONENTS AND MATERIAL SUMMARY
(Cont'd)

COMPONENT	MATERIAL	MATERIAL FORM	MATERIAL SPECIFICATION
Fuel	$^{238}\text{PuO}_2$	Ceramic Compact Spheres	
Post Impact Shell	Ir		
Graphite Impact Shell	T-50	Composite	
Aeroshell	POCO AXF-5Q		
Ablation Sleeve	Pyro-Carb 406	Composite	
IHS Internal Graphite	Pyro-Carb 508	Composite	
<u>PRD</u>			
Penetration Fitting	SST-304	Bar	
Diaphragm	SST-304	Bar	
Bellows Assy			
Spring	Inconel-X 750	Wire	AMS 5698
Guide	Al 2024		
Convolutions	SST-AM 350	Sheet	AMS 5548
End Plate	SST-300	Sheet	
Fittings	SST-300	Plate	
Housing/Back Plate	Al-2024	Bar	
Lance	SST-440C	Bar	QQ-S-763
E-Ring	SST-PH15-7 Mo	Sheet	

The results of the analysis show that only with an initial charge of 30 PSIA and minimal continuous cooling (Case 1) will the RTG be capable of meeting its 30-day pressurization requirements (see Figures 6.3.1-3 and -5). Results obtained from Case 2 show that RTG pressurization requirements cannot be met utilizing this cooling mode (see Tables 6.3.1-1 and -2).

This analysis considered only the case of an RTG with a 100% argon cover gas.

6.3.1.2 Analytical Approach

Several basic assumptions were made in performing this analysis. They were as follows:

1. The RTG is initially charged in the RTG-SC and all conditions are maintained until the RTG is removed from the RTG-SC.
2. After removal from the RTG-SC the RTG is subjected to a two-day period in an ambient atmospheric environment during which RTG mating and integration activity is performed.
3. RTG cover gas temperature response to changes in RTG operational conditions is small (2-3 hours) and is therefore neglected.
4. The RTG overall leak rate is assumed to remain constant despite changes in RTG case temperatures. The leak rate used is that defined in the RTG Specification (see Figure 6.3.1-1).

The analysis was broken down into three segments or events corresponding to a particular set of RTG operational conditions. The events and their associated operational conditions are as follows:

Event I: Final Pressurization of the RTG

- a. RTG in RTG-SC.
- b. 100% argon environment in the RTG-SC.
- c. RTG in short circuit mode.
- d. Case Temperature (T_C) = 887.67°R (428°F); Heat Source Temperature (T_{HS}) = 2003.67°R (1544°F)

TABLE 6.3.1-1

RTG Pressure Response to Case 2 Cooling Mode

T_C (initial) = 350°F ; Initial Charge = 25 PSIA

Day	M (lbm)	Corresponding ΔP (lbf/in ²) at $T_C = 100^\circ\text{F}$	Time to .5 PSID (Days)	Total Time to .5 PSID (Days)
0	.0475	4.24	21.41	21.41
5	.0409	1.61	11.64	16.64
6	.0399	1.2	8.76	14.76
7	.0391	.89	5.77	12.77
8	.0383	.57	1.31	9.31
9	.0376	.29	--	--

TABLE 6.3.1-2

RTG Pressure Response to Case 2 Cooling Mode

T_C (initial) = 350°F ; Initial Charge = 30 PSIA

Day	M (lbm)	Corresponding ΔP (lbf/in) at $T_C = 100^\circ\text{F}$	Time to .5 PSID (Days)	Total Time to .5 PSID (Days)
0	.0559	7.51	31.7	31.7
5	.0459	3.60	19.7	24.7
6	.0444	3.00	17.9	23.9
7	.0432	2.52	16.2	23.1
8	.0420	2.04	14.08	22.08
9	.0409	1.61	11.64	20.64
10	.0399	1.2	8.76	18.76
11	.0391	.89	5.77	16.77
12	.0383	.57	1.31	13.31
13	.0376	.29	--	--

FIGURE 6.3.1-1 RTG-ETG ALLOWABLE PRESSURE DECAY

10
1.0
0.1

PRESSURE DIFFERENTIAL (PSI)

Event II: RTG Installation and Integration

- a. RTG in ambient air
- b. RTG in short circuit mode
- c. $T_C = 815.67^\circ\text{R}$ (356°F); $T_{HS} = 2021.67^\circ\text{R}$ (1562°F)

Event III: On-Pad Cooling Phase

- a. RTG in cooled air environment
- b. RTG carrying a 30-volt load

Beginning with Event I, two initial pressurization conditions were considered: $P_1 = 25$ PSIA and $P_2 = 30$ PSIA. These values for P_1 and P_2 were then used in conjunction with the Gas Equation of State

$$PV = mRT_{BG} \quad (1)$$

where

- P = pressure
- V = RTG volume
- m = mass of cover gas
- R = gas constant for argon
- T_{BG} = cover gas bulk temperature

to assess the available mass within the converter. The values for T_{BG} are obtained from the relationship

$$T_{BG} = .5 (T_C + T_{HS}) \quad (2)$$

where

- T_{BG} = cover gas bulk temperature
- T_C = RTG case temperature
- T_{HS} = Heat Source temperature

This relationship was derived from previous RTG operational data.

In Event II, cover gas characteristics were determined for the event's specific operational conditions. Internal pressure was found by applying eqs. (1) and (2). The RTG pressure differential was then found by

$$\Delta P = P_C - P_A \quad (3)$$

where

$$\begin{aligned} \Delta P &= \text{RTG pressure differential} \\ P_C &= \text{Absolute converter pressure} \\ P_A &= \text{Atmospheric pressure} = 14.7 \text{ lbf/in}^2 \end{aligned}$$

The maximum allowable leak rate (Figure 6.3.1-1) is defined by the equation

$$y(t) = \Delta P e^{-zt} \quad (4)$$

where

$$\begin{aligned} y(t) &= \text{RTG pressure differential at} \\ &\quad t \text{ days} \\ \Delta P &= \text{RTG pressure differential at} \\ &\quad \text{time } t = 0 \\ z &= \text{constant} = 0.09986 \\ t &= \text{time in days} \end{aligned}$$

This relationship was used to establish the RTG pressure differential at the end of Event II. Remaining available mass is found from Equation (1).

Event III was divided into two cases. In Case 1 the RTG was assumed to be subjected to cooling to a constant case temperature. The temperatures examined ranged from 100°F to 350°F in 50° increments. Equations (1), (2), and (4) were then used to determine Event III initial pressure conditions and then to establish the time required for the RTG pressure differential to decay to 0.5 PSI from the start of Event III. In Case 2 the RTG was assumed to be cooled to a constant case temperature of 350°F until prior to launch when it is further cooled to 100°F. Again Equations (1), (2), and (4) were used to determine the time to attain a 0.5 PSI pressure differential.

For Event III calculations the relation

$$\Delta T_{HS} = .85 \Delta T_C \quad (5)$$

where

$$\begin{aligned} \Delta T_{HS} &= \text{change in Heat Source temperature} \\ \Delta T_C &= \text{change in RTG case temperature} \end{aligned}$$

was used to determine the Heat Source temperature with respect to RTG case temperature. This relationship was derived from RTG experimental data.

6.3.1.3 Discussion

A. Case 1: Constant Cooling

Analysis shows that with an initial charge of 25 PSIA argon, and subject to constant cooling, the RTG cannot meet its 30-day pressurization requirements. Time to decay is very sensitive to initial RTG differential pressure (ΔP). Figure 6.3.1-2 shows initial Event III ΔP as a function of case temperature; it can be seen to drop rapidly with increased cooling.

The maximum time to attain a 0.5 PSI differential is about 27.5 days with minimum cooling of 350°F. For maximum cooling (100°F) time to decay is about 21.5 days (see Figure 6.3.1-3).

A somewhat brighter picture is obtained if an initial RTG charge of 30 PSIA is used. Figure 6.3.1-4 shows the initial Event III ΔP as a function of case temperature. As expected, the initial ΔP 's are higher than for the previous pressurization condition. Figure 6.3.1-5 shows the time to decay to a 0.5 PSI differential for these ΔP 's at specified cooling temperatures. Provided the case temperature is not forced below 250°F, the RTG pressurization requirements can be satisfactorily maintained. The worst condition is cooling to 100°F, where the time to decay is about 27 days.

B. Case 2: Continuous Cooling at 350°F with Additional Cooling Prior to Launch

In Case 2 it was assumed that the RTG would be cooled to 350°F until prior to launch it would be cooled to 100°F. The results obtained for this case were very poor as noted in Tables 6.3.1-1 and -2. The first two columns of these tables show the number of days of cooling

FIGURE 6.3.1-2
6-25

FIGURE 6.3.1-3

FIGURE 6.3.1-4

FIGURE 6.3.1-5

at $T_C = 350^{\circ}\text{F}$ and the mass available at these times. The third column shows the ΔP that would exist if the RTG case were cooled to 100°F at this time; column four shows the subsequent decay time required to achieve a ΔP of 0.5 PSI. Column five gives the total decay time required to achieve a ΔP of 0.5 PSI for both cooling levels.

An examination of Tables 6.3.1-1 and -2 quickly reveals that RTG pressure response to this cooling mode is inadequate to meet the 30-day pressurization requirements unless initial RTG charges much higher than 30 PSIA are used. Since this is not desired, individual actual leak rates of the RTG's can be used to determine pad life.

6.3.2 FEASIBILITY STUDY OF SPOOL PIECE ELIMINATION FROM MJS PROGRAM CONVERTERS

6.3.2.1 Introduction

A study was conducted to determine the feasibility of eliminating the spool piece from the ETG configuration for the MJS program. Advantages and disadvantages of such a change were determined to be as follows:

6.3.2.2 Advantages of Spool Piece Elimination

If the spool piece was eliminated, but the heater instrumentation retained, the principal advantage would be that the time required to perform the following operations would be eliminated from the converter assembly sequence at RCA:

- a. Welding of instrumentation leads to spool piece
- b. Joining of spool piece leads to heater instrumentation
- c. Installation of spool piece
- d. Connection and leak check of flex hose

6.3.2.3 Disadvantages of Spool Piece Elimination

Pursuit of the subject approach would have the following disadvantages:

1. The procedure and tooling for setting the pre-load would have to be revised.
2. The converter would have to be processed in the station forward end up. This would necessitate revised handling and mounting fixtures.
3. New heater power and instrumentation connections would have to be developed for the converter-to-station interface.

4. The electrical disconnects for the EHS would have to be made using the gloves in the outer container.
5. The piping arrangement for pressurization of the converter to 10 psig and the pressure transducer would have to be revised, presumably using the gas management valve and the heat source vent assembly, respectively.
6. The established control for the thermal processing sequence, i.e., maintenance of vacuum levels in the internal converter, would be eliminated. Since internal converter pressure and external (bell jar) pressure behavior do not correlate closely, a new thermal processing schedule would have to be established. Certainly, the longest processing time experienced to-date would be proposed, but this would not provide means to detect anomalies and take corrective action as was necessary during the internal converter pressure surge experienced in F-2 processing.
7. The specifications for converter assembly and processing would have to be revised significantly.
8. Processed converter would be shipped with loose heater and instrumentation connections placed in the forward end enclosure.
9. If the heater instrumentation were also eliminated, there would be no over-temperature protection for the converter during thermal processing.

6.3.2.4 Conclusions and Recommendations

Although it is possible to process and convert an ETG to an RTG without the use of a spool piece, it is not recommended because of the many limitations it induces.

Of all the disadvantages, the loss of internal pressure monitoring and overtemperature protection are regarded as the most serious. Subjecting the converter to possible damage by eliminating the spool piece and heater instrumentation cannot be worth any potential advantage. It should also be recognized that no real advantage exists, because the reduced assembly time resulting from the hardware deletion would be more than offset by the additional time anticipated for processing. Another major limitation would be the inability to energize the ETG after processing should any anomaly occur or any performance checks be desired. It is, therefore, recommended that the spool piece and heater instrumentation be retained in the MJS ETG Configuration.

6.3.3 MJS FLIGHT CONVERTER WEIGHT

During the reporting period, a new determination was made of total and subsystem weight estimates for the MJS/77 RTG. Tables 6.3.3-1 and -2 list the detailed estimated weight breakdowns for the Converter and Heat Source Assemblies. The total RTG weight was found to be 81.749 lbs.

It should be noted that the PIC's weight (see Table 6.3.3-2) was calculated by using the maximum allowable wall thickness (0.027 in.). If the nominal PICS wall thickness (0.024 in.) is considered, the total PIC's weight becomes 3.688 lbs. (a reduction of 0.488 lb.) with a resulting RTG total weight of 81.261 lbs.

As a check against reality, the converter shell assembly for F13 was weighed and found to weight 32.536 lbs. This weight was then compared against a derived converter shell assembly weight obtained by using the components for the assembly as described in Drawing 47J302411 (minus the aft end dome and 24 dome screws). The derived weight, as shown in Table 6.3.3-3, was found to be 32.491 lbs. Although the actual weight is slightly higher than the derived weight, these figures compare very favorably, indicating that the maximum weight of the flight RTG's will indeed be approximately 82 lbs.

6.4 CONVERTER PERFORMANCE AND ANALYSIS

6.4.1 CONVERTER Q1A PRESSURE DROP TESTS

6.4.1.1 Test Objectives

Pressure-drop testing was conducted on Converter Q1A as part of the carbon monoxide evaluation program. The primary objectives of the test were to evaluate the flow characteristics of the insulation foil basket and the PRD. In addition, the test was designed to determine the effect of removing plugs in the foil basket to allow direct venting of the inner cavity containing the heat source into the dome adjacent to the PRD tube. From this data, a prediction of the inner foil cavity pressure can be made under conditions of CO and He generation rates.

