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BI-MONTHLY PROGRESS REPORT

CONTRACT E(49-15)-3076

CONTRACT E(49-15)-3066

MULTI-HUNDRED WATT RADIOISOTOPE
THERMOELECTRIC GENERATOR PROGRAM
LES 8/9 PROGRAM
MJS PROGRAM

MASTER

Period from 1 September - 31 October 1975

prepared for:

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

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Approved by:

C. W. Whitmore
Program Manager
LES 8/9 Program

Approved by:

G. Drenker
Program Manager
MJS Program

Approved by:

E. W. Williams
Manager
Nuclear Programs

SPACE DIVISION

P O Box 8661 • Philadelphia, Penna 19101

GENERAL ELECTRIC

1 SEPTEMBER 1975 TO 31 OCTOBER 1975

BI-MONTHLY PROGRESS REPORT

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1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This bi-monthly progress report covers significant activities performed or monitored by the General Electric Company on the MHW-RTG Program during the months of September and October 1975. The report includes work on both the LES 8/9 and MJS contracts in the areas of safety, design, development, integration with ERDA and associate contractors, product assurance, hardware fabrication and acceptance testing.

1.2 SUMMARY

The following summarizes some of the more significant activities for the period which are detailed in subsequent sections of this report.

A. Safety

- The Safety Analysis Report for MHW-IHS Operations at GE/VFSC for the MJS Program, GEMS-422, was approved by ERDA/Operational Safety in October.
- The MHW Radiological Protection Program plan, GEMS-409, Revision C, was prepared to reflect new ERDA standards for radiation protection per Manual Chapter 0524 plus MJS design changes.
- The MHW thermal vacuum test facility in Building 300 at GE-VF is being modified to satisfy ERDA/ALO Minimum Radiological Safety Criteria and other safety requirements.
- The first MJS Radiation Safety Training Class was held, with 60 persons in attendance.
- Modifications to facilities, equipment and procedures are being implemented to minimize personnel radiation exposure on the MJS program during the following operations: Load and Unload RTG from SC, Mass Properties measurements, Dynamic Testing, Load SPC into LAS, and RTG Assembly.

B. Systems

- Comments were received from SNS, Sandia and JPL on the four top GE/MJS specifications and AN's to these specs. are being prepared to reflect these comments.
- The fourth revision to the Lincoln Lab. Source Control drawing and interface parts list was reviewed by GE and comments were provided to LL. Final approval is expected shortly.
- RTG/ETG Operations and Maintenance Handbook, GEMS-421, was published in October.
- A number of JPL interface and requirements specifications and drawings were reviewed and commented upon during the period.
- An updated Safety Test Plan was prepared and forwarded to ERDA for review and approval.
- The Final Reliability Assessment Report for LES 8/9, GESP-7120, was issued.
- JPL-supplied RTG limit load data was evaluated and critical load conditions were identified.

C. Isotope Heat Source

- Several design changes were incorporated in applicable drawings to provide increased structural margin in the ablation sleeve.
- A special fixture was designed and fabricated to eliminate a possible interference fit and resulting deformation during bakeout of the ablation sleeve/aeroshell assembly.
- PISA vent testing continued at LASL with fueled specimens operating at conditions simulating those of LES 8/9 and MJS.
- A study of possible GIS-thread sealing methods was terminated before completion.
- Gas samples from the Q-2/IHS at ML/MRC indicated that the middle 8-pack contained residual H₂O from exposure during storage.

- Studies by BMI verified that the revised bakeout schedule for the T-50 GIS material (36 hours at 1500°C under $\leq 3 \times 10^{-4}$ Torr) was also adequate for the other carbon parts.
- 13 GIS's destined for the F-6 IHS were unacceptably contaminated by water from a failed cooling line in the ML/MRC vacuum outgassing furnace.
- Thermal stress analyses were carried out on the MJS end cap using several support conditions and times of re-entry.
- Tests were carried out to determine the effects of bake-out and testing methods on tensile strength measurements of graphite material samples.
- Thermal analyses were conducted to provide a summary of converter and IHS temperatures under a variety of conditions that may be encountered during assembly, test and operation.

D. Converter

- 18-couple module testing was continued to investigate the relative performance and long-life benefits to be gained from Si_3N_4 coating and other couple design changes.
- A plan was formulated for the investigation of the causes of resistance degradation between the thermo-electric circuit and the outer case.
- Selected components from test module 18-I were utilized in electron probe and x-ray diffraction analyses of coatings.
- Temperature limits were established for the LES 8/9 RTGs at lift-off.
- Vibration and shock spectra for the PRD Bellows assembly were developed, based on the dynamic test requirements of the MJS mission.
- A procedural modification was developed for installation and checkout of the RTG/LL gas management system at the Cape to accommodate the excessive leakage exhibited by the F4 gas management valve.

- An extensive investigation was conducted to determine the cause of a high CO generation rate during LAS processing of the F4 heat source.
- The E5 Converter Assembly and F6 Thermopile Assembly were completed at RCA. Fabrication in all other areas proceeded with no major problems.

E. Product Assurance

- 111 AN's and 6 ECN's were processed.
- Pre-shipment buy-off reviews were completed on the F3 and F13 RTGs.
- 206 Non-conformance Reports (NRs) were prepared and dispositioned.

F. Hardware Fabrication

- Converter hardware for E5 was processed and delivered to RCA.
- Converter modification activity was completed on F1E and continued on Q1A.
- Modification of SPC's from LES 8/9 to MJS configuration continued.
- Final modification of LAS fixture hardware was accomplished.

G. Acceptance Testing

- Conversion of the F1 ETG to the F1E configuration was started during the reporting period.
- The F2 RTG completed OA vibration testing, post-vibration air performance/pressure decay tests, thermal vacuum testing, and post-T/V air performance/pressure decay tests, after which the unit was shipped to MRC on 9/15/75 via ERDA SST van.
- After a damaged RTG-SC vent valve and a leaking IHS-GMV penetration fitting were replaced, the F3 RTG was subjected to the following tests: Pre-vibration air performance/pressure decay, OA vibration, post-vibration air performance/pressure decay, thermal vacuum, and post-T/V air performance/pressure decay. The unit was shipped to MRC on 10/8/75 via ERDA SST van.

- F4 RTG remained in storage at MRC.
- F5 RTG was shipped to MRC on 9/8/75 via ERDA SST van.
- The S/N-1 IHS was installed in the F13 converter, and the resulting F13 RTG was subjected to the following operations: vacuum processing in the LAS including IHS gas sampling, pre-vibration air performance/pressure decay test, OA vibration test, post-vibration air performance/pressure decay test, thermal vacuum performance testing and post T/V air performance/pressure decay testing. The F13 RTG was then used for a fit check with the Lincoln Lab fixture and clevis.
- After installation into its RTG-SC, the F13 unit was used in a system gas exchange operation in which the argon fill gas in the RTG was replaced with xenon. An air performance test was performed, during which trial PMD and PRD bellows installations were made. After the air performance test was completed, another system gas exchange was performed in which the xenon was replaced with argon in the RTG and helium in the IHS.
- The F13 RTG was shipped to MRC on 10/15/75 via ERDA SST van.

3.0 SAFETY

3.1 OPERATIONAL SAFETY

3.1.1 MJS Ground Safety Analysis Report

The Safety Analysis Report of MHW-IHS operations at GE/VFSC for the MJS Program (GSAR, GEMS-422, dated 8/29/75) was approved by ERDA/Operational Safety in October 1975. In response to ERDA/ALO Operational Safety comments, the revisions transmitted by GE letters to J. J. Lombardo from R. E. Clayton dated October 1, and October 8, 1975 will be incorporated in the revised MJS-GSAR.

3.1.2 MJS Operational Analysis

In response to ERDA/SNS letter dated October 1, 1975, J. J. Lombardo to E. W. Williams concerning MJS Operations Analysis Support, F. J. Witt has been designated as the team member to coordinate MJS operations analysis activities on behalf of GE. He will be supported in this endeavor by R. E. Clayton, Mgr., Systems Engineering and Safety.

3.1.3 MHW Radiological Protection Program

The MHW Radiological Protection Program plan was revised for the MJS Program (GEMS 409, Rev. C, October 1975). This revision reflects the implementation of the revised ERDA Manual Chapter 0524, Standards for Radiation Protection, which reduces the allowable radiation exposures to personnel and requires that exposures are limited to the lowest levels technically and economically practicable. The normal and emergency procedures for handling the MJS IHS and RTG have been revised to reflect the MJS design changes and modifications to the RTG assembly and test operations.

3.1.4 Building 300 Long Life Lab Facility Modification

The MHW Thermal Vacuum Facility in Building 300 is being modified to accomplish the following:

- Satisfy ERDA/ALO Minimum Radiological and Criticality Safety Criteria (which, among other things, requires appropriate filtration of all air exhausted from an area in which a capsule, heat source or system is being used or stored).
- Reduce the probability of false plutonium alarms due to radon and daughter product activity.
- Improve the capability for discriminating between plutonium and radon gases and particulates.

To insure safe MJS/RTG test operations in the Long Life Lab, a HEPA-filtered ventilation system is recommended. The proposed specifications for this facility modification are as follows:

- 1 - 2500 cfm exhaust fan at 3 in. water to the outside of Building 300.
- 2 -- Dual HEPA filter system.
- 3 - Ventilation ducting to:
  - a) exhaust of roughing pumps
  - b) exhaust of turbomolecular/rotary vane pumps
  - c) provide cross flow in entire Long Life Lab (no dead spots).
- 4 - Wall to roof at second bay, so that air conditioning system will be contained in second bay.
- 5 - Wall and roof sealed along perimeter of Long Life Lab and other required areas to provide a leaktight room.
- 6 - Negative differential pressure of 0.1 to 0.2 in. water between Long Life Lab and rest of Building 300.
- 7 - Photohelic gages across primary and secondary filters.
- 8 - Sampling lines at exhaust of roughing pumps and turbomolecular/rotary vane pumps.
- 9 - Sampling lines across HEPA filters for particulate efficiency tests.
- 10 - Design HEPA filters for easy replacement.
- 11 - Modification must be completed and HEPA filter particulate efficiency tested by February 1976.
- 12 - Double Door

3.1.5 Radiation Safety Training

The first MJS Radiation Safety Training class was held on October 30, 1975 for approximately 60 test personnel. The lecture was based on the revised Radiological Protection Program (GEMS 409, Rev. C dated October 1975). A second class will be held in November to complete the MJS training.

3.1.6 Implementation of Minimizing Radiation Exposure On MJS Program

Positive steps are being taken to minimize personnel radiation exposure on the MJS program. The detailed changes and the status of implementation of each change are discussed in the following paragraphs.

In Building 800, modifications have been made and are being used which are contributing to lower radiation exposures. A 40 x 10 foot personnel trailer is parked alongside Building 800 to the left of the entrance. This trailer contains the following:

- a - desks
- b - chairs
- c - closed circuit TV of Bldg. 800 test area
- d - intercom to Bldg. 800
- e - telephone
- f - toilet and sink
- g - coffee dispenser

The primary purpose of the trailer is to provide a facility for visitors and non-essential personnel so that test operations will be completed with the fewest number of personnel in the radiation area.

Podiums are being used at all test locations so that the test conductor can follow the SI and direct test operations remote from the IHS or RTG. The test conductors also remind test personnel step back from the IHS or RTG when task is completed and to avoid loitering in radiation areas.

The MHW/MJS Program Office will schedule delivery of IHS's to as close as practicable to the RTG assembly need date so that radiation exposures during storage will be minimized. MJS SI's are being scrutinized for changes which will effectively reduce radiation exposures.

For example:

1. In SI-249638, "IHS Receiving, Storage and Shipment" the IHS gas taps will be performed every 6 months instead of monthly as they were on the LES program. Monthly requirements on the LES program were related to concerns over CO problems, which have been alleviated on the MJS program by improved bakeout and handling procedures.
2. In SI-249638, the Gas Service Cart readiness will be performed before the IHS-SC is moved from the storage area to the test area.

3. Portable shielding will be used during more operations.
4. In SI-249269 the gas tap prior to loading the SPC into the LAS will be eliminated. Gas tap will be made in the LAS prior to removal of the EPC lid.

The specific modifications and their status which will result in reductions in radiation exposures for the MJS test operations are indicated in Table 3.1-1.

TABLE 3.1-1. MODIFICATIONS TO REDUCE RADIATION EXPOSURES

OPERATION	MODIFICATION	STATUS
Load and Unload RTG from Shipping Container	A-1 RTG retention pin has been re-designed to facilitate faster and easier insertion and removal. Pin diameter has been reduced 2 mils, surface finish improved and material has been changed to titanium to reduce galling potential.	A-1 available for use beginning with Q2 operations. GE Drawing 47B303671.
	A-2 Internal Shorting Module (G4) removal/installation operations have been modified to significantly reduce exposure time by providing a longer power cable and performing operations remote from RTG with cable disconnected.	A-2 GE Drawing 47D303500 Procedures have been modified.
	A-3 RTG attachment to Handling Sling has been modified to replace Stacking Adaptors with clamps.	A-3 Modified RTG attachment to Handling Sling successfully demonstrated on Oct. 7 with LES F-3. GE Drawings 47E303643, 47J302959, TR-1E45-0343 dated 10/6/75. Estimated 300 to 400% reduction in radiation exposure.
	A-4 For storage and interplant transfer of RTG Shipping Container only 12 of the 48 lid bolts will be used to provide pressure and seal requirements. 48 lid bolts will be used in transfer to and from Building 300.	A-4 SI-249639 and SI-249640 are being changed; revised procedures will be implemented on Q2.
	A-5 The gas management gage covers shall be positioned into place and one cover bolt installed finger tight on each cover instead of torquing down all cover bolts.	A-5 SI-249639 and SI-249640 will include this change.

TABLE 3.1-1. MODIFICATIONS TO REDUCE RADIATION EXPOSURES

OPERATION	MODIFICATION	STATUS
Load and Unload RTG from Shipping Container (continued)	A-6 The orientation of the lid to cask will be marked to provide a more visible means to aid the guide pin locations.	A-6 Change in process; drawing due 12/1/75.
	A-7 The angle bracket for the shorting module on the top of the lid is being modified to provide vertical access to switch cover fasteners.	A-7 Change in process; drawing due 11/15/75.
	A-8 GE is evaluating the use of an air cushion cart for an RTG Shipping Container for movement within a test facility.	A-8 SI-249639 and SI-249640 will include this change.
	A-9 Pressure transducers are being proposed to monitor RTG Shipping Container and RTG pressures when installed in the Shipping Container.	A-9 Proposal in preparation 10/24/75.
	A-10 An in-line silver membrane filter is being installed inside the RTG Shipping Container between flexible gas hose quick disconnect and lid of Shipping Container. RTG radiological gas samples will be less frequent due to reduction in requirements for gas samples related to CO concerns.	A-10 GE drawing 47E303339 for reworked LES 8/9 units, GE drawing 47J303322 for new units, also SI-249639.
Mass Properties	B-1 A new mass property fixture design is being proposed to improve CG accuracy and to reduce radiation exposure.	B-1 Proposal in preparation.
	B-2 CG measurements will not be made on Q-2 due to elimination of requirement by user.	B-2 SI-249640 will include this change.

TABLE 3.1-1. MODIFICATIONS TO REDUCE RADIATION EXPOSURES

OPERATION	MODIFICATION	STATUS
Dynamic Testing	C-1 See A-3 above.	C-1 See A-3 above.
	C-2 Elimination of IHS outer clad reduces number of radiological gas samples required since IHS vents directly into RTG cavity.	C-2 SI-249640 will include this change.
	C-3 Flight RTG's will be vibrated from pad end. Therefore, RTG will be mounted to shaker head when attached to Shipping Container lid. Handling sling is not required since RTG doesn't have to be inverted.	C-3 SI-249640 will include this change.
Load SPC into LAS	D-1 An EPC radiological sample will not be taken before the SPC is loaded into LAS. An EPC sample will be taken inside the LAS prior to disassembly of lid.	D-1 SI-249639 will include this change.
	D-2 The SPC flange has been modified to eliminate the need to insert shims between flanges prior to insertion into the LAS.	D-2 GE Drawing 47J303316.
RTG Assembly	E-1 Because of MJS design differences from LES 8/9, radiation exposures are expected to be reduced due to following: a. No IHS vent tube bending or connecting to RTG feed-through operations. b. No IHS pressure decay test. c. No ablation sleeve gaging and installation operations. MJS ablation sleeve installed at MRC.	E-1 LAS ready for MJS operations by time of Q2 IHS receipt.

TABLE 3.1-1. MODIFICATIONS TO REDUCE RADIATION EXPOSURES

OPERATION	MODIFICATION	STATUS
RTG Assembly (continued)	d. MJS IHS lifting operation simplified. e. Vacuum processing time for flight RTG's will be reduced from 200 to less than 72 hours due to improved bakeout of graphitics at the component level.	

4.0 SYSTEMS

1. Comments on the four top level GE/MJS Specifications (System Spec., Environmental and Test Requirements Spec., RTG Spec. and ETG Spec.) were received from SNS, Sandia and JPL. To the extent possible, all comments will be incorporated into AN's on the subject specs. Where not possible, rationale and/or proposals will be prepared to stimulate discussion and resolution of all points of difference. Per agreement with SNS, approval of submitted AN's will constitute SNS approval of the associated specifications.
2. The fourth revision to the Lincoln Lab Source Control drawing and interface parts list was reviewed by GE and comments were provided to Lincoln Lab on 6 October 1975. Comments were primarily concerned with the parts list and parts call-outs on the drawing. Assuming Lincoln Lab concurs with the suggested modifications, final approval on both sides of the interface is anticipated shortly.
3. Final delivery of LES 8/9 flight hardware was completed on 15 October 1975 with the delivery of F-13 to Mound Laboratory for storage. Portable Test Unit (PTU) tests indicate nominal performance on all units in storage. Field procedures for Xenon gas exchange were satisfactorily demonstrated on F13 prior to shipment from GE.
4. The RTG/ETG Operations and Maintenance Handbook (GEMS-421) was completed and published in October. Delivery to customer and user agencies was accomplished on 14 October (Letter 1K00-REC-094).
5. Comments on the JPL draft Interface Specification (ES 509290) were provided on 15 October 1975 in letter 1K00-REC-097, Clayton to Lombardo.
6. Comments on the JPL Specification ES 509289-4, "Detailed Specification for RTG Design Environments" were provided on 8 September 1975 in letter 1K00-GD-036, Drenker to Lombardo.
7. A marked-up copy of JPL Specification ES 509289-1, "Detailed Specification for RTG Requirements" was received at GE for review on 6 October 1975. This is currently under review in conjunction with comments previously supplied by GE on 18 April (1K00-RJK-392). Differences in basic requirements still exist. These will hopefully be clarified by the forthcoming additional GE comments.
8. A considerable effort was put forth during the period of this report to reconcile differences between Standing Instructions (SI's) being prepared for MJS testing and the requirements set forth in the recently-issued GE/MJS Specifications and the RTG/ETG Operations and Maintenance Handbook.

9. The Systems input to the LES 8/9 Final Report was prepared.
10. The JPL Interface Control Drawing, Rev. B, was reviewed and comments were provided on 22 October in letter 1K00-REC-107.
11. An updated flight safety test plan was prepared to cover changes in the definition of the MS-1 explosion test hardware and to summarize a test program schedule compatible with a November 1976 date for the FSAR (Doc. No. GESP-7114-R2 dated October 1975). This was transmitted to ERDA on 16 October 1975 by letter 1K00-REC-098.
12. The Final Reliability Assessment report for the LES 8/9 MHW-RTG (GESP-7120) was completed and issued on 15 October 1975.
13. The JPL-supplied RTG limit load data was evaluated by GE and critical load conditions were identified for inclusion in the JPL Interface Control Specification. (Letter 1K00-GD-105 dated 21 October 1975).
14. PIR 5622, dated 10/8/75, "Q-2 Shock and Vibration Test Sequence" was issued to document GE/ERDA/JPL interface agreements on MJS/RTG qualification testing.
15. The time-temperature profile for pre-conditioning of hardware for flight safety tests was provided in letter 1K00-REC-109 dated 23 October 1975. Results were based on estimates of RTG test and storage conditions through all phases of the ground test program prior to launch. (Note: Data received subsequent to the transmittal of this letter will require a slight upward revision in preconditioning times. This will be covered in an update to the above letter).

5.0 ISOTOPE HEAT SOURCE (IHS)

During this reporting period, September/October 1975, the heat source design and analyses continued with special attention to:

- Conditions for degassing of the IHS carbon components
- Minor design changes to the MJS ablation sleeve
- Thermal analyses of the use of xenon in the RTG

5.1 GENERAL

5.1.1 Design

The design changes to the ablation sleeve discussed in 5.1.2 were incorporated in the drawings. Bakeout procedures for the carbon components were revised and the relevant drawings were updated. A special fixture for bakeout of the aeroshell/ablation sleeve combination was designed and fabricated.

5.1.2 Ablation Sleeve/Aeroshell

5.1.2.1 Changes to Ablation Sleeve

The shear strength test data on the Pyrocarb-406 material showed values lower than those used in the initial design. To provide the desired structural margin, an increase was made in the length of the tabs which support the ablation sleeve when they are trapped between the aeroshell wall and the aft end cap.

The wall thickness of the ablation sleeve was increased from 0.100 inch to 0.130 inch to give additional margin on sleeve burn-through during steep-angle reentry.

The thermal contact between the aeroshell and the ablation sleeve during reentry was reduced by grooving the inner wall of the sleeve. Grooves 0.075-inch wide by 0.004-inch deep on a 0.100-inch thread pitch are cut with a 0.178-inch radius tool.

5.1.2.2 Bakeout Fixture for Ablation Sleeve/Aeroshell

Bakeout of the aeroshell at 1500°C with the ablation sleeve fully assembled in place could result in an interference fit. The difference in the thermal expansion coefficients of the POCO aeroshell material and the Pyrocarb-406 ablation sleeve material would cause the sleeve to be subjected to excessive stress. An

analysis indicates an axial bending stress in the sleeve of > 20,000 psi where the ultimate stress of the material is reported to be 4500 psi. In all re-entry modes, there is sufficient ΔT between the ablation sleeve and aeroshell to prevent the large interference fit which results in the high stresses. To eliminate the interference fit and to bake-out the assembly without causing deformation of the components, a special fixture was devised. The fixture was fabricated by GE from POCO material to support the aeroshell assembly (47D303325) with the end caps moved outward from the aeroshell $.30 \pm .05$ inches. The fixture also secures the ablation sleeve so no axial movement in relation to the aeroshell will occur. The lockrings are removed from the end caps and their opening is restrained during the bakeout cycle. The fixture was used successfully by ML/MRC for the bakeout of the aeroshell/ablation sleeve for the F-6/IHS.

5.1.3 Fuel Sphere Assembly (FSA)

5.1.3.1 Graphite Impact Shell (GIS)

The possibility of providing a seal for the threaded cap of the GIS was discussed in the BiMonthly Report for July/August 1975. After review of the problems involved in attempting to develop a reliable seal which demonstrably did not adversely affect the impactability of the GIS or the properties of the Ir PISA, it was concluded that the MJS flight schedule did not allow sufficient time for a satisfactory development. The effort was terminated by direction from ERDA-SNS.

