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AEC RESEARCH AND
DEVELOPMENT REPORT

QUARTERLY REPORT -
SPACE ISOTOPE POWER PROGRAM
July - September 1967 (U)

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Space Isotope Power Department 9330

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SYSTEMS FOR NUCLEAR
AUXILIARY POWER (SNAP) -
ISOTOPIC SNAP PROGRAM C-92a
M-3679 (53rd Ed.)

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SPACE ISOTOPE POWER PROGRAM
July - September 1967

Space Isotope Power Department 9330
Sandia Laboratories

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SUMMARY

Systems

SNAP 19 -- System 4, which consists of generators No. 7 and No. 8, was disassembled and defueled. Examination of generator No. 7 revealed evidence of fuel capsule movement. The failure of all three resistance temperature detectors appears related to the capsule movement.

System 5 was conditionally accepted and shipped to GE Valley Forge. The acceptance was conditional because of a high frequency ripple in the telemetry signal conditioner unit (TSCU) and out-of-tolerance dimensions on the same unit. The former condition has been eliminated; the latter has resulted in a change in final inspection procedures (Martin and AEC) to prevent a recurrence.

System 6 has completed the flight-level tests successfully. The TSCU is undergoing requalification testing after being modified to eliminate a high frequency ripple.

System 7 experienced a thermal shock due to an equipment malfunction during its thermal vacuum test. The TSCU is being reworked to preclude the occurrence of a high frequency ripple.

Ground support test console No. 3 was conditionally accepted based on a Martin specification revision which changed the nonoperating low temperature requirement from -35° to 32°F.

Four capsules have been pressure-tested to failure while at operating temperature in generators. The failure modes indicate that the probability of fuel release resulting from pressure buildup in the capsule is low. As a result Martin has reduced the postmission hazard probability from 0.5 to 0.5×10^{-3} .

A SNAP 19 interface agreement has been accepted by Martin Marietta and signature is pending.

Generator No. 19 has been shipped to NASA Marshall Space Flight Center, Huntsville, where it will be used for engineering evaluation and additional endurance testing.

SNAP 27 -- This is a summary of the status of qualification testing of end items:

Flight handling tool - Qualification completed.

Ground handling tool - Qualification completed.

IPU test consoles - Qualification completed.

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Generator assembly - Qualification tests for all dynamic environments completed. Qual model generator (Mod 10) is now undergoing thermal vacuum life-testing.

Generator assembly shipping container - Qualification completed except for a redesigned valve which must be qualified on the container.

Shipping containers for the flight handling tool, ground handling tool and IPU test console have been completely qualified.

The maximum predicted fuel capsule clad temperature of 2260°F, resulting from a side-on-spin reentry from earth orbit decay, is 165°F below the low range of the solidus temperature of the Haynes-25 capsule clad material. The probability of achieving a no-melt design for the reference design conditions now appears to be excellent.

It has been decided that neither oxidation nor emissivity coatings are required for the fuel cask.

An operational walk-through at Mound Laboratory has demonstrated Mound's ability to fabricate the heat source. Hardware for the first fueling (qualification capsule) and the second fueling (first flight capsule) were shipped to Mound Laboratory and the first fueling has begun.

The draft of the final report for the thermoelectric leg product specification has been reviewed.

SNAP 29 -- Mound is proceeding with the design of polonium facilities to handle the estimated quantities of fuel necessary for this size radioisotopic thermoelectric generator.

Martin is developing a design for a graphite fuel block using ATJ (commercial fine-grained) graphite. Included in the design is a means of retaining the capsule for adequate shock and vibration protection.

A thermoelectric (T/E) module employing beryllium hot and cold plates with an inert, gas-pressurized diaphragm replacing the springs and pistons on each T/E element is being fabricated.

Martin has fabricated water heat pipes of several different wick configurations for evaluation with the heat-rejection system. These configurations include annulus, artery, double-artery, corrugated, standard, and hybrid types.

Large Radioisotope Heat Source System -- The scope-of-work for the 25 kW thermal large radioisotope heat source system has been prepared and distributed for comment among concerned agencies.

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Technology Studies

1. During this period two tubular modules of the Westinghouse compact converter program using 3p PbSnTe have exhibited electrical stability superior to 2p PbTe modules. The new modules are operating at hot side temperatures of 1000° and 1100°F, respectively. While test time is limited, this experiment indicates that the upper temperature limit for tubular modules has not been reached, and that operation above 1100°F appears feasible.
2. The RCA SiGe compact converter program is being redirected to put more emphasis on hot shoe materials, bonding, and the hot shoe junction. Emphasis is also being applied to the determination of an acceleration factor for time/temperature testing.
3. An analytical study at Linde has shown the importance of minimizing gaps in foil type insulation. Effective conductivity was increased by as much as 10 times when there were gaps.
4. Test results on Min-K 2002 show a 12 percent improvement over Min-K 2000, and thermal conductivity compatibility testing with SiGe shows no affects on thermoelectric properties.
5. Posttest examination of the heat pipes that were life-tested at RCA shows it is possible to build long-life pipes using potassium as a working fluid.
6. Continued life testing of SiGe modules still shows extremely low rates of degradation at times ranging from 23,000 to 27,000 hours.
7. Impact testing by Sandia of Haynes-25 and Ta-10W spherical capsules shows a significant decrease in impact resistance when capsules are subjected to 1500° or 1800°F for 1000 hours.
8. The General Atomic Isotec program passed a milestone in September with the choice of a design for the two 30-watt converters to be constructed. After several design modifications, an accelerated test program is under way to extend the life of the n-element bond beyond 2 years.
9. Atomics International has been given a contract for a 2000°F capsule test program. Data from this program should be useful for capsule design in this temperature range.

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1. SPACE ISOTOPE POWER SYSTEM PROJECTS

1.1 SNAP 19

Martin Marietta
AT(30-1)-3607

R. J. Luikens,	505-264-2534
R. E. Stewart,	505-264-2534
F. L. McFarling,	505-264-2138
W. M. Bray,	505-264-2138

Introduction

The SNAP 19/Nimbus B power supply system consists of two radio-isotope thermoelectric generators (RTG's; Figure 1), a power conditioner unit (PCU; Figure 2), and a telemetry signal conditioner unit (TSCU; Figure 3). In addition to the flight hardware, various ground support equipment is required. The system is expected to provide a nominal 40 watts to the satellite power bus (about 1/7 of the maximum Nimbus load) after a 2-year shelf life and a mission duration of 1 year.

Figure 1.
SNAP 19 arrangement
(courtesy Martin
Marietta)

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Figure 2. Power conditioner unit

Figure 3. Telemetry signal
conditioner unit
(courtesy Martin
Marietta)

SNAP 19 uses lead-telluride thermoelectric elements and ^{238}Pu fuel. It has a volume of about 2.5 cubic feet and is in the 1-pound-per-watt weight range.

Significant Events

System 4 was disassembled and, after defueling, generator No. 8 was made available for the Intact Reentry Heat Source (IRHS) program. Generator No. 7, the top RTG, showed evidence of fuel capsule movement. This is a probable cause for the failure of all three resistance temperature detectors (RTD's).

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System 5 was conditionally accepted and shipped to General Electric, Valley Forge, on June 30. The condition was made because of a high frequency ripple in the TSCU, on the lines to the spacecraft regulated bus, which has since been resolved. However, GE Valley Forge did find out-of-tolerance dimensions on the TSCU and, as a result, Martin Marietta and AEC final inspection procedures have been increased to prevent a recurrence of this problem.

System 6 has completed all the flight-level tests (vibration, thermal vacuum, functional after test) successfully and is on short circuit awaiting AEC direction. The PCU and the stand-off have been shipped to GE Valley Forge on a loan basis. The TSCU is undergoing requalification testing after a modification to fix the same high frequency ripple noted on System 5.

System 7 has completed all its flight-level testing and is on short circuit. An evaluation is being conducted of the effects of a rapid temperature loss because of equipment malfunction during thermal vacuum testing. Also pending is a review of the fuel capsule information by Martin and a statement that these capsules are compatible with the SNAP 19/Nimbus B program. The TSCU is being reworked to incorporate the modification for high frequency ripple.

Ground support test console (GSTC) No. 3 was conditionally accepted and shipped to GE Valley Forge June 30 rather than June 19 as stated in the last quarterly report. The condition was a result of Martin's issuing a change to the GSTC specification MN-10220 revising the nonoperating low temperature capability from -35° to +32°F. The resolution of this condition is awaiting GE's review of the latest information obtained by Martin.

Four capsules have been pressure-tested at operating temperature in generators until they failed. The nature of the failures establishes that the probability of fuel release after mission completion is very low. There was no damage to the generator housing and Martin has reduced the postmission hazard probability from 0.5 to 0.5×10^{-3} .

The three major product specifications have been reviewed by the Sandia Technical Director, and the AEC Sandia Area Office has been notified that the specifications are satisfactory for use for acceptance of product. These specifications are:

- MN-10210 Specification for a SNAP 19/Nimbus B Radio-isotope Thermoelectric Power Supply System.
- MN-10220 Specification for SNAP 19/Nimbus B Power Supply System Ground Support Test Console.
- MN-10230 Specification for SNAP 19/Nimbus B Power Supply System Support Equipment.