Table 6.3.3-1
MJS/77 Converter Weight

Component	Quantity	Weight - Lbs.	
		Unit	Total
Outer Shell (Including Coating)	1	9.796	9.796
End Enclosure - Fwd	1	1.312	1.312
End Enclosure - Aft	1	1.375	1.375
Mounting Bracket - Fwd	6	.0430	.258
Mounting Bracket - Aft	6	.0395	.237
Bushing	1	.101	.101
Heat Source Support - Fwd	1	.878	.878
Heat Source Support - Aft	1	.878	.878
Preload Screw - Fwd	1	.232	.232
Preload Screw - Aft	1	.205	.205
Bearing Disk	2	.134	.268
Unicouple - Wrapped	312	.020503	6.468
T/E Sealing Screw	312	.00268	.837
C-Seal (Unicouple)	312	.00022	.069
Pressure Dome	2	.727	1.454
Power Out Connector	1	.155	.155
Wafer	2	.0015	.003
Barrier	2	.0015	.003
Insulation - Thermopile	1	7.844	7.844
Insulation - End Caps	2	.940	1.880
Insulation Frame (Includes Hot Foil)	1	1.200	1.200
C-Seal - Vent Line	1	.001	.001
Valve - Gas Management/Handle	1	.258	.290
Tubing - Valve	1	.024	
Feedthru	1	.004	
Fitting	1	.002	
Adapter	1	.002	
C-Seal - Gas Management	1	.001	.001
Electrical Straps	X	----	.587
Rivets	364	----	.360
Screw - Pressure Dome	48	.00528	.253
Screw - Mounting Bracket	24	.0057	.137
Screw - End Enclosure	6	----	.103
Nut - End Enclosure	6	----	.020
Degaussing Loop Ass'y	1	.100	.100
C-Seal - Pressure Dome	2	.058	.116
Other Insulation	X	----	.636
Nut Plate	156	.00278	.434
Self-Aligning Bearing	3	.149	.447
Spacer (Al2O3)	312	----	.349
PRD Assy	1		1.05
RTD & Cable Ass'y	1		.200
Total - Lbs.			40.537

Table 6.3.3-2

MJS/77 Heat Source Weights

<u>Component</u>	<u>Unit Wt.</u>	<u>Qty.</u>	<u>Total Wt.</u>
Fuel Sphere	.563	24	13.513
PICS	.174	24	4.264
Body } Cap }	.283	24	6.792
Retaining Ring	.404	3	1.212
End Crush-Up	.630	2	1.260
Compliance Pad, Inner Layer	.012	5	.060
Compliance Pad, End	.062	2	.124
Sphere Lock	.060	6	.360
Tie Bolt	.026	3	.078
Ablation Sleeve	1.970	1	1.970
Aeroshell, Cylinder	7.531	1	7.513
Lock Ring	.072	2	.144
Lock Screw	.002	2	.004
Spacer	.008	2	.016
Fwd End Cap	1.935	1	1.935
Aft End Cap	1.943	1	1.943
Aeroshell Plug	.024	1	.024
			<u>41.212</u>

Table 6.3.3-3

MJS/77 Converter Shell Assembly Derived Weight

<u>Component</u>	<u>Unit</u> <u>Wt.</u>	<u>Qty.</u>	<u>Total</u> <u>Wt.</u>
Shell	9.272	1	9.272
End Encl., Aft	1.375	1	1.375
Mtg. Bkt., Fwd	.0430	6	.258
Mtg. Bkt., Aft	.0395	6	.237
Pre-load Screw, Aft	.205	1	.205
Sealing Screw	.00268	312	.837
C-Seal (T/E)	.00022	312	.069
Receptacle	.155	1	.155
Thermopile	16.808	1	16.808
End Cap Insul., Aft	.940	1	.940
Gas Mgt. Assy	.291	1	.290
C-Seal (Recpt.)	.001	1	.001
C-Seal (GMA)	.001	1	.001
Nut Plate	.00278	156	.434
Bearing	.149	3	.447
Retainer	.003	1	.003
Nut, Lock	.003	1	.003
Mtg. Bkt. Screw	.0057	24	.137
Screw, Valve	.020	4	.080
Insulation	.636	AR	.636
Pad Insul.	.003	1	.003
Washer	.002	4	.008
Nut, Lock	.003	6	.018
Screw, Hi-Torque	.020	6	.120
Lockwire		AR	.004
Pin-Spring	.002	3	.006
Nut, Lock	.002	1	.002
Rivets	.002	4	.008
Bearing Disk	.134	1	.134
			<u>32.491</u>

6.4.1.2 Test Description

Pressure drop testing of the Q1A converter was conducted from March 27, 1975 to April 11, 1975 in the 8 x 10 thermal/vacuum chamber located in Building 100 at GE-VF. Schematics of the test setup are shown in Figures 6.4.1-1, -2 and -3.

As shown on Figure 6.4.1-2, ion gauges were located both outside the Q1A converter foil basket and inside the foil basket to serve as the primary instrumentation for the test. The ion gauges were calibrated prior to installation, using four vacuum levels. Calibration served to indicate that the gauges were reading properly prior to use and a post-test calibration was conducted for use in data reduction.

The test conditions for which pressure measurements were taken included:

- a) inner foil basket vented through insulation
- b) inner foil basket vented through insulation and one opening in the insulation due to removal of one plug in the end cap blanket (one hole).

Gas flows introduced into the inner foil basket area included 5×10^{-5} scc/sec of helium, 1×10^{-4} scc/sec. of helium and 1×10^{-4} scc/sec of Argon using a calibrated leak.

A total of 14 different test conditions were utilized, as described in Table 6.4.1-1.

The pressure drops recorded with no open holes were very small. The flow rate of 6×10^{-4} scc/sec was used in an attempt to greatly amplify the pressure differences. A new calibrated-leak orifice was added after test 3 to eliminate the possibility of a bad calibration. With the new orifice in place, tests were continued using flows at three flow points used for the calibration. Low pressure levels and low pressure drops still existed. The ion gauges were calibrated in Nitrogen instead of Helium and a correction factor was required which had to be determined after the test through a separate calibration program.

FIG 6.4.1-1
 ΔP TEST SCHEMATIC

OVERALL ASSY SET-UP
SEE 47E303482

Q1A MODIFIED SET-UP

DELTA PRESSURE TEST

FIG. 6.4.1-2

TABLE 6.4.1-1
Q1A ΔP TEST CONDITIONS

TEST NO.	DATE	CONDITIONS*
1	3/29/75	NO OPEN HOLES, HELIUM LEAK @ 6×10^{-5} scc/sec
2	3/29/75	NO OPEN HOLES, HELIUM LEAK @ 1×10^{-4} scc/sec
3	3/31/75	NO OPEN HOLES, HELIUM LEAK @ 6×10^{-4} scc/sec
4	4/1/75	NO OPEN HOLES, HELIUM LEAK @ 1.4×10^{-4} scc/sec
5	4/2/75	NO OPEN HOLES, HELIUM LEAK @ 2.13×10^{-4} scc/sec
6	4/2/75	NO OPEN HOLES, HELIUM LEAK @ 4.5×10^{-4} scc/sec
7	4/4/75	ONE OPEN HOLE, HELIUM LEAK @ 1.4×10^{-4} scc/sec
8	4/5/75	ONE OPEN HOLE, HELIUM LEAK @ 4.5×10^{-4} scc/sec
9	4/9/75	ONE OPEN HOLE, NITROGEN LEAK @ 1.4×10^{-4} scc/sec
10	4/9/75	ONE OPEN HOLE, NITROGEN LEAK @ 7×10^{-5} scc/sec
11	4/9/75	ONE OPEN HOLE, NITROGEN LEAK @ 1×10^{-4} scc/sec
12	4/10/75	ONE OPEN HOLE, HELIUM LEAK @ 4.5×10^{-4} scc/sec
13	4/11/75	NO OPEN HOLES, NITROGEN LEAK @ 1.4×10^{-4} scc/sec
14	4/11/75	NO OPEN HOLES, NITROGEN LEAK @ 7.0×10^{-5} scc/sec

*LEAK RATES BASED ON PRE TEST CALIBRATION OF ORIFICE METER

The tests were repeated for the one open-hole condition using two flow rates. Little change in the pressure level was detected. Following test number 7, a series of transient pressure profiles were obtained to aid in understanding the test conditions. When the steady state measurements were completed, the solenoid valve was closed with gas still entering the converter. The pressure rise was recorded as a function of time. The results of this test served as a check on the orifice meter. The pressure measurements were continued until the pressure increased beyond the 1×10^{-3} torr point. The gas inlet valve was then closed to stop the gas flow and the vent valve was reopened. Pressure decay measurements were recorded as a function of time to serve as a check on the conductance of the system. After the pressure reached a low level, around 1×10^{-5} torr or in the 10^{-6} torr range, the vent valve was closed and pressure measurements were recorded versus time to determine outgassing rates. These transient tests were implemented for specific test conditions.

Tests 9, 10, and 11 were performed using Nitrogen instead of Helium or Argon as the source gas. The rationale was simply to use the gas for which the gauges were calibrated as a means of obtaining reliable data. Flow rates were approximated by correcting the orifice meter calibration curve by the square root of the molecular weight ratio. As expected, the measured pressures were higher than observed with Helium. The transient pressure tests were repeated after each test with Nitrogen, principally to determine the flow rate of Nitrogen for each test condition.

Test 12 was a repeat of test 8 to determine repeatability of the data. A set of transient tests followed.

Tests 13 and 14 were conducted to use Nitrogen gas in the no-open-hole configuration. This test series was determined to be necessary in order to more accurately evaluate the effect of one open hole in the converter foil basket. A set of transient tests followed each of the steady state tests.

6.4.1.3 Test Results

In reviewing the steady state data for the 14 cases, it became apparent that there were discrepancies in the results when helium was used as the source gas. The cause for concern lay in the observation that pressure outside the foil basket (P_{OFB}) should be dependent only on the source gas leak rate, but it wasn't. As one example, Test 4 and Test 7 had the same nominal He leak rate, yet P_{OFB} was nearly three times higher in Test 7 than in Test 4. As another example, Test 8 and Test 12 also had the same nominal leak rate, but P_{OFB} in Test 12 is one-half that of Test 8.

As a contrast, the test results showed much more consistency when nitrogen was used as the source gas. Test 9 results compared to those of Test 13 and showed P_{OFB} to be 1.9×10^{-4} vs. 1.8×10^{-4} . Similarly, Test 10 compared with Test 14 showed P_{OFB} to be 5.9×10^{-5} vs. 6.2×10^{-5} . This excellent agreement is evidence of good instrument sensitivity using nitrogen and pressure levels high enough to overcome the effects of outgassing.

A post-test literature search has indicated that the sensitivity of ion gauges to helium is significantly lower than that for nitrogen (between 5 to 7 times lower). Also, outgassing is present in the converter, as determined by the transient tests, with water vapor as the most likely constituents. Water vapor and nitrogen are equally responsive in ion gauges. A consequence of this is that corrections to the helium pressure readings is difficult at best and would leave a large margin for error. On that basis, the most reliable information regarding the flow properties of the QIA converter comes from the tests using nitrogen. The flow properties for helium and CO source gases can be reliably deduced from the nitrogen flow properties using the known thermodynamic relationships in the free molecule flow regime. The data using helium should not be counted as lost, but rather as less reliable than the data using nitrogen gas flows.

6.4.1.4 Data Interpretation

The purpose of the test was to determine the flow properties of the insulation foil basket. The conductance of the converter in the free molecule flow regime is determined from the expression

$$F = \frac{P_s}{T_s} \frac{\dot{S} T}{P}$$

where $P_s = 1 \text{ atm in Torr}$

$T_s = 200^\circ\text{C} = 293^\circ\text{K}$

$T = \text{Test Temperature}$

$P = \text{Pressure Gradient}$

$\dot{S} = \text{Leak rate in scc/sec}$

$F = \text{Conductance in cc/sec}$

A separate conductance from inside the foil basket to outside the foil basket (F_{FB}) exists from that outside the foil basket to outside the converter. The latter conductance is primarily determined by the conductance of the Pressure Relief Device (PRD) of the converter. Therefore, the conductance from outside the foil basket to the chamber was called F_{PRD} , and the data reduction equations used to determine the conductances are:

$$F_{FB} = 2.594 \frac{\dot{S} T}{P_{IFB} - P_{OFB}}$$

$$F_{PRB} = 2.594 \frac{\dot{S} T}{P_{OFB} - P_{CHAMBER}} \quad 2.594 \frac{\dot{S} T}{P_{OFB}}$$

Table 6.4.1-2 contains the corrected test data for tests 9, 10, 11, 13, and 14. Only the tests using nitrogen as the source gas were considered for data interpretation. Also contained in the table are the calculated values of F_{FB} and F_{PRD} .

TABLE 6.4.1-2

USE OF CORRECTED PRESSURES
USE OF CALIBRATED LEAK

TEST NO.	CONDITION			P _{IFB} Torr	P _{OFB} Torr	F _{FB} cc/sec	F _{PRD} cc/sec
	HOLE	GAS	S scc/sec				
9	1	N ₂	2.22 - 4	5.3 - 4	3.0 - 4	819	628
10	1	N ₂	1.11 - 4	1.7 - 4	0.94 - 4	1229	994
11	1	N ₂	1.67 - 4	3.4 - 4	2.1 - 4	1081	669
13	0	N ₂	2.22 - 4	6.2 - 4	2.9 - 4	569	648
14	0	N ₂	1.11 - 4	2.1 - 4	0.99 - 4	847	950

The resulting values of F_{FB} and F_{PRD} vary according to the flow rate. This observation does not support the theories of conductance being primarily geometry, temperature, and gas molecular weight dependent. The "PRD" in this test was the solenoid valve and its fitting which had the internal configuration shown below:

Davis (Ref. 1) has analyzed the molecular flow through tubes with 90° bends. A comparison between the probability of molecules entering the tube that leave the other end (related to flow in a linear manner) between a straight tube and a tube with a bend is shown below:

$\frac{A + B}{R}$ or $\frac{L}{R}$	Tube with 90° Bend	Straight Tube
2	.52	.51
3	.43	.42
4	.36	.36
5	.31	.31
6	.28	.28
7	.24	.25
8	.22	.23
9	.20	.21
10	.19	.20

The close agreement indicates that in free molecule flow there is no difference between a tube with a 90° bend and an equivalent length straight tube. On that basis, the conductance of the "PRD" can be computed from the relationship for short tubes found in Dushman (Ref. 2); i.e.

$$\frac{1}{F} = \frac{1}{d^2} \left(2.394 \frac{\ell}{d} + 3.184 \right) \left(\frac{M}{83.144 \times 10^6 T} \right)^{\frac{1}{2}}$$

with $d = 1.118$ cm, $\ell = 10.87$ cm, $M = 28$, and $T = 325^\circ\text{K}$,

$F = 1254$ cc/sec.

Compare this value with those found in Table 6.4.1-2. The test values are lower than theoretical and at high flow rates are about one half of this theoretical value.

A second approach is taken to understand the data. The transient data should be analyzed to determine the leak rate into the converter. The relationship to be used is

$$\dot{P}V = \dot{N}KT$$

The expression for $\dot{N}$ can be related to the leak rate at standard conditions by the following

$$\dot{N} = \frac{P_s \dot{V}_s}{KT_s} = (\dot{S})_{STP} \frac{P_s}{KT_s}$$

Substitution produces

$$(\dot{S})_{STP} = \frac{V_{Conv.}}{T} \frac{T_s}{P_s} \frac{dP}{dt}$$

In reducing the test data, $\dot{P}$ is approximated by

$$\dot{P} = \frac{dP}{dt} \approx \frac{\Delta P}{\Delta t}$$

Also $V_{conv.}$ is 37100 cc including the spool piece and accounting for the flat cover used in place of the dome. Therefore, using all of the pertinent values results in

$$\dot{S} = 43.74 \frac{\Delta P}{\Delta t} \text{ scc/sec}$$

The results applied to the transient tests following the steady state test numbers 9, 10, 11, 13, and 14 are presented in Table 6.4.1-3.

TABLE 6.4.1-3
LEAK RATES DETERMINED FOR TEST DATA

TEST	$\dot{S}$ NOMINAL scc/sec	P/ T Torr/sec	$\dot{S}$ scc/sec
9	2.22×10^{-4}	1.396×10^{-5}	6.10×10^{-4}
10	1.11×10^{-4}	4.36×10^{-6}	1.91×10^{-4}
11	1.67×10^{-4}	8.65×10^{-6}	3.78×10^{-4}
13	2.22×10^{-4}	1.30×10^{-5}	5.70×10^{-4}
14	1.11×10^{-4}	4.25×10^{-6}	1.86×10^{-4}

The values of $\dot{S}$ determined from the pressure rise test are higher than the value obtained from the calibration data by factors of 2 to 3. Using these values for S produces the results shown in Table 6.4.1-4.

TABLE 6.4.1-4

CORRECTED PRESSURES USE OF TRANSIENT DATA FOR $\dot{S}$ USING CORRECTED PRESSURES							
TEST NO.	CONDITION			P_{IFB}	P_{OFB}	F_{FB}	F_{PRD}
	HOLE	GAS	S				
9	1	N_2	$6.06 - 4$	$5.3 - 4$	$3.0 - 4$	2236	1715
10	1	N_2	$1.90 - 4$	$1.7 - 4$	$.94 - 4$	2104	1701
11	1	N_2	$3.78 - 4$	$3.4 - 4$	$2.1 - 4$	2447	1515
13	0	N_2	$5.70 - 4$	$6.2 - 4$	$2.9 - 4$	1466	1668
14	0	N_2	$1.86 - 4$	$2.1 - 4$	$.99 - 4$	1420	1592

A review of the data indicates both higher values for F_{FB} and F_{PRD} and much more consistency between values. These observations lead to the acceptance of this data as being representative of the Q1A converter. Acceptance values for F_{FB} and F_{PRD} result in

$$F_{PRD} = 1638 \text{ cc/sec}$$

$$(F_{FB}) \text{ No Holes} = 1443 \text{ cc/sec}$$

$$(F_{FB}) \text{ One Hole} = 2262 \text{ cc/sec}$$

for nitrogen at $325^\circ K$.