5.1.3.2 Post Impact Containment Shell (PICS)

5.1.3.2.1 Fabrication

- A. Details of the production of Ir sheet and Ir hollow hemispheres are given, respectively, in the reports of the HNL Metallurgy and Ceramics Division and the Weekly Status TWX of ML/MRC.
- B. An approved specification for the HNL DOP-4 Ir has not yet been formulated.

5.1.3.2.2 Impactability Verification Tests

No verification tests on the impactability of the ML/MRC production PICSs were performed during this reporting period.

5.1.3.3 PISA Venting

5.1.3.3.1 He Release

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

- A. MHFT-37 is operated in vacuum at an effective fuel/Ir PICS interface temperature of $\sim 1335^{\circ}\text{C}$. The erratic behavior of intermittent He release continued during the reporting period. The He release dropped below the detection limit and remained below this level (plugged) for ~ 20 days after which sporadic bursts of He were observed. The effective release of He was sufficient to preclude pressurization of the PICS. This unit has been on test for $\sim 13,600$ hours.
- B. MHFT-44 is operated in He with the fuel/Ir PICS interface temperature at $\sim 1220^{\circ}\text{C}$. This unit was placed on test in June 1974 and is checked once a month for He release, since continuous monitoring is precluded by the He furnace atmosphere. The He release was steady and equal to the generation rate. The erratic behavior reported in the May/June Bi-Monthly Report has apparently been cleared. This unit has been on test for $\sim 11,700$ hours.
- C. MHF-30, one of the FSAs removed from the Q-1/IHS, is operated in vacuum with the fuel/Ir PICS interference temperature at $\sim 1335^{\circ}\text{C}$. The He release from this unit continued steadily at the generation rate during the current reporting period. This unit has been on test for 9,200 hours.
- D. The vent designs are shown in Figure 5.1-1 and the performance is shown in Table 5.1-1.

5.1.3.3.2 Pu Release

The activity levels found in the GISSs analyzed at ML/MRC and at LASL are shown in Table 5.1-2. Since the last report, July/August 1975, MHFT-20 was examined after an exposure of 18,000 hours in vacuum at 1440°C . The GIS from this unit contained approximately 305 micrograms of ^{238}Pu . Comparison of this value

Pre-Flight MHW PISA Vent Design

MJS & LES 8/9 Vent Design

Figure 5.1-1 MHW-LMS Vent Filter Designs

TABLE 5.1-1 MHW PICS VENT TEST DATA - FLIGHT DESIGN

5-5

		TEST CONDITIONS					VENT CONDITION						
SPECIMEN NUMBER	STATUS	TEMPERATURE - °C	EXPOSURE TIME - HOURS	EXPOSURE ENVIRONMENT	DIMENSIONAL CHANGE	He MASS SPEC.		BUBBLE CHECK		TESTING ORGANIZATION	METALLOGRAPHY/COMMENTS		
						IN FURNACE (1)	IN LAB. (2)	Vent No. 1	Vent No. 2				
MHFT-37 (1)	On test	1335	13,600	vacuum	nyr	erratic	n/a	nyr	nyr	LASL	nyr; test continuing; vent test specimen		
MHFT-44 (1)	On test	1220	11,700	helium	nyr	n/a	open	nyr	nyr	LASL	nyr; test continuing; vent test specimen		
MHF-30	On Test	1335	9,200	vacuum	nyr	open	n/a	nyr	nyr	LASL	nyr; test continuing; removed from Q-1/IHS		

(1) Mass spec. measurement in furnace @ test temp.

n/a = not applicable

(2) Mass spec. measurement in lab. vac. chamber
@ self-heat temp. = 900 C.

nyr = not yet reported

C&E = test complete and specimen examined

with other exposures (see Table 5.1-2) for much shorter periods strengthens the position that all of the observed Pu is not being released to the interior of the GISs through the vents at any definable rate consistent with the total quantity of Pu found. The experiments with MHD-26 discussed in the previous Bi-Monthly reports indicate that current decontamination methods are not consistent and that substantial contamination levels, not detectable by either wipe or direct alpha counting techniques, remain on decontaminated hardware.

5.1.4 Gas Analyses on the MHW/IHS

Gas samples were taken on the Q-2/IHS at ML/MRC. The results of the analyses are shown in Table 5.1-3. The analytical data on the first two samples from the Q-2/IHS showed H₂ and H₂O levels significantly higher than in any other unit examined to date. These data indicate that the middle 8-pack used in the Q-2/IHS did contain residual H₂O from the exposure of the sub-assembly during storage. The third and fourth gas samples indicate that the H₂ and H₂O had reached levels similar to those previously observed.

5.1.5 Degassing of Carbon/Graphite Components

5.1.5.1 Degassing Schedule

Studies conducted by BMI-CL under ERDA-SNS direction verified that the revised bakeout schedule for the T-50 composite (GIS material) of 36 hours at 1500°C under $\leq 3 \times 10^{-4}$ Torr vacuum was also adequate for all remaining carbon parts: the POCO, the Pyrocarb-508 and -406, and the graphite cloth. This requirement was incorporated in the ML/MRC bakeout procedure.

5.1.5.2 ML/MRC Furnace Malfunction

A failure of an internal water cooling line in the ML/MRC vacuum outgassing furnace during bakeout of 13 GISs for F-6 allowed water to enter the furnace while it was at 1500°C. The malfunction occurred during the night when no personnel were present and water accumulated in the furnace after it was automatically shutdown. It was decided that the GISs had been unacceptably affected by their contact with water vapor. The furnace was rebuilt in less than two weeks and operations were resumed.

TABLE 5.1-2
TOTAL PLUTONIUM CONTENT ON MHW GIS's

Sample No.	EXPOSURE CONDITIONS			Filter Design	Total Pu μg
	Time, h	Temp. °C	Atmosphere		
MHFT-15	7395	1450	vacuum	pre-flight	19
MHFT-18	1332	1250	helium	pre-flight	17
MHFT-19	1100	1450	vacuum	pre-flight	56
MHFT-20	18293	1450	vacuum	pre-flight	305
MHFT-21	4500	1250	helium	pre-flight	8
MHFT-22	3400	1450	vacuum	pre-flight	625
MHFT-39 (1,2)	2009	1335	vacuum	flight	720 (3)
MHFT-40 (1,2)	2009	1335	vacuum	flight	15 (3)
MHFT-41 (1)	2009	1335	vacuum	flight	8
MHFT-42	5440	1335	vacuum	flight	1600
MHFT-45 (1,2)	720	1335	vacuum	flight	460
MHFT-47 (1,2)	720	1335	vacuum	flight	18700 (3)
MHFT-48 (1,2)	720	1335	vacuum	flight	14700 (3)
MHFT-49 (1,2)	720	1335	vacuum	flight	160 (3)
MHF -27	200	1220	Q-1 heat source, He	flight	38
MHF -29	200	1220	Q-1 heat source, He	flight	0.05 (4)

(1) SVT sample
(2) Impacted

(3) Measured after PISA fracture on impact
(4) Measurement at ML/MRC; all others by LASL

TABLE 5.1-3 GAS ANALYSIS RESULTS

MM-1HS

CONSTITUENT	VOLUME PERCENT								SAMPLING DATE	ANALYSIS BY
	CO	CO ₂	H ₂	H ₂ O	N ₂	C ₂	Ar	He		
Q-2/1HS	3.89	5.15	0.65	0.07	0.30	0.01	0.20	89.73	13 Aug. 1975	ML/MRC
Sample No. 1	3.89	5.15	0.65	0.07	0.30	0.01	0.20	89.73	13 Aug. 1975	ML/MRC
(a) 1	3.43	0.24	0.76	0.04	0.04	--	--	95.45	13 Aug. 1975	ML/MRC
2	3.74	1.73	0.22	0.91	0.10	0.01	0.03	94.18	26 Aug. 1975	ML/MRC
(a) 2	0.87	0.15	0.16	0.01	0.16	0.03	0.01	98.62	26 Aug. 1975	ML/MRC
3	1.21	0.54	0.10	0.01	0.14	0.02	0.07	97.92	8 Sep. 1975	ML/MRC
(a) 3	0.16	0.03	0.08	0.01	0.02	----	----	99.72	8 Sep. 1975	ML/MRC
4	0.69	0.28	0.08	0.00	0.26	0.05	0.20	98.47	1 Oct. 1975	ML/MRC
(a) 4	0.09	0.01	0.06	0.01	0.05	0.00	----	99.79	1 Oct 1975	ML/MRC

(a) = backfill

5.1.5.3 Protection against Metal Deposition

The ML/MRC vacuum bakeout furnace uses tungsten heating elements. Under some conditions tungsten, as the oxide, can be transported and deposited on the hardware being baked out in the furnace. To preclude this possibility, all bakeouts in the ML/MRC furnace are performed with the hardware covered with a graphite blanket. The efficacy of this protection is checked for each furnace load by inclusion of two test specimens, one exposed to the furnace environment and the other protected along with the hardware. The test results on the specimens exposed during this reporting period show that the protective blanket is completely effective, within the limits of the analyses, in preventing contamination.

5.2 IMPACT TESTS

No impact tests with either fueled or simulant-loaded FSAs were performed during the September/October reporting period.

5.3 AEROTHERMAL AND MISCELLANEOUS ANALYSES AND TESTING

5.3.1 Reentry

The reentry data reported in the Bi-Monthly Report for May/June 1975 were used to provide input to the thermal stress analysis of the MJS end cap reported in paragraph 5.3.2.

5.3.2 Stress Analyses

Results of previous analyses were based on end cap temperatures based on a uniform internal heat source temperature. These results predicted a margin of safety between $-.01$ and $+.22$ depending on the choice of material properties (billet or the higher plate data).

The results of the current analyses are based on end cap temperatures derived using a more accurate thermal model including a modeled heat source. The results of this more detailed thermal modeling show that the peak surface temperatures occur at approximately 850 seconds and that the thermal gradient across the cap is reduced from the previous analysis.

The structural analyses were performed using the BIG-2D composite program with an end cap model consisting of 222 elements and 269 nodal points. Four analyses were performed using two support conditions for the cap and for times of 850 and 875 seconds. Figures 5.3-1 and 5.3-2 show the end cap support conditions assumed. Figure 5.3-3 shows the location of the critical stressed area. Table 5.3-1 summarizes the results of the four analyses performed.

TABLE 5.3-1

MJS END CAP STRESS ANALYSES RESULTS

Case	Support Condition	Time (Sec)	Stress (psi)	Temp. (°F)	MS*
1	1	850	4306	2876	+.81
2	2	850	5007	2876	+.56
3	1	875	4027	2854	+.94
4	2	875	4558	2854	+.71

$$MS = \frac{F_{all}}{\{ } - 1$$

where F_{all} = allowable tensile stress
(Billet data = 7800 psi)

$\{$ = calculated octahedral stress

From the results of these analyses, it is concluded that the MJS end cap is adequate to survive the end-on earth orbital decay condition described above. The calculated margin of safety shown is calculated using the material properties for POCO billets. Acceptance test data currently being evaluated, indicate that the allowable tensile strength of plate material may be as much as 2000 psi greater than the billet data. Should this greater tensile strength be used, the minimum margin of safety is increased from +.56 to .96.

MIS ENO. CAP
SUPPORT COND 1

FIGURE 5.3-1

MJS END CAP
SUPPORT COND 2.

FIGURE 5.3-2

END CAP
EARTH ORBITAL DECAY

CRITICAL STRESSED
SECTION

FIGURE 5.3-3

5.3.3 Review of Test Data on Degassing of Carbon

Existing specifications require that graphite components be baked out to minimize the amount of carbon monoxide present in the system (see para. 5.1.5). Tensile specimens, tested to assure quality of these components, are not baked out prior to testing. Three test programs and the results as applied to tensile testing were reviewed to evaluate the effects of bakeout.

5.3.3.1 Description of Test Programs

The tests, reported in Reference 1, were performed on 3/32-inch diameter rod fabricated from Speer 580. Speer 580 is a high density, fine-grained graphite. To reduce the scatter in the test results, all specimens were made from the same mix of graphite with the nominal diameter ground to a tolerance of $\pm .0005$ inch. The tensile strength was determined from three-point bending tests. Control samples tested at room temperature in air showed the "as received" strength to be 8200 psi. Using this strength as a basis of comparison, a test program was conducted on specimens baked in vacuum ($p < 10^{-4} \frac{\text{mm}}{\text{Hg}}$) at 1000°C for four hours. Preliminary testing established that tensile strength increased for bakeout times up to four hours and that the strength was essentially constant for bakeout times between four and 120 hours.

Results of these tests showed that the strength of graphite tested at 1000°C in vacuum was 9700 psi. This is an 18% $\left(\frac{9700}{8200}\right)$ increase in strength compared to the strength of untreated specimens tested in air at room temperature.

Additional tests performed to evaluate the effect of high temperature and vacuum separately showed:

- (1) Approximately one half the increase in strength was due to temperature effects.
- (2) The remaining increase in strength was due to vacuum degassing.

To evaluate any permanent change in the material properties due to the vacuum bake, a series of tests were performed at room temperature in air on specimens which had been baked out. The results of these tests showed no change in tensile strength compared to the strength of untreated specimens.

Reference 2 describes a similar test program. In this case, the test specimens were cut from various blocks of British reactor grade graphite (coarse grained) to the following dimensions: 3.30" x 0.40" x 0.30". All measurements were made using the four-point bend test. In the first series of tests the specimens were baked out (degassed) in vacuum ($p < 10^{-4}$ Torr) at 1250°C for various times (up to 26 hours) prior to testing at room temperature in vacuum. As in the previous (Reference 1) test program, no additional increase in strength was noted for bakeout times in excess of four hours. In these tests the author notes that the strength increase compared to untreated specimens was about 40%. This is not inconsistent with the results of Reference 1 considering the differences in grain structure and tensile strength.

A second series of tests were performed on vacuum baked out samples at room temperatures and at pressures ranging from 10^{-5} Torr to one atmosphere. In these tests four gases (air, nitrogen, oxygen and carbon dioxide) were used. It was found that no significant decrease in strength was noted for samples tested in nitrogen, oxygen or carbon dioxide. All of these gases were dry (less than 20 ppm of water). In air (moisture content between 7,000 and 11,000 ppm of water), the strength of the samples was reduced to that of the untreated specimens at pressures as low as 10^{-5} Torr.

In another series of tests, the effect of temperature on degassed (vacuum bakeout) and untreated specimens was evaluated. In these tests it was found that the strength of treated and untreated specimens (while significantly different at room temperature) was essentially the same at test temperatures above 400°C.

Reference 3 presents the results of a tensile test program performed by Southern Research Institute. In these tests, the specimens were machined from one 4 1/2 inch diameter x 12 1/2 inch long billet of POCO grade AXF-5Q Graphite. The specimens, 6 inches long with the test section 1/4 inch diameter, were tested in direct tension. A total of eleven specimens were tested at room temperature. Table 5.3-2 is a summary of the test results taken from Reference 3. As shown, the pretest treatment has no significant effect on the tensile strength when the specimens are tested in air at room temperature. This is consistent with the results of the two test programs previously discussed.

TABLE 5.3-2

Tensile Test Summary

<u>SPECIMEN TREATMENT</u>	<u>TENSILE STRENGTH (PSI)</u>
As Received	8000
	8000
	<u>8160</u>
	AVG. 8050
100% Relative Humidity Soak ¹	7380
	7060
	7440
	<u>8360</u>
	AVG. 7560
Vacuum Degassed ²	7400
	8600
	8100
	<u>7800</u>
	AVG. 7970

¹Specimens maintained in high (95% to 100%) relative humidity for 100 hours.

²Specimens were baked at temperatures between 1000°C and 2000°C in vacuum (average pressure $2 \times 10^{-4} \frac{\text{mm}}{\text{Hg}}$) for about 70 hours.

After cooling in dry Argon, the specimens were transported in an argon atmosphere and tested as soon as practical.

5.3.3.2 Interpretation of Tests

Based on the results of the three test programs referenced above, it is concluded:

1. The presence of moisture is detrimental to the strength of graphite. For coarse-grained low-strength graphites, this effect at room temperature may be as much as 40%. In fine-grained high-strength graphites, the room temperature effect is on the order of 9%.
2. Since the amounts of moisture necessary to adversely affect the strength of graphite is extremely small, the effect of moisture on room temperature strength can only be demonstrated by testing in vacuum (or dry inert atmosphere) after outgassing and without exposure to air (moisture).
3. The strength of vacuum-baked graphite, when tested at room temperature in air, is the same as untreated graphite.

5.3.3.3 Application to MHW Testing

1. The strength of fine-grained graphite components as determined by tensile testing of specimens which have not been baked out and tested in vacuum may be as much as 9% lower than the actual strength of the graphite installed inside the converter.
2. Any attempt to utilize this potential 9% increase in strength would require that tensile specimens be tested in the vacuum furnace in which they were baked out. In addition an extensive test program would be required to assure that the actual graphite components had equivalent treatment prior to launch.
3. Based on the above, it is recommended that the existing method of testing be retained.

5.3.4 Evaluation of Ablation Sleeve SN 924577 for F-6

Ablation sleeves for the MJS RTG are fabricated to the requirements of GE Drawing 47D303326 and material specification NS0060-01-13. This specification requires that a hoop tensile test be performed on specimens cut from each part. Longitudinal tensile properties and shear strength are performed on each lot of parts. The sleeve designated for use on F6 is one of three sleeves fabricated in a manufacturing lot (SN 924576, 924577 and 924578). During the hoop tensile test of material cut from

SN 924577 (designated for F6), the vendor failed to obtain the elastic modulus. The tensile strength of 13,100 psi exceeded the specification minimum of 12,500 psi and compared closely with the tensile strength of 12,900 psi for SN 924576. The tensile modulus for SN 924576 was 2.16×10^6 psi. Based on GE experience with Pyrocarb 406 and the lot identify, it is reasonable to assume that the hoop tensile moduli for these two sleeves are similar.

The ablation sleeve was designed to withstand the maximum thermal stresses generated during a steep-angle reentry. The maximum thermal stresses occur in the hoop direction and were derived using the ANISO machine computation program. The elastic modulus assumed in the hoop direction was 3.0×10^6 psi. The maximum calculated tensile stress occurring on the inner surface was approximately 5000 psi. The margin of safety based on an ultimate tensile strength of 12,500 psi is 1.5.

Since the only significant stresses in the ablation sleeve are due to the thermal gradient across the wall thickness, it can be assumed that the maximum tensile stress is directly proportional to the modulus of elasticity. On this basis the modulus of elasticity could be increased by a factor of approximately 2.5 before the maximum calculated stress equals the minimum tensile strength allowed by the specification. This assumes that the modulus of elasticity is independent of the tensile strength. Tests performed in support of the SNAP-27 program indicate that the tensile strength increases as the modulus of elasticity increases. The results of these tests are reported in Reference 4. Figure 5.3-4 shows these data for Pyrocarb 406 tested in the warp direction of the fabric. This corresponds with the hoop direction of the MJS ablation sleeve (test data also shown on Figure 5.3-4). Using the most conservative estimate from Figure 5.3-4, it is found that the minimum tensile strength, corresponding to a modulus of 3.0×10^6 psi, is approximately 14,000 psi. From this we can conclude that the modulus of elasticity of the F6 ablation sleeve in the hoop direction is less than 3.0×10^6 psi since the tested value of the hoop tensile strength is 13,100 psi. Based on the SNAP-27 tests, Figure 5.3-4 shows that the modulus corresponding to the MJS hoop tensile value of 13,100 psi lies between 2.3×10^6 psi and 2.9×10^6 psi. Using these two values of the modulus as limits, the maximum expected hoop tensile stress and the resulting margins of safety are shown in Table 5.3-3.

TABLE 5.3-3

<u>Modulus (psi x 10⁶)</u>	<u>Allowable Stress (psi)</u>	<u>Maximum Calculated Stress (psi)</u>	<u>Margin of Safety*</u>
2.3	13,100	3800	2.4
2.9	13,100	4800	1.7

*NOTE: Calculated minimum margin of safety is 1.35 in the longitudinal direction.

CONCLUSIONS

Based on the above, it is concluded that:

- (1) The SN 924577 ablation sleeve is adequate to survive the thermal stress environment during reentry.
- (2) The minimum margin of safety in the hoop direction is greater than 1.7.
- (3) The actual margin of safety (based on the modulus obtained from test of material from the same manufacturing lot) is closer to 2.4.

5.3.5 Thermal Analyses

The converter and IHS temperatures have been summarized for a variety of conditions that may be encountered during assembly, test and operation; these are shown in Table 5.3-4. All temperatures listed are steady state averages for the condition described. The RTG case temperature would be the average of the three fin RTD readings. Since the MJS IHS has no clad, the RTG gas fill is assumed to fill the cavities within the IHS as well, except for the fuel-to-PICS gap. This region was assumed to be filled with helium at all times, including vacuum operation. For heat transfer purposes, this assumption is valid if the helium pressure within the PISA is on the order of 1 psia or greater. Assuming the RTG gas fill in this gap would increase fuel temperatures by roughly 50°F.

TABLE 5.3-4

M J S   S T E A D Y   S T A T E   I H S / R T G   T E M P E R A T U R E S

CONDITION	RTG ¹ VOLTAGE	IHS/RTG GAS FILL	IHS/RTG SINK TEMPERATURE	RTG CASE TEMPERATURE	RTG HOT SHOE TEMPERATURE	IHS SURFACE TEMPERATURE	PICS TEMPERATURE	FUEL ² SURFACE TEMPERATURE	FUEL CENTERLIN TEMPERATU
IHS in EPC in SPC	---	Helium	900°F	-----	-----	1040°F	1550°F	1630°F	1795°F
IHS in LAS	---	Argon	70°F	-----	-----	700°F	1525°F	1605°F	1770°F
RTG in LAS	O/C	Argon	70°F	400°F	1615°F	1670°F	2080°F	2135°F	2325°F
	30V	Argon	70°F	390°F	1515°F	1570°F	2020°F	2075°F	2265°F
	S/C	Argon	70°F	400°F	1400°F	1455°F	1930°F	1990°F	2175°F
RTG in RTG-SC	O/C	Argon	140°F	465°F	1680°F	1725°F	2125°F	2175°F	2370°F
	30V	Argon	140°F	455°F	1580°F	1630°F	2055°F	2110°F	2300°F
	S/C	Argon	140°F	465°F	1465°F	1515°F	1975°F	2030°F	2220°F
RTG in Air	O/C	Argon	70°F	360°F	1570°F	1625°F	2050°F	2100°F	2295°F
	30V	Argon	70°F	350°F	1470°F	1525°F	1980°F	2040°F	2225°F
	S/C	Argon	70°F	360°F	1355°F	1410°F	1900°F	1960°F	2145°F
RTG in Air	O/C	Xenon	70°F	360°F	1830°F	1875°F	2290°F	2330°F	2535°F
	30V	Xenon	70°F	345°F	1625°F	1680°F	2165°F	2215°F	2410°F
	S/C	Xenon	70°F	360°F	1505°F	1560°F	2075°F	2130°F	2320°F
Vacuum Operation	30V	Vacuum	100°F	505°F	1895°F	1930°F	2370°F	2410°F	2615°F
	S/C	Vacuum	100°F	520°F	1815°F	1860°F	2320°F	2360°F	2560°F

¹OPEN CIRCUIT, 30 VOLTS, SHORT CIRCUIT.²ASSUMES > 1 PSIA HELIUM RETAINED WITHIN PISA.