The contract rewrite has still not been consummated. The sole issue of contention is the insistence on the part of Martin Marietta that the term "best effort" be inserted in the contract in regard to their responsibility.

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Martin has issued a letter indicating its willingness to sign the interface agreement with the inclusion of a few minor changes. They have discussed the changes with GE and all are acceptable to GE. A part of the agreement is that there will be no changes by any party without the knowledge and consent of the others. The parties signing this agreement are: GE Valley Forge, NASA, Martin Marietta, and Sandia.

Generator No. 19 has been removed from endurance testing and prepared for shipment to NASA's Marshall Space Flight Center, Huntsville. The unit will be used for engineering evaluation and further endurance testing.

Program Management

A new form of monthly report has been devised. It is more cost-oriented and comprises Objectives, Major Program Changes, Potential Problem Areas, Critical Action Items, Related Work, Highlights, and Funding. These section titles are also used for each of the individual tasks that make up the report. The funding sections give cumulative costs, estimated cost to completion by the month, and actual monthly cost for the specific task and for all tasks combined. This information is also plotted in graphic form.

The delivery of a flight system to GE Valley Forge is being delayed pending AEC review of the power, system performance, and nuclear safety aspects of the dispersal system as compared to the intact reentry system. This decision by the AEC Space Nuclear System Division is to be made by October 15.

On the basis that the contract rewrite will supersede outstanding Martin contract change proposals (CCP's), there are only three that have been initiated lately and would not be covered. These are:

- CCP-62 Provide a Generator for Fire Test.
- CCP-63 Capsule-In-Generator Burst Test.
- CCP-64 Additional Generator with 2N-3P Elements.

Status of Systems

System 2 -- This system is an electrically heated engineering model, delivered to GE Valley Forge in July 1966 for bench testing. It is still at GE and is being used for various electrical checks.

System 4 -- This system was fueled and subjected to prototype-level environmental tests. Upon completion of this program the fuel capsules were removed and used in System 7. With the exception of malfunctioning RTD's the system performance was satisfactory. Generator No. 8 was transferred to the IRHS program. Generator No. 7 (the top one) received a post mortem examination which revealed that the capsule had moved, pulverizing the restraining Min-K disc and denting the metal loading plate in several places. It was concluded that improper pre-load of the Min-K disc was the reason for capsule movement and the

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major cause for the malfunctioning of all three RTD's. This was corrected by selective fitting of the capsule load discs in System 7, and the following reasons assure that this condition has not and will not occur in System 6:

1. radiographs show no displacement;
2. RTD data which would indicate any damage were reviewed and showed no such indication; and
3. generator No. 8 was disassembled and no Min-K damage observed. This generator, because the lower one in a subsystem, was tested to a prototype vibration level more representative of the flight vibration environment of the upper generator in System 6.

System 5 -- This system is electrically heated and has been tested to prototype levels of environment. It was conditionally accepted by AEC and shipped to GE Valley Forge on June 30 for electrical integration tests with the spacecraft. The acceptance was conditional because the TSCU was unable to meet the 50 millivolt maximum radio frequency (RF) noise requirement. As a result of discussions with NASA personnel it was decided to ship the complete system to determine if the RF noise ripple would still exist when tested on the bench integration test board; this test more closely simulates the actual spacecraft signals. The noise was still objectionable on this test, and it was agreed that GE would return the TSCU to Martin for rework. Martin accomplished this and the unit was subjected to agreed-upon requalification testing. The unit was returned to GE on a loan basis on September 5--on loan because the interface dimensional discrepancies are still not corrected, but the unit was needed at GE for testing.

System 6 -- All testing for this system, presently the flight system, has been completed and the generators are in storage on short circuit. The overheating mentioned in the last quarterly has been evaluated; it will not be detrimental to the system's capability of performing its function on the Nimbus B. The system was retested: a 7-day endurance test, a flight-level vibration test, and an 11-day endurance test; the results showed no abnormal results. The PCU was reworked because one of its terminals had been overtorqued and rotated, thereby affecting the internal alignment and the conformal coating. It has been requalified and shipped to GE with the standoff, but on a loan basis because an official acceptance drawing defining the hardware as a baseline for deviations was not ready in time for GE testing. The TSCU is being requalified after modification to eliminate the same RF noise problem as System 5.

System 7 -- This system is the backup flight system. The generators have completed all testing and are in storage on short circuit. During the initial stages of the thermal vacuum (TV) test two electrical anomalies were observed. The first was a broken wire in the harness between the TSCU and the PCU; it was repaired, and the TV test resumed. The second, not identified until after the TV test, was a defective resistor in the PCU; Martin is evaluating the problems associated with its replacement. At this time the defective resistor is considered a random failure.

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Also during the TV test, the liquid nitrogen pump which maintains the low temperature of the chamber failed. The chamber was opened to prevent overheating of the system but the rate of temperature change exceeded the rate then specified. The allowable rate of temperature change has since been increased from 15°F/10 minutes to 35°F/15 minutes. This increase still does not allow for the rate experienced by System 7, but this requirement is being completely reviewed.

The TSCU is being reworked to eliminate the RF noise, and Martin is determining the compatibility of the fuel capsules. The latter problem was resolved on System 6 but Martin still has reservations about the System 7 capsules.

Ground Support Test Console (GSTC)

There are three GSTC's required in this contract; they were funded by NASA and are NASA equipment. GSTC No. 1 is an engineering model and was sent to GE Valley Forge along with System 2; No. 3 was shipped to the same location with System 5. GSTC No. 2 is maintained at Martin Marietta to be used with Systems 6 and 7, and this unit is being modified to be compatible with the modifications required in the TSCU's. Since No. 1 was an engineering model it has not and will not be modified to keep it up to date. GSTC No. 3 will be modified to reflect this change and the present plan is that Martin will prepare a modification kit to send to GE.

GSTC No. 3 was accepted conditionally because Martin realized that it did not have substantiation from the commercial equipment suppliers for the nonoperating capability of -35° to 125°F. As Martin has since determined, the power supply unit has a storage temperature limitation of -4°F. Because this may require special handling by GE, Martin has been directed to resolve this with GE as part of the interface agreement.

Module Test Generators

The endurance test on generator No. 4 began September 20, 1966. The initial power output was about 28.7 watts at 2.7 volts load. On September 7, 1967, after 820 hours of operation under load, the generator was producing about 21.3 watts.

Generator No. 17 was placed on endurance testing on April 10, 1967; the initial power output was about 28.3 watts. On September 8, 1967, after 3568 hours of operation under load, the power output was 24.5 watts.

Generators Nos. 5 and 6 are joined as a subsystem for endurance testing but have different elapsed test times because of heater failures on No. 5. When generator No. 5 was shut down, No. 6 remained on test, so the results on the two are not directly comparable. At the beginning of life, the power outputs of Nos. 5 and 6 were about 30.0 and 29.5 watts, respectively. By September 11, 1967, No. 5 had 7,547 hours and No. 6 had 10,263 hours under load, with outputs of about 22.7 and 18.1 watts, respectively. The times they were on short circuit, about 1500 hours for No. 5 and 1000 hours for No. 6, are not included in the hours under load, but any degradation taking place during short circuit operation is of course reflected in the power output figures.

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Generator No. 18, which is at the Annapolis Division, Naval Ship Research and Development Center (NSRDC) for endurance testing, has a deteriorated emissive coating on the top cover and on a small region at each fin root. This is the result of magnesium chloride inclusions being exposed in touch-up areas, when grit-blasting was used after pickling and before the application of the coating. (This procedure is no longer allowed; System 5 was processed this way, but the flight systems, 6 and 7, were not.) Repair or recoating of generator No. 18 is not considered necessary because the total affected area is small and confined to surfaces which contribute relatively little to the radiating area. This generator was bench-tested at NSRDC beginning on February 3, 1967, and ending officially on May 24, 1967, when the bench power failed. Before the bench power failure, the main line power supply failed from March 14 to March 20, 1967. The total hours on bench test, excluding down time, was 2494 hours. The initial power output was about 27.0 watts and, at the end of the bench test, about 24.8 watts. By September 15, 1967, after 500 additional hours of operation at full power there had been no further change in the power output.

Generator No. 19 endurance testing began on December 22, 1966; its initial power output was about 25.7 watts. The test was ended on August 9, 1967, to prepare the generator for delivery to the Marshall Space Flight Center. A parametric test was conducted before cool-down, after 5350 hours of operation, and the power output was about 21.6 watts. Before delivery to MSFC the electric heater wiring harness was replaced, and after this rework the power was measured at 21.9 watts--the same as the shut-down power within the limits of measurement accuracy. The unit was shipped to MSFC for further endurance testing.

Generator No. 20 was placed on endurance testing April 6, 1967, and its power output at that time was about 25.8 watts. On September 7, 1967, after 3757 hours of operation under load, its power was about 25.2 watts.