The conductance of the hole is obtained by subtracting the F_{FB} without holes from that with the hole, with the result

$$F_{Hole} = 819 \text{ cc/sec}$$

From the pre-test analysis, the hole should have a conductance of 1300 cc/sec. The theoretical conductance is based on a smooth tube whereas the hole in the foil end cap is irregular with a small amount of mismatching of layers due to normal handling of the Q1A converter. Using the conductance of 819 cc/sec and a 0.7 inch hole, the effective diameter of the hole is 0.212 inches. This value is not too far removed from the nominal hole size of .27 inches.

The conductance of the foil basket without the hole is not truly representative of the flight converters. In the Q1A converter, the T/C legs are wrapped with two layers of cord and covered with a flat spacer. In the flight units, the T/C legs are wrapped with three layers of cord and no flat spacers. The flow passages can be expected to be larger for the Q1A converter than the flight units. On that basis the hole should remain for adequate venting of the converter.

REFERENCES

- 1) Davis, D. H., "Monte Carlo Calculation of Molecular Flow Rates Through a Cylindrical Elbow and Pipes of Other Shapes", Journal of Applied Physics, Vol. 31, No. 7., July, 1960.
- 2) Dushman, S., Vacuum Techniques, General Electric Co., 1949.

6.4.1.5 Post-Test Analysis

The test results obtained are useful for forecasting the pressure levels in a flight converter at operating conditions. The test results were used to determine the allowable generation of CO to maintain a desired pressure level by correcting the results for temperature effects. The molecular weight of CO is the same as for N₂ and therefore no correction for that variable is necessary. The analysis considered parametric values for the flight PRD conductance, which needs to be evaluated separately.

The pressure level inside the foil basket is determined from the relationship

$$P = 2.594 \dot{S} \frac{T_{HS}}{F^*}$$

where S = source flow rate of gas

T_{HS} = hot side gas temperature

T_{CS} = cold side gas temperature

and T_O = temperature for which F_{FB}, F_{PRD} are known

$$F^* = \frac{F_{FB} F_{PRD} (T_{HS} T_{CS})^{\frac{1}{2}}}{\sqrt{T_O} (F_{FB} T_{HS}^{\frac{1}{2}} + F_{PRD} T_{CS}^{\frac{1}{2}})}$$

For this analysis the following temperatures were used:

$$T_{HS} = 1308^{\circ}\text{K}$$

$$T_{CS} = 578^{\circ}\text{K}$$

$$T_O = 325^{\circ}\text{K}$$

Also, the following parameters were used for the flow conductances corresponding to a gas molecular weight of M = 28 @ 325°K:

$$F_{FB} = 820, 1440, \text{ and } 2260$$

$$F_{PRD} = 200, 400, 600$$

The partial pressure of helium in the converter is based on an $S = 1 \times 10^{-4}$ cc/sec coming from the IHS. Then

$$F_{He}^* = \sqrt{\frac{28}{4}} \frac{F_{FB} F_{PRD} (869.5)}{18.03 (36.2 F_{FB} + 24.0 F_{PRD})}$$

or

$$F_{He}^* = \frac{5.316 F_{PRD}}{1.5 + \frac{F_{PRD}}{F_{FB}}}$$

Using the expression for F^*

$$P_{He} = \frac{0.0638 \left(1.5 + \frac{F_{PRD}}{F_{FB}} \right)}{F_{PRD}}$$

Table 6.4.1-5 contains values of P_{He} for all combinations of the parameters.

TABLE 6.4.1-5

PARTIAL PRESSURE OF HELIUM IN FLIGHT CONVERTER (TORR)

$F_{PRD} \backslash F_{FB}$	820	1440	2260
200	5.6×10^{-4}	5.2×10^{-4}	5.1×10^{-4}
400	3.2×10^{-4}	2.8×10^{-4}	2.7×10^{-4}
600	2.4×10^{-4}	2.0×10^{-4}	1.9×10^{-4}

The results are also presented in Figure 6.4.1-4. As can be seen, the pressure is much more dependent on F_{PRD} than F_{FB} due to the high values of F_{FB} .

Using the above results as a guide, the partial pressure of CO is computed using $F_{FB} = 820$ cc/sec (valid for the one open hole alone).

$$F_{CO} = \frac{2.01 F_{PRD}}{1.5 + \frac{F_{PRD}}{F_{FB}}}$$

and

$$P_{CO} = \frac{1688 \dot{S}_{CO}}{F_{PRD}} \left(1.5 + \frac{F_{PRD}}{820} \right)$$

Results are presented in Table 6.4.1-6 for $\dot{S}_{CO}$ of 1×10^{-6} and 1×10^{-5} scc/sec and also in Figure 6.4.1-5.

TABLE 6.4.1-6
PARTIAL PRESSURE OF CO IN FLIGHT CONVERTER (TORR)

$F_{PRD} \backslash \dot{S}_{CO}$	1×10^{-6} scc/sec	1×10^{-5} scc/sec
200	1.47×10^{-5}	1.47×10^{-4}
400	8.4×10^{-6}	8.4×10^{-5}
600	6.3×10^{-6}	6.3×10^{-5}

The effect of the F_{PRD} is noticeable but not overwhelming. The best method of keeping P_{CO} down is to reduce the generation rate.

FIGURE 6.4.1-4

6.5 RCA ACTIVITIES

Production proceeded normally throughout the reporting period. Converters F-4 and F-5 were shipped to G.E. on May 12 and June 3, respectively. Converter F-13 completed its thermal processing sequence and its pressure decay test was initiated. The thermopile assembly for Converter Q-2 was completed.

As a result of the F-4 processing anomaly previously reported, a new clamping arrangement was incorporated into the processing station which places the clamps on the outside of the bell jar where it can be tightened after the bell jar is under vacuum. This system was demonstrated and used successfully in the processing of F-5.

A review was conducted of the thermopile-to-shell resistance data accumulated on 18-couple modules. Application of this data to full scale converters (312 couples) shows less than 1/2% power loss at 5 years as a result of thermopile-to-shell leakage resistance.

Eighteen couple modules S/N-4, S/N-5 and S/N-6 were fabricated and submitted to the test group for processing and long-term evaluation testing. These are part of a series of modules which are being fabricated and tested to provide additional reliability data for the LES 8/9 and MJS design using Si_3N_4 coated couples. Half the complement of unicouples in each module have their cold stacks coated with plasma-sprayed alumina. The modules and the planned operating temperatures are as follows:

<u>Module</u>	<u>Hot Shoe Temperature</u>	<u>Status</u>
S/N-4	1135°C	Being rebuilt
S/N-5	1085°C	In Processing
S/N-6	1035°C	In Processing
PCM-19	1135°C	To be fabricated

The following hardware was shipped to JPL:

- 15 - Si_3N_4 coated SiMo hot shoes
- 10 - Uncoated SiMo hot shoes
- 10 - Si_3N_4 coated 78% "N" SiGe legs
- 5 - Si_3N_4 coated 78% "P" SiGe legs

6.5.1 THERMOELECTRIC MATERIALS FABRICATION AND THERMOCOUPLE BONDING & UNICOUPLE FABRICATION

Table 6.5.1-1 shows the status of the thermoelectric materials fabrication, thermocouple bonding, and unicycle fabrication for each converter. During the reporting period, fabrication proceeded normally in all areas with the exception of the first bond operation. As a result of a personnel transfer, bonding yield for 1st bond has been slightly lower than prior experience due to training of the new bonder. Yield is expected to return to normal levels with continuing production.

6.5.2 FOIL INSULATION ASSEMBLY AND THERMOPILE & CONVERTER ASSEMBLY

Delineated below is the status as of 6/27/75 of the foil insulation assemblies and thermopile and converter assembly for each converter worked on during the reporting period.

	<u>Inner Moly Frame</u>	<u>T/P Foil Ins. Ass'y</u>	<u>Foil End Cap Ass'y</u>	<u>T/P Ass'y</u>	<u>Conv. Ass'y</u>
<u>LES 8/9</u>					
F-4 (Shipped)	C	C	C	C	C
F-5 (Shipped)	C	C	C	C	C
<u>MJS:</u>					
F-13	C	C	C	C	C
Q-2	C	C	C	C	-
E-5	C	In Pro	C	-	-
F-6	In Pro	-	-	-	-

LEGEND: C - Sub-Assembly Completed for that Converter
In Pro - Fabrication of that Assembly is in Progress
— - Fabrication Has Not Commenced

TABLE 6.5.1-1 - UNICOUPLE PARTS AND MATERIAL STATUS
(as of 6/27/75)

<u>Good Req./Converter</u>	<u>Matl's T/E</u>	<u>1st Bond</u>	<u>Si3N4 Coating</u>	<u>2nd Bond</u>	<u>Mach. Couple Ass'y.</u>	<u>Cold Stack Ass'y.</u>	<u>Unicouple Ass'y.</u>	<u>Wrapped Unicouple</u>
MJS	478	421	408	342	335	335	323	320
<u>Fabrication Status</u>								
F-13	C	C	C	C	C	C	C	C
Q-2	C	C	C	C	C	C	C	C
E-5	C	C	C	C	C	C	241	227
F-6	C	C	C	C	251	C	-	-
F-7	C	285	268	257	-	-	-	-
F-8	C	-	-	-	-	-	-	-
F-9	In Pro	-	-	-	-	-	-	-
<u>Yield History:</u>								
<u>MJS:</u>								
Planned:		88.1%	96.0%	83.9%	97.9%	95.0%	96.4%	99.3%
Actual:								
F-13		90.5	98.2	92.4	95.4	98.8	96.8	99.3
Q-2		91.6	98.9	91.9	98.2	98.5	96.1	99.1
E-5		87.2	98.8	94.7	99.1	100.0	98.0*	98.7*
F-6		88.2	98.4	97.4	99.6	-	-	-
F-7		79.6*	98.9*	95.9*	-	-	-	-
<u>Overall Inception</u>								
To Date Yields:		84.2%	97.5%	81.0%	95.1%	97.5%	94.3%	99.4%
(Includes LES 8/9)								

LEGEND:

C	-	Complete Complement of Assemblies have been fabricated
In Pro	-	Fabrication in Progress
—	-	Fabrication Has Not Commenced
*	-	Complement Not Completed, Yield to date given

6.5.3 TESTING

6.5.3.1 Module Testing

The modules operating during the reporting period are listed in Tables 6.5.3-1 through 6.5.3-3. Unless otherwise indicated below, all tests are proceeding normally. Test results are shown in the curves of Figures 6.5.3-1 through 6.5.3-26.

The 18 - Couple Converter DC-11 was shipped to G.E. for post test analysis after 5336 hours operation at 1135°C nominal hot shoe temperature. The converter test was terminated at this point because of failure of the graphite heater.

Module PD-2 was cycled to room temperature as a result of a temperature control failure. The control has been replaced and the module has been returned to operating temperature.

Module 18-G was cycled to room temperature as a result of a momentary interruption in the Ion gage circuit power. The module was promptly returned to operating temperature.

Module S/N-3 was cycled to room temperature due to a malfunction of the LN₂ level controller for the vacuum station cold trap. Loss of the cold trap allowed the condensed gases to be released. S/N-3 was returned to operating temperature using a processing cycle.

6.5.3.2 Converter Processing

Converter F-13 underwent most of its processing during the reporting period, having completed the thermal outgassing and operational data point sequence.

TABLE 6.5.3-1 AIR VAC LIFE TEST STATUS - 18 COUPLE CONVERTERS

Device	Device Description	Type of Test	Average Hours Operation	Average Hot Shoe Temp. °C	Average Cold Shoe Temp. °C	Pin	Po	EL	IL	E _{oc}	Status
18-C	18 TBC-3 Design Couples Moly/Astro Foil	Long Life Vac	18,164	1028	308	156.77	7.939	3.476	2.284	6.866	At Operating Temp.
18-D	18 TBC-3 Design Cpls.-Moly/Astro (Ionization Gauge on Shell) Al ₂ O ₃ Barrier (slip-on)	Long Life Vac (Turbo Stat.)	16,825	1023	303	152.82	7.987	3.553	2.248	6.755	At Operating Temp.
18-E	18 TBC-4 Design Cpls.-Moly/Astro Foil; Al ₂ O ₃ Barrier (slip-on) Iridium Heater Sleeve.	Long Life Vac	16,578	1028	306	157.54	7.943	3.499	2.270	6.797	At Operating Temp.
18-G	18 TBC-4 Design Cpls.-Moly/Astro Foil; Al ₂ O ₃ Barrier; Iridium Heater Sleeve removed at 4227 Hrs.	Long Life Vac (Turbo Stat.)	17,078	1028	307	154.34	8.078	3.476	2.324	6.783	At Operating Temp.
18-H	18 TBC-4 Design Cpls.-Moly/Astro Foil.	Long Life Vac	17,580	981	300	140.69	7.210	3.480	2.072	6.365	At Operating Temp.
18-O	Si ₃ N ₄ Coated SiMo H.S. (N-P W/Ti, N-P W/O Ti, all P).	Long Life Vac	10,255	1129	306	188.66	10.378	3.479	2.983	7.506	At Operating Temp.

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TABLE 6.5.3-1 - (CONTINUED)

Device	Device Description	Type of Test	Average Hours Operation	Average Hot Shoe Temp. °C	Average Cold Shoe Temp. °C	P _{in}	P _o	EL	IL	E _{oc}	Status
DC-12A	3 Separate Circuits of 6 Cpls. ea. (1-DC-9 type (2-DC-9 type with 28 mil wrap (3-DC-9 type with 12 mil wrap Isothermally Processed to 315°C.	Long Life Vac	6,029	1135 (nominal)	295	195.37	10.285	3.527	2.916	7.597	At Operating Temp.
DC-13	.450" SiO ₂ Barriers	Long Life Vac	8,864	1035 (nominal)	291	161.27	8.964	3.496	2.564	6.905	At Operating Temp.
SN-1	Like 18-0, except all LES 8/9 Hot Shoes (Si ₃ N ₄ Coated 1st Bonds)	Long Life Vac	7,839	1135 (nominal)*	300	190.78	10.553	3.533	2.987	7.477	At Operating Temp.
SN-2	Like 18-0, except all LES 8/9 Hot Shoes (Si ₃ N ₄ Coated 1st Bonds) includes provision for sampling residual gas.	Long Life Vac	4,268	1089	301	187.74	10.142	3.502	2.896	7.173	At Operating Temp.
SN-3	Like 18-0, except all LES 8/9 Hot Shoes (Si ₃ N ₄ Coated 1st Bonds) Includes provision for sampling residual gas.	Long Life Vac	5,652	1040	299	167.98	8.802	3.486	2.525	6.792	At Operating Temp.

NOTE: Nominal temperature shown where converter has no hot shoe instrumentation

* All hot shoe instrumentation deteriorating. Nominal temperature determined from open circuit voltage.