SECTION 5.3

R E F E R E N C E S

1. The Effect of Atmosphere on the Strength of Graphite, R. J. Diefendorf, Proceedings of the Fourth conference on Carbon, Pergamon Press, 1960.
2. The Effect of Gaseous Environment on the Flexure Strength of Graphite, D. H. Logsdail, A.E.R.E.-R5721, U.K.A.E.A. Research Group, Atomic Energy Research Establishment, Harwell, May, 1968.
3. The Effects of Atmosphere on the Tensile Properties of Graphite, Final Report to McDonnell Douglas Corporation, Santa Monica, California (Subcontract L5-1511-A), Southern Research Institute, Birmingham, Ala., December 14, 1967.
4. Revision of Pyrocarb-406 Material Properties Data, J. Poland, GE PIR-2241, dated 6/5/68.

5.4 MATERIALS DEVELOPMENT AND TESTING

5.4.1 Compatibility Tests

5.4.1.1 Unfueled Tests with Ir

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 FSAs are given in the LASL monthly reports. No Ir/PuO₂ interactions have been observed in any of the test specimens examined to date.

The status of the FSA compatibility tests is shown in Table 5.4-1; see Figure 5.4-1 for the test configuration. As noted in Paragraph 5.1.3.3, the only currently observable behavior is He venting for those units continuing on test. See also Table 5.1-1.

MHFT-20 was removed from test and examined after an exposure of 18,290 hours (> 2 years) in vacuum at 1440°C. No interaction was observed between the PuO₂ and the Ir. In the laboratory vacuum apparatus at ~900°C, He venting was observed at the same rate as the generation rate. Bubble tests after sectioning showed no flow. The tests on MHFT-16 and MHFT-17 were also ended but the results of the examination are not yet reported.

5.4.2 Fuel

5.4.2.1 Fuel Fabrication

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

5.4.2.2 Feed Material

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

5.4.2.3 Fuel Characterization

The status of the fuel characterization is shown in Tables 5.4-2 and 5.4-3.

TABLE 5.4-1

MHW FUEL SPHERE ASSEMBLY COMPATIBILITY TESTS AT LASL

SPECIMEN NUMBER	MHW OPERATIONAL MODE - GAS IN Ir/FUEL GAP	HELIUM VENT HOLE DIAMETER - INCH	EXPOSURE TEMPERATURE - DEGREES CELSIUS		TEST START - DATE	EXPOSURE TIME - HOURS		STATUS (AS OF 31 OCTOBER 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	18293	" " " "
MHFT-22	"	0.005	"	"	15 June 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	17339	Exposure complete; data not reported
MHFT-17	"	0.005	"	"	7 May 1973	3300		" " " "
MHFT-23	"	0.005	"	"	Test not begun	--	--	Transferred to environmental test
MHFT-37	vacuum	0.005	1210	1335	24 Feb. 1974	3000	13600	Test continuing
MHFT-42	"	0.005	"	"	21 Feb. 1974	3000	5440	Exposure complete; data reported
MHF-30	"	0.005	"	"	Nov. 1974	3300	9200	Test continuing
MHFT-44	helium	0.005	1180	1250	3 Jun. 1974	1500	11000	Test continuing

FSA COMPATIBILITY TEST CONFIGURATION

Figure 5.4-1

TABLE 5.4-2

MHW FUELS CHARACTERIZATION - 11.0 FUEL PROPERTIES(STATUS - as of **31 OCTOBER 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; $^{238}\text{PuO}_2$ UNLIKE UO_2 SHOWS NO PLASTICITY AT HIGH TEMP. He INGROWTH BEING CHECKED; TESTS PLANNED ON $^{239}\text{PuO}_2$
o COMPRESSIVE	CONTINUING	
o 4-POINT BEND	" "	
o YOUNG'S MODULUS	" "	
o POISSON'S RATIO	" "	
o SHEAR	CANCELLED	NO WORK PLANNED
o TENSILE	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; <u>DATA NEEDED</u> 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 MHFT-13 RELEASED NO Pu AFTER 1 YEAR; SPHERE FAILED
1.9 VAPOR PRESSURE	AVAILABLE	DATA ARE FOR "PURE" $^{239}\text{PuO}_2$; DATA CHECKS ON PRODUCTION MATERIAL ARE REQUIRED; <u>Cu, Si, Al, Fe, Ni</u> OXIDES FOUND IN VENT FILTERS
1.10 RADIATION	CONTINUING	NEUTRON COUNTS AND GAMMA MEASUREMENTS MADE ON ALL FLIGHT UNITS ALL IHSs TO DATE ARE WELL WITHIN SPEC.
1.11 SINTERABILITY	IN PROCESS	SEE LASL REPORTS FOR FUEL DEVELOPMENT STUDIES; 10000 HOURS DATA REQUIRED AT OPERATIONAL TEMPERATURE

MINI FUELS CHARACTERIZATION - 2

2.0 FUEL BEHAVIOR/RESPONSE

(STATUS as of 31 October 1975)

CATEGORY	STATUS	RESULTS/COMMENTS
2.1 VIBRATION		
o FSA @ MRC/ML	IN PROCESS	MHFT-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 (1) 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 (FUELED)	IN PROCESS	9 IMPACTS WITH ORNL-ML Ir PISAs; 1 PASS; 8 FAILURES
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 PISAs 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 $^{239}\text{PuO}_2$ ARE 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; DATA REPORTED ON 13 SPECIMENS 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

6.1.1 18-Couple Module Testing

6.1.1.1 18-Couple Modules DC-9 & DC-11 Shunt Resistance Performance

Figure 6.1-1 shows the resistance to foil for the uncoated Module 18K, two Si_3N_4 -coated Modules 180 and SN-1 and Modules DC-9 and DC-11. All modules operated at an 1135°C hot shoe temperature. Modules DC-9 and DC-11 contain the following design characteristics:

0.200" SiO_2 block in gap between N&P legs.

0.500" SiO_2 barriers around the outside surface of the legs.

18-mil SiO_2 yarn.

The purpose of the 0.2" solid SiO_2 block was to reduce the large surface area of SiO_2 provided by the microquartz normally used in the spacing between the N&P legs. This would reduce the reaction,

in the hot zone as long as the collisions per reaction are greater than unity.

The .500" barriers serve as a basic resistance in series with the Si and SiO deposit as long as high conductance cracks are not formed.

The smaller 18-mil yarn provides a more tightly-packed and less-penetratable insulation which should provide more resistance to conductive deposit buildup.

Both the DC-9, DC-11 and Si_3N_4 approaches show large improvement over the uncoated 18K performance. In terms of the Si generation rate, operation for 5 years at a constant 1035°C is equivalent to 2,750 hours at 1135°C . Considering fuel decay and the lowering of the hot junction temperature during the mission ($\sim 30^\circ\text{C}$ after 5 years), the equivalent time at 1135°C is 1520 hours for a 5-year mission.

FIGURE 6-10

From Figure 6.1-1 the Si_3N_4 module shunt resistance remains constant out to this point. Consequently, there will be no power loss due to shorting effects.

The DC-9 and DC-11 modules have a shunt resistance of 1000 ohms at 1500 hours. This is equivalent to a 58-ohm resistance in a full scale converter, which would result in a 1.3 watt power loss at the end of a 5-year mission.

6.1.2 Investigation Plan to Determine Thermoelectric Circuit to Case Shunt Resistance Degradation

A plan was formulated for the investigation of the causes of resistance degradation between thermoelectric circuit and outer case. More specifically, the investigation will concentrate on the cause of cold stack ceramic apparent loss of insulating properties during operational life. Tabulated below are the -18 couple test modules to be investigated and some of their design and test parameters.

Module	Design Features	Test Temp. ^{°C} , HS	Test Time-Hrs.
DC-9	.500" SiO_2 Barriers .200" SiO_2 Block in Gap .018" SiO_2 Wrap	1135	4768
DC-10 (DC-4 Type)	.450" SiO_2 Barriers	1135	1645
DC-11	Same as DC-9	1135	5336
DC-18I	TBC-4 Type Couples	1085	12658

6.1.2.1 Investigative Plan

Outlined below is a stepwise procedure for disassembly and analysis of each 18-couple - DC-9, DC-10, DC-11 and 18I.

- (1) Review all couple fabrication data to validate conformance to flight hardware requirements and record significant data and relationships.

- (2) Review module processing and test conditions. Record significant conditions such as vacuum environments, type vacuum systems, temperature, etc.
- (3) Measure resistance from T/E (+) lead to foil and to case.
- (4) Measure resistance from T/E (-) lead to foil and to case.
- (5) Measure heater resistance and resistance from $\pm$ leads to foil and case.
- (6) Measure resistance from foil to case, from both hot side and cold side of foil to case.
- (7) Measure resistance from hot to cold side of foil.
- (8) Measure total module T/E circuit resistance.
- (9) Measure resistance of each vertical row.
- (10) Measure resistance of each individual couple.
- (11) Cut all strap connections between couples. Measure resistance from each couple to foil with couples in place.
- (12) Measure resistance across Al_2O_3 insulator of all cold stacks with couples in place.
- (13) Remove couples in place-1 row of couples to be sent to RCA for bond resistance and cold stack measurements.

Before sending to RCA record the following observations:

- (a) Photograph, at 60X, the hot shoe N-P bond
  - (b) Wrap discoloration
  - (c) Photograph, at 60X, cold stack Al_2O_3 surface structure.
- (14) Remove 6 additional couples
    - (a) Send 2 couples (1 low and 1 high cold stack resistance) to C. Alexander at Battelle Memorial Institute for the following analysis:
      - Composition of quartz wrap surface deposit
      - Composition of Al_2O_3 cold stack insulator surface deposits on elevation and between legs.

- Composition of quartz barrier surface deposits.
  - Composition of N and P surface deposits in the condensation zone.
- (b) Use 2 couples for above analysis by GE.
  - (c) Use 2 couples for measurement of leg dimensions along the couple length. These measurements are to be followed by metallographic sectioning along couple axis through the plane that includes both legs.

Evaluate hot shoe N-P bond, leg bonds and cold stack structure. Determine degree of SiC formation on hot shoe and the location thereof.

6.1.2.2 Other Observations

- (1) Examine and record condition of heater, alumina insulators, foil insulation, astroquartz and alumina spacers.
  - (a) Surface structure
  - (b) Film deposit distribution
  - (c) Surface reactions
- (2) Examine couples for discoloring films, quartz barrier effects, wrap structure, completeness of microquartz stuffing, degradation in high temperature zone, condition of quartz blocks. Record all observations.

6.2 MATERIAL ANALYSES

6.2.1 Electron Probe and X-Ray Diffraction Analyses of Coatings on Components from Test Module 18-I

As part of the program outlined in Par. 6.1.2 above, the following components from Test Module 18-I were utilized for analysis of the coatings listed below at General Electric's Space Sciences Laboratory (SSL):

- 1. Couple #16, D950
  - a. coating on hot side of the hot shoe
  - b. deposit on quartz yarn wrapped around N & P legs
  - c. deposits on N & P legs

- d. coating on hot side of Al_2O_3 spacer
  - e. deposit on sides of ceramic spacer in cold stack
2. Aluminum Radiator at Couples 16, 17 and 18
    - a. surface coating
  3. Couple #9, D-944
    - a. crystalline structure of coating on N-P bond in hot shoe

Electron probe and x-ray diffraction analyses were performed as specified in the work statement (see Table 6.2-1). Results of the analyses and detailed discussions for each components are presented in the sections which follow.

6.2.1.1 Analysis and Results

The electron probe x-ray microanalyzer was utilized to determine the elemental (chemical) composition of the surface coatings of interest. Analyzing crystals employed in the probe permit the detection of elements of atomic number 5 (boron) or greater. (Note, however, that the probe is not as sensitive for C, B, N and O as it is for the higher atomic number elements). X-ray diffraction analyses were performed as required to identify the crystalline structure of the surface deposits.

6.2.1.1.1 Couple #16, D950, Module 18-I

In the as-received condition, the N-side of the hot shoe was broken away from the uncouple assembly and the mica spacer was missing. The mica spacer was supplied later; however, the task to identify the coating on the mica was subsequently deleted.

a.) HOT SHOE - yellow coating on hot side

Under optical microscopic examination it was found that the yellow-colored deposit on the hot side of the hot shoe was not uniformly distributed throughout the surface, nor did it appear to be of uniform thickness. Randomly scattered grey-colored "islands" ($\approx 50 \mu\text{m}$ linear dimension) which contained very little of the yellow coating were found in all of the surface areas examined. Electron probe microanalyses (EPMA) indicate only silicon with a trace of aluminum in the yellow-colored areas; silicon, molybdenum, aluminum, and germanium were detected in the grey-colored regions. X-ray diffraction analyses indicate the presence of beta silicon carbide and molybdenum silicide on the hot shoe surface. The combined EPMA and x-ray diffraction results for the coating on the hot side surface

TABLE 6.2-1
WORK STATEMENT FOR MODULE 18-I

Couple Analysis at SSL - Module 18-I

1. Determine crystal structure of coating on HS.
2. Determine elemental composition of coating on HS.
3. Determine crystal structure of material in NP bond.
4. Establish elemental composition of deposit on quartz yarn and coating on N&P leg.
5. Determine composition of coating on hot side of Al_2O_3 spacer.
6. Determine elemental composition of deposit on cold stack ceramic surface.
7. Determine elemental composition on mica spacer. (this task deleted)
8. Determine elemental composition on Al radiator.

of the hot shoe are shown schematically in Figure 6.2-1.

FIGURE 6.2-1. COMPOSITION OF COATING ON THE HOT SIDE OF THE HOT SHOE, 181, D950, #16

b.) Quartz Yarn Wrapped Around N&P Legs

The astroquartz yarn wrap varied in color along the length of the N&P legs. No apparent deposit or discoloration was found either within the region extending ≈ 7 mm from the cold stack or within the region ≈ 4 mm of the hot shoe (see Figure 6.2-2). The yarn covering the central portions of the legs was found to range from gold to brown in color; elemental analyses indicate the presence of Si in this region. A thick dark grey deposit extending along the legs between ≈ 4 and 6 mm from the hot shoe surface was found to be very rich in Ge and Si. Some localized Ge-rich regions were also found to occur on the brown-colored fibers.

FIGURE 6.2-2. DEPOSITS ON ASTROQUARTZ WRAP AROUND N&P LEGS

DARK BLUE	DARK BROWN	YELLOW-BROWN	GREY
Ge	Si	Ge	Ge
Si	P	Si	Si
Mg	Al	Na	Na
Na	Ge	Al	Al
P		Mg (trace)	? N
? N		P (trace)	

FIGURE 6.2-3. SURFACE COATINGS ON N-LEG, 18-I, D950, #16

GREEN	MAGENTA-ORANGE	THICK YELLOW	DARK GREY
Ge	Ge	Si	Ge
Si	Si	Ge	Si
Mg	Mg	P	Al
P	Na	Mg (trace)	Na
Na	?N	Fe (trace)	Fe (trace)
Fe (trace)			
Ni (trace)			
?N			

FIGURE 6.2-4. SURFACE COATINGS ON P-LEG, 18-I, D950, #16

c.) N and P Legs

When the astroquartz wrap was removed, the N&P legs were found to contain several areas of discoloration. Some variation of the deposits was noted between the two legs, with apparent thicker deposits on the P leg in some regions. Schematic representations of the coating distribution and composition as determined by EPMA are shown in Figure 6.2-3 for the N leg and Figure 6.2-4 for the P leg. Elements detected are listed in order of decreasing concentration. The nitrogen response is questionable due to higher order Ge spectral response in the same wavelength regime for the analyzing crystal employed.

d.) Alumina Spacer - Yellow-Grey Coating on Surface Facing Hot Shoe

A yellow-grey colored coating was found to extend over almost all of the surface of the alumina spacer which interfaces with the hot shoe. About one-third of the surface area was also coated with a thicker deposit which ranged in color from white to yellow to grey.

Some of the thicker deposit was scraped off for analysis. EPMA of the scrapings indicate the presence of silicon, aluminum, carbon, and possibly a trace of zinc. From x-ray diffraction analyses the crystalline structure was determined to be that of beta silicon carbide. The appearance of the coating is shown schematically in Figure 6.2-5.

FIGURE 6.2-5. ALUMINA SPACER, 18-I, D950, #16. SURFACE FACING HOT SHOE.

e.) Ceramic Spacer in Cold Stack - grey deposit on transverse surface between the legs and the cold stack

The grey-colored surface of the ceramic spacer between the legs and the cold stack is depicted in Figure 6.2-6. The cold stack of the specimen analyzed is identified as #4511. EPMA indicated that the surface contains aluminum, silicon, manganese, magnesium, germanium, oxygen, sodium, and traces of iron, copper, titanium, and chromium. The composition did not appear uniform across

FIGURE 6.2-6. CERAMIC IN COLD STACK, 18-I, D950, #16.

the surface. In particular, it was noted that the Mn distribution varied across the thickness as well as with lateral position. There was no observed apparent correlation between high Mn distribution and location of the legs. Figure 6.2-7 shows scanning specimen current and Al, Mn, Si, and Mg x-ray images of a region of relatively low Mg response which is located mid-way through the thickness of the ceramic. It is noted that no conductive coating of carbon was put down on the surface before analysis/evidence of surface charge buildup is seen in the right hand portion of Figure 6.2-7a, the specimen current image. From the x-ray images, it is apparent that the Mn concentration increases toward the hot side of the spacer; most of the Al-poor regions seem to be rich in both Mn and Mg.

a. Specimen Current Image

b. Manganese X-Ray Image

c. Magnesium X-Ray Image

d. Aluminum X-Ray Image

e. Silicon X-Ray Image

FIG.6.2-7. Scanning specimen current and x-ray images of a low-Mn response region on transverse surface of the ceramic spacer in cold stack of Couple #16, D950, Module 18-I. Magnification $\approx 500X$.

a. Specimen Current Image

b. Manganese X-Ray Image

c. Magnesium X-Ray Image

d. Aluminum X-Ray Image

e. Silicon X-Ray Image

FIG. 6.2-8. Scanning specimen current and x-ray images of a high Mn response area on the transverse surface of the ceramic spacer in the cold stack of Couple #16, D950, Module 18-I. Magnification $\approx 500X$.

Scanning images of a region relatively high in Mn response are shown in Figure 6.2-8. It is observed that this surface region is more conductive than the region shown in Figure 6.2-7; this is evidenced by the decrease in the amount of surface charge buildup as seen in the specimen current image, Figure 6.2-8a. There is no apparent gradient in Mn response across the thickness in this region; Mg tends to be associated with the Mn.

6.2.1.1.2 Aluminum Radiator at Couples 16, 17, 18; Module 18-I

The surface of the aluminum radiator which interfaces with Couples 16, 17 and 18 contained a deposit which ranged from light grey to dark grey in color. In the areas where the coating was thickest, an apparent light-yellow colored "growth" was found on top of the grey deposit. Scrapings taken from the region of thickest deposit were analyzed by both x-ray diffraction and EPMA. No crystalline structure was evident in the amorphous x-ray diffraction pattern. Electron probe analyses indicate the presence of two types of particles in the scrapings; some are Ca-rich and the others are Si-rich. The results of these analyses are presented in Figure 6.2-9.

X-ray Diffraction: non-crystalline		
EPMA:	<u>Ca-rich</u>	<u>Si-rich</u>
	Al	Al
	Ca	Mg
	O	Si
	Si (trace)	Cu (trace)

FIGURE 6.2-9. ALUMINUM RADIATOR AT COUPLES 16, 17, 18,
MODULE 18-I

6.2.1.1.3 Couple #9, D944, Module 18-I

An assembled couple identified as #9, D944, 18-I was received for x-ray diffraction analysis to determine the crystalline structure of the material in the NP bond on the hot side of the hot shoe and of the coating on the hot side of the alumina spacer. No electron probe analyses were performed on this sample.

a.) Hot Shoe - coating in N-P bond on hot side

The coating in the N-P bond on the hot side of the hot shoe in couple #9, D944 from Module 18-I was found to vary in thickness along the length of the bond, being thickest in the region between the N&P legs. A micrograph of the deposit in this area is shown in Figure 6.2-10. X-ray diffraction analyses show the crystalline structure of the coating to be that of alpha aluminum oxide and beta silicon carbide.

6.3 CONVERTER SYSTEMS AND DESIGN

6.3.1 Temperature Limits for LES 8 and LES 9 RTGs at Liftoff

The temperature limits for the RTG cases and stacking adapters have been established, based on the results of an assessment of the effects of reduced RTG temperatures during launch.⁽¹⁾

The minimum temperature limit for the stacking adapters and adjacent case areas at liftoff is 60°F. The maximum permissible temperature for the RTG cases at liftoff is 380°F.

Since the RTDs provide the only means for monitoring the RTG temperatures at liftoff, the following limits in terms of RTD temperature are given:

Minimum temperature for dome RTDs (#4 on instrumentation dwg.) adjacent to spacecraft truss	70°F ⁽²⁾

Maximum temperature for any fin RTD (#1, 2, 3 on instrumentation dwg.)	380°F

The temperatures of the RTGs should be maintained as high as mission constraints permit within these bounds to minimize risks.

(1) "Evaluation of Effects of Reduced Launch Temperature on LES 8 and LES 9 RTG Structure", Section 6.3-2 of July-August Bimonthly Report.

(2) Based on TRW airconditioning test results.

A. Photomicrograph of coating in N-P bond. Magnification = 120X.

FIG. 6.2-10. Coating in N-P bond on hot side of hot shoe from #9, D944, Module 18-I.

6.3.2 PRD Dynamic Test Requirements for the MJS Mission

6.3.2.1 Introduction

The PRD Bellows assembly used in the MJS mission will undergo extensive vibration and shock testing to establish reliability during the prelaunch vibration and shock environment.

6.3.2.2 Installation

The installation of the PRD on the generator case of the MJS mission is different from the LES 8/9 installation and is shown on the installation drawing - GE 47E303623. It directly penetrates the converter case close to the lower reinforcement ring. Due to this location,, the PRD-bellows assembly will see its greatest response during any vibration test with the RTG mounted with its forward end to the shaker tables.

6.3.2.3 Test Fixture, Dwg. 47E303444G4

The test fixture used for the LES 8/9 PRD vibration testing was modified to reflect the MJS installation as shown in Figure 6.3.2-1.

6.3.2.4 Test Specimens

The test specimen consists of the following hardware:

- PRD penetration fitting with "C" seal
- Puncture diaphragm
- Spring loaded bellows
- Bellows housing

The lance will be removed for this test and an adaptor for carrying three "Mini" accelerometers will be installed in the lance thread. The Mini-accelerometers are:

Picomini (Endevco)
Model No. 22
Serial No. ZQ 26

TYP 2 PLS
TORQUE TO
10-12 IN. LBS.

REMOVE INSUL.
SLEEVE BEFORE
CRIMPING
4 PLS

#10-32 UNF-28
THREAD
.38 DEEP
2 PLS

INSULATION VARIFLEX CORP OR EQUIV
VARGLAS S-1600 TYPE H
2 LAYERS P35 #2 AWG
1 LAYER P36 #10 AWG
STRANDED CUP WIRE #16 AWG
CUT LENGTHS TO SUIT ON ASSY

TIGHTEN TO PROVIDE A MAXIMUM
GAP OF .001 BETWEEN FACE OF
PENETRATOR FITTING & ITEM 1.
TORQUE SHALL NOT EXCEED
450 IN. LBS.