Generator No. 21 was placed on endurance testing July 28, 1967, with an initial power output of 26.7 watts. By September 7, 1967, after 1052 hours of operation under load, the output was about 26.3 watts.

Handling Equipment

The portable monitor package, the generator subsystem shipping container, and the shipping container sling used in the walk-through have all been returned to Martin for rework to the latest specifications. After modification these units will be assigned to a particular generator subsystem along with the similar units already modified, and delivery to GE will be made on a per system basis.

The possibility of not revising the mobile carriage and generator hoisting adapter assembly originally furnished for the walk-through is being considered. Two each of identical units have been brought up-to-date and are available, so there seems to be no need for updating the first ones delivered. NASA has been asked to concur, and Martin has been requested to furnish cost-savings information.

The Western Test Range walk-through film has been reviewed by Sandia and the revised procedures from General Electric are now being written. The details of the revisions to the equipment have been reviewed with the AEC representative at NASA for inclusion in the procedure discussions.

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Safety

It was reported in the last quarterly that Martin Marietta had published all three volumes of the Interim Safety Analysis Report. In this quarter each of these volumes has been revised and republished. The word "interim" was removed from Volumes I and II. (It has been removed from Volume III before redistribution.) Martin has also published an addendum which, together with the three volumes already published, complete the Safety Analysis Report (SAR). This essentially fulfills the contractor's safety requirements on this contract; the remaining effort is limited to supporting the safety aspects of the Nimbus B launch.

The questions about the quantity of fines in the production fuel and the apparent crush strength still remain open items. Because both are related to safety, the AEC plans to qualify its acceptance of System 6, pending the Commission's decision. By October 15 the Space Nuclear Systems Division will have completed the nuclear safety assessments of both the dispersal and intact systems. The system which offers the best in power and system performance, as well as nuclear safety, will be selected and recommended to the Commission for launch approval.

The safety-related test programs that have been completed this quarter are:

Capsule Burst in Generator -- This established quite conclusively that the failure mode of the capsule under simulated long-term pressure and temperature would be nonviolent to the extent, at least, that the fuel pressure buildup would be released in a manner that would not cause the generator housing to rupture and release the fuel. Therefore, this substantially reduces the postmission hazard.

Fuel Impact -- A more definite fuel particle distribution as a result of capsule impact has been obtained. Three test capsules with ^{238}Pu fuel were impacted into granite at 100 ft/sec. The results were incorporated in the SAR for launch pad abort analysis.

Fire -- A SNAP 19 generator with a simulated fuel capsule was placed in a JP-4 fire. Unfortunately the generator fell off its support stand after 4-1/2 minutes and was extinguished. The test was re-run and the results of this one test, if meaningful, tend to substantiate the thermal analysis and the predictions in the SAR.

Gas Gun -- This series of tests run at the AC Electronics Defense Research Laboratories did not produce any meaningful results applicable to the SNAP 19 program. Another program has now been planned but any conclusive results will not be available for several months.

As indicated above, the Martin Marietta safety effort is essentially complete and continuing tests, such as the SNAP 19 capsule seawater-immersion, fuel-solubility, and ocean-bottom-burial tests (all being conducted by Naval Radiological Defense Laboratory), have little effect on the present contract.

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1.2 SNAP 19 Intact Reentry

Martin Marietta
AT(30-1)-3607

V. G. Redmond, 505-264-5255

This program was begun in late April to develop a heat source capable of remaining intact during reentry from orbit and to flight qualify a system comprising SNAP 19 generators and the new heat sources. Progress has been satisfactory. Two isotope-loaded heat sources are now installed in SNAP 19 generators and the flight qualification tests are under way.

The adequacy of the heat-source design has not been fully demonstrated in that the capability of venting the fuel-evolved helium has not been established. Tests now under way are expected to prove or disprove the need for an alternative filtering medium.

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1.3 SNAP 27

General Electric
AT(30-1)-3535

J. A. Leonard,	505-264-2433
E. F. Johnson,	505-264-2433
A. E. Stephenson,	505-264-3830
T. D. Harrison,	505-264-3830
G. W. Elliott,	505-264-2433

Introduction

The SNAP 27 is a radioisotope thermoelectric generator which uses ^{238}Pu as fuel in the form of plutonium dioxide microspheres. It will be the power source for the Apollo lunar surface experiment package (ALSEP). The SNAP 27 is designed to deliver a minimum of 63.5 watts following 2 years of storage and 1 year of operating life.

The over-all generator diameter is 15.75 inches, and the over-all length is 18.12 inches. There are four components of SNAP 27 flight hardware:

<u>Major Component</u>	<u>Weight (lb)</u>
Generator Assembly	28.2 (without fuel)
Fuel Capsule Assembly	14.5
Graphite LM Fuel Cask	25.5
Flight Handling Tool	0.6

The SNAP 27 program also requires the design and fabrication of ground shipping containers, ground handling tools, electric fuel-capsule simulators, test equipment, and mockups. The prime contractor for the program is the Advanced Nuclear Systems Operation, Missile and Space Division, General Electric Company, Valley Forge, Pennsylvania.

The generator assembly (GA) without fuel will be transported to the moon, stowed inside the lunar module (LM). The fuel capsule assembly (FCA) will be carried inside the graphite LM fuel cask (GLFC) which will be mounted on the outside of the LM. The GLFC will protect the FCA from reentry heating in the event of an abort, thereby preventing atmospheric dispersion of the fuel.

Upon arrival on the moon, the astronaut will deploy the GA as part of ALSEP. He will extract the FCA from the GLFC, using the flight handling tool, and insert the capsule in the generator. Warmup will begin immediately and the generator will soon be producing full power.

Plans for the SNAP 27 call for delivery of generators or generator mockups as follows:

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<u>No. of Units</u>	<u>Serial Numbers</u>	<u>Planned Use</u>	<u>Delivery</u>
3	M1, M2, M3	Mechanical integration mockup	Dec. 65
2	Mods 5, 8B	Engineering development models	Mod 5 Oct. 66 Mod 8B Mar. 67
1	M4	Thermal test mockup	Nov. 66
1	Mod 14	System compatibility and performance test unit	Jan. 67
1	M5	Flight test mockup system	Mar. 67
2	M6, M7	Astronaut training unit mockups	May 67
1	Mod 10	Qualification model generator	June 67
1	Mod 15	System qualification test unit	Apr. 67
5	Mods 13, 19, 21, 22, 23	Flight units	Oct. 67 to Jan. 68

In the above schedule, the 7 generators designated by the prefix "M" are mockups and do not contain thermopiles. Of the remaining 10, 6 will ultimately be fueled with plutonium dioxide and 4 will derive input power from electric fuel-capsule simulators. The schedule applies generally to all contract end items except the GLFC and the FCA; the cask and fuel capsule flight models will be delivered to NASA beginning in the second quarter of 1968.

Technical Direction

Considerable technical direction was required this quarter in many areas of SNAP 27 program activity. Chronologically, direction was issued as follows:

1. GE was directed to undertake a development program for the production of welded fuel capsule center section assemblies.
2. Concurrence was given not to retrofit the valve on the Mod 15 shipping container at Bendix.
3. GE was requested to extend their distribution for the SNAP 27 Hardware Matrix.
4. GE was directed to place an order for new liner heads for the fuel capsule.
5. Comments were requested of GE regarding changes to the integrated power unit (IPU) consoles that have been requested by NASA.

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6. GE was requested to attend a capsule fueling specification meeting and a GLFC/fuel compatibility meeting at Mound, as well as to brief Mound personnel on the design and function of the fuel capsule components.
7. GE was requested to brief AEC Headquarters Fuels Branch on the fuel capsule development program.
8. GE was authorized to remove the outer shell from the Mod 20 thermopile if other repair procedures could not be developed. (Subsequently Mod 20 was canceled as a cost reduction measure.)
9. GE was requested to send Sandia preliminary copies of portions of the Safety Analysis Report (SAR) as soon as available to improve understandings and agreements.
10. GE was requested to mark beryllium backplates to indicate their nonflight status.
11. The fuel capsule burst and verification test programs were placed on "hold" (subsequently lifted, and these programs were revised).
12. GE was directed to reduce their level of effort in order to stay within the fiscal year 1968 funding limitation.
13. A meeting was requested to agree upon the steps necessary to complete the SAR.
14. All activities relating to the assembly of the Mod 23 generator were placed on "hold" (subsequently lifted when Mod 20 was canceled).
15. Direction was provided to help solve the FY 68 budget problem: (a) reduce the qualification program for the generator assembly to one unit, Mod 10; (b) redesignate the Mod 13 generator assembly as a prime deliverable flight unit; (c) cancel the requirement for one flight model generator assembly by terminating all work on either Mod 20 or Mod 23 (it was decided later it would be the Mod 20); (d) place all 10- and 104-couple modules on test in a "warm hold" pending disposition (testing of modules was subsequently resumed but without reducing the data; and (e) cancel the interim program motion picture.