TABLE 6.5.3-2
AIR-VAC LIFE TEST STATUS

4-COUPLE PCMS

<u>Device Designation</u>	<u>Principle Feature</u>	<u>Test Temp. Hot Shoe</u>	<u>Hours 6/25/75</u>	<u>Status</u>
PCM 1	Q1 Unicouple Design-Control	1035°C	9,645	At Temp.
2	Q1 Unicouple Design-Control	1085	9,647	At Temp.
3	Q1 Unicouple Design-Control	1135	9,645	At Temp.
4	Q1A Unicouple Design-Control	1135	9,644	At Temp.
5	Simulated Unicouple	1135	9,343	At Temp.
6	JB-40 and UT6-ST-Graphite H.S.	1015	9,934	At Temp.
7	JB-40 and UT6-ST-Graphite H.S.	1115	9,343	At Temp.
8	JB-40 and UT6-ST-Graphite H.S. Si ₃ N ₄ Coated	1115	9,343	At Temp.
9	Si ₃ N ₄ Coated N-P W/Ti & W/O Ti SiMo H.S.	1035	9,935	At Temp.
10	Si ₃ N ₄ Coated N-P W/Ti & W/O Ti SiMo H.S.	1085	9,935	At Temp.
14	Same as PCM's 9-10 plus Si ₃ N ₄ Coated Al ₂ O ₃	1135	8,037	At Temp.
15	Si ₃ N ₄ Coated <u>Hot Shoes Only</u>	1135	5,964	At Temp.
16	Si ₃ N ₄ Coated <u>Legs Only</u>	1135	5,983	At Temp.
17(R)	Special Construction to determine Location of Leakage	1135	7,365	At Temp.
18	Si ₃ N ₄ Coated (Interim Facility)	1135	3,522	At Temp.
PD-2	1 Cpl. N-P W/Ti; 3 Cpls. N-P W/O Ti	1035	16,213	At Temp.
PD-3	All P SiMo H.S.	1035	11,343	At Temp.

TABLE 6.5.3-3 - RCA SiGe THERMOELECTRIC MODULE LIFE TESTS - SNAP 17A MODULES

DATE 6/11/75

Module Number	Module Hours Total	Number of Couples	Leg Dia. Inches	Vac. Torr	Nominal T_h °C	Measured T_h °C	Measured T_c °C	Measured ΔT °C	Normalizing ΔT °C	R mΩ per cpl	E_{oc} Mv Per Couple Normalized	P_o mw	% of 500 Hour Po	Couple Hours
MTA4-5	89,791	6	.230	1×10^{-6}	850	849	248	601	606	84.0	261	203	75.2	538,746
MTA7-10	86,641	6	.275	1×10^{-6}	850	850	295	555	606	84.3	346	355	95.2	519,846
MTA8A-9	86,238	4	.275	1×10^{-6}	1050	1052	370	682	606	78.0	333	355	87.4*	423,932
MTA8A-18	85,848	6	.275	1×10^{-6}	825	821	274	547	612	76.0	329	356	87.9	515,088
MTA9-1	86,967	14	.275	Air	325	847	199	648	612	74.3	297	297	88.4	1,217,538

*Adjusted for removal of 2 couples at 39,210 hours.
See May 69 report for details.

TOTAL COUPLE HOURS 3,215,150

REMARKS:

18 CPL. CONVERTERS

18 CPL CONVERTERS RMPR SHELL AND R SHELL-FOIL VS TIME

FIGURE 6.5.3-2

OHMS

18 CPL CONVERTERS NOT PLOTTED (P 200 MA)

	T_H °C	HRS		T_H °C	HRS
DC-2	1135	295	18-F	1085	2844
DC-3	"	2701	DC-13	1035	8864
DC-5	"	2477	SN-2	1085	4268
DC-6	"	1848			
DC-10	"	1645			
18 D	1035	16,825			

18 CPL CONVERTERS

RM00-SHELL AND R-SHELL-FOIL VS TIME

FIGURE 6.5.3-3

IB CPL CONVERTERS R MOD-SHELL AND R-SHELL-FOIL VS TIME

FIGURE 6.5.3-4

19-6 CONVERTER

LEAKAGE RESISTANCE VS. TIME AT TEMP.

18.0 CONVERTER

FIGURE 6.5.3-6

$T_H = 113.5^\circ\text{C}$

DC-12A LEAKAGE RESISTANCE VS TIME AT TEMP

DC-12A RMOD-FOIL IS TIME AT TEMP.

FIGURE 6.5.3-10

SN-1 CONVERTER
LEAKAGE RESISTANCE VS TIME AT TEMP.

HOURS

MOD - FOIL RESISTANCE

DC-13 CONVERTER

FIGURE 6.5.3-14

PERFORMANCE VS. TIME AT TEMPERATURE

NOMINAL $T_H = 103.5^\circ\text{C}$

17

16

15

P_{IN} (WATTS)

10

9

8

P_{OUT} (WATTS)

30

29

28

27

26

T_{OS} ($^\circ\text{C}$)

T_{SHELL} ($^\circ\text{C}$)

HOURS

10

100

1000

10000

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DC-13
LEAKAGE RESISTANCE VS. TIME AT TEMP.

SN-3 LEAKAGE RESISTANCE VS TIME AT TEMP.

5N-3 CONVERTER
PERFORMANCE VS TIME AT TEMPERATURE

FIGURE 6.5.3-17

SN-2 CONVERTER

PERFORMANCE VS TIME AT TEMPERATURE

FIGURE 6.5.3-18

SN-2 LEAKAGE RESISTANCE VS TIME AT TEMP

MOD. FOIL RESISTANCE

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MOD. FRI. RESISTANCE

$T_H = 1135^\circ C$

FIGURE 6.5.3-21

x-x-x PCM 4A INSTRUMENTED
 [] [] [] PCM-4B UNINSTRUMENTED

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PCM-17

R. Cpl. #1 - Foil Layers
VS Time AT Temp.

FIGURE 6.5.3-22

PCM-17

R-CPL #3- FOIL LAYERS
VS. TIME AT TEMP.

TH: 11.35°C

FIGURE 6.5.3-23

OHMS

MOD - FOIL RESISTANCE

MOD-FOIL RESISTANCE

100 1000 10,000

Operating Time - Hours

FIGURE 6.5.3-26

Nominal Operating Conditions

$T_{\text{Hot Shoe}} = 1035^{\circ}\text{C}$

$T_{\text{Cold Shoe}} = 315^{\circ}\text{C}$

All data normalized to nominal conditions

P_o Calculated from

$$P_o = \frac{E_{oc}^2}{4R}$$

Remaining operations include backfilling and aft-end dome installation, the 48-hour pressure decay test, and loading into the shipping container.

Performance of F-13 at the 2400 watt acceptance point, after 48 hours at 2430 watts input and 48 hours at 2400 watts, is shown in Table 6.5.3-4. Performance is compared to specification requirements and to measured performance of earlier converters.

The only anomaly observed during F-13 processing was that both thermopile-to-shell and thermopile-to-foil resistances were lower at high temperatures than on previous converters. This is attributed to the assembly and handling of the converter assemblies during particularly humid weather, with the result that a higher level of water vapor was contained in the converter. Low resistances were in fact observed during the assembly operations, and found to respond to changes in humidity level. To alleviate this problem, additional dehumidifying capacity has been installed in the assembly area.

Converter F-13 was held longer at 2400 and 2430 watts input to allow additional time for removal of water vapor during processing. The converter was held at both 2430 and 2400 watts for 48 hours, the maximum period established in the specification. (Earlier converters have been held for the 24-hour minimum period). Both thermopile-to-foil and thermopile-to-shell resistances increased during these extended periods.

6.5.4 PRODUCT ASSURANCE

6.5.4.1 Reliability

6.5.4.1.1 Major Design Changes - There were no new major configuration changes made during this report period.

6.5.4.1.2 Failure Reports - None

6.5.4.1.3 Next Report Period - During the next report period these events should occur:

Flight Mode F-13 should be delivered to G.E.
MJS Qualification Model Q-2 should be in Thermal-Vacuum Processing.

6.5.4.2 Configuration Management

The following specifications either have been approved for initial use on the MHW ETG Converter or have been revised:

TABLE 6.5.3-4 - CONVERTER PERFORMANCE AT DESIGN CONDITIONS

	<u>F-1A</u>	<u>F-2</u>	<u>F-3</u>	<u>F-4</u>	<u>F-5</u>	<u>F-13</u>	<u>Specification</u>
Power In - Watts	2400.0	2402.6	2400.3	2401.5	2396.2	2402.1	2400 $\pm$ 5
Power Out - Watts	158.2	159.0	159.5	159.2	159.0	158.2	155 minimum
Output Voltage - Volts	30.1	30.1	30.2	30.0	30.0	30.0	30 $\pm$ 1
T/P Shell Resistance - Ohms	15.0 K	14.5 meg *	8.5 K	10.0 K	14.5 K	7.4 K	8 K minimum **
T/P Foil Resistance - Ohms	4.5 K	4.3 K	4.1 K	5.3 K	7.5 K	2.4 K	2 K minimum

* Instrumentation Fault

** As directed by G.E. in NR # 1327, the T/P Shell Resistance limit is being revised to 2K minimum

6.5.4.2.1 Initial Specifications - The following new specifications have been approved:

<u>Spec. No.</u>	<u>Description</u>
RA18B1 Rev. A	Procedure for Mounting the Converter in the Shipping Container
RM5D2	End Cap Foil Insulation Fabrication
RM5E2	End Cap Fibrous Quartz Panel Fabrication
A6E3	End Cap Foil Insulation Assembly
P12S17-32	Formed Metallic Panels
P12R17-32	Metallic Foil Panels
P13P18-32	Fibrous Panels
P13P33	Fibrous Panel
P13P34	Fibrous Panel

6.5.4.2.2 Specification Revisions - The following specifications have been revised through the approval of these ECN's:

<u>ECN No.</u>	<u>Engineering Data No.</u>	<u>Description</u>
969	RQ24A1 Rev. D	Product Acceptance for Silicon Nitride Coating 1st Bond
972	RA6F1 Rev. C	Procedure for Fabrication of Thermopile Assembly, Phase III
974	P11G3 Rev. C	Machined Hot Shoe
975	RG21B1 Rev. E	Preparation for Converter Processing
977	RA13B1 Rev. K	Cold Stack Assembly Fabrication Procedure
978	P12K2 Rev. A	Foil Panel
979	P21A1 Rev. C	Degaussing Loop Wire
981	RA6D1 Rev. E	Procedure for Fabrication of Thermopile Assembly, Phase I
982	RM2C2 Rev. C	Mfg. Thermoelectric Materials by Vacuum Hot Pressing
985	RA6E1 Rev. K	Procedure for Fabrication of Thermopile Assembly, Phase II

<u>ECN No.</u>	<u>Engineering Data No.</u>	<u>Description</u>
986	M4C2 Rev. B	Metallized Alumina Insulator
987	RA15C1 Rev. J	Converter Assembly Fabrication Procedure
990	RG21A2 Rev. F	Converter Processing Procedure
976A	RM5A2 Rev. E	Fabrication of Punched Foil Panels
992	RA18B1 Rev. B	Mounting Converter into Shipping Container
993	RM1B1 Rev. N	Vacuum Casting of Silicon Alloys
995	RA15C1 Rev. K	Converter Assembly Fabrication Procedure
AT(49-15) 3066-1	RG21A2 Rev. G	Converter Processing Procedure

6.5.4.3 Quality Assurance

6.5.4.3.1 Quality Assurance Progress

6.5.4.3.1.1 Prime Converter Assembly - Flight Model F-5 was shipped to G.E. on June 3, 1975.

Flight Model F-13 is in processing. This converter should be shipped to G.E. early in July.

MJS Qualification Model Q-2 is nearing completion of Thermopile Assembly.

6.5.4.3.2 Nonconforming Reports

6.5.4.3.2.1 MRB Actions - Table 6.5.4-1 lists the Nonconformance Reports (NR's) issued during the report period for MRB Authorization to use the noted discrepant items.

6.5.4.3.2.2 Nonconformance Report Sheet (NRS) Summary - Disposition of defective items found at inspection is obtained through approvals contained in Nonconformance Report Sheet (NRS). The summary of items

TABLE 6.5.4-1 - NONCONFORMANCE REPORTS REQUIRING MRB ACTION

MONTH OF MAY 1975

<u>RCA NR #</u>	<u>G.E. NR #</u>	<u>Item</u>	<u>Spec No.</u>	<u>Discrepancy</u>	<u>Disposition</u>	<u>Problem Cause</u>
1313	40901	Metallized Electrical Insulators	P4G2	.020" Dimension Undersize	Use as is	Vendor Problem
1314	43051	Rivets	P19C1	Corners Not Broken	Rework	Vendor Problem
1315	40929	Angle Bracket	P8M3	Surface Oxidized	Rework	Vendor Problem
1316	40930	Thermopile Assembly (E-4/F-13)	A9E2	Replace Unicouple	Rework	Unicouple has has had rise in resistance.
1317	40933	ETG Converter Assembly (F-4)	47J302596G4	EHS T/C Lead #8 Open	Use as is	Unknown
1318	43052	Formed Plate	P8B4	Tab Height of 5/32" is 0.110"	Use as is	Vendor Problem

TABLE 6.5.4-1 (CONT.) - NONCONFORMANCE REPORTS REQUIRING MRB ACTION

MONTH OF JUNE 1975

<u>RCA</u> <u>NR #</u>	<u>G.E.</u> <u>NR #</u>	<u>ITEM</u>	<u>SPEC #</u>	<u>DISCREPANCY</u>	<u>DISPOSITION</u>	<u>PROBLEM</u> <u>CAUSE</u>
1319	43061	ETG Converter Assembly, F-13	47J302594G4	Astroquartz Outer Panel has cuts, holes and framed areas.	Use as is	Excessive handling while vacuum cleaning.
1320	43090	ETG Converter Assembly F-5	47J302596G4	EGS T/C #4 Reads low	Use as is	Connector pin is bent
1321	43097	Inner Moly Frame	A7B3	Dimension across flats	Use as is	Unknown
1322	43098	Formed Plate	P8B4	Dimension of Tab	Use as is	Vendor problem
1323	43213	Foil Panel	P12K2	Workmanship	Use as is	Vendor problem
1324	43212	Pedestal	PLA6	Plating Thickness	Reject for Prime hardware.	Plating rack problem
1325	43108	ETG Converter Assembly F-13	47J302596G4	EGS T/C # 2, 3, & 8 reads low.	Use as is	Unknown

placed on NRS is shown below and in Table 6.5.4-2. These are defective pieces for all causes that must be dispositioned for use, such as, submit to MRB Action, rework, or reject for prime hardware. They do contain rejects from lots that have been accepted or supplier-known rejects that must be submitted since the material was RCA-supplied. Since the lot is dispositioned by defect, a single NRS may have multiple dispositions. Thermopile and Converter Assembly is not included in this summary, since the information is contained in the Fabrication History Logbook for the unit.

Number of NRS's and Their Disposition

<u>Month</u>	<u>No. of NRS's</u>	<u>Submit to MRB</u>	<u>Return to Vendor</u>	<u>Rej. for Prime Hardware</u>	<u>Rework to Spec.</u>	<u>ECN Required</u>
May	103	5	4	94	0	0
June	<u>84</u>	<u>3</u>	<u>5</u>	<u>76</u>	<u>0</u>	<u>0</u>
Totals	187	8	9	170	0	0

6.5.4.3.3 Problem Areas - The metallized ceramic insulators used in the Cold Stack Assembly have had an excessive rejection rate during the report period. The largest reject item was metallizing defects, however, camber and fracture defects were also noted. The body thickness rejects were used with MRB authorization. The remaining rejected insulators are being returned to the vendor to resolve these problems.

Problems reported last period that occurred with F-4 Converter processing have been resolved. All FRB action items for F-4 were implemented. The converter was given a rapid thermal-vacuum reprocessing. The remainder of the processing operations were completed and the converter was shipped to G.E. without any further anomalies.