QUAL TEST ITEM
[50 FOR G3 ONLY
REMOVE ARMING
PIN PRIOR TO TEST]

[19] 2
[26] 2
[13] REF
FOR G
[18] 24
TE
SC

(33) NIS QUALIFICATION TEST (PRD)
(41) NIS ACCEPTANCE TEST (PRD BELLOW'S SUB)

GE 47E 303444
VIBRATION TEST FIXTURE

6-20

6.3.2.5 Vibration Spectrum

Based on the response of the .5g sine survey conducted with the inverted Q-1A generator, the basic mission vibration spectrum for the vibration in the lateral direction had to be adjusted in the 300 Hz frequency range.

The vibration and shock spectra for the PRD reliability test are listed below:

- A. Sinusoidal vibration acceptance level (FA)
  - Longitudinal Axis: Y   Figure 6.3.2-2
  - Lateral Axes: X and Z   Figure 6.3.2-3
- B. Random vibration acceptance level (FA)
  - Longitudinal Axis: Y   Figure 6.3.2-4
  - Lateral Axes: X and Z   Figure 6.3.2-5
- C. Transportation shock
Shock spectrum   Figure 6.3.2-6

MJS 77 RTG SINUSOIDAL VIBRATION ACCEPTANCE (FA) TEST

6-22

ACCELERATION, G (O-P)

MJS 77 RTG RANDOM VIBRATION ACCEPTANCE (FA) TEST

FIGURE 6.3.2-5

SHOCK SPECTRUM FOR ACCEPTANCE SHOCK TEST

ALL THREE AXES

6.3.3 Procedural Modifications for F-4 RTG Vent System Installation & Checkout

6.3.3.1 Background

During testing of the F-4 RTG excessive leakage occurred across the valve seat of the RTG Gas Management Valve (GMV). Such leakage presents no problem during the 30-day on-pad period since the valve is in the open position. However, because of this leakage, procedures must be modified to install and checkout the RTG/Lincoln Lab Gas Management System before installing the RTG's onto the spacecraft. This section documents the general procedures to be followed for installation and checkout of the RTG/LL Gas Management System.

6.3.3.2 Pre-Installation Procedures

The planned Xenon gas exchange and RTG removal from the shipping container can proceed as planned. The only modification required is that after the flex line is removed from the F-4 RTG, a cap will be installed onto the closed RTG-GMV. RTG truss installation and stacking will be per the planned procedures.

6.3.3.3 Vent Tube Installation/Checkout Procedure Modification

The RTG configuration at the time of vent tube installation will be as follows:

- F-4 RTG & F-5 RTG stacked and mounted on truss
  - Both RTG-GMV valves are closed
  - F-4 RTG-GMV valve capped
1. Install LL vent tube to F-5 RTG-GMV and to LL GMS valve (ref. Fig. 6.3.3-1).
  2. Install cap on LL vent tube (which mates with the F-4 RTG-GMV) and install vent tube to LL GMS valve. Do not install LL vent tube to F-4 at this time. (ref. Fig. 6.3.3-1).
  3. Using LL Gas Service Cart, evacuate vent tubing and LL GMS valve (herein, called Vent System) to $\leq 100 \mu$ pressure.
  4. Perform leak up test of Vent System to determine leak tightness of all mechanical connections. (This test can only determine gross leakage (10^{-3} scc/sec) due to the overall GSC leakage. Once the LL GSC and system volume is known, a better assessment of the leak sensitivity can be made.

FIGURE 6.3.3-1

SCHEMATIC - F-4/F-5 RTG VENT TUBE INSTALLATION & CHECKOUT

5. Evacuate Vent System to $\leq 100 \mu$ pressure.
6. Backfill Vent System with helium gas to $20 \begin{smallmatrix} +0 \\ -1 \end{smallmatrix}$ psia.
7. Sniff all mechanical connections between F-5 RTG and LL GMS valve and between capped off line (for F-4) and LL GMS valve. Leakage to be $\leq 1 \times 10^{-5}$ scc/sec. The time to perform the sniffing operation shall be minimized in order to minimize the diffusion of helium into the RTG.
8. Having demonstrated leak tightness, break torque on the capped F-4 vent tube and remove cap. This will vent the system to atmospheric pressure.
9. Break torque on F-4 valve cap and remove cap.
10. Connect vent tube to F-4 RTG-GMV.
11. Evacuate Vent System to the lowest level that can be achieved in a reasonable period of time. (Because of the valve seat leakage, the system cannot be evacuated to 100μ).
12. Backfill lines with helium to $20 \begin{smallmatrix} +0 \\ -1 \end{smallmatrix}$ psia.
13. Sniff the F-4 GMV/vent tube attachment for leakage. Leakage to be $\leq 1 \times 10^{-5}$ scc/sec (Because of the leakage across the valve seat, a meaningful leak-up test cannot be performed). The time to perform the sniffing operation shall be minimized in order to minimize helium diffusion into the RTG.
14. Evacuate Vent System to the lowest practicable level.
15. Immediately after isolating vacuum pump, backfill the Vent System with Xe gas to $26 \begin{smallmatrix} +0 \\ -1 \end{smallmatrix}$ psia.
16. Repeat steps 14 and 15 a total of three times. Three purge/evacuation cycles will minimize the oxygen residual in the Vent System.
17. After the last purge cycle, isolate the F-4 and F-5 Vent Systems via the LL GMS valve.
18. Backfill the F-5 Vent System with Xe gas to the last measured F-5 RTG pressure. Open the F-5 RTG-GMV.
19. Record stabilized pressure.
20. Adjust pressure in F-5 RTG to $26 \begin{smallmatrix} +0 \\ -1 \end{smallmatrix}$ psia.

21. Close F-5 RTG-GMV.
22. Regulate the F-4 Vent System (with Xe gas) to the last measured F-4 RTG pressure. Open the F-4 RTG-GMV.
23. Adjust pressure in the F-4 RTG to $26 \begin{smallmatrix} +0 \\ -1 \end{smallmatrix}$ psia.
24. Close F-4 RTG-GMV.
25. Close LL GMS valve.
26. Perform leak up test on LL GMS valve to assure leak tight closure.
27. Continue with regularly scheduled procedures.

6.3.4 Report on the F-4 Heat Source CO Anomaly

6.3.4.1 Background

A significant increase in the CO generation rate was observed during LAS processing of the F-4 heat source. The increase occurred after the transition from a purging processing cycle to a soaking processing cycle. An investigation was conducted to determine the cause of the anomaly. The investigation examined all possible causes, some of which are: (a) erroneous gas analysis; (b) air in-leakage into the heat source; (c) reduction of the fuel to form CO; and (d) normal outgassing characteristics of the graphites. This section documents the results of the investigation.

6.3.4.2 Description of Problem

6.3.4.2.1 F-4 Processing Description

The test set-up for processing the F-4 RTG in the LAS is shown schematically in Figure 6.3.4-1. During processing, the gas samples from the heat source were performed according to the following procedures.

- 1) Evacuate Gas Service Cart (GSC) lines and sample bottle to < 100 microns pressure.
- 2) Valve off vacuum pump.
- 3) Open valve #14 (on LAS penetration).
- 4) Allow pressure in IHS and lines to stabilize.
- 5) Close valve #14; close valve #11; close gas sample bottle valve.

The first heat source gas sample (Tap #1) was performed prior to LAS evacuation. After taking the gas sample, the heat source pressure was reduced to ~2 psia in preparation for LAS evacuation. This was done to minimize IHS pressure buildup due to an increase in temperature and outgassing rates caused by LAS evacuation. Approximately 6 hours after LAS evacuation a second gas sample (Tap #2) was obtained. Following this sample a purging cycle of the heat source was initiated. The cycle consisted of evacuating the lines open to the IHS for 30 minutes, after being pumped down initially to ~1000 microns pressure.

COMPONENT WORK STATIONS AND PNEUMATIC LINES

FIGURE 6.3.4-1

NOTE: All pressures were read on the GSC and may not be indicative of IHS internal pressures.

The heat source was then backfilled with helium gas to ~15 psia. (During certain instances, the IHS was only pressurized to 10 psia to minimize pressure buildup in the IHS). The purging cycle was repeated every 2 hours and was continued for ~80 hours. (This was the same procedure that was followed for processing the F-3 IHS). Gas samples of the heat source were obtained every 6 hours during the first 24 hours of purging. After that time gas samples were obtained once every 24 hours. After ~3 days of continuous purging the heat source was evacuated and backfilled with helium gas to a pressure of ~2 psia. After soaking for 24 hours under these conditions, a gas sample was obtained (tap #9). This mode of operation continued for several days. The anomaly occurred after the transition from the purging cycle to the soaking cycle.

6.3.4.2.2 F-4 CO Anomaly

The CO anomaly is defined as the significant increase in CO generation rate observed between gas taps #8 (purge cycle) and gas tap #9 (soak cycle).

Table 6.3.4-1 summarizes the results of all gas samples obtained during processing of F-4 and Figure 6.3.4-2 indicates CO generation rate vs. processing time. This behavior was not observed during processing of the F-3 IHS, which was processed in the same manner as F-4. (Figure 6.3.4-3 shows CO generation rate vs. processing time for the F-3 heat source).

6.3.4.2.3 Immediate Action Taken

When the anomaly was discovered, the heat source was immediately pressurized to a positive pressure (~18 psia) in the event that the increase was caused by air in-leakage. (The gas sample analyses had also indicated significant increases in N₂ levels in those samples exhibiting the high CO concentration. These high N₂ values were later proved to be erroneous). A positive pressure was maintained in the heat source until all external lines could be leak tested. Leak testing showed no leakage from valve #14 (Reference Figure 6.3.4-1) to the LAS chamber penetration. (Valve #14 was closed during the soak period). Having determined that the processing system was leak tight, the heat source was evacuated and backfilled every 2 hours in an attempt to reduce the CO concentration. After purging for several days, the IHS soak cycle was repeated. Once again the

TABLE 6.3.4-1

F-4 IHS GAS SAMPLE ANALYSES DURING LAS PROCESSING

SPECIES	TAP#1	TAP #2	TAP #3	TAP #4	TAP #5	TAP #6	TAP #7	TAP #8	TAP#9	TAP10	TAP11	TAP12	TAP13	TAP #14	TAP #15	TAP #16	TAP #17	TAP #18		TAP #19	TAP #20	TAP #21			
CO	8.9	35.3	2.25	.61	.20	0.16	.038	.042	73.35	78.35	78.13	70.21	69.46	.81	.35	.18	.74	.36	CORRECTED .387	51.02	10.8	.53			
CO ₂	.0013	.024	ND	ND	ND	ND	ND	ND	.04	.043	.044	.042	.041	ND	ND	.0062	.0035	.015	.016	.021	.0067	.0057			
H ₂	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.0028	.02	.013	ND	ND	ND	.0045	.0032	.0034	.019	.0055	.003			
N ₂	.85	3.2	.065	.14	.064	.46	.06	.088	.71	.67	.68	.81	4.3	.055	.025	.57	air in sample	.42	air in sample	5.6	air in sample	----	2.3	.84	.61
O ₂	.062	.09	.0025	.017	.014	.11	.0094	.017	.0043	ND	.12	.21	.07	.010	.001	.11	sample	.09	sample	1.33	sample	----	.098	.09	.13
Ar	49.0	19.1	.026	.0035	.002	.0067	.0013	.0013	.0083	.0055	.012	.019	.012	.0010	ND	.007	.0053	.064	----	.036	.009	.0077			
He	40.6	42.0	97.65	99.23	99.72	99.26	Bal	Bal	19.5	14.9	14.9	21.4	26.1	Bal	99+	99+	98+	92+	Bal	46.5	Bal	Bal			
IHS Pressure (PSIA)	14.87	8.78	21.65	14.08	19.55	21.54	17.64	11.02	6.52	7.21	5.43	3.52	2.56	25.04	16.74	1.00	1.06	1.00		.217	.348	.956			
Grams - CO	.120	.248	3.9x10 ⁻²	6.89x10 ⁻³	3.13x10 ⁻³	2.76x10 ⁻³	5.37x10 ⁻⁴	3.71x10 ⁻⁴	.383	.453	.341	.196	.1428	1.63x10 ⁻²	4.69x10 ⁻³	1.44x10 ⁻⁴	5.42x10 ⁻⁴	3.099x10 ⁻⁴		1.03x10 ⁻²	2.88x10 ⁻³	6.37x10 ⁻⁴			
Rate - Grams CO/Day		9.92x10 ⁻¹	5.03x10 ⁻¹	1.79x10 ⁻¹	9.39x10 ⁻²	3.68x10 ⁻²	1.14x10 ⁻²	7.88x10 ⁻³	.383	.517	.355	.207	.144	2.2x10 ⁻²	3.2x10 ⁻²	1.84x10 ⁻³	7.147x10 ⁻³	4.13x10 ⁻³		2 x 10 ⁻²	6.1x10 ⁻³	8.45x10 ⁻³			

FIGURE 6.3.4-2

FIGURE 6.3.4-3

CO generation rate increased, although the magnitude of the increase was substantially less than the earlier excursion. After additional purging the CO generation rate was determined to be $\sim 9 \times 10^{-3}$ grams CO/day. LAS processing was terminated after ~ 365 hours (~ 15 days) under the provision that additional gas samples would be obtained during storage and T/V testing to monitor CO generation.

An investigation was initiated to determine the cause of the CO anomaly. The results of that investigation are presented below.

6.3.4.3 Investigation into Anomaly

The logic diagram shown in Figure 6.3.4-4 summarizes the investigative approach to the problem. The diagram identifies:

- 1) All hypotheses which could explain the cause of the excursion
- 2) Supporting and conflicting evidence for each hypothesis identified
- 3) Further action required to help prove or disprove the explanations presented

The sections below discuss each of the possible explanations in more detail.

6.3.4.3.1 Hypothesis 1 - Erroneous Analysis

This hypothesis states that the gas sample analyses provided by Gollob Laboratories were incorrect; i.e., the reported CO increase was erroneous. It can be argued that since Gollob had initially reported erroneous N₂ concentrations for taps 9 thru 12, they could also have made an error in the CO analysis.* Gas samples #8 and #9 were resubmitted to Gollob under disguised serial numbers for reanalysis. Gollob repeated the analysis with the same CO result. It can be argued, however, that a repeatable analysis does not necessarily mean an accurate analysis.

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*(The erroneous N₂ concentrations were found to be the result of an error in the computer code used by Gollob).

FIGURE 6.3.4-4 LOGIC DIAGRAM

Two steps were taken to insure the accuracy of the analysis. The first step was to have Dr. Alexander (BMI) visit Gollob and review their apparatus and methods of analysis. Dr. Alexander indicated that all equipment and procedures were satisfactory. The second step was to submit an unknown gas standard to Gollob to determine the accuracy of their analysis. The standard submitted was supplied by Mattheson Gas Products and contained the various gases normally found in IHS gas samples. The Gollob analysis of the Mattheson Standard is shown below:

<u>Mattheson Analysis</u>		<u>Gollob Analysis</u>	
(V/O)		(V/O)	
2.11	CO ₂	1.80	
2.70	H ₂	3.2	
5.22	Ar	5.2	
7.01	CO	6.7	
10.4	N ₂	9.5	
Balance	He	Balance	

The Gollob analysis closely correlated with the Mattheson analysis. It was concluded, therefore, that the observed increase in CO concentration in the heat source was indeed real.

The LAS monopole mass spectrometer data also confirms a significant increase in CO concentration between gas samples #8 and #9 (6/5-6/6). The monopole data is shown in Figure 6.3.4-5 and shows > 1 decade increase in CO concentration. The fact that this gas could be measured in the LAS indicates communication between heat source and LAS. Having concluded that the CO increase in the heat source was real, all possible causes were investigated.

F-4 PROCESSING MONOPOLE DATA

FIGURE 6.3.4-5

6.3.4.3.2 Hypothesis 2 - Air In-Leakage

It can be hypothesized that air had leaked into the IHS and reacted to form CO, thereby causing the significant increase that observed. A calculation was made that showed that if the IHS and all GSC lines were filled with 1 atm of air, the CO produced could approach 2 grams if all the O₂ in the lines (IHS) reacted to form CO. The total quantity of CO reported by analysis for taps #9 thru #13 was ~ 1.5 grams.

All operational records and procedures were reviewed to determine if an operational error could have occurred which would permit air to enter the heat source. No evidence of error or anomaly was found. The possibility of an unnoticed operator error is extremely remote in light of both GE and Sandia QA surveillance of all critical gas-related operations.

There is one major inconsistency between the air in-leakage theory and the results of the gas sample analysis. That inconsistency is that the concentrations of N₂ and Ar reported in the gas samples are not indicative of air concentrations that would be required to produce the quantity of CO formed. It is believed that if air had entered the heat source, it would immediately react to form CO gas. Only a small fraction of the CO that was formed would reside in the graphitics and be released at a later time. Therefore, if an operational error were made which permitted air to enter the heat source, the very next gas sample or evacuation of the IHS would remove not only the N₂ and Ar contained in the air, but also essentially all of the CO that was produced. In short, the gas sample analysis does not support this theory.

A comparison was made between the quantity of CO generated in the heat source and the quantity of CO that could have been formed based on the air residuals seen in the gas sample analysis. The air indicator used was Argon, which is normally ~1% of air. Nitrogen was not used because its mass is the same as CO. This approach is conservative because it assumes that the total quantity of air calculated from the gas sample had reacted in the IHS to form CO. In reality, the air residual in the sample is primarily from air leakage into the sample cylinder after the IHS sample was obtained. (The sample cylinder is at a negative pressure). The comparison is shown in Figure 6.3.4-6.

The data clearly show that the quantity of CO observed in the heat source cannot be accounted for on the basis of residual air constituents in the gas sample.

FIGURE 6.3.4-6

After the F-4 RTG was removed from the LAS, the LAS penetration fittings and valve #14 were again tested for leakage. The leak test was repeated because a more thorough test could be performed without the RTG present. No evidence of leakage was detected, including leakage across the seal of valve #14.

The mass 28/mass 30 ratio of the gas samples obtained before and after the observed CO increase was reviewed for indications of air in-leakage. The production of CO from normal air contains ~ 0.2% of mass 30 ($O_{18} + C_{12}$) due to the natural abundance of O_{18} in the air. As will be discussed later all heat source gas samples have exhibited an abnormal mass 28/mass 30 ratio. If air in-leakage caused the CO production, the mass 28/mass 30 ratio would be expected to shift towards a more normal ratio. This shift was not observed.

The F-5 heat source completed LAS processing according to the same procedures described for F-4. A significant increase in the CO generation rate was observed for F-5 at the same point in the processing cycle; i.e., between purge and soak cycles (Reference Figure 6.3.4-7). In view of all the evidence presented, it is highly unlikely that the increase in CO generation was produced by air in-leakage.

6.3.4.3.3 Hypothesis 3 - Fuel Reduction

It can be hypothesized that the increase in CO generation was produced by loss of oxygen from the fuel and reduction of the O/Pu ratio.

The disproportionation of $PuO_{2.00}$ at temperatures above $1200^{\circ}C$ in vacuum, neutral and reducing environments can produce oxygen by the reaction:

In the IHS this would lead to

Other reactions include:

and

followed by

RATE - GRAMS CO/DAY

- SOAK
- PURGE

F-5 PROCESSING

FIGURE 6.3.4-7

F-4 PROCESSING

RATE - GRAMS CO/DAY

Direct contact between the PuO_2 and C does not occur in the MHW-IHS but with the large amount of carbon present, it has been argued that the CO will have effectively the activity of C.

A supporting argument for this hypothesis is that the mass 28 ($^{12}\text{C } ^{16}\text{O}$) to mass 30 ($^{12}\text{C } ^{18}\text{O}$) ratio shown in the IHS gas samples was found to be significantly greater than would be expected if all the O_2 in the CO were present in its normal atmospheric isotopic concentration.

An investigation was conducted to (1) determine if the aforementioned reactions could have caused the increase in CO concentration and (2) to determine the meaning of the abnormal mass 28/30 ratio. Section 5.4.4.4 of the July-August Bimonthly Report presents a detailed discussion of this investigation. For the sake of continuity, the sections below summarize the results and conclusions of that investigation.

Thermal analyses were first performed to determine fuel temperature during storage and processing conditions. Thermodynamic considerations indicate that reactions reducing the fuel are marginal at storage temperatures. At operational temperatures reactions between PuO_2 and C do occur whereas the reaction with CO appears marginal, based on the thermodynamic considerations.

LASL, however, has conducted a series of experiments wherein PuO_2 was exposed to flowing Ar + CO at various temperatures. The CO partial pressure was ~ 76 torr (0.1 atm). It was concluded that the maximum reduction at 1400°C was to $\text{PuO}_{1.85}$.

The results of FSA compatibility tests conducted at LASL were studied to determine if there was evidence of fuel reduction. The fuel/PICS interface temperature for these tests were 1450°C , 1225°C in He, and at the current vacuum MJS operational temperatures for times > 6000 hours. Post-test examination of these units indicated no measurable reduction of the PuO fuel. It should be noted that there is currently no accepted technique for reliably analyzing the O/Pu ratio to better than $\pm .02$. If reduction did occur, it is to an O/Pu ratio ≥ 1.98 . The fact that some oxygen came out of the fuel was inferred by the presence of a small crater in the inner surface of the GIS adjacent to the PICS vent.

The Q-1/IHS is the most representative configuration in which fuel reduction under storage or operational conditions might have been observed. The CO phenomena was first found in the gas samples taken from the Q-1/IHS. ML/MRC examined MHF-28 removed from Q-1 explicitly to determine whether fuel reduction had occurred during IHS fabrication, storage, shipping and testing at GE-VF. The results of the ML/MRC analysis on PPS-39, the fuel sphere from FSA MHF-28, showed no reduction of the fuel within the limits of accuracy of the analyses, $O/Pu = 2.00 \pm 0.02$.

The absence of measurable reduction in the fueled tests discussed in the preceding paragraphs do not preclude the possibility that some fuel reduction could have occurred. However, if such reduction has occurred, it has lowered the O/Pu ratio by less than 0.02 assuming that the fuel was initially at exact stoichiometry, $O/Pu = 2.00$. Alexander and others have suggested that some of the CO observed could be explained on the basis of a reduction of the fuel to an O/Pu ratio of $= 1.995$. The loss of oxygen from PuO_2 in the amount needed to effect the reduction to $PuO_{1.995}$, could produce $= 3.5$ grams of CO. This reduction is possible but cannot be proven because of measurement limitations. If all of the oxygen involved with the CO formation came from the fuel, it would be reasonable to expect that, given the same thermal conditions and the same fuel stoichiometry, the same amount of CO would be generated in every case, since the O_2 source is fixed. This assumes that the degassing observed at GE-VF is indeed approaching an effective end point. There has been a variation in the amount of CO observed in the heat sources processed to date, suggesting that some of the oxygen is coming from some source other than the fuel. As will be discussed later, the quantities of CO calculated to be left in the carbon/graphite parts by the initial and the current bakeout schedules, is sufficient to account for the observed totals without invoking the fuel reduction hypothesis.

6.3.4.3.4 Hypothesis 4 - Normal Outgassing

This hypothesis states that the phenomena observed was the normal outgassing of the heat source graphitics when reaching an equilibrium condition such as during the soak period. The obvious argument against this hypothesis is that F-3 did not behave in the same manner. For unknown reasons the F-3 heat source has released the smallest quantity of CO when compared to all other heat sources. However, the comparison of the F-4 heat source with the F-2 and F-5 heat sources during LAS processing are strikingly similar. Figure 6.3.4-8 shows the gram quantities of CO removed from the F-2 and F-4 heat source during 24-hour soak periods under a cover gas pressure of 2 psia. Figure 6.3.4-7 compares the F-4 and F-5 CO generation rates vs. processing time. Perhaps the real question is why F-3 did not behave like F-2, F-4 and F-5.