The following additional agreements were documented: (a) the old-style monthly reports will be cancelled in favor of new monthly financial reports; (b) reliability and Kennedy Space Center (KSC) Support tasks costs will be reduced; (c) interagency cost sharing will be implemented for the GLFC acceptance and qualification testing; and (d) GLFC costs will be reduced by selecting the vendor as early as possible and by eliminating some thermal modeling.

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16. GE was requested to attend a meeting to discuss the preliminary hazard assessment study.
17. The GLFC program hardware and delivery requirements were supplied to GE.
18. GE was requested to supply data on the compatibility testing done under the SNAP 27 program for any combination of fuel/Haynes-25/graphite, to be included in an all-agencies report.
19. GE was requested to review their quality control procedures for production of radiant heat capsules in an effort to increase the number of usable capsules.
20. GE was advised to make a section of the broken GLFC cylinder available for determination of flash points of rocket fuel on graphite.
21. GE was requested to provide a history of vacuum chamber failures plus their assessment of the integrity of the remaining chambers, so as to predict testing uncertainties and inefficiencies.
22. GE was requested to present reviews of the aerothermodynamic considerations, materials properties, and structural analysis of the GLFC before a design release.
23. GE was requested to supply a material review board summary with all end items and/or deliverable items submitted to the AEC for acceptance.
24. GE was advised that the electromagnetic interference levels of the IPU test consoles were satisfactory.
25. Direction was provided for including Reliability and KSC Support tasks into the program.

Qualification Testing

During the reporting period, qualification testing of almost all end items has been conducted. The following summarizes the status of qualification testing:

Flight Handling Tool - Completely qualified.

Ground Handling Tool - Completely qualified.

IPU Test Consoles - Completely qualified.

Generator Assembly - Qualification tests of all dynamic environments have been successfully completed and the Qual Model Generator (Mod 10) is now in thermal-vacuum life testing.

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Fuel Capsule Assembly and Graphite LM Fuel Cask - Qualification tests with the Bendix mounting structure will be conducted about March or April 1968.

Generator Assembly Shipping Container (Figure 4) - Qualification is complete except for a redesigned valve which has gone through component qualification but must now be requalified on the container.

Ground Shipping Cask (Figure 5) - Qualification testing has been delayed pending redesign of the nickel shot egress orifice and seals.

Shipping Containers for Other End Items - Completely qualified.

Figure 1. SNAP 27 generator shipping container

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Figure 5. SNAP 27 fuel capsule ground shipping cask

Proposals and Negotiations

A negotiation meeting June 26 resulted in establishing a requirement for actual costs on all contract change proposals (CCP's) completed, and actual costs up to a reasonable cutoff date prior to submission. Another meeting was held on July 25 to review the status of all CCP's and to establish ground rules for negotiating both CCP's and Phases III and IV of the contract. Following the meeting, Sandia and SAO revised GE's suggested scope-of-work on each CCP and returned these to GE for their consideration and approval. GE will review the proposed scope-of-work and prepare actual costs on all outstanding proposals and submit them for negotiation as soon as possible. It is hoped that all CCP's may be included in the contract within 60 days.

A negotiation session was held September 11 to consider proposal "P" (Multiple Capsule Liners), which had been submitted before and was now resubmitted with actual costs, and current proposals "QQ" (Welded Capsule Assemblies) and "RR" (Liner Head Material Evaluation). All three proposals were successfully negotiated and will be included in the contract.

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Phases III and IV scope-of-work proposals, submitted by GE, were reviewed and rewritten by Sandia. However, the budget ceiling for FY 68 has required substantial revision of the scope-of-work. It has also been decided to combine Phases III and IV into one scope-of-work and one program negotiation. The combined Phase III/IV scope-of-work has been submitted to Sandia and AEC for review. GE will reestimate the costs of Phase III/IV in line with the new scope-of-work and the FY 68 budget ceiling.

Technical Support to AEC

In its role of providing technical support to the AEC Contracting Officer, Sandia routinely reviews and makes recommendations on the technical aspects of subcontracts, purchase orders, and similar documents submitted by contractors for AEC approval. Some typical technical analyses submitted to AEC/SAO dealt with the following:

1. Modification 2, Supplemental Agreement No. 1 to GE/3M subcontract which incorporated costs from scope changes and overruns.
2. A rental-purchase agreement for 16 recorders entered into by 3M as part of the GE/3M subcontract.
3. Technical assistance to the AEC in preparation for approval of Phase IV of the GE/3M subcontract.
4. Other analyses of subcontracts included 3M's labor subcontract with Possis Machine Company and their machinery subcontract with Midwest Automation, Inc.
5. The GE/Solar subcontract, Phase IV, which included the Solar production effort on flight generators, and several special studies undertaken at the direction of GE concerning the beryllium case study.
6. Modification 4 to the GE/Solar subcontract which was the Phase II cost to complete proposal.
7. The GE Vallecitos irradiation processing operation for the emissive coating and nondestructive testing of the fueled capsule.
8. Modification 2 to the GE/TEEC Co subcontract which is Phase III and IV of the contract. It contained testing and production activities.
9. The GE/Speed Ring contract termination claim. It appeared that too little credit was being given for beryllium scrap. A review of the parts produced from hot pressed blocks indicated that, indeed, the material left in the piece parts was a very small portion of the total material purchased. However, because this was a fixed-price contract, the scrap cutting value was used to reduce the material cost.
10. The fixed-price order with ACF Industries for fuel capsule hardware.

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11. The GE/Supertemp and GE/Hitco purchase order for graphite cask components for engineering evaluation.
12. Evaluations and recommendations on technical details including rental of IBM, Datafax, and other equipment, consultant agreements, contractor and subcontractor overtime approvals, and capital funds expenditure.

Graphite LM Fuel Cask (GLFC)

Design -- The GLFC comprises two heat shields and contains the fuel capsule assembly (FCA) as shown in Figure 6. The primary (outer) shield is of reinforced graphite. The secondary heat shield is a form of silicon dioxide cast into rings and mounted on a columbium cylinder. Heat rejection during transportation to the moon is provided by circumferential fins of silver projecting through the silicon dioxide. During normal operation, these fins conduct the 1500 watts (5120 Btu/hr) produced by the FCA. During reentry heating following an abort the fins melt and the secondary heat shield then blocks the flow of heat from outside to inside the cask.

Figure 6. Graphite LM fuel cask with fuel capsule assembly installed

Figure 7 shows a mockup of the GLFC mounted on a mockup lunar module (LM). Behind the GLFC is a gold-plated heat shield which protects the LM from the heat of the GLFC. To the right of the GLFC is a silver-plated door which reflects heat away from the Apollo lunar surface experiment package (ALSEP).

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Figure 7. Mockup of lunar module with the graphite LM fuel cask installed

Figure 8 shows the GLFC tilted forward, putting it into a position such that the astronaut can remove the FCA. The astronaut unlocks the safing mechanism and performs the tilting operation by pulling lanyards. When the GLFC is tilted to the proper position, the astronaut removes the dome by attaching a dome-removal tool to the metal projection on top of the GLFC. He stows the hot (800°F) dome safely under the lunar module where he cannot come into contact with it. He then removes the FCA with the flight handling tool.

The compartments behind the open door are for storage of the ALSEP which includes the SNAP 27 generator.

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Figure 8. Mockup of the lunar module with the GLFC tilted for removal of the fuel capsule assembly

Cask Requirements Schedule -- The following cask requirements have been received from NASA through the AEC, and were forwarded to GE on August 21, 1967:

<u>Type of Cask</u>	<u>Number</u>	<u>Delivery Date</u>
Engineering cask	2	To be furnished later
M6 (1-g trainer) cask	1	Oct. 1, 1967
M7 (1/6-g trainer) cask	1	Oct. 1, 1967
Flight quality cask	3*	Apr. 15, 1968
Flight quality cask	3	June 30, 1968

*Includes M5 and a spare.

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At present, it appears that GE will be able to meet this delivery schedule, even though the requirement for engineering casks was not included in the original cask program.

Major Changes to Design During Quarter -- During this quarter the insulation for the secondary heat shield was changed from alumina (Al_2O_3) to silicon dioxide (SiO_2). The necessary structural and insulative properties could not be achieved in alumina.

Calculations for Temperature Predictions -- GE and Sandia evaluated three important constituents in their temperature predictions: the view factor for the cask on LM reentry; the equations for the reference heating rate; and the heating rate multipliers. Using selected values and formulas for each of the three, GE predicted maximum temperatures for the capsule clad material for a side-on-spin reentry:

From Earth Orbit Decay - Entering at 0-degree latitude, heading 32-degrees, the maximum temperature is 2260°F. Entering at 32-degree latitude, heading 0 degree, the maximum temperature is 2200°F.

From Lunar Return - Entering at -6.4 degrees from the horizontal, the maximum temperature is 1950°F. Entering at -20 degrees from the horizontal, the maximum temperature is 1710°F.

In a meeting at Sandia on September 13, GE and Sandia agreed to use the GE view factors, reference heating rate equations, and heating rate multipliers. Agreement was also reached on initial trajectory parameters. These then become reference design conditions. The values of capsule clad temperatures listed above are not final; some changes will occur as the result of refinements in the initial trajectory conditions, but these changes are not expected to be significant.