Discussions were held with Western Gold and Platinum Company (WESGO) to resolve the problems encountered with the metallized ceramic insulators used in the Cold Stack Assembly. A visit was made to their plant by Engineering. The vendor has indicated that he will undertake corrective action to resolve the camber and Metallizing discontinuity problems. During the visit WESGO reported that some of the reject pieces returned to them were made from 99.5% alumina ceramic bodies (AL 99.5); AL300 is required by specification. These had been

TABLE 6.5.4-2 - NRS NONCONFORMANCE SUMMARY BY PARTS

MONTH OF MAY 1975

<u>Item</u>	<u>Dwg. #</u>	<u># Lots Inspected</u>	<u># Lots W/Defects</u>	<u>% of Parts Inspected W/Defects</u>	<u>Problem Areas</u>
<u>Parts</u>					
Rad. Attach. Ass'y.	A12A7	8	2	1.2	None
Cold Stack Ass'y.	A19A8	5	1	1.2	None
Compensator (Tung.)	P1B10	1	1	0.7	None
Compensator (Moly)	P1F5	1	1	5.0	None
Pellets "N"	P1G25	6	6	11.8	Chips
Pellets "P"	P1G26	10	10	18.3	Chips
Segments "N"	P1G27	2	2	20.3	Chips, Fractures
Segments "P"	P1G28	4	4	0.7	None
Pellets (Rough)	P1T1	9	5	35.4	3 Lots Rej. for Resistivity
Pellets (Rough)	P1T2	8	4	0.3	None
Electrical Insulator	P4F3	13	4	1.1	None
Metallized Elec. Insulator	P4G2	4	4	69.8	Camber, Fractures, Metalliz Dimensions.
Mach. Radiator Attach.	P11C2	11	2	0.9	None
Hot Shoes (Rough)	P11G2	7	2	18.0	Fractures
Hot Shoes (Ground)	P11G3	7	4	2.7	None
Hot Shoes	P11G4	7	6	3.8	None
<u>Materials</u>					
Vacuum Cast 78% SiGe	M28A1	3 Compacts Rejected for Low Density			
<u>Unicouple Assemblies</u>		<u>No. Rej. For Prime Hardware</u>			
First Bond	A26A2	31			
Coated First Bond	A30A6	8			
Second Bond	A1C1	18			
Preassembly	A2C1	38	(Diverted for use in Eng. Test Modules)		
Unicouple Assembly	A3H1	14			
Wrapped Unicouples	A8E1	4			

TABLE 6.5.4-2 (CONT.) - NRS NONCONFORMANCE SUMMARY BY PARTS

MONTH OF JUNE 1975

<u>ITEM</u>	<u>DWG. #</u>	<u># LOTS INSPECTED</u>	<u># LOTS W/DEFECTS</u>	<u>% of PARTS INSPECTED W/DEFECTS</u>	<u>PROBLEM AREAS</u>
<u>PARTS</u>					
Radiator Attach. Assembly	A12A7	11	6	6.3	None
Compensator	P1B10	2	2	1.7	None
Compensator	P1F5	2	2	0.9	None
Pellets "N"	P1G25	5	5	20.5	Chips
Pellets "P"	P1G26	4	4	5.6	None
Segments "N"	P1G2	2	2	10.4	Chips
Segments "P"	P1G28	2	2	6.5	None
Pellets (Rough) "N"	P1T1	4	1	1.1	None
Pellets (Rough) "P"	P1T2	5	3	1.5	None
Electrical Connector	P3H1	4	1	0.2	None
Mach. Electrical Insulator	P4F3	17	10	1.7	None
Metallized Electrical Insulator	P4G2	3	3	20.4	Holes in Metallizing Color (white)
Formed Plate	P8B4	2	1	57.1	Dimension
Formed Center Plate	P8B6	3	1	7.6	None
Angle Bracket	P8M3	1	1	0.8	None
Machined Radiator Attachment	P11C2	3	2	0.8	None
Hot Shoe (Rough)	P11G2	6	4	6.0	None
Hot Shoe (Ground)	P11G3	7	6	3.8	None
Hot Shoe	P11G4	5	5	6.4	None
Foil Panel	P12K2	7	1	13.0	Dimension & Dents
Hot Shoe Spacer	P20H1	6	5	4.1	None
Coated Hot Shoe Spacer	P20J3	4	3	3.0	None

UNICOUPLE ASSEMBLIES

NO. REJECTS FOR PRIME HARDWARE

First Bond	A26A2	45
Coated First Bond	A30A6	4
Second Bond	A1C1	3
Preassembly	A2C1	5
Unicouple	A3H1	1
Wrapped Unicouple	A8E1	2

inadvertently mixed at WESGO during a grinding operation prior to metallizing. WESGO identified the possible lots that could be involved with mixed ceramic bodies. RCA is reviewing these lots for mixed product. In the lots discovered to contain mixed ceramic bodies, about 3 to 5% of the ceramic parts were from the AL99.5 body. One of these lots had gone into production. RCA is screening all parts and assemblies from this lot by use of X-ray fluorescence to assure that they contain the proper Cold Stack Assembly ceramic. All Metallurgical Laboratory Archive samples from previous lots are being reviewed to assure no mix-up of ceramics has occurred in any of the other lots used for production.

The Formed Plates used on the Inner Moly Frame that were inspected during this report period had a high reject rate for dimension across the flats. This problem is being resolved with the vendor.

6.5.4.3.4 Quality Audits - The audit performed by G.E. on the MHW Quality system at RCA has been reported in Audit Report #75-8. An audit of the RCA Quality system was conducted by ERDA/DANES and Sandia. A verbal debriefing was made at the conclusion of the audit. The formal audit report is now being written.

6.5.5 CONVERTER DESIGN

6.5.5.1 Design Changes

6.5.5.1.1 Converter Processing Station

As a result of the problem with a loose clamp during F-4 processing as described in the last Bimonthly report, a new clamping arrangement was designed, placing the clamps on the outside of the bell jar where it can be tightened after the bell jar is under vacuum. This system was installed, demonstrated, and used successfully in the reprocessing of F-4 and the processing of F-5. Necessary changes were incorporated in the processing specification to specify use of the new clamp system.

6.5.5.1.2 Tooling and Equipment

The new tooling and fixtures required by the modified configuration for Converter E-5 were designed and released for fabrication. The drawings for the process station were brought up to date.

6.5.5.2 Design Proposals

Design proposals were prepared covering the following items.

- 1) Converter E-5 - G.E. has directed a modified configuration for ETG E-5 which does not include a spool piece. An investigation of the impact of this change on fabrication, processing, tooling, and specifications was conducted, and an estimate of the costs involved in the necessary changes was prepared. Work is proceeding in accordance with the directive.
- 2) Automatic Inert Gas Backfill System - In response to the directives contained in G.E. FRB memorandum of 4/30/75, an investigation of the modification necessary to incorporate an automatic inert gas backfill system on the Converter Processing Station was conducted, and an estimate of the time and costs involved was prepared.
- 3) Oxygen Monitoring System - In response to the directives contained in G.E. FRB memorandum of 4/30/75, an investigation was conducted into the modifications necessary to install an Oxygen Monitoring System for the Inert Gas Backfill of the Converter Processing Station. An estimate of the costs and time involved for the hardware and specification changes was prepared.
- 4) Modified Foil Insulation End Cap - In accordance with direction received from General Electric, a modified Aft end foil insulation end cap was designed to incorporate a hole for escape of gas generated in the heat source cavity. Necessary Process Specification changes are being made. A proposal covering the additional work required was prepared.

6.5.5.3 Specification Modifications

The following specifications were reviewed and revised, as appropriate, in accordance with the continuing effort to reflect actual experience into the specifications:

- RA6D1 - T/P Assembly Fabrication Procedure Phase I
- RA6E1 - T/P Assembly Fabrication Procedure Phase II
- RA15C1 - Converter Assembly Fabrication Procedure
- RG21A2 - Converter Processing
- RA14A1 - Procedure for Fabrication of Inner Moly Frame
- A6E3 - End Cap Foil Insulation
- RA15C2 - Converter Assembly Fabrication Procedure. (This is a new procedure for Q-2, F-6 and Subs).
- RG21A2 - Converter Processing Procedure

In addition, a new specification was issued:

- RA18B1 - Procedure for Mounting Converter in Shipping Container

6.5.6 MATERIAL ANALYSIS AND THERMOPILE CHARACTERIZATION AND TESTING

6.5.6.1 Analysis of Chlorine in Silicon Nitride Coated Process

The determination of the actual level of chlorine in ppm of the silicon wafer standards by the Turbidimetric Method was completed. A series of specially prepared silicon wafers were coated, in the vertical position, for 60, 90 (1st Bond Coating Cycle) and 120 minutes. All of the wafers, 20 per group, were analyzed for chlorine content by X-ray fluorescence. The entire surface of the wafers is scanned and an average X-ray intensity measured as counts/minute, see Figure 6.5.6-1. Four wafers from each group were maintained as Reference Samples for X-ray fluorescence measurements and the remainder were analyzed by the Silver Chloride Turbidimetric Method for actual chlorine level in ppm. The Si_3N_4 coating is dissolved off the silicon wafer and the turbidity resulting from the reaction of silver nitrate with the chloride solution is read on a spectrophotometer. The relationship between chlorine level in counts/minute and ppm is also shown in Figure 6.5.6-1.

Upon establishment of the chlorine levels in the reference standards, all of the archive samples from the initiation of the coating process through May were submitted for X-ray fluorescence measurement, see Table 6.5.6-1. The first group of archive samples, from L-4 thru L-124, were from 8-Couple runs with the wafers coated in the vertical position. This resulted in a heavier silicon nitride coating as compared to wafers coated in 16-Couple runs, which were placed flat on the quartz fixture. This variation in coating thickness results in two levels of chlorine as shown in Table 6.5.6-1. The chlorine level of the two groups, 8-Couple and 16-Couple runs, were statistically analyzed and the distribution plots are shown in Figures 6.5.6-2 and 6.5.6-3.

FIGURE 6.5.6-1 - X-RAY INTENSITY COUNT

TABLE 6.5.6-1 - CHLORINE LEVEL - SILICON WAFER ARCHIVE SAMPLES

<u>Run No.</u>	<u>Wafer ¹ Position</u>	<u>Deposited²</u>	<u>Cl/Count</u>	<u>ppm</u>
L-4	Vertical 8-Couple Run ↓	Somerville ↓	4815	544
L-16			4557	524
L-29			5203	612
L-40			5188	608
L-53			5093	610
L-70			4548	504
L-82			5245	618
L-91			4150	440
L-109			4821	544
L-124			3426	344
L-155	Horizontal 16-Couple Run ↓	Harrison ↓	3061	292
L-224			2906	280
L-240			3191	310
L-246			3454	348
L-252			3650	368
L-258			3535	352
L-264			2831	270
L-270			3889	404
L-276			3427	344
L-282			3836	396
L-288			3216	312
L-294			3600	364
L-300			3827	392
L-306			3329	328

NOTES:

(1) - L-140 1st 16-Couple Run

(2) - L-240 1st Harrison 16-Couple Run

CHART FOR DETERMINING MEAN DISTRIBUTION AND STANDARD DEVIATION

8 COUPLE RUNS

FIGURE 6.5.6-2

PPM CHLORINE

CHLORINE LEVEL IN Si_3N_4 COATED SILICON WAFERS

1	TALLY	2	5	6
X		1	Acc 2	5-4
630				
620	I	1	1	5
610	III	3	5	25
600				
590				
580				
570				
560				
550	I	1	9	45
540	I	1	11	55
530				
520	I	1	13	60
510				
500	I	1	15	75
490				
480				
470				
460				
450				
440	I	1	17	85
430	I	1	19	95

3 TOTAL	10
4 DOUBLE TOTAL	20
σ	$\bar{x}$

To plot points, use for x axis, the values in Column 6, and for y axis, follow arrow on right of box in which the Column 6 number is located

CHART FOR DETERMINING MEAN DISTRIBUTION AND STANDARD DEVIATION

PPM Chlorine

1 X	TALLY	2 1	5 ACC. 2	6 5 ÷ 4 1.25
440				
430				
420				
410				
400	11	2	2	7.1
390	1	1	5	17.9
380				
370	1	1	7	25
360	1	1	9	32.1
350	11	2	12	42.9
340	1	1	15	53.6
330	1	1	17	60.1
320				
310	11	2	20	71.4
300				
290	1	1	23	82.1
280	1	1	25	89.3
270	1	1	27	96.4

3 TOTAL	14
4 DOUBLE TOTAL	28
$\bar{x}$	

FIGURE 6.5.6-3

16 Couple Runs

Chlorine Level in Si₃N₄ Coated Silicon Wafer

To plot points, use for x axis, the values in Column 6, and for y axis, follow arrow on right of box in which the Column 6 number is located.

The mean value for the wafers coated in the horizontal position, Figure 6.5.6-3, is 340 ppm of chlorine. This value is in excellent agreement with electron probe analyses of Si_3N_4 coated hot shoes conducted by BMI (Letter Dr. C. A. Alexander to Dr. J. S. Griffo, July 22, 1974) which showed a level of 340 ± 50 ppm of chlorine in the Si_3N_4 coating. Those shoes were also coated in the horizontal position as were the silicon wafer archive samples. Using the 3 sigma limit with allowance for measurement accuracy of ± 14 percent (± 10 percent for X-ray fluorescence measurement and ± 10 percent for Turbidimetric measurements), the maximum acceptance values of chlorine level in the silicon coated wafers for the two groups are given below:

	8-Couple Runs	16-Couple Runs
Max Chlorine, Level, ppm	850	550

An ECN incorporating the above limits, to the Si_3N_4 Coating Products Specification has been submitted to G.E. for CCB action.

6.5.6.2 Thermopile-to-Shell Resistance Degradation

A review of thermopile to shell resistance data accumulated on 18-Couple Converters was conducted, primarily to answer two questions:

1. Is there any indication that a problem might develop on flight units which would cause significant power loss in the thermopile to shell resistance?
2. Can some of the variations in development of this leakage from converter to converter be attributed to identifiable configuration or testing differences between modules?

No significant power loss is expected due to thermopile-to-shell resistance degradation. The extrapolation of data from 18-Couple Converters operating at 1035°C (Design) hot shoe temperature indicates less than $1/2$ % power loss at 5 years as a result of thermopile-to-shell leakage resistance degradation.

With regard to the second question, in addition to the significant influence of test temperature on test results, better than average leakage resistance results are associated with (A) Si_3N_4 coated couples, (B) devices operated in Turbo pump test stations rather than oil diffusion pumped test stations, and (C) devices with the cold stack insulator protected with Astroquartz yarn and improved microquartz stuffing between couple legs. The Turbo-molecular pumps are used to provide an oil-vapor-free vacuum which is more representative of space vacuum than that produced by oil diffusion pumps, even with continuous LN_2 trapping in the latter. Si_3N_4 coating, Astroquartz wrap over cold stack ceramics, and improved Microquartz stuffing are all included in the flight hardware configuration. Thus, all conditions providing better than average leakage resistance performance are associated with flight hardware configuration or flight operating conditions.

Details of the thermopile-to-shell resistance performance review are presented below.

Data on thermopile-to-shell resistance has been routinely reported in the format of Figure 6.5.3-2. To aid in separating some of the variables, the 1035°C converters have been replotted in a separate graph as shown in Figure 6.5.6-4. Added to the 1035°C plots are reference lines at the bottom of the graph indicating the level of leakage resistance required for 1% power loss and 1/2% power loss. These values are calculated from:

$$P_L = \frac{1}{3} \frac{(E_{cc})^2}{R_L} \quad \text{Where } E_{cc} = \text{Converter Closed Circuit Voltage}$$

$$R_L = \text{Leakage Resistance}$$

$$P_L = \text{Power Lost in Leakage Resistance}$$

This relationship holds for the case where the leakage resistance is uniformly distributed and one end of the electrical circuit of the converter is connected to the case, which is understood to be the condition of use of LES 8/9 and MJS converters. (NOTE: If the electrical circuit were isolated from the case, the power lost in the leakage resistance is

$$P_L = \frac{1}{12} \frac{(E_{cc})^2}{R_L}, \text{ which gives an even lower power loss}).$$

For a nominal 30V, 150 watt output:

$$R_L \text{ 1\%} = \frac{1}{3} \frac{E_{cc}^2}{P_L} = \frac{30^2}{3 \times 150 \times .01} = 200 \text{ ohms}$$

$$R_L \text{ 1/2\%} = \frac{1}{3} \frac{E_{cc}^2}{P_L} = \frac{30^2}{3 \times 150 \times .005} = 400 \text{ ohms}$$

These values are for a full size converter. Adjusting for the 18-Couple Converter -

$$R_L \text{ 1\%} = 200 \times \frac{312}{18} = 3446 \text{ ohms}$$

$$R_L \text{ 1/2\%} = 400 \times \frac{312}{18} = 6933 \text{ ohms}$$

These values have been plotted on the leakage resistance curves of Figure 6.5.6-4.