○ SOAK
 □ PURGE

FIGURE 6.3.4-8

CONC. IN IHS

10^{-1}

[1 2 PROCESSING]

[1 2 PROCESSING]

10^{-1}

10^{-3}

10^{-9}

A visit was made to MRC to discuss air exposure times for all LES 8/9 heat source graphitics and, in particular, the differences between F-3 and F-4. In summary it was learned that: (a) typically, the GIS components for F-1 thru F-4 were exposed to air for ~20 minutes after bakeout; (b) the GIS components used in F-5 were not exposed to air after bakeout but one of the containers containing the GIS had leaked small concentrations of air; the components were not reprocessed (c) all FSA's were stored in sealed containers in the MRC glovebox (before assembly into the heat source) for the following times:

F-1	~ 11 weeks
F-2	~ 3 - 7 weeks
F-3	~ 2 - 3 weeks
F-4	~ 11 - 15 weeks
F-5	~ 3 - 6 weeks

MRC indicated that the gloveboxes in which the containers were stored were periodically opened to air for maintenance purposes; and (d) all aeroshells were typically exposed to air for 20-30 minutes after bakeout.

The data indicate that the F-3 FSAs had the shortest storage period and the F-4 FSAs had the longest storage period. However, if all storage containers were leak tight, the length of storage time should not be a factor. Aside from the longer FSA storage, the only other difference noted was the fact that the neutron production in the F-4 heat source was higher than any of the other LES 8/9 heat sources. The significance of this has not yet been determined. The discussions revealed no obvious explanation for the F-3/F-4 differences.

BMI recently performed degassing experiments on the heat source graphitics which seem to support the normal outgassing supposition. In summary, the experiments indicate:

- (1) There is a sufficient quantity of residual CO in the IHS graphitics at the time of LAS processing to account for the concentrations observed in the F-4 heat source excursion. Although testing is still in progress, it indicates that --
  - a) The initial bakeout at 1200°C for 5 hours for the POCO aeroshell and 1 hour for all other materials used in the F-1, F-2, and F-3 IHS's was ineffective. This confirms previous test results.
  - b) The initial bakeout at 1350°C for 24 hours for the GIS components used in the F-4 and F-5 heat sources was probably also inadequate.

- c) The air exposure of the aeroshell after bakeout can, in itself, produce the CO concentrations (~ 1.5 grams) observed during the F-4 excursion.
- (2) The time to degas the graphitics appears to be significantly longer than previous experiments indicated.
- (3) The degassing rate under a 1-atmosphere cover gas pressure, as experienced during the purging operation, will tend to suppress the CO release rate, if there is a sufficiently higher CO inventory to be released. The degassing rate under a cover gas pressure of 2 psia (soak condition) is essentially the same as vacuum conditions.

The above information indicates that there is a sufficient residual quantity of CO in the graphitics due to inadequate bakeout and subsequent air exposure without invoking any other CO producing mechanisms to account for the CO seen in the excursion. The F-4 IHS storage period was relatively short; i.e., ~ 40 days, and consequently, the IHS had little time to release significant quantities of CO during storage. It is postulated that the more representative degassing rate is not measured during the purging cycle because of (a) the aforementioned effects of 1 atm cover gas pressure, and (b) the fact that the purging cycle is probably providing rates at which basically the external surfaces are degassing. When permitted to equilibrate, such as during the soak period, a more representative heat source CO generation rate can be realized.

If the CO excursion was indeed due to normal degassing, then the degassing rate can be expected to decrease with temperature. Gas samples were taken of several of the heat sources in storage, after LAS processing. The CO generation rate in storage was compared to the CO generation rates during LAS processing (Reference Table 6.3.4-2). The operating temperatures of the graphitic components, for both sampling conditions, is also shown in Table 6.3.4-2. The data indicate a decrease in CO release rate with decreasing temperature. This information is consistent with the normal degassing supposition.

6.3.4.4 Final Conclusions

Based on the evidence presented, the following conclusions are drawn:

- 1) The increase in CO generation rate was a real phenomena and was not the result of an erroneous analysis.

TABLE 6.3.4-2

GRAPHITIC TEMPERATURES

<u>RTG STORAGE</u> <u>(°C)</u>	<u>COMPONENT</u>	<u>RTG OPERATION</u> <u>IN LAS (°C)</u>
904	Aeroshell OD	1088
1016	GIS OD	1160
1060	GIS ID	1204
954	Retainer Ring	1116

CO GENERATION RATES

<u>EVENT</u>	<u>CO GENERATION RATE</u> <u>(GRAMS CO/DAY)</u>	
	<u>F-4 IHS</u>	<u>F-2 IHS</u>
a) End of LAS Processing	8.5×10^{-3}	5.6×10^{-3}
b) RTG Storage	$1.1 \times 10^{-4} / 9 \times 10^{-6}^*$	2.2×10^{-5}

* Max. Rate Assumes IHS Leakage.

Min. Rate Assumes No IHS Leakage.

- 2) Air in-leakage did not produce the observed CO excursion in the F-4 heat source.
- 3) It is possible that fuel reduction could have occurred between the limits of $\text{PuO}_{2.00}$ to $\text{PuO}_{1.98}$ to produce gram concentrations of CO. However, because of the limitations of analytical methods, there is no way to prove or disprove this theory by experimentation.
- 4) The concentrations of ^{18}O formed in the CO by various analyses indicate that some of the oxygen may have come from the fuel. The normal back exchange explanation is sufficient to explain abnormalities in the mass 28/mass 30 ratio. However, the extent of the abnormality caused by fuel reduction and the extent of the abnormality caused by back exchange is not known.
- 5) There is a sufficient residual quantity of CO in the IHS graphitics due to inadequate bakeout and subsequent air exposure to account for the CO in the excursion without invoking other CO-producing mechanisms. The soak period provides a more representative heat source CO generation rate than the rate obtained during the purging periods. The phenomena observed was also noted during the processing of the F-2 and F-5 heat sources.

It is concluded that the excursion observed in the F-4 heat source was caused by a change in the processing conditions and that the CO release was according to the normal degassing characteristics of the graphitics for that processing condition.

6.4 RCA ACTIVITIES

E-5 Converter Assembly was completed, and its processing was initiated. The thermopile assembly for Converter F-6 was completed. Fabrication in all other areas progressed without any major difficulty.

The delivery schedule for the next four converters is as follows:

E-5	-	11/20/75
F-6	-	12/22/75
F-7	-	2/4/76
F-8	-	3/24/76

6.4.1 Thermoelectric Materials Fabrication and Thermocouple Bonding & Unicouple Fabrication

During the reporting period, fabrication proceeded normally in all areas. Table 6.4.1-1 shows the status of the thermoelectric materials fabrication, thermocouple bonding, and unicouple fabrication for each converter.

6.4.2 Foil Insulation Assembly and Thermopile & Converter Assembly

Delineated below is the status as of 10/31/75 of the foil insulation assemblies and thermopile and converter assembly for each converter worked on during the reporting period.

	<u>Inner</u> <u>Moly Frame</u>	<u>T/P Foil</u> <u>Ins. Ass'y</u>	<u>Foil End</u> <u>Cap Assy's</u>	<u>T/P</u> <u>Ass'y</u>	<u>Conv.</u> <u>Ass'y</u>
<u>MJS:</u>					
E-5	C	C	C	C	C
F-6	C	C	C	C	In Pro
F-7	C	C	C	-	-
F-8	C	In Pro	-	-	-

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

TABLE 6.4.1-1 - UNICOUPLE PARTS AND MATERIAL STATUS
(As of 10-31-75)

	<u>T/E Mat'ls.</u>	<u>1st Bond</u>	<u>Si3N4 Coating</u>	<u>2nd Bond</u>	<u>Mach. Couple Preass'y</u>	<u>Cold Stack Ass'y</u>	<u>Unicouple Ass'y</u>	<u>Wrapper U/C Ass'y.</u>
<u>Good Req'd./Conv't.</u>	478	421	408	342	335	335	323	320

Fabrication Status:

F-7	C	C	C	C	C	C	C	C
F-8	C	C	C	C	C	113	13	13
F-9	C	C	210	185	66	-	-	-
F-10	In Pro	21	-	-	-	-	-	-
F-11	In Pro	-	-	-	-	-	-	-

Yield History:

MJS:

Planned:	88.1%	96.0%	83.9%	97.9%	95.0%	96.4%	99.3%
Actual:							

F-7	79.6	99.2	95.2	96.0	99.1	98.8	99.4
F-8	90.3	100.0	97.7	97.7	98.3*	100.0*	100.0*
F-9	91.2	100.0*	92.0*	98.5*	-	-	-
F-10	95.5*	-	-	-	-	-	-

Overall Inception
To Date Yields:
(Includes LES 8/9)

84.5%	97.9%	82.2%	95.3%	98.9%	94.7%	99.3%

Legend:

- C - Complete Complement of Assemblies Has Been Fabricated
- In Pro - Fabrication In Progress
- - Fabrication Has Not Commenced
- * - Complement Not Completed, Yields to Date Given

6.4.3 Testing

6.4.3.1 Module Testing

All modules operated normally during the reporting period with the exception of those discussed below. Tables 6.4.3-1 thru 6.4.3-3 show the status of all units. The performance curves for all devices on test are shown in Figures 6.4.3-1 through 6.4.3-30.

PD-2 - Module PD-2 was cycled to room temperature as a result of a minor leak in the test station. The station was repaired and the module returned to operating temperature.

PD-3 - This module was cycled to room temperature as a result of a broken backer pump belt. The module is being returned to operating temperature.

18-C - This module was cycled to room temperature as a result of a failure in the electronics of the Ion Gage Control Unit. The control unit has been repaired and the 18-Couple Converter returned to operating temperature. The life test station experienced no loss of vacuum.

18-G - The 18-Couple Converter, 18-G, was cycled to room temperature as a result of a broken Ion gage at 18,829 hours. Although the heater power was automatically turned off, the device did see air exposure at temperatures near normal operating temperature for a short period. Room temperature measurements showed no indication of damage to the thermoelectric couples, heater, or instrumentation. It was, therefore, decided to return the device to operating temperature and observe the effects of the air exposure on performance, and to determine if any degraded performance will be corrected by continued vacuum operation. The expected area of degradation would be an increase in the emissivity of the moly foil, with a resulting increase in conductivity of the foil insulation. Past experience has indicated that this would probably improve with operation. The converter was brought back to the same power input as before the shutdown, following established 18-couple processing instructions. As expected, power output and hot shoe temperature were both lower (7.5 vs 8.0 watts and 1000°C vs 1027°C), indicating increased thermal conductivity of the foil insulation. After approximately 100 hours operation, by the end of the reporting period, neither power output nor hot shoe temperature has shown any significant change.

TABLE 6.4.3-1 - 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	P _o	EL	IL	E _{oc}	Status
18-C	18 TBC Design Couples Moly/Astro Foil	Long Life Vac	20,822	1027	307	156.30	7.863	3.526	2.230	6.887	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.)	19,685	1022	303	152.48	7.948	3.550	2.239	6.780	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	19,127	1026	305	157.68	7.878	3.481	2.263	6.812	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.)	19,240	1000	306	154.14	7.446	3.539	2.104	6.573	At Operating Temp.
18-H	18 TBC-4 Design Cpls.-Moly/Astro Foil.	Long Life Vac	20,055	978	299	140.27	7.130	3.480	2.049	6.373	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	13,206	1129	305	188.92	10.241	3.494	2.931	7.529	At Operating Temp.

TABLE 6.4.3-1 (Continued)

Device	Device Description	Type of Test	Average Hours Operation	Average Hot Shoe Temp. °C	Average Cold Shoe Temp. °C	Pin	P _o	EL	IL	E _{oc}	Status
DC-13	.450 SiO ₂ Barriers	Long Life Vac	11,841	1035 (nominal)	290	160.42	8.834	3.552	2.487	6.920	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	10,836	1135 (nominal)*	302	191.09	10.409	3.532	2.947	7.526	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	7,316	1092	303	187.66	10.046	3.520	2.854	7.256	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	8,264	1039	298	168.09	8.774	3.490	2.514	6.840	At Operating Temp.
SN-4	Like SN-1	Long Life Vac	99	1135	315	191.42	11.422	3.527	3.244	7.181	At Operating Temp.
SN-5	Like SN-1, except one-half of couples have plasma sprayed Al ₂ O ₃ on Heat Shunts.	Long Life Vac	1,297	1089	306	174.31	10.255	3.552	2.887	7.058	
SN-6	Like SN-5	Long Life Vac	1,531	1038	291	161.26	9.037	3.511	2.574	6.613	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 6.4.3-2

AIR-VAC LIFE TEST STATUS4-COUPLE PCMS

<u>Device</u> <u>DeSignation</u>	<u>Principle Feature</u>	<u>Test Temp</u> <u>Hot Shoe</u>	<u>Hours</u>	<u>Status</u> <u>(10-24-75)</u>
PCM 1	Q1 Unicouple Design-Control	1035 ⁰ C	12,841	At Temp.
2	Q1 Unicouple Design-Control	1085	12,840	At Temp.
3	Q1 Unicouple Design-Control	1135	12,842	At Temp.
4	Q1A Unicouple Design-Control	1135	12,841	At Temp.
5	Simulated Unicouple	1135	12,537	At Temp.
6	JB-40 and UT6-ST-Graphite H.S.	1015	13,270	At Temp.
7	JB-40 and UT6-ST-Graphite H.S.	1115	12,538	At Temp.
8	JB-40 and UT6-ST-Graphite H.S. Si ₃ N ₄ H.S.	1115	12,538	At Temp.
9	Si ₃ N ₄ Coated N-P W/Ti & W/O Ti SiMo H.S.	1035	13,271	At Temp.
10	Si ₃ N ₄ Coated N-P W/Ti & W/O Ti SiMo H.S.	1085	13,271	At Temp.
14	Same as PCM's 9-10 plus Si ₃ N ₄ Coated Al ₂ O ₃	1135	11,255	At Temp.
15	Si ₃ N ₄ Coated <u>Hot Shoes Only</u>	1135	9 202	At Temp.
16	Si ₃ N ₄ Coated <u>Legs Only</u>	1135	9,202	At Temp.
17(R)	Special Construction to determine Location of Leakage.	1135	10,559	At Temp.
18	Si ₃ N ₄ Coated (Interim Facility)	1135	6,736	At Temp.
19	Si ₃ N ₄ Coated U/C & Al ₂ O ₃ Coating on 2 Heat Shunts.	1135	26	At Temp.
PD-2	1 Cpl. N-P W/Ti; 3 Cpls. N-P W/O Ti	1035	18,270	At Temp.
PD-3	All P SiMo Hot Shoes	1035	13,475	At Temp.

TABLE 6.4.3-3 - RCA SiGe THERMOELECTRIC MODULE LIFE TESTS - SNAP 17A MODULES

DATE 10/21/75

<u>Module</u> <u>Number</u>	<u>Module</u> <u>Hours</u> <u>Total</u>	<u>Number</u> <u>of</u> <u>Couples</u>	<u>Leg</u> <u>Dia.</u> <u>Inches</u>	<u>Vac.</u> <u>Torr</u>	<u>Nominal</u> <u>T_h</u> <u>°C</u>	<u>Measured</u> <u>T_h</u> <u>°C</u>	<u>Measured</u> <u>T_c</u> <u>°C</u>	<u>Measured</u> <u>ΔT</u> <u>°C</u>	<u>Normalizing</u> <u>ΔT</u> <u>°C</u>	<u>R</u> <u>mΩ</u> <u>per</u> <u>cpl</u>	<u>E_{oc}</u> <u>Mv</u> <u>Per Couple</u> <u>Normalized</u>	<u>P_o</u> <u>mw</u>	<u>% of</u> <u>500</u> <u>Hour</u> <u>Po</u>	<u>Couple</u> <u>Hours</u>
MTA4-5	92,940	6	.230	7x10 ⁻⁷	850	851	250	601	606	84.0	261	205	75.9	557,640
MTA7-10	89,828	6	.275	4x10 ⁻⁷	850	847	292	555	606	84.3	347	357	95.7	539,968
MTA8A-9	89,406	4	.275	4x10 ⁻⁷	1050	1052	386	666	606	78.0	332	353	86.9*	436,604
MTA8A-18	88,997	6	.275	7x10 ⁻⁷	825	828	276	552	612	77.3	334	361	89.1	533,982
MTA9-1	89,780	14	.275	Air	325	847	200	647	612	74.8	301	303	90.2	1,256,920

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

TOTAL COUPLE HOURS 3,324,114

REMARKS:

The increase in Mod-Shell resistance shown in Figure 6.4.3-5 is concluded to be a result of the oxidation of electrically-conductive contaminants that were depositing on the cold stack ceramics with time at temperature. This phenomenon has been observed before.

S/N-2 - A review and analysis of S/N-2 test data was made, prompted by the sharp drop in the S/N-2 Mod-Foil resistance starting at about 4000 hours and accelerating at about 6000 hours, see Figures 6.4.3-15 and 6.4.3-29. Figure 6.4.3-29 shows the measured resistance of the 3 and 15-couple sections of the converter as well as the measured resistance of all 18-couple in series, as plotted in Figure 6.4.3-15. Also shown in Figure 6.4.3-29 is the calculated resistance of the parallel combination of 3 and 15-couple sections,

where
$$R_{18} = \frac{R_3 \times R_{15}}{R_3 + R_{15}} .$$

The most striking thing about this plot is the large discrepancy between calculated and measured values for 18-couples in series. Review of testing conditions show that connections are correct, and the smooth shift in relationship between measured and calculated values (curves C and D, Figure 6.4.3-29) confirms that the results are real and not the result of a testing error.

The only plausible explanation of the relationship between curves C and D is that the resistance being measured is voltage-sensitive, and therefore the level is shifted by the addition of the voltage developed by the two strings of couples, when the entire converter is connected in series. The voltage sensitivity of this type of resistance has been observed many times in the past. Probably the shifting relationship of curves C and D results from an initial concentration of deposits at some localized area, such that the addition of the voltage from a few couples caused a significant shift resistance. After a prolonged period of testing, as more general dispersion of deposits occur over the entire converter, the shifts in voltage become less of an influence on the total measured R mod-foil. This is consistent with the observation that the measured curve has moved into agreement with the calculated curve at later time periods.

Based on the above premise, it follows that the calculated curve D is a better indication of the long term behavior than the measured curve. It can be expected that as deposits continue to develop with time, they will become even less concentrated at any one location, and the voltage sensitivity R mod-foil will continue to decrease with time. If curve D is taken to represent converter performance, it can be seen to be trending downward after 4000 hours, but not at a rate which would imply significant power loss for present mission durations. While the number of data points is not sufficient to be conclusive, the slope of the measured 18-couple R mod-foil indeed appears

to be approaching the slope of the calculated curve.

Thus, despite the apparently alarming drop in curve C, it appears that this was merely a correction of a aberration caused by voltage sensitivity of the deposits, and the "real" resistance of the converter is following essentially the expected pattern. Future performance will continue to be closely monitored to confirm those conclusions. The rate of decrease of thermopile-to-foil resistance showed a significant improvement in October as shown in Figures 6.4.3-15 and 6.4.3-29.

S/N-3 - The plot of R mod-foil for S/N-3 shown in Figure 6.4.3-16 suggests the possibility that the resistance of the converter has "turned the corner" and started a down trend similar to that observed on 18-0 and S/N-1 (see Figure 6.4.3-1). However, S/N-1 and 18-0 are operating at 1135°C, and the start of the characteristic degradation of R mod-foil is not expected for S/N-3 at approximately 7500 hours of operation at a hot shoe temperature of 1035°C.

An expanded plot of R mod-foil for S/N-3 is shown in Figure 6.4.3-30. This includes all intermediate data points in addition to the points shown in Figure 6.4.3-16. Also shown are the times of thermal cycling the converter to room temperature. Table 6.4.3-4 shows the details of each thermal cycle. The most significant item in the table is that the cycle at 5600 hours resulted from a pressure rise in the bell jar due to loss of LN₂ to the cold trap of the vacuum system. The loss of LN₂ permitted the material condensed on the cold trap to evaporate at too rapid a rate to be accommodated by the vacuum (diffusion) pump. The rise in pressure exceeded 1×10^{-3} Torr, causing the pressure controller to trip and turn off the converter heater power supply. S/N-3 was subsequently brought back to temperature using a processing schedule.

Examination of the expanded plot of Figure 6.4.3-30 suggests that R mod-foil may have started on a down trend immediately following the pressure burst at 5600 hours. It can be postulated that this could result from some of the material evaporating from the cold trap moving into the bell jar during the pressure burst. If this caused the down trend in R mod-foil, two conclusions may be drawn:

- A. The cause is a testing problem not representative of actual flight operation.

- B. Since the source of contamination is finite, the decay in R mod-foil should not continue indefinitely, but should end after the reaction of the contaminants is completed. That this may be occurring is suggested because the Thermopile-Foil resistance now shows an essentially constant value. This supports the conclusion that the down trend after 5,600 hours was caused by a brief loss of LN₂, and that therefore, the down trend should not persist. See Figures 6.4.3-16 and 6.4.3-30.

If it were assumed that the cause of the degradation of R mod-foil was not related to the pressure burst, and therefore would continue, it is instructive to determine what the effect on converter performance would be if the down trend had continued.

TABLE 6.4.3-4 - THERMAL CYCLES - CONVERTER S/N-3

<u>Cycle</u>	<u>Hours</u>	<u>Cause & Comments</u>
A	1,567	Short power failure. LN ₂ cold trapping maintained. No loss of vacuum.
B	2,800	Short power failure. LN ₂ cold trapping was maintained. No loss of vacuum.
C	5,600	Short power failure to the LN ₂ Controller. LN ₂ cold trapping was lost, resulting in an increase of bell jar pressure to above 1×10^{-3} Torr. System operated under vacuum, but without LN ₂ in cold trap for approximately 16 hours. The unit was reprocessed.
D	5,993	Short power failure. LN ₂ cold trapping was maintained. No loss of vacuum.
E	6.572	Power Supply (heater) relay failure. LN ₂ cold trapping was maintained. No loss of vacuum.

The rate of decrease after 5,600 hours, if extrapolated as a straight line in a log-log-graph, indicates a leakage resistance of approximately 1000 ohms after 50,000 hours (5.7 years). Scaling this to a full-size 312 couple converter and calculating the power loss in the leakage resistance gives:

$$P_{I^2R} = \frac{(E \text{ Load})^2}{3 R} \frac{30^2}{3 (1000 \times \frac{18}{312})} = 5.2 \text{ watts,}$$

or less than 4% of EOM power. This assumes the worst case situation where one side of the converter output is grounded to the shell.

S/N-4 - This 18-Couple Converter with Si_3N_4 -coated couples reached operating temperature for the first time during the reporting period. Early hour thermopile-to-foil leakage resistance falls between that of the other two 18-Couple Si_3N_4 -coated Converters operating at 1135°C hot shoe temperature (18-0, S/N-1).