The importance of these values is that the maximum predicted capsule clad temperature of 2260°F is 165°F below the low range of the solidus temperature (2425°F) of the Haynes-25 capsule clad material. The probability of achieving a no-melt design for the reference design conditions now appears to be excellent.

Coatings -- Three types of coatings had been considered for the graphite. These were

1. a coating to inhibit oxidation while the cask is on the pad, in air, with the FCA installed,
2. a coating to provide an emissivity value of 0.80 or higher, and
3. a coating to protect the graphite from molten Haynes-25 which might be present during an abort.

A decision was made by NASA to cool the cask on the pad to about 400°F. This temperature is low enough that the graphite will not oxidize, so it was decided that an oxidation coating was not needed. It

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has been determined that the minimum emissivity value on the graphite is 0.70. Calculations show that the effect on the cask surface temperature of reducing emissivity from 0.80 to 0.70 is negligible. In addition, experiments now in progress show that oxidation would raise the emissivity above the 0.70 value. It was decided that no emissivity coating is needed.

A decision on the need for a barrier coating is contingent upon

1. final predictions on the temperature of the latch plate and capsule clad material (see paragraph "Calculations for Temperature Predictions"),
2. the results of a radiant heat test to determine whether the pressure of helium generated by the decaying isotope will rupture the capsule during re-entry, and
3. the results of compatibility tests to determine whether Haynes-25 and/or the fuel attack the graphite.

Ignition Temperature of Leaking Hypergolic Fluids -- Sandia is conducting tests to determine the ignition temperature of hypergolic fluids striking hot graphite. These tests, to be reported by Aerospace Nuclear Safety Department, 9310, will help NASA determine the temperature to which the cask should be cooled while on the pad.

Secondary Heat Shield -- The pacing item on the cask is the secondary heat shield. GE was authorized to go to two vendors for the engineering hardware; both are having difficulties coating the columbium structure and brazing the silver rings to the coated columbium. GE is supplying technical support to both vendors. The hardware is expected to be available about October 1, 1967.

Low Temperature Release System -- On August 3, 1967, Sandia requested the AEC to give serious consideration to having NASA incorporate a low-temperature release system in the mounting structure for the cask. The goal of the suggested system was to free the cask if its surface temperature reached 1300°F following an abort. (In normal operation the cask surface temperature does not exceed 800°F.) The primary purposes of such a system would be to minimize damage to the cask from local heating amplification caused by the irregularities of the mounting structure and to preclude stabilization in flight.

After continued investigation, however, Sandia estimated that a low-temperature release system would reduce the probability of a fuel release in the melt zone by only about 20 percent. It was agreed that this small improvement did not appear to justify the effort or expense required of NASA to incorporate a low-temperature release system.

Contributions of Consultants -- GE plans to issue the final cask design in October 1967. The Aerospace Nuclear Safety Department, 9310, is reviewing the aerothermodynamic considerations which contributed to the design. The Sandia Materials and Process Department, 1130, is reviewing information on materials properties coming from that testing program. The Engineering Analysis Department, 1540, is checking the structural analysis. The design will be released to production following these reviews.

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Safety

Several meetings were held during the quarter at which Sandia and the AEC reviewed GE's preliminary hazard assessments and the progress and format of the Safety Analysis Report. (See "Technical Direction," Items 9, 13.)

Fuel Capsule

During the quarter, a development program was undertaken both at GE Valley Forge and Mound Laboratory to resolve difficulties encountered in welding the SNAP 27 fuel capsule. Considerable progress was made early in this quarter in the resolution of this problem; Mound had success in performing the liner weld using the present material but new weld fixtures. The backup material, which was to be used in case of a failure in performing the liner weld, was received by GE. The new backup liner heads will be used in the second and subsequent fuelings at Mound since it has been determined that the material does possess somewhat improved qualities, thereby adding to confidence in the integrity of the fuel capsule. An operational walk-through at Mound Laboratory during the week of August 28, 1967, demonstrated the ability of Mound to fabricate the heat source. At GE the development program for welding the center joint of the cladding by electron beam also met with success. The production of prime center section assemblies began in mid-August.

A meeting was held at Mound Laboratory on July 25 to update the fueling specification as a result of the above development programs. Both the updated Mound fueling specification and the GE specification being used in the GE production were approved in a meeting August 1 at GE.

An operational walk-through at GE Vallecitos during the week of August 14, 1967, indicated that their portion of the heat source fabrication was ready to go into operation. Sandia is fabricating a duplicate of the master fuel capsule gage, now at Mound, to maintain the calibration of the final acceptance gage at Vallecitos. Mound will calibrate the new master gage against their own so that differences can be recognized by Vallecitos. By having two master gages in the system, confidence in the calibration of the final acceptance gages will be improved.

Hardware for the first fueling (qualification capsule) and the second fueling (first flight capsule) were shipped to Mound in late August and in September. Fueling of the first SNAP 27 fuel capsule at Mound Laboratory commenced late in September.

Thermoelectric Leg Product Specification (TELPS)

Work was started on the TELPS program in May 1966 by GE in cooperation with the Minnesota Mining and Manufacturing Company. The subcontract ended in August 1967. This test and evaluation program was initiated as part of SNAP 27, Phase II, to develop an authoritative base on which a meaningful product specification could be written for unbonded lead-telluride and lead-tin-telluride thermoelectric legs of the compositions used on the SNAP 27. A draft of the end-item product

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specification was reviewed at the 3-M Company on August 28 and 29, 1967, along with the draft of the final TELPS report. Publication of the product specification as part of the final report, is expected early in October 1967.

Performance Tests

Tables I, II, and III show performance test summaries for the generators, 104-couple modules and 10-couple modules compiled from the latest GE data. Also presented for general interest are: Figure 9, which plots the Model 5 generator assembly total accumulated test time versus normalized power P/P_{BEG} (power measured/power beginning of life); Figure 10 which shows the Model 5 heat input versus power output; and Figure 11 which gives a summary of the 10-couple module data.

The 10-couple modules at the 3-M Company and the 104-couple modules at GE were placed on "warm hold" as a cost saving measure. Performance data are now being taken again but data analysis has not been resumed.

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TABLE I

SNAP 27 Generator Testing
Program Status as of 9/8/67

Mod 5 Test in progress: 8800 hour life test/lunar night cycle
 Power out: 71.8 watts
 Power in: 1500 watts
 Operating parameters: -280°F sink; load voltage 16.0
 Total time in vacuum test: 4260 hours
 Total operation time: 4870 hours

Mod 8B Test in progress: Operational life test/lunar day cycle
 Power out: 65.0 watts
 Power in: 1415 watts
 Operating parameters: 170°F sink; load voltage 16.0
 Total time in vacuum test: 2091 hours
 Total operational time: 2292 hours
 Comments: Mod 8B was removed from test chamber
 and placed in storage pending leak re-
 pair of the thermal shroud of the vacuum
 chamber.

Mod 10 The qualification generator (Mod 10) has successfully passed all qualification level dynamic tests. These are vibration, shock, and acceleration to 1.5 times flight levels. This accomplishment is a major program milestone in that the SNAP 27 is now dynamically qualified for the Apollo mission. Thermal-vacuum life testing is now in progress.

	<u>P_{in}</u> (watt)	<u>Load</u> (ohm)	<u>P_{out}</u> (watt)
First I-V map in air	1450	4.7	71.5
First thermal vacuum point 170°F sink	1505	4.7	70.3

Total time in vacuum test: 1002 hours
Total operating time: 1225 hours

Comments: Mod 10 was removed from the test chamber
 and placed in storage pending leak re-
 pair of the thermal shroud of the vacuum
 chamber.

Mod 13 Test in progress: This unit is undergoing AEC acceptance.
 It is ready for installation of the re-
 sistance temperature detectors, which
 will be followed by dynamic and thermal-
 vacuum acceptance tests.

Mod 19 Test in progress: This unit is undergoing AEC acceptance.
 It is ready for installation of the re-
 sistance temperature detectors, which
 will be followed by dynamic and thermal-
 vacuum acceptance tests.

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TABLE II
Summary of 104-Couple Module Tests

Module	Module Condition	Power (watt)		Last Power 8/1/67 (watt)	Elapsed Time (hr)
		Initial	Maximum		
104B-1	Off design hot junction 1080°/525°F	15.7*	--	15.9	314
104B-2	Efficiency	16.5	17.0	17.0	1178
104B-3	Off design hot junction 1120°F	16.7*	--	--	316
104B-4	Lunar cycle 1100°/525°F 1045°/470°F	14.9*	--	--	300
104B-5	Reduced pressure (16 psi) 1100°/525°F	15.1	--	--	335
104B-6	Shock and vibration	15.7	16.5	16.5	1480
104B-7	Cycle performance	16.2	17.3	17.2	3360
104B-8	Lunar cycle	13.7	16.5	15.5	1796
104B-9	Long term stability	15.1	17.2	17.2	2650
104B-10	Efficiency	15.3	17.5	17.1	2570
104B-11	Off design hot junction 1150°F	17.5*	19.5	18.2	2400
104B-12	Long term stability	16.2	17.5	17.5	2260
104B-13	Shock and vibration cycle performance	16.2	16.9	16.9	1820
104B-14	Off design hot junction 1050°F	16.0*	13.5	13.0	2070
104B-15	High spring pressure	17.1	--	--	310

*At 1100°/525°F, the design hot and cold junction temperatures.