The 1035°C curves of Figure 6.5.6-4 can be classified into 4 groups -

- (1) Those representing uncoated couples operating in oil diffusion stations (18A, 18B, 18C and 18E).
- (2) Those representing uncoated couples operating in Turbo-molecular stations (18G, 18D).
- (3) Those representing Si_3N_4 coated couples operating in oil diffusion stations (S/N-3).
- (4) Those representing devices with Astroquartz yarn over Cold Stack insulators, improved stuffing between legs, and SiO_2 barrier plates on legs (DC-13). It should be noted that S/N-3 also has been fabricated with the improved couple leg stuffing procedure.

The only identifiable difference in either construction or operation of converters in the first group which would appear to have any effect on leakage resistance performed is the fact that 18A, B and C were initially operated without LN_2 trapping of the vacuum system. This probably accounts for faster initial drop of these three devices. The results of all devices in group (1) can therefore be combined by calculating the resistance at selected operating times of all 4 converters connected in parallel. This in effect gives a single curve for uncoated couples in oil diffusion systems based on a larger sample size than the individual converters.

18 CPL CONVERTERS

RMOD-SHELL AND R-SHELL-FOIL VS TIME

FIGURE 6.5.6-4

The results of the above calculation, (multiplied by 4 to make the resistance level comparable with the single converter tests of 18-G and S/N-3) are plotted in Figure 6.5.6-5. Also on this figure, the graphs for each classification of converters have been extrapolated to 5 years.

Inspection of Figure 6.5.6-5 leads to the following observations:

- (a) Any one of the three classifications plotted yields a circuit-to-shell resistance which may be expected to result in less than 1/2% power loss out to at least 5 years. Since there is no trend established for DC-13 it cannot be extrapolated, but it should be good or better than the others.
- (b) The suppression of vaporization products by the Si_3N_4 coating in S/N-3 results in better leakage resistance performance than that obtained with the uncoated couples.
- (c) The operation of 18-G in an oil vapor free Turbo-Molecular Test Station results in better leakage resistance performance than for converters in oil diffusion pumped stations. This is confirmed by the performance of 18-D.
- (d) The combination of features used on DC-13 appears to provide superior circuit-to-shell leakage resistance performance. These features include:
 - (i) Astroquartz yarn wrapped over Al_2O_3 cold stack ceramic to provide protection from deposits. This feature is included in flight hardware.
 - (ii) Improved stuffing of Microquartz between legs of couples, so that the path for streaming of vaporization products toward the cold stack has higher impedance. This feature is included on flight hardware.
 - (iii) Quartz barrier plates over SiGe legs, intended to provide improved electrical isolation between foil and SiGe couples. This feature is not included in flight hardware - it has been replaced by Si_3N_4 coating. Tests of SiO_2 leg barriers on higher temperature (1135°C) converters showed that while short barriers (.450") as

18 CPL CONVERTERS R.M.C. - SHELL - AND R.SHELL - FAIL VS TIME

FIGURE 6.5.6-5

used on DC-13 improved circuit-to-foil resistance with no apparent degradation of circuit-to-shell resistance, longer barriers (.580") resulted in degradation of circuit-to-shell resistance by channeling vaporization products toward the cold stack insulator. It therefore seems improbable that improved circuit-to-shell performance of DC-13 is due to use of leg barriers.

The flight converters combine the desirable construction features of Si_3N_4 coating, Astroquartz yarn over the cold stack ceramic, and improved Microquartz stuffing with an oil-vapor free environment. Thus performance of flight hardware should be even better from the circuit-to-shell resistance standpoint than that obtained on any of the 1035°C 18-Couple Converters. It can therefore be stated with a high degree of confidence that circuit-to-shell resistance will not result in significant power loss for a 5-year mission.

6.5.6.3 Thermopile-to-Foil Resistance Degradation

An investigation of the thermopile-to-foil resistance behavior of 18-Couple Converter S/N-1 was conducted to determine if an assignable cause could be found for the abrupt stabilization of the resistance after approximately 5000 hours at temperature (See Figure 6.5.3-1). This behavior has not been observed in any other 18-Couple Converter at the particular resistance level, and, especially, has not been observed in 18-0. Similar to S/N-1, 18-0 has Si_3N_4 coated couples and is operated at a hot shoe temperature of 1135°C. Thermopile-to-foil resistance performance of the two converters is therefore expected to be the same. The investigation included a review of the life test data and a detailed comparison of construction features of 18-0 and S/N-1.

The conclusions reached were that the apparent improved performance of S/N-1 is probably due to a combination of:

- (A) Slightly lower hot shoe temperature than 18-0 - not enough itself to account for the different resistance performance and,
- (B) Less streaming of sublimation and reaction products toward the cold end of the uncouples, due to the tighter uncouple wrap and fuller stuffing used on S/N-1 as compared to 18-0. It is possible that the slightly lower hot shoe temperature may result from degradation of the foil insulation thermal properties at a slightly higher rate due to reaction products and sublimates being forced into the insulation at higher temperature levels by the tighter stuffing and wrapping.

If the above suppositions are indeed the cause of the improved leakage resistance of S/N-1 relative to 18-0, then similar performance should be expected from flight converters which include the same features as S/N-1. Verification, however, must await tear-down analysis of S/N-1.

The following paragraphs detail some of the life test data and construction information on which the above conclusions are based.

Constructional Features

The only differences between 18-0 and S/N-1 which have been identified are:

- (1) S/N-1 has Si_3N_4 coated Al_2O_3 hot shoe spacers while 18-0 has uncoated spacers.
- (2) S/N-1 has two sections, one with (3 couple string) and one without (15 couple string) hot shoe instrumentation.
- (3) S/N-1 has all standard hot shoes, while 18-0 has 6 standard hot shoes, 6 all-P SiMo hot shoes and 6 hot shoes with no Titanium shim in the N-P bond.
- (4) S/N-1 has tighter unicouple wrap and stuffing which was instituted for LES 8/9 flight hardware as a result of the streaming of reaction products discovered on DC-8 tear-down analysis.

Feature 1, above, is not considered to be a probable cause of a change in thermopile-to-foil resistance performance, because any reaction between hot shoe spacers and hot shoes would be expected to continue, rather than end near the 5000 hour point.

Feature 2, above, does not appear to be related to the leakage resistance performance, since the leakage of sections with and without hot shoe instrumentation follows the same trend.

Feature 3, above, cannot be evaluated experimentally with respect to the affect on leakage resistance, since the sections of the converter with different hot shoe construction are not isolated from each other for leakage resistance measurements. However, it is difficult to postulate a mechanism by which the variations in hot shoe construction could cause a difference in leakage performance.

Feature 4, above, appears to be the most likely cause of difference in S/N-1 vs 18-0 performance. It is postulated that the tighter uncouple wrap and stuffing on S/N-1 could cause the reaction products to form a partial seal against penetration further down the leg toward the cold end of the uncouples. This could force the reaction products out into the foil in a higher temperature region, thereby accounting for the slightly lower hot shoe temperature observed on S/N-1. The formation of a "Seal" could also account for the shift in the shape of the thermopile foil resistance curve after 5000 hours.

If this is the cause of the observed performance, it can be expected to also be present in flight converters which include the same uncouple wrap and stuffing as used in S/N-1.

Life Test Data

A summary of life test data from S/N-1 and 18-0, covering the period after approximately 5000 hours where S/N-1 shows constant thermopile-to-foil resistance, is shown in Table 6.5.6-2.

The major conclusion drawn from this table is that S/N-1 is operating approximately 7°C cooler at the 7839 point than 18-0. Although the hot shoe thermocouples of S/N-1 indicates an even larger temperature drop, this is inconsistent with a temperature derived from the open circuit voltages of the SiGe couples. It is believed that the W/Re thermocouples of S/N-1 are starting to degrade, and the S/N-1 temperature calculated from open circuit voltage is the best estimate of the actual temperature. These temperatures are shown as the final entries in the S/N-1 columns, and were calculated by assuming that the effective Seebeck ($E_{oc}/\Delta T$) is the same for 18-0 at the same operating time.

TABLE 6.5.6-2 - COMPARISON OF 18-0 and S/N-1 At COMPARABLE TIMES

<u>ITEM</u>	<u>18-0</u>		<u>S/N-1</u>	
Hours	7905	4974	7839	4921
P _o	10.595 W	10.798 W	10.553 W	10.92 W
Δ P _o	-.203 W	-	-.367 W	-
Efficiency	5.67 %	5.71%	5.53 %	5.71 %
Δ Eff	-.10%	-	-	-
T _c Avg. °C	305	306	300	302
T _H (W/Re T/C) °C	1135	1132	1117	1124
R T/P-Foil	.48K	1.7K	2.0K	2.2K
E _{oc} Volts	7.495	7.448	7.477	7.501
Eff. Seebeck (E _{oc} / T)	9030 x 10 ⁻⁶	9017 x 10 ⁻⁶	9152 x 10 ⁻⁶	9152 x 10 ⁻⁶
T _H of S/N-1, Calculated from E _{oc} / T of 18-0 Comparable Time.	-	-	1128°C	1134°C

Based on thermopile-to-foil resistance-versus-temperature data from the cool down of DC-4 after 2700 hours of operation, the temperature difference between 18-0 and S/N-1 is not considered large enough to account for the difference in thermopile foil resistance performance between the two converters.

6.5.6.4 MJS Engineering Modules

During the reporting period, 18-couple modules designated S/N-4, S/N-5 and S/N-6 were fabricated and submitted to the test group for processing and long-term evaluation testing. These are part of a series of modules which are being fabricated and tested to provide additional reliability data for the LES 8/9 and MJS design using Si₃N₄ - coated couples. Half the complement of unicouples in each module has their cold stacks coated with plasma sprayed alumina. The modules and the planned operating temperatures are as follows:

<u>Module</u>	<u>Hot Shoe Temperature</u>	<u>Status</u>
S/N-4	1135°C	To be rebuilt
S/N-5	1085°C	In Processing
S/N-6	1035°C	In Processing
PCM-19	1135°C	To be fabricated

Module S/N-4, which was submitted to processing in the prior reporting period, is being rebuilt. The life test station, in which it was installed, malfunctioned releasing oil vapor into the vacuum enclosure and contaminating the module. Only the unicouples and structural hardware will be reused after suitable cleaning. All other components and assemblies will be replaced.

8.0 PRODUCT ASSURANCE

8.1 CONFIGURATION MANAGEMENT - LES 8/9

During the report period there were 80 Alteration Notices (AN's) processed for GE Specifications/Drawings. There were no ECN's or PCP's during the period.

8.2 QUALITY ASSURANCE - LES 8/9

- The major quality assurance effort on LES 8/9 has shifted to preparation for the Buyoffs of RTG's F2, F3, F4 and F5. Much work effort is required to prepare the configuration and data packages. Since Q.C. heads up the Buyoff Meetings, integration is also required for the preparation of the charts and view-graphs used in the meetings.
- Quality effort was also required in expediting F13 hardware shipped to RCA and through the processing cycle.
- Another major endeavor involves Q.C. support of the Systems Test activities with major emphasis now being placed on the acceptance testing of the F2, F3, F4 and F5 units, Q.C. surveillance and monitoring of the test areas is a 24-hour around-the-clock work effort.

8.3 CONFIGURATION MANAGEMENT - MJS

During this reporting period there were 68 Alteration Notices (AN's) processed for Specifications/Drawings. There were also 13 ECN's received from RCA, while no PCP's were processed.

8.4 QUALITY ASSURANCE - MJS

- The new Quality Plan for MJS has been prepared and is undergoing review by both GE and DANES. It is anticipated that all modifications shall be completed by late July with the final copy due out the first week of August.
- Policy document SI249630 has been revised and is now titled GEMS-420. It is presently in effect under a 30-day preliminary DANES approval.
- Continued Q.C. effort is being expended on the PRD and PMD/PRD components. All design specifications have now been released.

Both components are presently in their Qualification Cycles which should be completed sometime in August.

- C of I packages continue to progress smoothly through the Sandia review cycle.
- All hardware for the Qualification unit (Q2) has been shipped to RCA for eventual processing.
- Charts which summarize the NR activity and status for the months of May and June are shown on Figures 8-1 and 8-2, respectively. Both LES 8/9 and MJS programs are covered on each monthly summary sheet.

FIGURE 8-1 MHW NONCONFORMANCE REPORT ACTIVITY & STATUS - MAY 1975

	TYPE OF NONCONFORMANCE					DISPOSITION				
	DIMENSIONAL	PROCESS	TEST	WORKMANSHIP	MISCELLANEOUS	ACCEPT AS IS	REWORK	RETURN TO VENDOR	SCRAP	TOTAL
LES 8/9										
GE SSO	4	3	20	10		26	10		1	37
RCA	2		6	7		8	7			15
MOUND LABS	1	2	1	1		4	1			5
ALL OTHER SUPPLIERS	4	5	4	8	2	14	3	4	2	23
M. J. S.										
GE-SSO	4	3		5	1	8	1		4	13
ALL OTHER SUPPLIERS	9	3		3	3	14	1	2	1	18
TOTALS	24	16	31	34	6	74	23	6	8	111

FIGURE 8-2 MHW NONCONFORMANCE REPORT ACTIVITY & STATUS - JUNE 1975

	TYPE OF NONCONFORMANCE						DISPOSITION			
	DIMENSIONAL	PROCESS	TEST	WORKMANSHIP	MISCELLANEOUS	ACCEPT AS IS	REWORK	RETURN TO VENDOR	SCRAP	TOTAL
LES 8/9										
GE SSO	1	1	4	9		4	7		4	15
RCA			1	2		1	2			3
MOUND LABS	8	1			2	10	1			11
ALL OTHER SUPPLIERS	1	3	1	4	2	4	3	1	3	11
M. J. S.										
GE-SSO	3	4	1	9		11	3		3	17
RCA	2	2	2			3	2		1	6
MOUND LABS	4					4				4
ALL OTHER SUPPLIERS	7	6		4		14	1	2		17
TOTALS	26	17	9	28	4	51	19	3	11	84

10.0 HARDWARE FABRICATION

1. F13 converter hardware was processed and delivered to RCA for assembly.
2. Q2 and E5 converter hardware is in process in the shops for delivery in the July - August period.
3. Additional review and integration work with Engineering was accomplished prior to issuance of cleanliness specifications for MJS application.
4. Rigid-design PRD vent tube assemblies were fabricated for the first time and vibration testing was completed on them.
5. Support hardware was supplied for Lincoln Laboratory operations involving F2 and F3.
6. The first group of MJS frit vents was fabricated and shipped to MRC.
7. All detail parts for PMD assemblies were completed in this period.
8. RTG conversion hardware was completed as required for F2, F3, and F4.

11.0 ACCEPTANCE TESTING

11.1 ETG ACCEPTANCE TESTING

11.1.1 F-1 ETG

The unit remained in storage in its Converter Shipping Container (CSC) in Building B throughout the reporting period.