18 CPL. CONVERTERS

R_{max} - Fail vs Time

T_h = 135°C

FIGURE 6.4.3-1

1B CPL. CONVERTERS R MED. SHELL AND R SHELL - FOIL VS TIME

FIGURE 6.4.3-2

OHMS

1B CPL. CONVERTERS NOT PLOTTED (P 200 MA)

	<u>TH °C</u>	<u>HRS</u>		<u>TH °C</u>	<u>HRS</u>
DC-2	1135	295	1B-F	1085	2844
DC-3	"	2701	DC-13	1035	11,241
DC-5	"	2477	SN-5	1085	1,297
DC-6	"	1848	SN-6	1035	1,531
DC-10	"	1645	SN-4	1135	99
1B-D	1035	19,685			

1B CPL CONVERTERS R MOD - SHELL AND R SHELL - FOIL VS TIME

FIGURE 6.4.3-3

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

FIGURE 6.4.3-4

6-66

18 CPL CONVERTERS RMod-SHELL AND R-SHELL-FOIL V.S. TIME

FIGURE 6.4.3-5

18-Ø CONVERTER

LEAKAGE RESISTANCE VS. TIME AT TEMP.

FIGURE 6.4.3-6

18A CONVERTER

FIGURE 6.4.3-7

SAI-1 CONVERTER
LEAKAGE RESISTANCE VS TIME AT TEMP.

MOD - FOIL RESISTANCE

DC-13 CONVERTER

PERFORMANCE VS. TIME AT TEMPERATURE

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

FIGURE 6.4.3-12

LEAKAGE RESISTANCE VS. TIME AT TEMP.

HOURS

6-75

SN-2 CONVERTER

LEAKAGE RESISTANCE VS TIME AT TEMP

FIGURE 6.4.3-15

SN-3
LEAKAGE RESISTANCE VS TIME AT TEMP.

FIGURE 6.4.3-16

SN-3 CONVERTER PERFORMANCE VS TIME AT TEMPERATURE

FIGURE 6.4.3-17

SN-5 CONVERTER

LEAKAGE RESISTANCE VS TIME AT TEMP

FIGURE 6.4.3-18

SN-6 CONVERTER

LEAKAGE RESISTANCE VS TIME AT TEMP

MOD. FOIL RESISTANCE

MOD. FOIL RESISTANCE

T_W = 1135°C

FIGURE 6.4.3-23

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

6-85

PCM-17

R. Cpl #1 - Foil Layers
VS TIME AT TEMP.

FIGURE 6.4.3-24

OHMS

HOURS

PCM-17

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

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

FIGURE 6.4.3-25

OHMS

MOD - FOIL RESISTANCE

MOD-FOIL RESISTANCE

$T_H = 10.25^\circ\text{C}$

FIGURE 6.4.3-27

SN-2 CONVERTER

RMOD-FOIL VS
TIME AT TEMPERATURE

$T_H = 1025^{\circ}C$

FIGURE 6.4.3-29

SN-3

RMRD-Foil Vs Time
AT TEMPERATURE

TN=1035

FIGURE 6.4.3-30

6.4.3.2 Converter Processing

Processing of Converter E-5 was initiated during the reporting period, and as of 10/30/75 the power input had reached 1500 watts. Because of the small diameter tubing connecting the converter to the Ion Gage on E-5, the bell jar vacuum level is being used to control the rate of heat-up of E-5 in place of the internal converter pressure as on previous converters. In addition to the heat-up rate being controlled by vacuum limits, there is also a maximum rate specified, which in the case of both Q-2 and E-5 to date has been the limiting factor on heat-up rate. Therefore, in effect, E-5 is being processed at the same heat-up rate as Q-2.

All other aspects of processing are proceeding normally, and, in particular, power output and leakage resistance are tracking previous converters as a function of input power.

As directed by G.E., E-5 will be held at temperature (2400 watts or more EHS input) for a total of 200 hours, to complete the Thermal Vacuum Burn-In requirement.

6.4.4 Product Assurance

6.4.4.1 Reliability

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

6.4.4.1.2 Failure Reports - None

6.4.4.1.3 Next Report Period - During the next report period these events should occur.

MJS Engineering Model, E-5 should complete Thermal Vacuum Processing.

MJS Flight Model, F-6 should complete Converter Assembly Fabrication.

6.4.4.2 Configuration Management

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

6.4.4.2.1 Initial Specifications - The following new specifications have been approved.

<u>Spec. No.</u>	<u>Description</u>
RG21B2 Rev. A	Preparation for Converter Processing
RA15C3 Rev. A	Converter Assembly Fabrication Procedure for E-5
M9D4 Rev. -	Fibrous Quartz Yarn

6.4.4.2.2 Specification Revisions - The following specifications have been revised through the approvals of these ECN's.

<u>ECN No.</u>	<u>Engineering Data No.</u>	<u>Description</u>
AT(49-15)-3066-019	M9D1 Rev. G	Fibrous Quartz Yarn (Fired)
-022	RA15C2 Rev. B	Converter Assly. Fabrication Procedure.
-023	RG21B1 Rev. G	Preparation for Conv. Processing
-026	M4C2 Rev. D	Metallized Alumina Ceramic
-028	RA2B1 Rev. D	Diffusion Bonding of First Bond Assembly.
-029	RG21A2 Rev. J	Converter Processing Procedure
-30	M28A Rev. P.	Silicon Alloys for Thermoelectric Materials.
-32	RQ24A1 Rev. F	Product Specification for Acceptance of Silicon Nitride Coated First Bond Assemblies.
-33	RA6E1 Rev. M	Thermopile Assembly Fabrication Procedure - Phase II.
-037	RA6E1 Rev. M	Thermopile Assembly Fabrication Procedure - Phase II.

6.4.4.3 Quality Assurance

6.4.4.3.1 Quality Assurance Progress

6.4.4.3.1.1 Prime Converter Assembly - MJS Engineering Model, E-5, has completed Converter Assembly Fabrication and MJS Flight Model, F-6 has completed Thermopile Assembly Fabrication.

6.4.4.3.1.2 Vendor Rating - The vendor rating for Second Quarter, 1975, was issued during the report period. There were no unsatisfactory vendors.

6.4.4.3.2 Nonconformance Reports

6.4.4.3.2.1 MRB Actions - Table 6.4.4-1 lists the Nonconformance Reports (NR's) issued during the report period for MRB Authorization to use the noted discrepant items.

6.4.4.3.2.2 Nonconformance Report Sheet (NRS) Summary - Disposition of defective items found at inspection is obtained through approval contained in Nonconformance Report Sheet (NRS). The summary of items placed on NRS is shown below and in Table 6.4.4-2. 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 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 Log book 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>	<u>Re- inspect</u>
Sept.	60	1	0	58	0	0	2
Oct.	<u>61</u>	<u>0</u>	<u>0</u>	<u>60</u>	<u>0</u>	<u>0</u>	<u>0</u>
Totals	121	1	0	118	0	0	2

TABLE 6.4.4-1 - NONCONFORMANCE REPORTS REQUIRING MRB ACTION

<u>RCA NR #</u>	<u>G.E. NR #</u>	<u>ITEM</u>	<u>SPEC. #</u>	<u>DISCREPANCY</u>	<u>DISPOSITION</u>	<u>PROBLEM CAUSE</u>
1332	43329	Thermopile Ass'y E-5	A9E2	Distance of Ball End of mandrel to top surface of rivet head exceed limit.	Replace (1) Rivet use as is (2) Rivet	Design
1333	43330	Si ₃ N ₄ Coat First Bond Assembly	A30A6	Exceed limit for chlorine content.	Use as is. Spread use of couples remaining converters.	Defective coating system hardware
1334	43331	Si ₃ N ₄ Coat Hot Shoe Spacer.	P20J3	Exceed limit for chlorine content.	Use as is. Spread over remaining converters.	Defective coating system hardware
1335	43351	Metallized Electrical insulators	P4G2	Pin holes in metallizing	Use as is	Vendor problem
1336	43369	ETG Converter 47J303602G1 Assly. E-5.		Terminal lug riveted to opposite face of T/P power output lead than shown on drawing.	Use as is	Operator Error

TABLE 6.4.4-1 (CONT.) - NONCONFORMANCE REPORTS REQUIRING MRB ACTION

<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>
1337	43424	Formed Plate	P8B4	Tab height below minimum spec.	Use as is	Vendor Problem
1338	43456	Thermopile Assembly F-6	A9E2	Distance of Ball End of mandrel to top surface of rivet head exceed limit.	Use as is	Design
1339	43457	Thermopile Assembly F-6	A9E2	Split Rivet Head	Replace rivet	Defective Rivet
1340	43458	ETG Converter Assembly E-5	47J303602G1	At specified torque value, heater lead clamp does not make satisfactory contact with heater lead.	Rework	Design
1341	43462	Thermopile	A9E2	Heater lead riveted to Row 2 can be rotated about rivet.	Replace rivet	Unknown
1342	43466	ETG Converter	47J303602G1	Heat Source measuring T/C #5 is intermittent	Use as is	Loose T/C wire in crimp conn. or loose crimp conn. on pin.
1343	43465	ETG Converter Assembly E-5	47J303602G1	When converter assembly rotated 180°, converter alarm bell rang.	Short could not be repeated, use as is	Cable terminal board could have been shorted across storage stand and caused alarm to ring.

TABLE 6.4.4-2 - NRS NONCONFORMANCE SUMMARY BY PARTS - SEPTEMBER 1975

<u>PARTS</u>	<u>DWG #</u>	<u># LOTS INSPECTED</u>	<u># LOTS W/DEFECTS</u>	<u># OF PARTS INSPECTED W/DEFECTS</u>	<u>PROBLEM AREAS</u>
Radiator Attachment Assembly	A12A7	4	3	10.0	None
Cold Stack Assembly	A19A8	11	4	1.1	None
Degaussing Loop	A28A2	1	1	20.0	X-Ray Reject
Pellets, 'N'	P1G25	6	6	9.7	None
Pellets, 'P'	P1G26	2	2	12.8	Chips, Fractures
Segments 'P'	P1G28	1	1	26.6	Chips, Fractures
Pellets (Rough), 'N'	P1T1	8	5	1.6	None
Pellets (Rough), 'P'	P1T2	2	2	2.2	None
Electrical Insulators	P4F3	8	3	8.9	
Metallized Elec. Insulators	P4G2	1	1	100.0	Holes in Metallizing
Plated Elect. Insulators	P4H2	3	1	0.2	None
Machined Radiator Attachment	P11C2	10	1	0.6	None
Hot Shoes (Rough)	P11G3	8	3	1.3	None
Hot Shoes	P11G4	7	6	3.9	None
Hot Shoe Spacers	P20H1	2	1	0.2	None
Coated Hot Shoe Spacers	P20J3	13	2	0.4	None

<u>MATERIALS</u>	<u>DWG #</u>	<u>NO. LOTS REJECTED</u>	<u>PROBLEM AREAS</u>

78 % SiGe 'P'			
Vacuum Hot Press	P1R6	1	Multiple Cracks
63.5 % SiGe 'N'			
Vacuum Hot Press	P1R7	1	Multiple Cracks
63.5 % SiGe			
Vacuum Hot Press	P1R8	1	Multiple Cracks

<u>UNICOUPLE ASSEMBLIES</u>	<u>DWG #</u>	<u>NO. REJECTED FOR PRIME HARDWARE</u>

First Bond	A26A2	40
Coated First Bond	A30A6	0
Second Bond	A1C1	2
Preambly	A2C1	12
Unicouple	A3H1	5
Wrapped Unicouple	A8E1	0

TABLE 6.4.4-2 (CONT) - NRS NONCONFORMANCE SUMMARY BY PARTS - OCTOBER 1975

<u>PARTS</u>	<u>DWG #</u>	<u># LOTS INSPECTED</u>	<u># LOTS W/DEFECTS</u>	<u># OF PARTS INSPECTED W/DEFECTS</u>	<u>PROBLEM AREAS</u>
Radiator Attachment Assembly	A12A7	19	9	4.5	None
Pellets, 'N'	P1G25	7	7	16.3	Chips
Pellets, 'P'	P1G26	5	5	11.0	Chips, Fractures
Segments 'N'	P1G27	3	3	7.5	None
Pellets (Rough), 'N'	P1T1	2	2	2.3	None
Pellets (Rough), 'P'	P1T2	1	1	1.0	None
Segments (Rough) 'P'	P1T1	1	1	100	High Resistivity
Electrical Insulators	P4F3	22	1	0.2	None
Machined Radiator Attachment	P11C2	7	1	0.7	None
Hot Shoes (Rough)	P11G3	10	4	40.0	High r-j (N-P Bond) Resistance.
Hot Shoes	P11G4	6	6	21.0	1 Lot Rej. for High r-j Resistance.
Hot Shoe Spacers	P20H1	4	2	0.3	None
Coated Hot Shoe Spacers	P20J3	11	3	0.6	None

<u>UNICOUPLE ASSEMBLIES</u>	<u>DWG #</u>	<u>NO. REJECTED FOR PRIME HARDWARE</u>
First Bond	A26A2	40
Coated First Bond	A30A6	0
Second Bond	A1C1	2
Preassembly	A2C1	12
Unicouple	A3H1	5
Wrapped Unicouple	A8E1	0

6.4.4.3.3 Problem Areas

As previously reported, the chlorine content of Silicon Nitride Coated First Bond Assemblies for eleven (11) Coating runs exceeded the specification limit. The disposition of the MRB action that permits the use of these couples requires that they be distributed across the seven (7) remaining converters. The next converter computer mapped since this occurrence was F-6. The complement of uncouples selected for F-6 includes 34 uncouples that have higher chlorine content. The amendment to the specification which specifies the chlorine content of the coating to be measured for each coating run is at G.E. for approval.

The resistance of the N-P bond (r-j resistance) on the cut and ground Hot Shoes was found to have increased. A review of the control charts for Hot Shoe r-j resistance showed the incidence coincided with the introduction of a new lot of Silicon material. Further evaluation confirmed the cause of the problem to be associated with part of this lot of Silicon. Engineering is conducting the investigation to resolve this problem. The portion of the lot that gave good product has been selected and is being used to sustain production. Upon determination of the parameters that gave rise to the problem, additional controls will be instituted to prevent future reoccurrence.

6.4.5 Converter Design

6.4.5.1 Specifications and Drawings

A new specification, RG21A3, was approved by CCB for the processing of Converter E-5.

6.4.5.2 Tooling and Equipment

The flexible hose connection for Converter E-5 used for joining the converter processing valve to the processing station's gas piping was completed and checked out after several modifications.

The foil punching holding trays indexing mechanism was redesigned and renovated to overcome the problem of abnormal wear.

The radiator attachment tooling was reviewed to resolve recurrent problems. Replacement of worn components and new tooling cleaning procedures have been instituted to alleviate them.

6.4.6 Material Analysis and Thermopile Characterization & Testing

6.4.6.1 Silicon Nitride Coating Process

Since resumption of production silicon-nitride coating, the chlorine level of the coating process has remained well within the established product acceptance limits for coated 1st bond assemblies. The chlorine levels of 1st bond assembly and hot shoe spacer runs have also been well within the established process control limits. The 1st bonds for Converter F-8 were coated this month. Since replacement of the defective components in the coating furnace, a yield of 100% has been realized.

6.4.6.2 Measurement of Si_3N_4 Coating Thickness

The "optical" measurement techniques used to determine Si_3N_4 coating thickness on "dummy" single crystal silicon 1st bonds were successfully resolved. The measurements of the coating thickness by this method is made on existing in-house equipment and provides immediate feedback for acceptance of the product. The optical (spectrophotometer) method views an area of 1/2 inch x 1/4 inch while the SEM method, originally specified, views a fracture of the piece along a line; however, samples measured by these two methods give good agreement in thickness as shown in the table below.

COATING THICKNESS IN MICRONS

<u>Position on the Couple</u>	<u>SEM Method (Sample #39)</u>			<u>Spectrophotometer Method (Sample #12)</u>		
	<u>Ave.</u>	<u>High</u>	<u>Low</u>	<u>Ave.</u>	<u>High</u>	<u>Low</u>
S1	1.60	2.20	1.10	1.55	1.61	1.52
S2	1.32	1.80	1.00	1.21	1.25	1.16
S3	1.52	1.80	0.80	1.64	1.75	1.56
S4	0.61	1.05	0.26	0.74	0.79	0.63
S5	0.59	1.00	0.22	0.75	0.79	0.64
S6	1.48	1.84	1.07	1.66	1.87	1.50

ECN No. 032, which proposed the spectrophotometric method as an alternate to the SEM measurement, was approved by G.E. and has been incorporated into the Product Acceptance Specification, RQ24A1. A summary of the runs measured to date including the first two coating runs was made since approval of the optical measurement techniques, is given in Table 6.4.6-1.

6.4.6.3 Alternate Source of Metallized Ceramic Insulators - P4G2

Effort continued in evaluation of alternate sources for metallized ceramic insulators. The approaches being pursued are as follows:

<u>Vendor</u>	<u>Alumina Body</u>		<u>Metallizing Vendor</u>
	<u>Type</u>	<u>% Al₂O₃</u>	
a. Frenchtown	4462	94	Frenchtown
b. Frenchtown	4462	94	RCA Lancaster*
c. Frenchtown	2082	95**	Frenchtown
d. Frenchtown	2082	95**	RCA Lancaster*
e. American Lava	AlSiMag 771	94	RCA Lancaster*
f. Wesgo	AL-300	97.6	RCA Lancaster

* RCA Lancaster - Same Metallizing Process used.

** Erroneously reported previously as 96% Al₂O₃

Combinations a and c have passed all M4C2 criteria with only several minor deviations, which can be accepted. These are given below:

- (a) Frenchtown #4462 - Passed all test criteria but alumina content of body is 94% rather than minimum 96% Al₂O₃ now specified, which would require a specification change.
- (c) Frenchtown #2082 - Passed all test criteria except (1) alumina 95% versus minimum 96% specified, and (2) maximum ceramic body pore size was 105 μ vs 100 μ specified.

Upon successful completion of the current evaluation of cold stack shear tests and unicouple beam deflection tests, a recommendation will be made to qualify the Frenchtown Ceramic Company as an alternate source of metallized P4G2 insulators.

TABLE 6.4.6-1 - SPECTROPHOTOMETRIC MEASUREMENTS OF Si_3N_4 COATING THICKNESS
(In Angstroms)

Couple No.	Coating Run No.	Couple Position	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆
1	L-280	5	15,517	12,220	16,137	6,518	6,391	16,320
2	L-280	12	15,471	11,938	16,527	7,590	7,528	15,006
3	L-295	5	15,311	12,149	17,230	7,666	7,702	17,192
4	L-295	12	15,266	12,053	15,930	7,812	7,863	16,749
5*	L-304	5	15,585	11,681	16,653	7,800	7,873	16,397
6	L-304	12	15,197	11,875	15,633	7,887	7,861	18,786
7	L-314	5	15,791	12,398	16,833	7,699	7,677	16,883
8	L-315	5	16,095	12,465	17,472	7,738	7,726	16,769
9	L-328	5	15,769	12,193	16,697	7,157	7,291	16,819
10*	L-342	5	15,257	11,452	15,632	6,370	6,431	15,814
11*	L-343	5	15,884	11,998	16,793	7,406	7,393	16,227
12*	L-349	5	15,897	12,026	16,212	7,162	7,186	16,125
13*	L-353	5	15,430	12,052	15,630	7,170	7,195	16,043
14**	L-358	5	15,964	12,193	16,915	8,354	8,060	16,407
15*	L-364	4	16,136	11,929	16,381	6,671	6,744	16,204

NOTES: * Samples Acid Etched and Reused.

** First Measurement made since Approval of the ECN.

Vendor combinations d and f have been discarded as the tests have shown that the RCA metallizing process schedule is not compatible with these two ceramic bodies.

Vendor b combination has passed all M4C2 test criteria and cold stack and uncouple structures are now being fabricated for evaluation. Vendor e combination has passed all M4C2 test criteria including cold stack shear test and uncouple beam deflection tests. These tests were initially made using parts from unground ceramic "blanks" (2" x 2" squares) because of their immediate availability. To confirm the excellent results obtained, the tests are being repeated on flat ground blanks, which will minimize camber rejects. The AlSiMag #771 body is 94% alumina vs the minimum 96% specified and would require a specification modification.

From the testing to date, it is apparent that the 94% alumina bodies are more suitable for metallizing and three of the combinations (a), (b), and (e) exhibit superior strength results over the present qualified product.

8.0 PRODUCT ASSURANCE

8.1 CONFIGURATION MANAGEMENT - LES 8/9

During the September-October reporting period, 20 Alteration Notices (AN's) were prepared, reviewed, and implemented on GE-issued drawings and specifications.

8.2 CONFIGURATION MANAGEMENT - MJS

For the MJS Program, 91 AN's were processed. Six (6) Engineering Change Notices (ECN's) were processed on RCA-issued drawings and specifications. No Program Change Proposals were submitted.

8.3 QUALITY ASSURANCE - LES 8/9

The Pre-Shipment Buy-Off Reviews were completed on the F-3 and F-13 RTG's.

Quality Assurance continued test support and test monitoring activities on a round-the-clock basis to support RTG testing.

8.4 QUALITY ASSURANCE - MJS

Major effort associated with the inspection, assembly, and test for parts and sub-assemblies for the F1-E, Q1-A, and Q2 Engineering Units continued in this reporting period.

Table Nos. 8-1 and 8-2 summarize the Non-Conformance Reports (NCR's) which were prepared during this reporting period. These reports show data for both the LES 8/9 and the MJS units. The LES 8/9 NCR's were primarily in the Test Area since most of this hardware has already been fabricated and is in test.

The regular monthly meeting on Quality Status was held in September and October with SNS, Sandia, and General Electric. A brief review of trends in Non-Conformance Reports and in PVS's (changes in test procedures) was included. Quality problems being experienced were reviewed.

TABLE 8-1 MHW NON-CONFORMANCE REPORT ACTIVITY & STATUS - SEPTEMBER 1975

	TYPE OF NON-CONFORMANCE						DISPOSITION						
	DIMENSIONAL	PROCESS	TEST	WORKMANSHIP	MISC.		ACCEPT AS IS	REWORK	REPAIR/RETEST	RTV	SCRAP	TOTAL	
<u>MHW</u>													
<u>MJS</u>													
GE/SSO	2	1	1	12	1		7	3	3	0	4	17	
MOUND LABS	4	2	1	0	1		8	0	0	0	0	8	
RCA	0	1	1	1	0		3	0	0	0	0	3	
GE-EVENDALE	3	0	0	2	0		4	1	0	0	0	5	
ALL OTHER SUPPLIERS	9	4	0	6	0		7	3	1	8	0	19	
<u>LES 8/9</u>													
GE/SSO	2	2	24	10	5		25	5	12	0	1	43	
ALL OTHER SUPPLIERS	0	1	0	4	0			2	1	1	1	5	
TOTALS	20	11	27	35	7		54	14	17	9	6	100	

TABLE 8-2 MHW NON-CONFORMANCE REPORT ACTIVITY & STATUS - OCTOBER 1975

	TYPE OF NON-CONFORMANCE						DISPOSITION						
	DIMENSIONAL	PROCESS	TEST	WORKMANSHIP	MISC.		ACCEPT AS IS	REWORK	REPAIR/RETEST	RTV	SCRAP	TOTAL	
<u>MHW</u>													
<u>MJS</u>													
GE/SSO	8	2	1	16	2		16	4	6	0	3	29	
MOUND LABS	3	1	2	0	2		6				2	8	
RCA	1	0	3	4	0		4	2	2	0	0	8	
GE-EVENDALE	1			1				1	1			2	
ALL OTHER SUPPLIERS	20	12	2	8	2		28	6	5	5	0	44	
LES 8/9													
GE/SSO	1	2	8	2	1		7	3	3	0	1	14	
ALL OTHER SUPPLIERS	1									1		1	
TOTALS	35	17	16	31	7		61	16	17	6	6	106	

10.0 HARDWARE FABRICATION

- Converter hardware for E5 completed processing and quality verification during this period and was shipped to RCA for assembly. The hardware for F6 progressed to the 90% completion point by the end of October.
- The converter modification activity on Q1A was approximately 75% completed, having been impacted by late delivery of connectors from Gulton Industries.
- The F1E modification was completed.
- Final modification of Loading and Assembly Station fixture hardware was accomplished as required.
- Special emphasis was placed upon improving the quality of our ACO packages being submitted to ERDA. Commitment has been made to complete the LES packages before year end. Good progress toward this goal was in evidence during this period.
- Problems related to achieving satisfactory leak rates on gas management valves were resolved by modifying the thread on the handle of the valve to minimize running torque. This removed a major schedule impediment.
- Much manufacturing effort was directed toward achieving an "in stock" position on most of the key hardware requirements of the program.
- The F7 replacement outer shell was completed at Speedring and was shipped to Solar for coating.
- PMD assembly is continuing at a reduced labor expenditure rate.
- Modification of SPC's from LES 8/9 to MJS configuration continued during this period.