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TABLE III
Summary of 10-Couple Module Tests
as of August 21, 1967

Module	Module Condition	Odd or Even	Power Measured/Power Theoretical			Elapsed Time (hr)
			Initial	Maximum	Latest Reported	
ST10B-1	1100°/525°F	O E	0.965 0.955	0.97 0.975	0.76 0.83	2206 Terminated 2/15/67
ST10B-2	Short term stability 1100°/525°F	O E	0.93 0.98	1.035 1.035	0.93 0.90	10678
ST10C-3	1100°/525°F	O E	0.975 0.945	0.98 0.945	0.83 0.93	1668 Terminated 2/15/67
ST10C-4	Short term stability 1100°/525°F	O E	0.99 0.885	1.035 0.995	0.88 0.91	10491
LT10C-5	Off design hot junction temperature 1130°/525°F	O E	1.025 0.945	1.095 1.093	0.79 0.81	8571
LT10C-6	Off design hot junction temperature 1130°/525°F	O E	0.95 0.95	1.055 1.055	0.83 0.84	8594
LT10C-7	Off design hot junction temperature 1150°/525°F	O E	0.925 0.81	1.035 0.90	1.03 0.89	7993
LT10C-8	Off design hot junction temperature 1150°/525°F	O E	0.98 0.96	1.07 1.055	1.05 1.05	7994
LT10C-9	Off design hot junction temperature 1200°/525°F	O E	1.035 1.05	1.05 1.05	0.76 0.76	7537
LT10C-10	Off design hot junction temperature 1200°/525°F	O E	1.03 1.03	1.09 1.055	0.83 0.83	7208
LT10C-11	Lower gas pressure 16 psi 1100°/525°F	O E	0.9 0.95	1.03 1.025	0.92 0.86	7490
LT10C-12	Lower gas pressure 0.5 psi 1100°/525°F	O E	0.77 0.91	0.80 0.915	0.66 0.60	5850 Terminated 7/67
LT10C-13	Lunar cycle 1100°/525°F 1040°/470°F	O E	0.80 0.82	0.91 0.90	0.89 0.81	5521
LT10C-14	Spring pressure 250 psi 1100°/525°F	O E	1.06 1.02	1.12 1.12	1.12 1.11	4485
LT10C-15	Spring pressure 250 psi 1100°/525°F	O E	0.94 0.72	1.12 0.80	1.12 0.79	4866
LT10C-17	Lunar cycle 1100°/525°F 1040°/470°F	O E	0.99 0.94	1.08 1.06	1.05 1.03	5491
LT10C-18	Off design cold junction temperature 1100°/575°F	O E	0.92 0.95	1.12 1.12	1.05 1.05	5454
LT10C-19	Off design cold junction temperature 1100°/625°F	O E	0.93 0.91	1.10 1.09	1.08 1.04	4485

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$P_{\text{Beg.}} = 73.0 \text{ W for Lunar Night}$
 $P_{\text{Beg.}} = 70.8 \text{ W for Lunar Day}$

@1500 W Input & 16 V Load Voltage

Figure 9. MOD 5 Generator Assembly total accumulated test time

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Figure 11. Summary 10-couple module data

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1.4 SNAP 29

Martin Marietta
AT(29-2)-2062

D. Spatz,	505-264-1159
P. Syroid,	505-264-1159
W. W. Joseph,	505-264-2970
E. F. Johnson,	505-264-2433
D. L. Krenz,	505-264-4041

The SNAP 29 program, initiated by the AEC to satisfy possible mission requirements, was contracted to the Martin Marietta Company in early 1966. Thermal energy from polonium-210 fuel is converted to electrical power by lead-telluride thermoelectric couples. A 90-day mission is to be supported by a multihundred-watt RTG built in a module concept. Water heat pipes are proposed for the heat rejection system. Thermal control is accomplished by an actuator-shutter system to radiate excess thermal energy.

Heat Source

Mound Laboratory is continuing the evaluation of materials and processes to improve the definition of the isotopic heat source. Materials capability testing has been completed at 1000°C and testing at 1200°C is in process. Initial safety testing of fuel release under atmospheric conditions has been run. Significant release of material from the test capsule was observed, but a complete analysis of the mechanisms of the release has not been completed.

Mound Laboratory has furnished typical inert matrices to Martin to include in exploratory impact and drop tests of the fuel block. Mound is proceeding with the design of polonium facilities to handle the estimated quantities of fuel necessary for this size RTG.

Heat Source Structure

Martin is developing a design for a graphite fuel block using ATJ (commercial fine-grained) graphite. Included in the design is a means of retaining the capsule for adequate shock and vibration protection. Present plans are to attach each capsule at its outside end by a flange extension on the cladding material and to use threaded plugs in the graphite. Discussions have been held with Mound on the methods of final oxidation cladding. Preliminary weld development for capsule claddings is in process. Weld and end-cap design for the liners is established. Arrangements are nearly complete for the initial exploratory impact testing of fuel blocks by use of the Sandia water-jet facility and helicopter drops at the Tonopah Test Range. Both of these series of tests are scheduled for the last quarter of 1967. Vibration testing of an assembled inert fuel block is in process with completion scheduled for next quarter.

Heat Source - Electrical

Testing and qualification of the three electrical heaters (TRW, Sanders Nuclear and Watlow) to simulate fueled capsules is under way. Data from vibration tests are being analyzed. Heater assemblies of two different lengths are planned, one for T/E module testing and one for complete RTG testing.

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Thermoelectric (T/E) Modules

The problem of spalling and fracture of 3p legs encountered previously has been resolved by an additional test on a sample basis. Future orders will require the same additional test for acceptance.

The assembly of five 90-couple T/E modules, fabricated to the original cold-end spring and piston configuration, is presently under way. These modules will be tested to verify the couple assemblies and to obtain additional life test data.

One of the recent versions of a T/E module, employing beryllium hot and cold plates with an inert, gas-pressurized diaphragm replacing the springs and pistons, is being fabricated to determine the feasibility of assembly and to verify the design. Considerable thermal advantage can be gained by using this kind of T/E module with heat pipes, since the predicted ΔT losses between the outside of the hot plate and the outside of the cold plate are very low. Additional testing and manufacturing development of T/E couples are also in progress. The interim version of T/E module employing pistons and springs on the hot plate side appears to show little promise because of inadequate high temperature spring materials. An analysis of the system showed excessive ΔT losses.

Heat Rejection System

Major program effort this quarter was expended on the water heat pipes and related problems. With the assistance of Division N5 at LASL, Martin made several evaluation heat pipes of different wick configurations. Each of these was built to a nominal 3/8 inch diameter and 7 foot length. The wick configurations are:

Standard -- Using 40 mesh screen against the ID of the pipe and 200 mesh screen inside of the 40 mesh.

Annulus -- Using 200 mesh stainless screen spaced out from the ID of the pipe by 0.02-inch wire spacers.

Artery -- Using 100 and 200 mesh screen against the ID of the pipe as a wick with a 0.09-inch diameter artery formed out of 200 mesh screen bonded to the wick parallel to the pipe centerline.

Double Artery -- Similar to the artery type but using two 0.09-inch diameter arteries bonded diametrically opposite each other inside of the wick.

Corrugated -- Using 200 mesh screen preformed into small corrugations and inserted against the ID of the pipe.

Hybrid -- Any combination of the above configurations using one type for the evaporator section (about 20 inches long) and another for the condenser (about 6 feet long)--for example, a standard type wick for the evaporator and an annulus wick for the condenser.

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Investigation of possible problems encountered in fabricating and operating heat pipes with relatively large (12 inch) radius bends has begun. Also under investigation is a means of joining heat pipes before charging them, since it may become necessary to fabricate the T/E module with heat pipes in this manner. The tests to date indicate that water heat pipes can satisfactorily handle the estimated thermal load requirement for proper operation of the RTG.

Investigation of the proposed use of heat pipes in fabricating the radiator portion of the RTG is planned, using the experience gained from early efforts on the NAK radiator system.

Thermal Control System

The thermal control shutters, bearings, linkage, and actuator components have all been in various phases of vibration, shock, life, and thermal testing. Adequate data are or will shortly be available to firm up the design for the demonstration RTG.

Safety Studies

Effort is continuing in all phases of safety analysis. Additional aerodynamic tests on fuel blocks of different aspect ratios will be performed to be better able to predict the aerodynamic behavior of a reentering fuel block. Preliminary, exploratory impact tests at velocities from 100 to 200 ft/sec on the Sandia water-jet facility are planned. Drops from altitude at the Tonopah Test Range are also planned to define better the mechanism of impact and the relative critical impact condition. Results from the air drops will be used to reduce the number of impact sled tests needed to verify capsule integrity upon reentry.