11.1.2 F-4 ETG

11.1.2.1 Receiving Inspection Operations

After receiving the F-4 ETG from RCA, initial inspection operations began on 5/13/75 in Building B. Upon opening the CSC, visual examination showed no severe abnormalities; some smudges on the emissive coating and discoloration of the IHS-Gas Management Valve (GMV) were observed.

Measurement of the thermopile circuit resistance yielded 2.08 ohms, which compared favorably with RCA's pre-ship measurement of 2.09 ohms. Isolation measurements at 50 VDC potential yielded greater than 200 megohms.

Cold pressure decay testing was completed on 5/17 and gave a converter leak rate of 0.0 psi/6-hours, showing a very tight unit.

Installation of the RTD instrumentation cable, power output cable and pneumatic flex hoses was completed on 5/19 and the unit was re-installed into the CSC.

11.1.2.2 ETG Disassembly

The F-4 ETG was received in Bldg. 800 on 5/20 and after LAS #1 preparations were completed, the unit was removed from its CSC and installed into the chamber early 5/21. Prior to securing the LAS, the PRD bracket became available and was installed.

The Segment Readiness Review was completed on 5/23, followed by chamber evacuation and argon backfilling and scrubbing operations, which were completed on 5/26.

Forward dome removal was completed on 5/27. Some difficulty was then encountered with removal of the spool piece from the converter case, caused by the rounding off of two of the internal hex's in the cap screws mounting the spool piece to the case. These screws were subsequently loosened with pliers and the spool piece was removed. EHS removal was completed late 5/27. Visual inspection of the converter interior showed no apparent abnormalities.

See Section 11.2.3 for the F-4 RTG operations.

11.1.3 F-5 ETG

11.1.3.1 Receiving Inspection Operations

After receiving the F-5 ETG from RCA, initial inspection operations began on 6/10/75 in Bldg. B. Upon opening the Converter Shipping Container (CSC), visual examination showed some discolorations, scuffs and scratches on the emissive coating. Also, the threads on the outlet port of the IHS-GMV were slightly galled. NR-43211 documented this condition.

Cold pressure decay testing was completed on 6/12 and gave a converter leak rate of 0.0 psi/6-hours.

DC resistance, continuity and isolation measurements were also performed on 6/12. Thermopile circuit resistance measured 2.070 ohms which compared favorably with RCA's pre-ship value of 2.076 ohms. Isolation measurements at 50 VDC potential yielded greater than 10,000 megohms. The RTD instrumentation cable was received from manufacturing and installed on 6/14. Since the flight power output cable for the F-5 unit was not available at this time, a GSE power output cable (Dwg. 47D302428) was installed on 6/17 as a work-around until the prime cable would be available.

The RTG and IHS flex hoses and the PRD bracket were also not available at this time and these were scheduled for a later installation.

The ETG was installed into its CSC on 6/18 and remained in Bldg. B until 6/25.

11.1.3.2 ETG Disassembly

The F-5 ETG was received at Bldg. 800 on 6/25 and after LAS #1 preparations were completed, the unit was removed from its CSC and installed into the chamber late 6/30.

11.2 RTG ACCEPTANCE TESTING

11.2.1 F-2 RTG

As previously reported, the F-2 RTG was placed into storage in Building 800 on 4/25/75. On 5/1 the RTG Shipping Container (SC) containing the F-2 RTG was transferred from the Bldg. 800 storage area to the test area for the retrofitting of new RTG-SC hardware. As the F-2 RTG has the shortest electrical cables of any RTG in the LES 8/9 program, there was some difficulty in mating the shorting module (at the end of the power output cable) and plug saver (at the end of the RTD cable) to the RTG-SC lid. After opening the RTG-SC, new bracketry was added to the underside of the lid to accommodate the shorting module and plug saver, thereby providing an adequate strain relief for the F-2 electrical cables. This addition of brackets proved satisfactory on the worst case condition (F-2's short cables) and is planned for incorporation into all of the RTG-SC's.

Prior to securing the F-2 RTG in the RTG-SC, the self-aligning bearing mounts were marked with their respective Lincoln Laboratory clevis identities. The unit was then installed into its RTG-SC and returned to storage in Bldg. 800 on 5/2.

The F-2 RTG was installed into the ERDA SST van on 5/10 for transfer to Lincoln Laboratory at Lexington, Mass. See Section 11.3 for the F-2 RTG testing at that facility.

11.2.2 F-3 RTG

Vacuum processing in LAS #1 of the F-3 RTG, which as previously reported, began on 4/26/75, ended on 5/3/75 with 179 hours of degassing time. The IHS was then re-pressurized to 10 psia with helium. After

the chamber was backfilled with argon to one atm, the IHS was pressurized to 19 psia for a pressure decay test which yielded an IHS leak rate of 0.71 psi/6-hours. The IHS vent tube coupling nut was retorqued to 80 in.-lbs. and a second short decay test yielded a leak rate of 0.11 psi/1-hour. NR 40897 was then written against this high IHS leak rate. Disposition was received late on 5/4 to torque the IHS coupling nut to 90 to 95 in.-lbs. The coupling was torqued to 94 in.-lbs. and a subsequent one-hour IHS pressure decay test showed no significant improvement in the leak rate. Continuing with FRB disposition, the "voi-shan" gasket at the vent tube coupling nut/feedthrough interface was replaced. Visual examination of the "used" gasket showed no abnormalities. The coupling nut was torqued to 96 in.-lbs. and an IHS pressure decay test was started at 19 psia initial pressure.

Early on 5/5, the forward dome was installed onto the converter case and after six screw torquing sequences, the less-than-2-mil gap was achieved.

At 1300 hours, 5/5, the IHS pressure decay test was completed and yielded a still-high 0.77 psi/9-hour leak rate. The test was repeated and gave a rate of 0.93 psi/8-hours. All of the aforementioned IHS pressure decay tests were with RTG pressure at one atmosphere argon.

Early on 5/6, both the IHS and RTG were pressurized to 20 psia (IHS with helium and RTG with argon) in an attempt to determine if the IHS leak rate was dependent upon pressure gradient. The IHS pressure decay test was run again and yielded a pressure drop of 0.54 psi/3-hours. There was no improvement in IHS leak rate with zero pressure gradient across the IHS. However, this was not conclusive that the IHS leakage path was not within the converter since the helium could still readily leak into the converter's argon atmosphere.

After the above IHS pressure decay test was completed, the external fittings at the IHS vent feedthrough were torqued to 120 inch-lb. These were the feedthrough fitting (itself) and the coupling nut attaching the tube from the IHS-GMV to the feedthrough. The subsequent IHS pressure decay from 0930 to 1640 hours, 5/6, yielded a leak rate of 0.35 psi/7-hours.

Late 5/6, the RTG was pressurized to 25 psia for the start of an RTG pressure decay test. This test ended at 1000 hours, 5/7, and yielded an anomalous 1.01 psi/14 hours leak rate. The RTG was repressurized to 25 psia and the subsequent RTG pressure decay test was completed on 5/8. This test yielded an RTG leak rate of 1.45 psi/24 hours, verifying that the rate was anomalous.

The F-3 RTG was removed from the LAS on the slide tray early 5/9. Weight measurement was completed and indicated 85.61 pounds. This did not include the PRD vent tube, PRD bellows assembly or PMD/PRD assembly which would bring the F-3 RTG flight-configured weight up to 87.39 pounds.

Installation into the RTG-SC began early 5/9 and was completed early 5/10. The F-3 RTG was then installed into the same ERDA SST van as the F-2 RTG and preparations were completed mid 5/10 for transfer to Lincoln Laboratory. See Section 11.3 for the F-3 testing at that facility.

11.2.3 F-4 RTG

11.2.3.1 F-4 RTG Assembly and Processing Operations

The S/N-4 IHS, in its SPC, was installed into the LAS #1 load lock early 5/29. After the SPC dome removal was completed late 5/29, the disassembly of the tripod and valve assemblies and vent tube straightening operation was completed early 5/30.

The IHS was hoisted out of the SPC and after dimensional gauging operations proved acceptable, the ablation sleeve was installed late 5/30. Visual examination of the IHS prior to sleeve installation disclosed only "scorch" marks from accidental contact with insulated gloves.

The IHS was routed to its position over the converter and after establishing IHS/converter concentricity, the IHS was lowered and seated into the converter without incident early 5/31. The forward graphite end cap was seated onto the IHS and the forward end enclosure assembly was installed. Preliminary preloading of the support system was accomplished mid 5/31, and after achieving thermal stabilization, final preloading of 29 mils dial indicator deflection was completed late 5/31. Final support system operations -- preload screw packing, retainer installation and preload screw/bushing lockwiring -- were also completed late 5/31.

IHS vent tube forming, routing and interconnection to its case feedthrough fitting were completed and an IHS gas sample was then obtained early 6/1. After evacuating the IHS to below 1000 microns, it was pressurized with helium to 19 psia for a short pressure decay test which yielded an IHS leak rate of 0.08 psi/one-hour.

Preparations were then made for the RTG processing cycle in the LAS. After the IHS pressure had been reduced to 2 psia, chamber evacuation for the start of processing began at 0200 hours, 6/2. IHS gas taps were taken at 6, 12, 18, and 24 hours after the start of chamber evacuation and every 24 hours thereafter during the processing cycle, which ran until 6/17. Starting after the initial gas tap, the IHS was purged every 2 hours. This purging consisted of an evacuation of the IHS for a one-half period after the 1000 micron point was achieved (usually attaining an ultimate vacuum of less than 400 microns), and then a backfilling with helium to 14.5 psia, except that after the 26th purge cycle on 6/4, the backfilling pressure was changed to 10 psia. This change was made to expedite the operation since there were only two hours between the starts of the cycles.

The initial 200-hour processing was completed on 6/10 with a total of thirteen IHS gas samples having been obtained and forty-two IHS purging cycles having been completed. The chamber then remained under vacuum while analyses were completed to determine if processing should continue.

On 6/11, another IHS gas sample was obtained and then, after a purging cycle had been completed, it was noticed that the IHS leak rate had significantly increased. IHS pressure was monitored during most of 6/12 and showed a leak rate of approximately one psi per hour. This was with the IHS initially pressurized to 18 psia and the outside of the iridium can at vacuum.

Late 6/12, direction was given to again begin IHS sampling and purging operations. These continued for a 48-hour period with the purging frequency at 2-hour intervals and gas sampling at 24-hour intervals. Since the start of processing on 6/2, a total of 70 purge cycles and 19 gas samples had been completed up to the end of this 48-hour period, late 6/14. A difference between the purging operations during this period and those prior to 6/12 was that the IHS was repressurized to only 2.0 to 2.5 psia, rather than 10 or 14.5 psia.

The LAS #1 vacuum processing of the F-4 RTG continued passively through late 6/16, when direction was received to again start sampling/purging operations on the IHS. These operations continued until 0900 hours, 6/17, when the decision was made to terminate the vacuum processing. A total of 76 purge cycles and 21 gas samples on the IHS had been performed over the period 6/2 to 6/17.

After the IHS pressure was increased from 2.5 psia to 10 psia, the chamber was backfilled with argon to one atmosphere and scrubbing began. IHS pressure was increased to 19 psia after the chamber was at one atmosphere. An IHS pressure decay test, with a 4 psi delta across its iridium can and tubulation, then yielded a leak rate of 0.19 psi/65 minutes.

The flight-configured forward dome with PRD was passed into the chamber through the load lock. Dome installation began early 6/19 and after several screw torquing sequences, the specified less-than-2-mil gap at the dome/case interface could not be attained. The discrepant gap ran from 2 to 5 mils.

The RTG was pressurized to 25 psia and an RTG pressure decay test was started late 6/19 which yielded an RTG leak rate of 0.20 psi/6 hours.

The forward dome/case interface was torqued several more times during 6/20 and the maximum gap decreased from 5 mils to 4 mils. Another RTG pressure decay test was started late 6/20 and the result was an improved leak rate of 0.11 psi/6 hours.

The F-4 RTG remained in storage in LAS #1 until mid 6/23, when some hardware necessary for the installation of the RTG into its shipping container was received. This was the RTG-SC lid sling which had been loaned to Lincoln Laboratory for the operations on F-2/F-3 at that facility.

The unit was removed from LAS #1 on the slide tray and routed to the Building 800 floor area where the mating of the PRD tube to bracket took place. Some difficulty was encountered in this mating operation as the running torque on the helicoil inserts in the PRD bracket exceeded the allowable torque on the mounting screws. This was corrected by burnishing of the helicoil female threads with non-prime screws followed by installation of the prime screws. Two of the three prime mounting screws were properly installed to the required 12 inch-lb. torque, but the third had to be torqued to 21 inch-lbs. to seat the screw which was then backed off and re-torqued to the 12 inch-lb. requirement.

The operations of installing the RTG into its RTG-SC began at 2200 hours, 6/23, and were completed at 2100 hours, 6/24, after which preparations were made for transfer of the RTG to Building 400.

11.2.3.2 Center of Gravity and Weight Measurement

The F-4 RTG was transferred to Building 400 early 6/25 and the operations of removal from the RTG-SC were completed late 6/25.

Weight measurement was performed and the result was 86.492 pounds. This did not include the PRD Bellows Assembly or PMD/PRD Assembly which would bring the F-4 flight-configured weight to 88.024 pounds.

Center of gravity measurements were completed early 6/26 and the results were given to design engineering for analysis.

11.2.3.3 Air Performance and Pressure Decay Testing

After weight and CG measurements were completed, the F-4 RTG was mounted on the vibration slip table in preparation for the pre-vibration air performance/pressure decay tests. The unit was interconnected with the Readout Console and Gas Service Cart and preparations were completed for start of the test. After conditions had stabilized with a 30-volt load, the 48-hour test began at 0100 hours, 6/27.

Leak rate for the pre-vibration pressure decay test was an acceptable 0.52 psi/48 hours. However, the output power shortly after the start of the test period was running at only approximately 75 watts, failing to meet the 80-watt minimum requirement. NR 43071 was written to cover this discrepancy in performance.

By the end of the 48-hour performance test on 6/29, RTG output had dropped to approximately 72.7 watts. It was assumed that helium was leaking from the IHS into the converter cavity, thereby increasing foil system thermal conductance and lowering the temperature gradient across the thermopile. This was verified by a gas sample taken on 6/29 which showed a 7.3% helium content in the RTG's argon fill gas.

With RTG output power still falling off due to helium build-up, the load panel in the Readout Console could no longer maintain a 30-volt load on 6/30 and direction was given on NR 43072 to change the load voltage to 26 volts. The 26-volt load was then used for the remainder of testing on this unit in Bldg. 400. As of 2400 hours, 6/30, preparations for the start of vibration testing were completed.

11.3 RTG TESTING AT LINCOLN LABORATORY (LL)

On 5/10/75, F-2 and F-3 RTG's were shipped via ERDA SST van from GE-King of Prussia, Pa., to Lincoln Laboratory, Lexington, Mass., where they were received early on 5/11/75. Although ERDA van temperature problems were anticipated and the van ran out of cooling LN₂ for which a stop had to be made enroute, temperature records from the van indicated the internal temperature never rose above 98°F. This is a perfectly acceptable RTG-SC storage environment. The RTG-SC's were inspected, shipping container and RTG pressures were measured, and the RTG-SC's were then transferred to the LL storage van. Subsequent to their placement in the LL van for storage, the RTG parameters were measured with the Portable Test Unit (PTU). All RTG-SC pressures, RTG pressures, and RTG performance data were normal.

During storage which lasted until 5/31 when the RTG's were transferred to the LES spacecraft system test area, the RTG-SC and RTG pressures were read daily and PTU data obtained weekly. All data was acceptable and is tabulated in Tables 11.3-1, 11.3-2 and 11.3-3. During the storage period, the F-3 RTG-SC pressure was reduced three times, on 5/15, 5/22, and 5/29, in order to maintain the F-3 RTG at + 0.5 psi with respect to the SC. This was necessary because of an excessive leak rate in the F-3 RTG as had been determined at GE prior to shipment.