11.0 ACCEPTANCE TESTING

11.1 ETG ACCEPTANCE TESTING

11.1.1 F-1 ETG

11.1.1.1 Conversion to F-1E Configuration

The unit remained in storage in its Converter Shipping Container (CSC) in Bldg. B until the week of October 11th, when conversion to the F-1E configuration for the MJS Program began. After the CSC was opened early 10/18, the Gas Service Cart was interconnected with the ETG and converter pressure was measured as 21.25 psia. The unit was then re-pressurized to 25.0 psia.

Circuit resistance, continuity and isolation measurements were also performed on 10/18. Thermopile circuit measured 2.36 ohms, which compared favorably to the measurement taken on 3/10/75, which was also 2.36 ohms. Isolation measurements between thermopile to case and to foil basket indicated greater than 1 megohm at 50 VDC potential.

The installation of a second (in-series) RTG-GMV and its connective tubulation to the original RTG-GMV began on 10/20. However, there was an interference between the connective tubulation and the ETG's lifting yoke and a decision was made to postpone the installation of the 2nd GMV and tubing until after the transfer of the ETG to Bldg. 800.

F-1E was installed into its CSC late 10/21 and received at Bldg. 800 early 10/22. The CSC was opened and the ETG was then transferred to the slide tray assembly. The power-out and RTD cables were installed, and resistance and isolation measurements were then completed satisfactorily. The 2nd GMV and its tubulation were installed onto the ETG and an evacuation and leak-up test was performed to successfully complete these operations at 2000 hours, 10/23.

The ETG was routed to LAS #2, preparations were completed and the unit was installed onto the chamber's rotab by late 10/24. LAS #2 was secured and chamber evacuation began at 1130 hours, 10/27. By 2030 hours, 10/27, the chamber had achieved a vacuum of 7×10^{-6} torr and argon backfilling operations were initiated. After "scrubbing" via the facility gas purification system, acceptable chamber purity levels were achieved by 0800 hours, 10/28.

The forward dome was removed on 10/28 and a visual examination of the internal converter cavity was performed. All surfaces appeared clean and free from oxidation, condensed films and discoloration. Limited areas on the moly frame that showed a small degree of discoloration in February, 1975, now appeared clean and showed the characteristic moly color. There was no evidence of condensed films of moly-oxide and the overall internal surfaces showed no abnormalities.

The EHS cable assemblies were disconnected from the EHS and the spool-piece feed-thru pins mid 10/28. The IHS-GMV assembly was then removed from the converter case and a cap was installed onto the IHS case feed-thru port and torqued to 75 inch-lbs. The effort of identifying and disconnecting the EHS thermocouples from their respective feedthrough pins at the spool-piece receptacle began late 10/28 and was completed mid 10/29. The spool-piece was then removed from the converter case and the accessible areas of the internal converter were vacuumed. Preload screw and bushing were then lock-wired together late 10/29.

The prime forward dome was passed into the chamber early 10/30 and mounted above the converter case into position for the connection of the EHS power leads and thermocouples. In attempting a mating of the EHS thermocouple test cable to its receptacle on the forward dome, it was found that several of the feed-through pins in the receptacle were bent, so the dome was routed out of the chamber to Bldg. B early 10/31 for straightening of the bent feed-through pins.

11.2 RTG ACCEPTANCE TESTING

11.2.1 F-2 RTG

11.2.1.1 OA Vibration Test

As previously reported, the F-2 RTG had been installed on the vibration slip table in the Bldg. 400 vibration facility and the X and Z lateral axes vibration testing had been completed late 8/31. With the completion of the lateral axes testing, the RTG was hoisted from the slip table and set-up on the exciter head for the longitudinal (Y-axis) vibration. The Y-axis vibration cycle was performed over the period 1000 to 1045 hours, 9/1, with no degradation to RTG structural integrity.

11.2.1.2 Post-Vibration Air Performance/Pressure Decay Test

After the vibration testing was completed, the RTG remained on the exciter head (Y-axis orientation) for the post-vibration performance testing. This testing ran from 1630 hours, 9/1 until 1630 hours, 9/3. Output power average 81.8 watts over this time period and the rate of pressure decay showed an increase of 0.10 psi/48 hours, the increase attributed to case temperature increasing by 2°C (as shown on the fin RTD's), due to a change in room ambient temperature.

Early 9/4, NR-43353 was written against the F-2 RTG regarding air performance output power being below the specified 83 watts minimum. An ERDA TWX, dated 9/5/75, waived this 83-watt minimum requirement.

11.2.1.3 Preparations for T/V Testing

Upon completion of the post-vibration air performance and 48-hour pressure decay test, the F-2 RTG was hoisted from the vibration exciter head, and installation into its shipping container began at 0030 hours, 9/4; installation operations were then completed by 1715 hours, 9/4.

Transfer of the F-2 RTG in its SC to the platform outside the Bldg. 300 Long Life Lab was accomplished at 1650 hours, 9/5. Removal from SC operations began shortly thereafter and the RTG was installed in the handling sling at 0900, 9/6. In parallel with these operations, the T/V chamber, data acquisition system, Readout Console and general facility check-outs were completed.

The RTG was moved from the handling sling to the portable lift truck and routed to T/V chamber #3 where it was installed onto the chamber's support frame at 1000 hours, 9/6. Pneumatic flex hose and electrical cable interconnections between the RTG and chamber penetrations were completed and the Segment Readiness Review certifying test preparedness was completed at 1630 hours, 9/6.

After the gas service cart lines had been purged/evacuated, the IHS and RTG-GMV's were opened, the chamber door was secured and all preparations for chamber evacuation were completed at 2030 hours, 9/6.

11.2.1.4 Thermal-Vacuum Performance Testing

Chamber evacuation for the start of T/V testing was initiated at 2120 hours, 9/6, and by 0100 hours, 9/7, a vacuum of 1×10^{-4} torr had been achieved. The RTG evacuation through the gas service cart then began and at 0540 hours, 9/7, chamber pressure was 8×10^{-6} torr and RTG internal pressure was 60 microns. After isolating the gas service cart from the RTG, pulse venting of the RTG's remaining argon fill gas into the chamber began and by 0600 hours, 9/7, the venting valve could remain open. Chamber pressure then increased into and remained in the 10^{-5} torr range until 1600 hours, 9/7, when the 10^{-6} torr range was again achieved.

The chamber pressure held in the mid 10^{-6} torr range until 1000 hours, 9/8, when the Health Physicist had obtained an IHS radiological sample and the IHS had been de-pressurized to 2 psia. With the decrease in IHS helium pressure, the chamber pressure dropped into the low 10^{-6} torr range

Just prior to achieving stable thermal/vacuum conditions at 1130 hours, 9/8, the data acquisition system gave an erroneous EHS over-temperature signal to the Readout Console (ROC) which caused the ROC to go into the "backfill" mode. Although no actual argon backfilling of the RTG occurred, since the backfill system was set-up for manual operation, the venting solenoid valve was de-energized and RTG internal pressure rose to 56 microns by 1300 hours. With the proper addressing of the data acquisition system, the false signal was deleted, thereby allowing the venting system to revert to normal operation.

Stability was achieved at 1400 hours and the four-hour T/V performance test was completed at 1800 hours, 9/8. RTG parameters were 156.55 watts output power, 57.31 volts open-circuit and 5.233 ohms internal resistance. Shunt resistance from thermopile to case indicated 8.3 K-ohms.

11.2.1.5 Post-T/V Air Performance/Pressure Decay Testing

Segment Readiness Review to allow the backfilling of the F-2 RTG to end T/V testing was completed at 2000 hours, 9/8. After the Health Physicist obtained an IHS radiological sample, the IHS pressure which had been at 2.16 psia just prior to sampling, was increased to its first backfilling plateau of 9 psia at 2220 hours. Backfilling of the converter with argon then began and at 0030 hours, 9/9, the first pressure plateau of 17 psia for the converter was achieved. At 1000 hours, 9/9, the IHS pressure was increased from 9 psia to 16 psia and by 1200 hours, the converter had been pressurized to 25 psia. Chamber backfilling with dry N_2 then began, and after attaining 13.5 psia, the chamber atmosphere was verified as being acceptable by the Health Physicist. He gave his approval to continue with the nitrogen backfill and chamber pressure was one atm at 1645 hours, 9/9.

The chamber shroud, which had been running at 100°F for T/V testing, was adjusted to 80°F for "air" mode testing and the unit was allowed to thermally stabilize. Thermal stability was achieved at 2200 hours, 9/9, for the start of the 48-hour post-T/V air performance and pressure decay test in the closed chamber #3. Output power over this test duration averaged 82.4 watts and rate of pressure decay was 0.04 psi/48 hours.

11.2.1.6 Post RTG Acceptance Test Operations

With the conclusion of RTG acceptance testing at 2200 hours, 9/11, the unit was placed into the short circuit mode at the ROC. After the chamber was opened, the RTG-GMV was closed at 0400 hours, 9/12, and an evacuation test up to the RTG-GMV was started in order to verify the integrity of this valve closure.

There was some concern when the lines up to the RTG-GMV could not be evacuated below the 1000 micron level. Leakage was traced to an improperly-torqued cap on the solenoid venting valve (this valve is in the pneumatic line going to the RTG-GMV in a "tee" arrangement). After this cap was secured, the lines to the RTG-GMV were successfully evacuated to below 100 microns (actually 40 microns) and the leak-up rate showed 20 microns/minute, which validated the proper closure of the RTG-GMV.

The RTG electrical cables (power-out and RTD) and pneumatic flex hoses were disconnected from their chamber penetrations and preparations were being made for removing the RTG from the chamber support frame at 2300 hours, 9/12, when a brownish deposit was observed on the emissive coating at the lightening ring area beneath the PRD and output power connector. The cause of this was traced to Genesolv-D, the chamber shroud coolant, having dripped onto the case from a fitting at the top of the chamber door. The initial disposition of NR-43375 was to clean the contaminated area with acetone, which after being done resulted in a reasonable return of the coating to its original condition. As there was no apparent deterioration, final disposition of the NR accepted the condition as is.

Installation of the F-2 RTG into its RTG-SC began at 2400 hours, 9/12, and by 1800 hours, 9/13, had been completed. The RTG was lowered to the ground floor of Bldg. 300 and transferred to Bldg. 800 for storage at 2300 hours, 9/13. On 9/15, preparations were made for shipment of the F-2 RTG to Mound Lab for storage. The unit was secured into the ERDA SST van at 1200 hours, 9/15, and approval was given to transfer it.

11.2.2 F-3 RTG

11.2.2.1 Storage Operations

As previously reported, the RTG vent valve port on F-3's shipping container was damaged and the RTG could not be re-pressurized while in the SC. Accordingly, the SC pressure had been reduced to maintain an approximate 2.5 psi delta between the RTG and the SC. On 9/4, the damaged RTG vent valve on the shipping container was replaced. With access to the RTG now available, the RTG internal pressure was increased to 10.6 psig and SC pressure was then increased to 7.6 psig.

11.2.2.2 Gas Sampling and Leak Detection Operations

The F-3 RTG remained in storage in Bldg. 800 in its RTG-SC until 9/8, when it was transferred to the Bldg. 800 test area. The gas service cart was interconnected with the RTG vent valve port on the SC and an RTG gas sample was taken late 9/8 for mass spectrographic analysis. Preparations were then made for obtaining an IHS gas sample. The RTG-SC was opened and the RTG was hoisted partially out of the SC to allow access to the IHS-GMV. After that valve was opened, IHS pressure indicated 21.68 psia. An IHS gas sample was then collected in an evacuated bottle. With sampling being completed late 9/9, the operations of removing the RTG from the SC were continued and by 0600 hours, the RTG had been installed onto the slide tray assembly.

Leak testing at all suspected RTG leakage paths was initiated at 0900, 9/10, using a helium mass spectrometer leak detector via the "sniffing" method. Sufficient helium concentration was already present in the RTG's argon fill gas to obtain a leakage indication without the addition of more helium to the RTG. A positive leakage indication was evident at the IHS penetration fitting through the case and at the "MS" connection which attached the tube between that penetration fitting and the IHS-GMV. NR-43371 was written against this discrepancy.

11.2.2.3 Air Performance/Pressure Decay Testing Prior to Rework Operations

The slide tray assembly was positioned in proximity to the chamber door and the RTG electrical cables and pneumatic flex lines were interconnected with their respective chamber test cables and hoses. Shortly thereafter, the Readout Console began behaving in an erratic manner in that the indicator lamps were dimming when the instrumentation cable at the RTG was being manipulated. The test cables were demated from the RTG's power-out and RTD instrumentation cables. Isolation and continuity measurements were then performed on the test cables with no anomalous indications. Trouble-shooting then turned to the RTD instrumentation cable on the RTG and after performing isolation measurements between the cable circuits, an intermittent short was found between the cable's shield tie and one of the RTD circuits. The plug saver was demated from the RTD instrumentation cable and it was verified that the short was in the plug saver and not in the cable. At 1100 hours, 9/11, a new plug saver was received and mated to the instrumentation cable. After the RTG cables were again interconnected with their respective test cables, there were no anomalous indications at the Readout Console. Evidently, the short in the original plug saver had been loading down the 24 VDC power supply in the console which fed both the RTD

circuits and the indicator lamps. RTG load was switched from short-circuit to loaded mode at 1740 hours, 9/11, and by 2300 hours, stability was achieved for the start of a six-hour air performance/pressure decay test. Output power over the test duration averaged 76.9 watts and rate of pressure decay was 0.14 psi/6 hours.

11.2.2.4 IHS-GMV and Forward Dome Exchange

The Segment Readiness Review to allow the start-up of the LAS #2 operations was completed at 1145 hours, 9/12. After securing the chamber, evacuation began at 1430 hours, 9/12 and by 1700 hours, 9/14, the chamber had been backfilled to one atmosphere argon and had attained acceptable purity levels.

The forward dome was removed from the converter case and preparations were being made to pass the dome out of the chamber through the load lock when the chamber became contaminated with air at 1745 hours, 9/15. During installation of the fixture which would support the forward dome in the lock, the facility gas purification system alarmed and subsequent purity level readings indicated an O₂ level of 526 PPM and N₂ level of 2534 PPM. The LAS was then evacuated to remove the contaminated gas and by 1930 hours, 9/15, had achieved 6×10^{-5} torr. Backfilling with fresh argon was initiated and by 0115 hours, 9/16, the gas purification system was "scrubbing" and the chamber attained acceptable purity levels by 0530 hours. NR-43349 documented the temporary high-impurity levels of the LAS atmosphere. It was theorized that the incident was caused by a too-rapid closure of the load lock door, thereby unseating the cover which is used to isolate the load lock from the chamber proper when the load lock door is open. A change to the method of securing the cover onto the lock by the addition of a clamping arrangement is to be incorporated and should preclude recurrence at subsequent LAS operations. The forward dome was passed out of LAS #2 at 0600 hours, 9/16, and given to manufacturing for the addition of a PRD.

At 1000 hours, 9/17, the operations of removing the discrepant IHS-GMV assembly and its feedthrough fitting began. The IHS vent tube coupling nut was disconnected from the penetration fitting at the inside of the converter case and the IHS vent tube was then routed aside to allow access to the penetration fitting's mounting nut. The removal of that nut and the two screws which secured the valve body of the IHS-GMV to the case fin allowed removal of the IHS-GMV and feedthrough fitting from the converter. The new IHS-GMV assembly and fitting were installed at 1300 hours, 9/17, and the mounting nut at the penetration fitting was torqued to 97 inch-lbs at 1400 hours. As the required less than 1-mil gap at the interface of the flange of the fitting and the converter face could not be attained, repeated torqueing of the fitting's mounting nut at 100 inch-lbs was performed until 2000 hours, 9/17.

At 0815 hours, 9/18, a final torqueing of the feedthrough fitting's mounting nut was performed. Since the gap at the fitting/case interface was still 2 to 3 mils at several sections of the perimeter, NR 43377 was written. Its disposition was to accept the gap "as is". After the IHS vent tube was interconnected with the feedthrough fitting, its coupling nut was torqued to 75 inch-lbs. The IHS was pressurized with helium and had stabilized at 19.15 psia by 1840 hours, 9/18, for the start of a short IHS pressure decay test. This yielded an IHS leak rate of 0.00 psi/one-half hour, showing a tight IHS gas system.

The refurbished forward dome, along with a new P5 "C"-seal, was passed into the LAS at 2130 hours, 9/18, and by 2330 hours, had been positioned onto the converter case. Screw torqueing was initiated shortly thereafter and continued through 1100 hours, 9/19, with completion of sixteen sequences at 38 inch-lbs. After this effort, the gap at one narrow section of dome/case perimeter still exceeded the less than 2-mil requirement, being between 3 and 4 mils. NR-43380 was written against the discrepant gap and initial disposition was to continue with the next operation, the 6-hour RTG pressure decay test. After that test yielded acceptable results, the final disposition of NR-43380 was to accept the discrepant gap "as is".

The RTG was backfilled with argon to 25 psia and conditions were stable for the start of pressure decay testing at 1740 hours, 9/19. Leak rate indicated for this test was 0.22 psi/6 hours.

11.2.2.5 Pre-Vibration Air Performance/Pressure Decay Test

Since the vibration cell in Bldg. 400 was being utilized for testing of the F-13 RTG, the F-3 RTG's pre-vibration air performance and 48-hour pressure decay test was conducted while the unit was still in Bldg. 800, set-up in LAS #2.

RTG load was switched from the short-circuit mode to the loaded mode at 0140 hours, 9/20, and had stabilized at 30 volts for the start of test at 1000 hours, 9/20. Output power over the 48-hour test duration averaged 77.7 watts, and rate of pressure decay was 0.21 psi/48 hours. Since output power did not meet the requirement of being 80 watts minimum, NR-43392 was written and its preliminary disposition was to continue testing.

The RTG was removed from LAS #2 on the slide tray assembly at 1330 hours and by 1530 hours, the PRD tube-to-bracket mating had been successfully completed. Installation of the RTG into its shipping container began at 1915 hours, 9/22, and this operation was completed by 1100 hours, 9/23.

11.2.2.6 Preparations for Vibration Testing

At 2030 hours, 9/23, the F-3 RTG had been transferred to the Bldg. 400 vibration facility. The operations of removing the RTG from the SC were then initiated and by 1330 hours, 9/24, the unit had been removed from the SC and installed in the handling sling.

The RTG was hoisted out of the handling sling cradle and set-up on the vibration slip table in X-axis orientation with the self-aligning bearings mounted in their clevis blocks. After inter-connections between the RTG and the ROC and gas service cart were completed, a Segment Readiness Review was held at 1930 hours, 9/24, to allow continuation of the vibration testing.

RTG load was switched from short-circuit mode to loaded mode at 1945 hours and stability at 30 volts was achieved by 2400 hours, 9/24. The stable pre-vibration performance baseline with the RTG set-up on the slip table at 0630 hours, 9/25 (just prior to start of vibration cycle) was 77.47 watts output and 4.791 ohms internal resistance.

11.2.2.7 OA Vibration Test

The clevis blocks were torqued to the slip table at 0520 hours, 9/25, and the vibration testing was ready to begin. The vibration cycle in the X-axis, consisting of (1) a 1/2G sine sweep from 20-2000 Hz, (2) a 15-to-20-second burst of random vibration at 3.18G (rms) overall level for system equalization and (3) a 60-second burst of OA random vibration at 9.54G (rms) overall level, was performed over the period 0630 to 0900 hours, 9/25.

After verifying that there was no thermopile circuit or structural degradation due to the X-axis vibration application, the RTG was rotated on the slip table to the Z-axis. The clevis blocks were torqued to the vibration plate and the Z-axis vibration cycle then ran from 1615 to 1715 hours, 9/25. There were no anomalous indications during the vibration application and post-test data scanning and visual examination showed no degradation.

With the completion of the lateral axes testing, the RTG was hoisted from the slip table and set-up on the exciter head for the longitudinal (Y-axis) vibration. The Y-axis vibration cycle was performed over the period 0045 to 0120 hours, 9/26, with no degradation to RTG structural integrity.

11.2.2.8 Post-Vibration Air Performance/Pressure Decay Test

After the vibration testing was completed, the RTG remained on the exciter head (Y-axis orientation) for the post-vibration performance testing. The baseline performance scan taken at the completion of the vibration testing (0125 hours, 9/26) compared favorably with the pre-vib baseline data (0630 hours, 9/25): post-test output power of 77.55 watts to pre-test output power of 77.47 watts and post-test internal resistance of 4.799 ohms to pre-test internal resistance of 4.791 ohms.

After the Health Physicist had obtained an IHS radiological sample, the 48-hour air performance/pressure decay test ran from 0600 hours 9/26, to 0600 hours, 9/28. Output power average 77.2 watts over this time period and the rate of pressure decay was 0.48 psi/48 hours.

11.2.2.9 Preparations for T/V Testing

Upon completion of the post-vibration air performance 48-hour pressure decay test, the F-3 RTG was hoisted from the vibration exciter head and installation into its shipping container began at 1230 hours, 9/28; installation operations were then completed by 0300 hours, 9/29.

Transfer of the F-3 RTG in its SC to the platform outside of the Bldg. 300 Long Life Lab was accomplished at 0930 hours, 9/29. The operations of removing the RTG from the SC began at 1800 hours, 9/29, and these operations were completed, with the RTG installed in the handling sling on the platform, at 0320 hours, 9/30.

Chamber #4 was scheduled to be used for the F-3 RTG T/V test and its evacuation capability had been verified on 9/19/75. The remainder of the general facility and Readout Console check-outs were performed over the period 0600 hours through 1300 hours, 9/30.

The RTG was moved from the handling sling to the portable lift truck and routed to T/V chamber #4 where it was installed onto the chamber's support frame at 1430 hours, 9/30. Pneumatic flex hose and electrical cable interconnections between the RTG and chamber penetrations were completed and the Segment Readiness Review certifying test preparedness was completed at 2300 hours, 9/30. After the gas service cart lines had purged/evacuated, the IHS and RTG-GMV's were opened, the chamber door was secured and all preparations for chamber evacuation were complete at 0700 hours, 10/1.