The AEC has a contract with Battelle Northwest to investigate a micro-encapsulated polonium fuel form. Success with this type of fuel encapsulation would eliminate a number of safety problems.

Development of the safety criteria for the program is still under way.

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1.5 Voyager Nuclear Power Systems

R. W. Hunke, 505-264-5255

The Voyager Nuclear Power Systems Panel met at Jet Propulsion Laboratories (JPL) on August 29 and 30. Principal items discussed were (a) application of radioisotope heaters to Voyager, (b) status of Voyager RTG studies (integration, power subsystem analyses, nuclear technology and safety analyses, and study schedules), and (c) work completed on Voyager Phase B, Task C.

JPL discussed plans to study the radiation sensitivity of scientific instruments using radioisotopic sources. Action items were accepted by panel members to assist JPL in implementing these tests through source procurement, handling, safety, etc.

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1.6 Large Radioisotope Heat Source System (LHS)

R. W. Hunke, 505-264-5255

This program for the development of a 25-kilowatt thermal radioisotope heat source system, for use with the NASA Lewis Research Center (LeRC) Brayton Cycle Power Conversion System (PCS). The current AEC program authorization calls for a flight-type source system to be delivered to NASA by mid-1971 for ground test and system evaluation. These tests are scheduled to be conducted at the NASA-LeRC Space Propulsion Facility, Plum Brook, Ohio. AEC-sponsored work with Atomics International (AT(04-4)-22) and General Electric (AT(30-1)-3526), and the NASA-LeRC-Oak Ridge National Laboratory Study (Interagency Agreement C-64217-A), "Brayton Cycle Radioisotope Heat Source System Design," provide a conceptual basis for the current activity.

For the AEC's competitive solicitation of proposals for the LHS, a work statement, SC-M-67-695, "Scope of Work: Large Radioisotope Heat Source System," August 1967, has been prepared and distributed for comment to AEC, NASA Headquarters, and LeRC. The work specified encompasses design responsibility of the LHS (isotopic reentry vehicle), component testing, LHS fabrication and test, fueling liaison, delivery to NASA-LeRC for test, participation in ground test and safety analysis, and review throughout the program. A limited activity on analysis of flight application to determine mission-dependent effects on the LHS is included. In preparing this scope of work, liaison was conducted and will be maintained between NASA Headquarters, LeRC, and the NASA Manned Spacecraft Center, Houston.

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2. SPACE ISOTOPE POWER TECHNOLOGY STUDIES

2.1 Compact Converter

Westinghouse
AT(30-1)-3584

W. W. Joseph, 505-264-2970

The Westinghouse converter uses lead-telluride (PbTe) thermocouples to convert thermal energy to electric energy (Figure 12). Alternating washers of p- and n-type lead telluride are electrically connected in series at their hot and cold junctions by iron conductor-rings; the washers are electrically insulated from one another by mica discs. The serpentine current flow is then brought from the module by terminals at each end. Heat is provided at the module bore and extracted from the outer surface.

During this quarter, progress was made in the definition, fabrication, and testing of additional modules in the TEM-9 series. These are designed to explore changes which will result in an improved module by (1) reducing end-closure heat losses, (2) reducing intracouple mica insulator heat losses, (3) improving thermal cycling capability, (4) investigating potential solutions to the 2p/iron conductor degradation problem, (5) increasing module voltage capability, and (6) evaluating an alternate n-type lead telluride which increases processing and operational temperature capability.

Heat pipe analysis efforts have continued, and an initial comparison with in-house-funded test data has been obtained. Heat-pipe/tubular-module integration studies are progressing toward specification of a set of interface requirements.

Figure 12. Tubular module used in Westinghouse compact converter

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The Seebeck probe experiments continue to verify the earlier observations of degradation from iron diffusion at the iron/2p PbTe interface. The most recent capsule tests indicated that a reduction in measured degradation warranted fabrication of a module with tungsten foil inserted between the hot side conductor rings and the 2p material.

Two modules fabricated with 3p lead-tin telluride in the p-leg exhibited superior electrical stability compared with earlier modules using 2p lead telluride. These modules are operating at hot side temperatures of 1000° and 1100°F, respectively. While test time is limited, this experiment indicates that the upper temperature limit for tubular modules has not been reached, and that operation above 1100°F appears feasible.

Construction of the Westinghouse autoclave facility has been resumed.

RCA
AT(30-1)-3582

W. F. Windle, 505-264-4942

The objective of this program is to develop and qualify for space applications a reliable, high-performance, thermoelectric module and other converter hardware for use in 1- to 20-kilowatt (electrical) compact thermoelectric converters, using either radioisotope or reactor heat sources. The RCA converter uses silicon-germanium thermocouples to convert thermal energy to electrical energy. The converter will operate with hot (heat source) and cold (radiator) liquid metal loops. Phase I (July-December 1965) was devoted to generating a reference design of a thermoelectric module which would meet performance requirements and specifications. Phase IIA investigated satisfactory solutions to the major mechanical design problems:

1. Electrical joining of thermoelement to thermoelement,
2. Mechanical joining of thermoelement to heat exchangers,
3. Electrical insulation of thermoelements from metallic portions of structure,
4. Thermal conductivity from hot heat exchanger through thermoelement to cold heat exchanger,
5. Differential expansion of materials between hot and cold heat exchangers caused by thermal gradients, and
6. Compatibility of materials used in solving the above problems.

The main areas of investigation in Phase IIA (January through December 1966) were:

Hot and cold heat exchanger plates--Demonstration of fabrication procedures which are consistent with requirements for liquid metal containment.

Thermoelectric elements--Demonstration of techniques to advance the high-temperature capability of contacts to silicon-germanium alloys.

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Hot and cold stack--Demonstration of solution to the problems of electrical isolation, thermal conduction, and stress relief.

Flexible connector--Demonstration of compliance with thermal and mechanical requirements.

Phase IIB, January 1, 1967, through December 31, 1967, is a continuation of the Phase IIA program and will complete the process and module development. The effort includes evaluation of the effect of process and design variables, satisfactory demonstration of module components, and providing drawings and specifications for the prototype module.

During this quarter, there has been a redirection of the program for the current Phase IIB activity. The fabrication of the 84-couple module has been deleted and the effort on hot junction technology and hot shoe material and bonding problems has been increased. The increased emphasis includes efforts on diffusion barriers, stress isolation, electrical isolation, and contacting materials and processes.

The investigation to determine an acceleration factor applicable to time/temperature characteristics of thermoelement evaluation test programs is continuing. Tests are being conducted at four temperatures, 800°, 835°, 865°, and 900°C, with evaluation after specified times to observe changes in bonds or materials.

Evaluation continues of thermoelements with No. 8826 graphite bonded to p-type silicon-germanium with aluminum added to reduce contact resistance. The void level in the SiGe/graphite interface has been consistently less than 1 percent.

The metallizing of the beryllia insulator by RCA and by the BeO suppliers continues to give inconsistent results. Tests with various metallic inks and application techniques continue at RCA and the suppliers.

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2.2 Thermal Insulation

Three contracts have been awarded for the development of thermal insulation for use in RTG's. Johns Manville will evaluate and develop bulk fibrous insulation materials for use in the 400° to 1800°F temperature range. The Linde Division of Union Carbide will develop vacuum foil insulation systems for use in the 400° to 1800°F temperature range. Thermo Electron Engineering Corporation (TEECO) will develop vacuum foil insulation systems for use in the 1800° to 3100°F temperature range. All three contracts are for an 18-month Phase I period with a Phase II follow-on program under consideration. The Phase I activities started in mid-FY 1966.

Linde
AT(30-1)-3632

H. J. Gay, 505-264-1751

An analytical study was made to determine the effects of air exposure on insulation materials during ground hold conditions typical of radioisotope power systems. Equations were derived to predict the temperature profiles existing in insulation systems during air exposure for a variety of systems. Curves have been prepared to predict the thickness of oxide layers formed on nickel, copper, and aluminum foils as a function of time and temperature during air exposure. Under the conditions of exposure investigated, the predicted thickness of oxide to form on aluminum foil would be negligible. Aluminum foil can be exposed to air with no adverse emissivity effects throughout its temperature range. The possibility of reduction, decomposition, and vaporization of these oxides was explored. The best possibility for the removal of copper and nickel oxides appears to be decomposition. The oxides of copper and nickel would probably decompose if the mission altitude were greater than 250 miles, thus restoring the metallic surface. An equation was developed to predict the effect of oxide formation on foil reflectivity.

An analytical study was made to assess the effect of various edge conditions on the thermal performance of insulation panel segments. The parameters investigated included insulation panel width, gap width between insulation panels, and insulation panel thickness. The most severe degradation of thermal conductivity occurred with short, thick panels having large gaps or angles between panels; under these conditions, the effective panel thermal conductivity can be as much as 10 times that of a panel with zero gap width. If metal-flake-opacified spacers are used to fill the gaps, the worst cases of thermal conductivity degradation were improved so that the thermal conductivity was only 40 percent higher than a similar panel with zero gap.