TABLE 11.3-1

F-2 & F-3 RTG STORAGE PARAMETERS

	5/10	5/11	5/11	5/12	5/12	5/13	5/14	5/15	5/15	5/16	5/17	5/18	5/19	5/20
				11:00	14:25	0900	0900	0900	1600	0900	0900	0900	0900	0900
F-2 SC PSIG	7.9	8.0	7.9	9.7	8.5	8.4	8.5	8.1	8.1	8.1	8.0	8.0	8.3	8.5
RTG PSIG	10.6	10.5	10.5	10.9	10.75	10.6	10.7	10.5	10.6	10.6	10.5	10.5	10.6	10.6
TC ON CYL OF SC	---	---	---	---	147°F	140°F	142°F	134°F	---	131°F	133°F	127°F	133°F	135°F
AMBIENT AIR	80°F	---	---	120°F	117°F	117°F	107°F	98°F	---	99°F	99°F	98°F	101°F	107°F
F-3 SC PSIG	7.6	8.8	8.6	9.15	9.1	8.8	9.0	8.8	7.1	7.2	7.1	7.1	7.3	7.5
RTG PSIG	10.8	10.5	10.3	10.25	10.2	10.0	9.8	9.6	9.6	9.4	8.9	8.8	8.8	8.6
TC ON CYL OF SC	---	---	---	---	143°F	136°F	137°F	129°F	---	129°F	129°F	126°F	131°F	133°F

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Pre-shipment @ GE

OPEN ERDA VAN

OPEN L.L. VAN

CLOSED L.L.
VAN

9.7 PSIG ON F-2 SC
POSSIBLY BAD DATA

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DATA AFTER REDUCING F-3
SC PRESSURE

TABLE 11.3-1 (CONT.)
F-2 & F-3 RTG STORAGE PARAMETERS

	5/21	5/22	5/22	5/23	5/24	5/25	5/26	5/27	5/28	5/29	5/29
	0900	0900	1310	1030	1000	1000	1000	0900	0830	0900	1600
F-2 SC PSIG	8.6	8.1	7.8	8.1	8.5	8.0	8.0	8.3	8.2	8.2	8.1
RTG PSIG	10.8	10.4	10.3	10.5	10.7	10.2	10.5	10.6	10.6	10.5	10.5
TC ON CYL OF SC	145°F	133°F	120°F	133°F	138°F	133°F	129°F	135°F	133°F	133°F	
AMBIENT AIR	109°F	99°F	---	---	108°F	99°F	97°F	101°F	100°F	99°F	
F-3 SC PSIG	7.6	7.2	6.0	6.5	6.8	6.3	6.3	6.6	6.5	6.4	5.5
RTG PSIG	8.5	8.1	8.0	8.0	8.0	7.5	7.5	7.6	7.5	7.2	7.2
TC ON CYL OF SC	140°F	128°F	117°F	129°F	135°F	129°F	126°F	129°F	129°F	129°F	

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CLOSED L.L. VAN

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DATA AFTER REDUCING F-3
SC PRESSURE

DATA AFTER REDUCING F-3
SC PRESSURE

TABLE 11.3-2

PTU DATA RECORD SHEET

RTG Serial No. F-2

PTU	NOMENCLATURE	DATA ENTRIES						
	DATE	5/11/75	5/15/75	5/22/75	5/29/75	5/31/75	6/3/75	6/13/75
	TIME	1215	1600	1400	1710	1045	1610	0900
DMM	GEN VOLTAGE V_L (VOLTS)	0.699	0.710	0.691	0.697	0.684	0.719	0.692
DMM	GEN CURRENT I (AMPS)	7.519	7.489	7.459	7.406	7.400	7.790	7.613
CALC	GEN OUTPUT POWR (WATTS)	5.256	5.317	5.154	5.162	5.062	5.601	5.268
DMM	RTD #1 (BET. +Z & -X) RESIST. Ω	1929	1935	1928	1935	1937	1692	1915
	$^{\circ}\text{C}$	247	249	246	248	249	181	243
DMM	RTD #2 (+X AXIS) RESIST. Ω	1928	1933	1927	1934	1936	1684	1914
	$^{\circ}\text{C}$	246	248	245	247	248	179	242
DMM	RTD #3 (BET. -X & -Z) RESIST. Ω	1933	1940	1934	1941	1943	1668	1921
	$^{\circ}\text{C}$	243	245	244	246	246	173	240
DMM	RTD #4 (AFT DOME) RESIST. Ω	1801	1810	1802	1810	1815	1469	1788
	$^{\circ}\text{C}$	213	215	213	215	217	123	209
DMM	RTD AVG $^{\circ}\text{C}$ #1, 2, & 3	245 $^{\circ}\text{C}$	247 $^{\circ}\text{C}$	245 $^{\circ}\text{C}$	247 $^{\circ}\text{C}$	248 $^{\circ}\text{C}$	178 $^{\circ}\text{C}$	242
DMM	GEN O/C VOLTAGE V_{oc} (VOLTS)	38.04	38.16	37.97	38.18	38.08	37.74	38.02
CALC	$R_I = (V_{oc} - V_L)/I$ Ω	4.966	5.006	4.998	5.061	5.054	4.75	4.93
CALC	$R_L = V_L/I$ Ω	0.093	0.094	0.093	0.094	0.0924	0.092	0.09
	RTG PRESSURE psig	10.5	10.6	10.3	10.5	10.6	STACKED	NOT AVAILABLE
	RTG-SC PRESSURE psig	8.0	8.1	7.8	8.1	8.4	ON F-3	7.0
	IHS PRESSURE psig	VALVE CLOSED					16.14 PSIA	VALVE CLOSED
		ARRIVAL @ L.L.	STORAGE	STORAGE	STORAGE	AFTER XFER TO TEST AREA		PRESHIPMENT TO G.E.

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TABLE 11.3-3

RTG Serial No. F-3 PTU DATA RECORD SHEET

PTU	NOMENCLATURE	DATA ENTRIES						
	DATE	5/11/75	5/15/75	5/22/75	5/29/75	5/31/75	6/3/75	6/12/75
	TIME	1300	1530	1310	1500	1100	1400	0930
DMM	GEN VOLTAGE V_L (VOLTS)	0.716	0.706	0.688	0.685	0.678	0.707	0.705
DMM	GEN CURRENT I (AMPS)	7.680	7.543	7.434	7.339	7.322	7.772	7.750
CALC	GEN OUTPUT POWR (WATTS)	5.499	5.325	5.114	5.027	4.964	5.495	5.460
DMM	RTD #1(BET.+Z & -X) RESIST. Ω	1920	1921	1915	1923	1927	1668	1909
	$^{\circ}\text{C}$	245	245	243	245	247	175	242
DMM	RTD #2(+X AXIS) RESIST Ω	1929	1932	1926	1934	1939	1702	1919
	$^{\circ}\text{C}$	247	248	246	249	250	184	245
DMM	RTD #3(BET.-X & -Z) RESIST Ω	1930	1933	1927	1935	1940	1694	1924
	$^{\circ}\text{C}$	247	246	244	247	248	180	244
DMM	RTD #4(AFT DOME) RESIST Ω	1814	1818	1813	1822	1830	1530	1806
	$^{\circ}\text{C}$	216	215	214	216	219	137	212
DMM	RTD AVG $^{\circ}\text{C}$ #1, 2, & 3	246 $^{\circ}\text{C}$	246 $^{\circ}\text{C}$	244 $^{\circ}\text{C}$	247 $^{\circ}\text{C}$	248 $^{\circ}\text{C}$	180 $^{\circ}\text{C}$	244 $^{\circ}\text{C}$
DMM	GEN O/C VOLTAGE V_{oc} (VOLTS)	36.41	36.11	35.81	35.91	35.82	35.75	37.05
CALC	$R_T = (V_{oc} - V_L)/I$ Ω	4.648	4.695	4.724	4.800	4.800	4.507	4.69
CALC	$R_L = V_L/I$ Ω	0.092	0.094	0.093	0.093	0.093	0.091	0.09
	RTG PRESSURE psig	10.3	9.6	8.0	7.2	7.1	STACKED ON	11.1
	RTG-SC PRESSURE psig	8.6	7.1	6.0	5.5	5.8	F-2	7.0
	IHS PRESSURE psig	VALVE CLOSED					17.25 PSIA	VALVE CLOSED
		ARRIVAL @ L.L.	STORAGE	STORAGE	STORAGE	AFTER XFER TO TEST AREA		PRESHIPMENT TO GE

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On 5/31, the RTG-SC's were transferred in the LL van from storage in Hanger Bldg. 1718 on Hanscom AFB to Lincoln Laboratory (M.I.T.), Bldg. I.

On 6/1, the F-2 RTG was removed from its shipping container, fit-checked with the LL yokes, and stacked to the LES 8 truss. On 6/2, the F-3 RTG was removed from its shipping container and stacked to F-2. On 6/3, cable routing and vent tube installation were initiated. Initial attempts to verify the integrity of the LL vent tubing as connected between the RTG's and the LL GMV were unsuccessful. At first, this was caused by inadvertent piercing of the diaphragms in the LL GMV during rework of their insulation by LL personnel. Next, a tight seal could not be obtained between the connection of the F-2 (inboard) RTG GMV to the LL vent tubing. A flight-backup vent tube was then installed, and it too proved to be defective. A third vent tube was fabricated with GE guidance, inspected, leak checked, and installed. This time, a leak-tight system was produced, and finally, on 6/5, the RTG-GMV's were opened and the pressures of the RTG's were measured and adjusted to 26 PSIA. On 6/5/75, the completed stack of F-2 and F-3 RTG's on the LES 8 truss was turned over to LL personnel for mating to the LES 8 spacecraft and subsequent thermal vacuum testing.

On 6/5/75, the stacked RTG's were mated to the LES 8 spacecraft. Spacecraft thermal-vacuum testing was initiated on 6/6/75, and concluded on 6/9/75. During the LES 8 spacecraft testing, the two RTG's produced 289.0 watts when evacuated by the LL gas service cart. RTG internal pressures were probably no lower than one torr during spacecraft testing.

On 6/10/75, RTG destacking operations were initiated. On 6/11/75, the F-3 RTG was secured in its shipping container. On 6/12/75, the F-2 RTG was removed from the LES 8 truss and installation into the shipping container was initiated. Attempts to verify the leak integrity of the F-2 RTG gas management flex hose attachment to the RTG-SC lid were unsuccessful. The leak was traced to the attachment of the flex hose to the F-2 RTG-GMV. Attempts to effect a seal by retorquing this connection were unsuccessful, and the flex hose was removed in order to attempt to remate. A great deal of force was required to remove the flex hose and once the hose was off, the cause was evident - severely damaged threads (the first 3) on the F-2 RTG-GMV. A remating of the flex hose was judged to be impossible, and a decision was made to install the F-2 RTG in its shipping container without the flex hose installed. Installation of the F-2 RTG into its SC was completed on 6/13/75.

The F-2 and F-3 RTG's remained in storage in the LL system test area until their return to GE via ERDA van on 6/16/75 and 6/18/75, respectively.

11.4 F-2/F-3 RTG ACTIVITY AFTER SYSTEM INTEGRATION TESTS AT LINCOLN LAB

11.4.1 F-2 RTG

11.4.1.1 Receiving from Lincoln Lab

The F-2 RTG was received from Lincoln Laboratory, Lexington, Massachusetts, at Bldg. 800 on 6/16/75, removed from the ERDA SST van and secured in the Bldg. 800 storage area without incident.

As reported in Section 11.3, the threads on the RTG-GMV had been damaged at Lincoln Lab and it was not possible to interconnect a flex hose between the RTG and its pressure gage on the shipping container lid. Although the RTG pressure measurement could not be made at the GE receipt, it was believed that the RTG internal pressure had not degraded. This premise was based upon the historically low leak rate for this unit and the fact that shipping container pressure was holding properly (not increasing due to RTG in-leakage).

11.4.1.2 Inspection of Damaged RTG-GMV

The F-2 RTG remained in storage in its RTG-Shipping Container (RTG-SC) until 6/27, when the unit was transferred to the Bldg. 800 test area. On 6/28, the RTG was hoisted out of the RTG-SC and while suspended from the RTG-SC lid, the damaged threads on the RTG-GMV were inspected and an assessment made as to practicality of reworking the valve.

A decision was made to attempt salvaging the valve. The RTG was again secured into its RTG-SC and placed into storage while preparations were made for the valve rework operations.

11.4.2 F-3 RTG

11.4.2.1 Receiving from Lincoln Lab

The F-3 RTG was received from Lincoln Laboratory, Lexington, Massachusetts, at Bldg. 800 on 6/18/75, removed from the ERDA SST van and secured in the Bldg. 800 storage area without incident.

13.0 GROUND SUPPORT EQUIPMENT

13.1 RTG SHIPPING CONTAINERS

F4, F5 and F13 RTG Shipping Containers were completed through the fabrication and assembly cycle. Only minor modifications and C of I acceptance remain to be accomplished on these units.

The F13 shipping container was shipped to JPL for walk-through purposes. It will be returned to GE-VF for F13 assignment.

13.2 STORAGE AND PROTECTION CONTAINERS

Modification of the SPCs to the MJS configuration was begun and is scheduled for completion to support MRC schedule requirements.

13.3 LOADING AND ASSEMBLY STATIONS

13.3.1 LAS #1

The processing of the F3 RTG, reported on during the last reporting period, was completed on May 3rd and the RTG was fitted with its forward dome by May 5th.

On May 21st, the F4 ETG was installed in LAS #1, and on May 22nd the PRD bracket was installed on the converter with the LAS open. A partial vacuum was pulled on the chamber on May 23rd to secure its contents, and the building was secured for the weekend.

Evacuation of LAS #1 was started at 2400 hours on May 25 and the backfill was started at 1515 hours of the following day. On May 26th at 2400 hours work was started on the disassembly of the F4 converter.

On May 28th, during a loadlock pass, some difficulty was encountered in closing the loadlock rough valve. After cycling the valve several times a successful "seating" of the valve was obtained. Subsequent investigation into the problem revealed that during the shift preceding the loadlock pass, Varglas sleeving, removed from the converter, was dropped into the loadlock. When the loadlock pass was made this material, which also included plastic bags, was sucked into the pumpout line and loadlock rough valve, preventing its full closure. The valve was removed from the LAS on May 29 and disassembled and cleaned. The valve

from LAS #2, which had been prepared prior to the removal operation, was installed in LAS #1 to minimize the down time. Purity levels in LAS #1 were maintained, as the changeover was effected with the loadlock isolated from the main chamber area. The change was completed in 45 minutes and F4 loading operation was resumed.

On June 1, F4 RTG processing was started in LAS #1 and continued until June 17th.

On June 6th, a 20-second power outage occurred in Building 800 and although vacuum (1.8×10^{-6} Torr) was restored in less than 30 minutes (after chamber pressure had risen to 1 micron) an area of concern was identified. The problem exists that we are unable to read chamber pressure during periods of power failures as the emergency power source only provides emergency lighting. This problem will be corrected as emergency power will be supplied to extend our capability in this area.

The F4 RTG was removed from LAS #1 on June 23rd.

On June 25th, a vacuum integrity check of LAS #1 was completed and the following day a leak check of the internal pneumatic lines was performed. Replacement of all valve seats, internal to the LAS, was made and a leak check was again performed to verify the integrity of the rework.

13.3.2 LAS #2

During June it was discovered that a mounting fixture (Drawing 303522) for the RTG shield had been omitted from the updating list for LAS #2; in addition, the latest modification for the work table (used in the event that the IHS vent tube must be reflared) was not incorporated to the fixture on hand. These omissions were corrected by the end of this reporting period.

No additional activity on LAS #2 occurred during this reporting period.