11.2.2.10 Thermal-Vacuum Performance Testing

Chamber evacuation for the start of T/V testing was initiated at 0900 hours, 10/1. After the chamber head attained 8 microns at 0930 hours, the RTG evacuation through the Gas Service Cart began and by 1030 hours, 10/1, chamber pressure was 1.5×10^{-4} torr with RTG internal pressure at approximately 1000 microns. At 1430 hours, 10/1, the chamber had attained a vacuum level of 4.7×10^{-6} torr with RTG internal pressure at 240 microns.

After isolating the Gas Service Cart from the RTG, pulse venting of the RTG's remaining gas load into the chamber began at 1600 hours. However, chamber pressure increased from the 10^{-6} torr range into the mid 10^{-5} torr range and at 1700 hours, the attempts at venting the RTG into the chamber were suspended until after the IHS pressure was decreased. After the IHS internal pressure was reduced to 1.5 psia at 1900 hours, 10/1, the evacuation of the RTG through the GSC continued and RTG internal pressure had attained the 80 micron level by 1950 hours. Pulse venting resumed and by 2000 hours, 10/1, the venting solenoid valve was allowed to remain open with chamber pressure at 3×10^{-5} torr.

Beginning at 0030 hours, 10/2, numerous attempts were made at bringing the chamber's ion pump on-line in parallel with the roughing pump in order to reduce chamber pressure into the 10^{-6} torr range. The ion pump cavity was repeatedly opened to the chamber but then quickly had to be again isolated, as it was being saturated with what was suspected to be helium gas leaking from the IHS, through the RTG and then into the chamber.

Except that the chamber pressure was not below the specified 1×10^{-5} torr, stable conditions were achieved at 2030 hours, 10/2, and the four-hour T/V performance test was completed at 0030 hours, 10/3. RTG parameters were 153.81 watts of output power, 56.073 volts open-circuit, 5.085 ohms internal resistance and 16.9 K-ohms shunt resistance from thermopile to case. Chamber pressure ran from 3.0×10^{-5} to 2.6×10^{-5} torr over the four-hour period. NR-43395 was written against the chamber pressure being above 1×10^{-5} torr, and was subsequently dispositioned to accept "as is".

Prior to backfilling the RTG to terminate T/V testing, a special test was conducted. This was the isolation of the venting solenoid valve while RTG internal pressure build-up and performance degradation were being monitored. The following table shows the performance parameter trend after the closing of the vent valve at 0122 hours, 10/3.

<u>TIME</u>	<u>PWR OUT</u>	<u>CONV. INT. PRESS.</u>	<u>CHMBR. PRESS.</u>
T zero	153.89	vented	2.6×10^{-5}
T + 3 min.	153.89	55 μ	2.0×10^{-5}
T + 12 min.	153.81	140 μ	1.2×10^{-5}
T + 30 min.	153.51	260 μ	7.1×10^{-6}
T + 40 min.	153.29	330 μ	6.4×10^{-6}

11.2.2.11 Post-T/V Air Performance/Pressure Decay Testing

Segment Readiness Review to allow the backfilling of the F-3 RTG to end T/V testing was completed at 1100 hours, 10/3. After the Health Physicist obtained an IHS radiological sample, the IHS pressure which had been at 1.70 psia just prior to sampling, was increased to its first backfilling plateau of 9 psia at 1440 hours. Backfilling of the converter with argon then began and at 1830 hours, 10/3, the first pressure plateau of 17 psia for the converter was achieved. At 0415 hours, 10/4, the IHS pressure was increased from 9 psia to 16 psia and by 0640 hours, the converter had been pressurized to 25 psia. Chamber backfilling with dry N₂ then began, and after attaining 600 mm/Hg, the chamber atmosphere was verified as being acceptable by the Health Physicist. He gave his approval to continue with the nitrogen backfill and chamber pressure was one atm by 1230 hours, 10/4.

The chamber shroud, which had been running at 100°F for T/V testing, was adjusted to 80°F for "air" mode testing and the unit was allowed to thermally stabilize. Thermal stability was achieved at 1600 hours, 10/4, for the start of the 48-hour post-T/V air performance and pressure decay test in the closed chamber #4. Output power over this test duration averaged 78.4 watts and rate of pressure decay was 0.61 psi/48 hours.

11.2.2.12 Post RTG Acceptance Test Operations

The chamber door was opened at 2000 hours, 10/6, and the task of RTG removal from the chamber and installation into the RTG-SC began then and was completed at 1700 hours, 10/7. The transfer of the F-3 RTG to the Building 800 storage area was completed at 1900 hours, 10/7. On 10/8, preparations were made for shipment of the F-3 RTG to Mound Lab for storage. The unit was secured into the ERDA SST van at 1400 hours, 10/8, and approval was given to transfer it.

11.2.3 F-4 RTG

11.2.3.1 Storage at Mound Lab

As previously reported, the F-4 RTG had been transferred to Mound Laboratory, Miamisburg, Ohio, on 8/18. The unit remained in storage at that facility through the reporting period.

11.2.4 F-5 RTG

11.2.4.1 Transfer to and Storage at Mound Lab

On 9/6, preparations began for shipment of the F-5 RTG to Mound Lab for storage. A final RTG gas sample was taken late 9/6 and shipping container preparations were completed mid 9/8. The F-5 RTG was secured into the ERDA SST van at 1700 hours, 9/8, and approval was given to transfer the unit to Mound Lab. The unit then remained in storage at that facility through the reporting period.

11.2.5 F-13 RTG

11.2.5.1 F-13 RTG Assembly and Processing Operations

The S/N-1 IHS, in its SPC, was installed into the LAS #1 load lock late 8/30. After the SPC dome removal was completed, the disassembly of the tripod and valve assemblies and vent tube straightening were completed 8/31. The IHS was hoisted out of the SPC late 8/31 and after dimensional gauging operations proved acceptable, the gantry position was changed from the 0° to the 90° LAS station and the installation of the ablation sleeve was completed.

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, mid 9/1. 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 and after achieving thermal stabilization, final preloading of 27.5 mils dial indicator deflection was completed early 9/2. Final support system operations -- preload screw packing, retainer installation and preload screw/bushing lock-wiring -- were also completed early 9/2. IHS vent tube forming, routing and interconnection to its case feedthrough fitting were completed and an IHS gas sample was then obtained late 9/2.

After the IHS pressure had been reduced to 2 psia, preparations were made to allow chamber evacuation for the start of the vacuum processing cycle. Chamber evacuation began at 0100 hours and by 0430 hours, 9/3, a vacuum level of 9×10^{-6} torr had been achieved.

During the operations of obtaining the first IHS gas sample at 0700 hours, 9/3, the IHS pressure was indicating an anomalous condition in that the evacuation/backfilling cycle was stabilizing much more rapidly than had been previously experienced. It was believed that either the chamber internal valve "C" or the IHS-GMV was closed, although the procedural indications were that both should have been open. The chamber was backfilled with argon at 1720 hours, 9/3, and work began through the glove ports. It was found that the valve stem of the IHS-GMV was "open", but the valve seat remained closed

until the valve body was lightly tapped. NR-43347 was written against the defective IHS-GMV. Chamber evacuation then began at 1800 hours and by 1830 hours, 9/3, a vacuum of 1×10^{-5} torr had been achieved.

The first IHS gas sample was taken at 1900 hours, 9/3. IHS gas samples were then taken at 0200 and 1000 hours, 9/4, at 1000 hours, 9/5, and then at approximately 1000 hours daily through the termination of processing on 9/12, with a total of thirteen IHS gas samples being obtained.

In addition to the gas sampling, the IHS was purged every 2-3 hours for the first 72 hours of processing and then once daily through termination. The purging cycle during the first 72 hours consisted of an evacuation of the IHS for a one-half hour period after the 1000 micron level had been achieved (usually attaining below 400 microns) and then backfilling with helium to 14.5 psia. The purging after the first 72 hours consisted of the same IHS evacuation, but the backfill pressure was reduced from 14.5 to 2-3 psia. A total of 32 purge cycles were performed over the processing duration.

Direction was received at 1430 hours, 9/12, to terminate the processing cycle. The chamber was backfilled to one atm argon and by 2000 hours, 9/12, the facility gas purification system had "scrubbed" the LAS environment to acceptable levels. After the Health Physicist had inspected the LAS atmosphere radiologically and given his approval to continue with operations, the IHS was pressurized to 19 psia and at 0700 hours, 9/13, an IHS pressure decay test was initiated, yielding a leak rate of 0.0 psi/one hour.

The flight-configured forward dome was transferred into the chamber through the load lock and positioned onto the converter case. Dome screw installation began and after six torquing sequences, the required less than 2-mil gap had been achieved by 1630 hours, 9/13. The RTG was backfilled with argon to 25 psia and conditions were stable for the start of pressure decay testing at 2200 hours, 9/13. Leak rate indicated for this test was 0.01 psi/6 hours.

The unit was removed from LAS #1 on the slide tray and routed to the Bldg. 800 floor area where the mating of the PRD tube to bracket was successfully completed. Installation of the RTG into its SC then began mid 9/14 and was completed early 9/15.

11.2.5.2 Pre-Vibration Air Performance/Pressure Decay Test

At 2200 hours, 9/15, the F13 RTG had been transferred to the Bldg. 400 vibration facility. The unit then remained in its RTG-SC while awaiting the facility set up for the pre-vibration air performance test. Upon completion of the facility set up, the

operations of removing the RTG from its SC began at 1300 hours, 9/16. The RTG was hoisted out of the SC and set up on the vibration slip table with the self-aligning bearings mounted in their clevis blocks at 0200 hours, 9/17.

The power output and RTD cables were mated to the ROC, GSC hoses were interconnected to the RTG-GMV and IHS-GMV and the evacuation/purging operations on the lines were completed. Segment Readiness Review to allow the start of performance testing was then held at 0930 hours, 9/17.

RTG load was switched from short circuit mode to loaded mode at 0940 hours, 9/17. Shortly thereafter, it was realized that the voltage readings used for calculating shunt resistance from thermopile to case were anomalous. Voltage across the shunt resistance was indicating the thermopile load voltage and then when the 10K ohm parallel resistor was switched onto the circuit, there was no change in the voltage drop. The ROC being utilized for this testing was of the recently designed "G2" vintage and this was the first time that shunt resistance measurements had been attempted with this ROC.

The "G2" ROC was disconnected from the RTG by demating the test cable at the shorting module and a special set-up was made with a 6-ohm load placed across the thermopile at its shorting module interface. After switching the shorting module to the open condition, the load resistor simulated an approximate 30-volt load which would ordinarily be from the ROC load panel. The voltage drop from the positive end of the thermopile to the converter case was measured. After switching a 10K-ohm resistor into the circuit in parallel with the thermopile-to-case, that voltage drop was measured. The resultant calculation indicated that shunt resistance was approximately 200K ohms and that the "G2" ROC was giving erroneous readings. The "G2" ROC was taken out of the test set-up and a "G1" ROC was set-up and checked out. Segment Readiness Review was repeated at 0800 hours, 9/18, this second review being required due to the change of consoles.

RTG load was again switched from short-circuit mode to loaded mode and conditions were stable at 30 volts by 2130 hours, 9/18, for the start of the 48-hour test. Output power over the duration of the test averaged 77.2 watts, which was below the 80-watt minimum requirement; therefore, NR-43378 was written. Rate of pressure decay indicated an increase of 0.13 psi/48 hours, attributed to the increase in room temperature from 78°F to 86°F, showing a change from 189°C to 193°C at the fin RTD's.

11.2.5.3 OA Vibration Test

The F-13 RTG had been set up on the vibration slip table in X-axis orientation prior to the start of the air performance pressure decay test. Upon the completion of that test, the clevis blocks were torqued to the slip table and the vibration testing was ready to begin. The vibration cycle in the X-axis, consisting of (1) a 1/2G sine sweep from 20-2000 Hz, (2) a 15-to-20-second burst of random vibration at 3.18G (rms) overall level for system equalization and (3) a 60-second burst of OA random vibration at 9.54G (rms) overall level, was performed over the period 0200 hours to 0410 hours, 9/21.

After verifying that there was no thermopile circuit or structural degradation due to the X-axis vibration application, the RTG was rotated on the slip table to the Z-axis. The clevis blocks were torqued to the vibration plate and the Z-axis vibration cycle then ran from 1340 to 1440 hours, 9/21. There were no anomalous indications during the vibration application and post-test data scanning and visual examination showed no degradation.

With the completion of the lateral axes testing, the RTG was hoisted from the slip table and set up on the exciter head for the longitudinal (Y-axis) vibration. The Y-axis vibration cycle was performed over the period 0215 to 0420 hours, 9/22, with no degradation to RTG structural integrity.

11.2.5.4 Post-Vibration Air Performance/Pressure Decay Test

Since the F-3 RTG was scheduled to use the vibration facility at this time, the 48-hour post-vibration performance test on the F-13 RTG was postponed until the unit was installed in the vacuum chamber in Bldg. 300, prior to starting the T/V test.

The F-13 RTG remained on the exciter head after the vibration test was completed for a 4-hour air performance test which ran from 1000 to 1400 hours, 9/22. Output power averaged 77.25 watts over this period and compared favorably with the pre-vibration output of 77.2 watts. After hoisting the RTG from the exciter head, the operations of installing the unit into its shipping container began at 1400 hours, 9/22, and were completed at 1700 hours, 9/23.

Transfer of the F-13 RTG in its SC to the platform outside of Bldg. 300 Long Life Lab was accomplished and removal from SC operations began at 0100 hours, 9/24, and the RTG was installed in the handling sling by 2330 hours, 9/24. The RTG was moved from the handling sling

to the portable lift truck and routed to T/V chamber #3 where it was installed onto the chamber's support frame at 0100 hours, 9/25. Pneumatic flex hose and electrical cable interconnections between the RTG and chamber penetrations were completed and the Segment Readiness Review certifying test preparedness was completed at 1200 hours, 9/25.

After the gas service cart lines had been purged/evacuated, the IHS and RTG-GMS's were opened, the chamber door was secured and all preparations for the post-vibration air performance/pressure decay test were completed at 1600 hours, 9/25.

The shroud was set-up for an 80°F air-mode heat sink and conditions were stable for the start of the 48-hour test at 2100 hours, 9/25. Output power averaged 76.5 watts over this duration and rate of pressure decay was 0.02 psi/48 hours.

11.2.5.5 Thermal-Vacuum Performance Testing

Prior to starting chamber evacuation, a special test was performed in order to verify that the IHS-GMV was open. This valve had a history of the valve seat "hanging-up" even though the stem indicated an "open" condition (reference Par.11.2.5.1). The lines up to the external chamber valve which isolated the IHS were evacuated and this isolation valve was then opened. The evacuated lines were backfilled by the system gas load from the other side of the isolation valve. Pressure stabilized at 5.1 psia, which proved that the system back-fill gas load included the IHS and that the IHS-GMV was indeed open. If the gas load had only been in the chamber tubulation between the external isolation valve and the IHS-GMV, the stable pressure after opening the isolation valve would have been much lower. The IHS was then re-pressurized with helium to 16 psia.

The chamber shroud temperature was changed from 80°F to 100°F and evacuation for the start of T/V testing was initiated at 0200 hours, 9/28, and by 0530 hours, a vacuum of 1×10^{-4} torr had been achieved. The RTG evacuation through the gas service cart then began and by 1200 hours, 9/28, chamber pressure was 7×10^{-6} torr and RTG internal pressure was approximately 400 microns.

After isolating the gas service cart from the RTG, pulse venting of the RTG's remaining gas load into the chamber began. Chamber pressure increased from the 10^{-5} torr range into the mid 10^{-6} torr range and at 1500 hours, attempts at venting the RTG into the chamber were suspended until after the IHS pressure was decreased. With IHS internal pressure reduced to 2.3 psia at 1800 hours, the pulse venting resumed and by 2100 hours, the venting solenoid valve was allowed to remain open with chamber pressure at 2×10^{-4} torr.

Chamber pressure recovered to the mid 10^{-6} torr range by 0500 hours, 9/29, and with the RTG vented to the chamber for the required 24 hours minimum at 2100 hours, 9/29, the four-hour T/V performance test began. Output power averaged 155.24 watts over this period.

In preparation for the termination of T/V testing, IHS pressure was measured at 0230 hours, 9/30, and indicated 2.68 psia. Since this was greater than the specified 1.5 to 2.5 psia, a Readiness Review Team decision was made to reduce IHS pressure to meet this range and repeat the performance test. IHS pressure was reduced to 1.90 psia at 0240 hours and an additional T/V performance test of 6 hours duration was run, ending at 0900 hours, 9/30. Output power averaged 154.55 watts over this 6-hour T/V test period. This was slightly greater than the average power over the four-hour period prior to reducing IHS pressure to 1.90 psia.

11.2.5.6 Post-T/V Air Performance/Pressure Decay Testing

After the Health Physicist obtained an IHS radiological sample, the IHS pressure was increased to its first backfilling plateau of 9 psia at 1330 hours, 9/30. Backfilling of the converter with argon then began and at 1530 hours, the first pressure plateau of 17 psia for the converter was achieved. At 0030 hours, 10/1, the IHS pressure was increased from 9 psia to 16 psia and by 0145 hours, the converter had been pressurized to 25 psia. Chamber backfilling with dry N₂ then began, and after attaining 13.5 psia, the chamber atmosphere was verified as being acceptable by the Health Physicist. He gave his approval to continue with the nitrogen backfill and chamber pressure was one atm by 0700 hours, 10/1.

The chamber shroud, which had been running at 100°F for T/V testing, was adjusted to 80°F for "air" mode testing and the unit was allowed to thermally stabilize. Thermal stability was achieved at 1200 hours, 10/1, for the start of the 48-hour post-T/V air performance and pressure decay test in the closed chamber #3. Output power over this test duration averaged 76.1 watts and rate of pressure decay was 0.08 psi/48 hours.

11.2.5.7 Post Acceptance Test Operations

The chamber door was opened at 1600 hours, 10/3, RTG electrical cables and pneumatic flex hoses were disconnected from their chamber penetrations and the RTG was transferred from the chamber support frame to the platform outside of the Long Life Lab. While the F-13 RTG was set-up in the handling sling, a fit check was performed using the Lincoln Lab fixture and clevis at the RTG's uniball interface.

No difficulties were encountered during this operation.

Installation of the F-13 RTG into its RTG-SC began at 2300 hours, 10/3, and by 1630 hours, 10/4, had been completed. The RTG was lowered to the ground floor of Bldg. 300 and transferred to Bldg. 800 for storage at 1830 hours, 10/4. On 10/8, the F-13 RTG was transferred from the Bldg. 800 storage area to the test area and preparations were initiated for an exchange of the RTG's argon fill gas for xenon gas.

A special tool had been designed and manufactured for the purpose of gaging whether or not the IHS-GMV seat on the F-13 RTG was open after opening the valve stem. (NR-43347 had documented this defect on F-13's IHS-GMV.) Early on 10/9, the RTG-SC was temporarily opened to attain access to the IHS-GMV which had been closed prior to the transfer of the unit from Bldg. 300 to Bldg. 800. After opening the IHS-GMV, an attempt was made at gaging the opening with the newly-designed special tool. Due to interference from the PRD assembly, which was mounted to the case fin adjacent to the IHS-GMV, the gaging operation could not be completed at this time. The tool was subsequently re-designed and another try-out is scheduled to be performed at the Cape.

The overall sequence of operations for the system gas exchange was the following:

- 1) After interconnecting the General Electric GSC (Gas Service Cart) with the RTG-SC vent port and the Lincoln Lab GSC with the IHS and RTG vent ports on the SC, the shipping container was initially evacuated to below 1 psia using the GE GSC and subsequently attained 0.05 psia prior to starting item (4) below.
- 2) The IHS pressure was decreased to 7.3 psia and the RTG internal pressure was then decreased from 22 psia to 1.2 psia using the Lincoln Lab GSC.
- 3) IHS pressure was reduced from 7.3 psia to less than 0.1 psia and after attaining this level, the IHS was backfilled with xenon gas to 8.7 psia.
- 4) The RTG internal pressure was decreased from the 1.2 psia level to 0.56 psia and the RTG was then backfilled with xenon gas to 25.0 psia.
- 5) To complete the gas exchange operations, the IHS pressure was increased from 8.7 psia to 16 psia xenon.

Maximum RTD fin temperature was 270°C during the above argon/helium-to-xenon gas exchange operations, which was well below the specified 290°C maximum allowable temperature.

After backfilling the shipping container to one atmosphere argon, the SC was opened and the RTG was hoisted out of the SC and stationed in ambient air while suspended from the SC lid. The shorting module was switched "open" at 1500 hours, 10/9, and a 26.5-volt load was established at the ROC load panel. The RTG stabilized at 1900 hours, yielding an air mode output power, with xenon fill and 26.5 volt load, of 118.9 watts. The 26.5-volt load was used for this performance test since that is the LES 8/9 vehicles' power distribution system voltage.

While awaiting the RTG stabilization for the above air performance test, a trial installation of the PMD to its RTG fin and its inter-connection with the IHS-GMV was performed. This operation was completed (minus the screw lockwiring, since it was a temporary installation) with no difficulty and in just a few minutes.

Also performed at this time was the trial installation of the PRD bellows into the PRD bracket. Installation tool 3491P1 could not be used at this time due to an interference of the tool with the PRD bracket; however, the bellows installation was successfully completed by hand. (The installation tool shall be modified for Cape installation of the PRD bellows.) After removing the bellows assembly, the mass simulator was reinstalled into the PRD bracket.

The RTG load voltage had been adjusted from 26.5 volts to 30 volts at 1930 hours, 10/9, and the unit was allowed to stabilize at that load voltage for the second phase of performance testing. RTG output power over the period 0100 to 0700 hours, 10/10, averaged 118.2 watts with xenon fill and 30-volt load.

After switching the shorting module to the short-circuit mode, the RTG was installed into the SC at 0900 hours, 10/10, and the operations of exchanging the xenon fill gas for argon and helium (in the IHS) were performed in the following sequence:

- 1) The shipping container was evacuated to below 1 psia using the GE GSC.
- 2) IHS pressure was reduced from 16 psia to 10 psia using the Lincoln Lab GSC.
- 3) RTG pressure was reduced from 25 psia to 1.0 psia and IHS pressure was then reduced to less than 0.1 psia using the Lincoln Lab GSC.
- 4) The IHS was pressurized to 8.9 psia with helium gas.
- 5) After evacuating the RTG from 1.0 psia to 0.5 psia, the RTG was pressurized to 25 psia with argon gas.

- 6) The IHS pressure was increased from 8.9 psia to 16 psia helium to complete the gas exchange.

By the end of the IHS pressurization to 16 psia (item 6 above), maximum RTD fin temperature was 289°C. With the start of shipping container pressurization with argon to one atmosphere (after item 6 above), case temperature began to decrease.

The instructions for this xenon-to-argon/helium gas exchange were from the Cape procedure which would be utilized in the event that the RTG had to be re-installed into its SC. That procedure was subsequently modified to start the SC backfilling operation concurrent with IHS pressurization with helium from 8 psia to 16 psia (item 6 above) in order to shorten the duration of elevated case temperature.

After the SC lid was temporarily raised to allow closure of the IHS-GMV, the installation of the F-13 RTG into the SC was completed at 1630 hours, 10/10, and the unit was transferred to the Bldg. 800 storage area, where final preparations were made for shipment of the RTG to Mound Lab. The F-13 RTG was secured into the ERDA SST van at 1400 hours, 10/15, and authorization was given to transfer the unit to Mound Lab for storage at 1500 hours.