The Hastelloy-X vacuum enclosure test specimen completed 2000 hours at 1400°F with no leakage. The test was interrupted at the 2000-hour point for examination. The examination of the specimen and material compatibility test samples disclosed no significant changes.

Tensile strength measurements were made on samples of Astroquartz cloth taken from the nickel foil/Astroquartz cloth combination thermal conductivity tests. A decrease in strength with exposure to increased temperature was noted, although all samples were still handleable.

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Thermal conductivity data points were established for the nickel foil/Refrasil quartz fiber paper combination, and approximately 535 hours of the scheduled 2000-hour thermal performance test were completed with no apparent degradation in thermal performance.

Thermal conductivity data were obtained for the copper foil/copper-flake opacified Refrasil quartz fiber paper combination, and about 1600 hours of the scheduled 2000-hour thermal performance test were completed with no apparent thermal performance degradation.

A 2000-hour thermal performance test was completed for the copper foil/Refrasil quartz fiber paper combination at a hot face temperature of 1260°F with no degradation of performance. Following this test, the test apparatus was revised for air exposure experiments by replacing the existing tungsten heater with a nickel-chromium alloy heater. Air exposure testing involves the initial establishment of a vacuum base point thermal conductivity, exposure of the insulation to air at a prescribed time and temperature level, and reevaluation of the thermal conductivity in vacuum at the base point conditions. After air exposure at a hot face temperature of 200°F for 24 hours, the vacuum thermal conductivity of this combination was only 4.2 percent greater than the base point thermal conductivity. Another air exposure experiment at a hot face temperature of 370°F is in progress.

After 517 hours of testing with no thermal performance degradation, a heater failure occurred in the tantalum foil/Astroquartz cloth insulation combination. After replacement of the heater, the calorimeter heat leak increased by a factor of about 2.4 as a result of damage to the insulation during heater repairs. When the testing was resumed, a constant hot face temperature could not be maintained at constant power input. The hot face temperature fluctuated between 1463° and 1590°F. During the next reporting period, the apparatus will be disassembled and carefully examined to determine the cause of the temperature fluctuation.

Johns Manville
AT(30-1)-3633

H. J. Gay, 505-264-1751

The thermal conductivity of Min-K 2002 was determined to be 0.35 and 0.38 Btu-in./hr-ft -°F at 800° and 1000°F mean temperature, respectively. These values are approximately 12 percent lower than the standard Min-K 2000 at the same density. This reflects the initial improvement made in the opacifier early in the program.

Outgassing analysis on Min-K 2002 at 2000 hours indicates that no additional gases were given off by the insulation. Min-K 2002 specimens contained numerous delamination cracks. Evaluation of evacuation rates showed that cracks would occur if the evacuation rate exceeds 1 atmosphere in 45 seconds. The outgassing specimens which cracked had been subjected to many rapid evacuations during the outgassing test. The silicon germanium (SiGe) Seebeck voltage and resistivity compatibility tests showed that Refrasil had no adverse affect on the room temperature property of SiGe elements. Formulation 2020 had no significant affect on SiGe elements.

The thermal stability of Formulation 2020 after 2000 hours of testing is shown in Tables IV, V, and VI.

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TABLE IV

Isothermal Stability of Formulation 2020
at 1800°F in Air and Vacuum

Time (hr)	Environment	Shrinkage (%)		
		Length	Width	Thickness
476	air	1.0	1.2	9.6
	vacuum	0.9	1.1	7.5
1027	air	1.7	2.0	13.2
	vacuum	1.3	1.5	9.1
1500	air	2.6	3.0	17.9
	vacuum	1.6	1.9	10.5
2000	air	3.6	4.1	20.5
	vacuum	1.8	2.2	11.4

TABLE V

Isothermal Stability of Formulation 2020
at 1600°F in Air and Vacuum

Time (hr)	Environment	Shrinkage (%)		
		Length	Width	Thickness
500	air	0.0	0.2	1.6
	vacuum	0.0	0.1	1.2
1000	air	0.1	0.3	2.1
	vacuum	0.1	0.2	1.5
1500	air	0.1	0.3	2.3
	vacuum	0.1	0.2	1.5

TABLE VI

Thermal Stability of Formulation 2020 in Air
at 1800°F Hot Face Temperature

Time (hr)	Shrinkage (%)		
	Length	Width	Thickness
500	0.1	0.1	0.6
1000	0.2	0.2	1.4
1500	0.1	0.1	1.4

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TEEC
AT(30-1)-3634

H. J. Gay, 505-264-1751

All of the Phase I work has been completed and a rough draft of the final Phase I report distributed for review.

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2.3 Theoretical-Density Integrally Bonded Thermoelements Study

Tyco
AT(30-1)-3605

G. H. Whiting, 505-264-4942

The purpose of this contract is to perfect a process for the preparation of improved thermoelectric elements based on lead-telluride alloys and to demonstrate the advantages of these elements over those currently available. The major innovation is an ultrasonic casting technique, the feasibility of which has been demonstrated by Tyco with support from the Bureau of Ships. This technique has been shown to produce a homogeneous, theoretically dense material of fine grain which appears to have increased mechanical strength and ductility compared with commercially available thermoelements. The improved strength of the elements is also expected to make it more feasible to attach metallurgically bonded electrodes to the elements.

During this quarter Tyco continued to evaluate the strength of the ultrasonically cast lead telluride at high temperatures and to analyze the three modules that failed during life test. Strength evaluation shows the p-type material to retain a brittle nature throughout the temperature range of interest. Comparison of the stress-strain relations for p- and n-type materials demonstrates the difference in ductility of the two materials. In the elastic range the n-type material exhibits a greater deformation than the p-type material for a given stress. In the plastic range for the same deformation the p-type material sustains higher stress.

Analyses of the three modules removed from life test showed a pronounced attack on the Fe electrodes on the hot side of the elements. The major source of degradation experienced by the modules is the oxidation of the hot junction electrodes. It was suggested by Tyco that the excessive attack was due to voids formed near the electrode during the brazing operation, which led to increased penetration of oxygen to the inner surface of the electrode.

The termination date for this contract was extended from August 31 to October 31 because of a change in Task II-3 of the contract. Ultrasonically cast 3n and 3p material will now be furnished to Sandia in place of the 2-couple modules originally required by the contract.

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2.4 Heat Pipe Development

RCA
AT(30-1)-3507

G. H. Whiting, 505-264-4942

The over-all objective of this contract is the development of a reliable, long-life, constant-temperature heat source for advanced power systems employing radioisotopes. The initial phase of the contract started January 1965 with the objectives of determining (1) the thermal stability of heat pipe assemblies over long periods of time, (2) the effectiveness of the inert-gas reservoir as a power-flattening device, and (3) the ability of such assemblies to withstand simulated launch conditions.

During this reporting period the posttest analyses continued on heat pipes 3 and 5; heat pipe 2 was removed from test after successfully completing 10,140 hours. Heat pipe 4 continues on test and has successfully completed 11,303 hours.

The posttest examination of heat pipe 5 was completed with no indication of mass transport. A black powdery material (later analyzed as KHCO_3) was found in the evaporator region over an area 1/8-inch wide by 4 inches long. The wick was attacked severely by this material but was still intact when disassembled and apparently still functioning.

The posttest examination of heat pipe 3 is nearly completed. The KHCO_3 was again found in its evaporator section but between the wick and the case. No attack on wick or case was reported.

During this period, approval was sought and received to extend the life test of heat pipe 4 to 20,000 hours.

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2.5 Thermoelectric Modules

RCA
AT(30-1)-3484

W. F. Windle, 505-264-4942

The objective of this contract was to develop and test cascaded SiGe-PbTe thermoelectric modules and to continue life testing of SNAP 17A SiGe, Air-Vac modules. The cascade work showed the feasibility of cascading SiGe (Air-Vac) with PbTe (sealed-module) thermoelectrics. The efficiency gains and power-to-weight ratios for such a system are discussed in the final report on the contract (dated June 1966).

The life test portion of the contract is to continue through February 28, 1969. The SNAP 17A-type modules continuing on life test are four 6-couple modules (in vacuum) and one 14-couple module (in air) with hot junction temperatures from 825° to 950°C and cold junction temperatures from 200° to 300°C. These modules have accumulated times on test ranging from 23,000 to 27,000 hours and presently are operating at 90 to 98 percent of their respective 500-hour power levels.

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2.6 Spherical Capsule Program

Hittman
AT(29-2)-2072

I. G. Waddoups, 505-264-4107

The objective of this program is to develop a spherical fuel capsule. The program consists of making analytical predictions of the capsule's bursting pressure, creep life, and impact survival against a granite target at the calculated impact velocity from ascent abort trajectory. These predictions are to be made as a function of the capsule radius, wall thickness, fuel loading, and operating temperature over the range of 1200° to 1800°F for two types of liner material. The liner materials are Haynes-25 superalloy and Ta-10W refractory metal.

Aerodynamic studies will also be performed to obtain terminal velocities and reentry heating conditions for capsules of various weights and diameters. The capsule is designed for reentry burning and fuel dispersal.

Haynes-25/Haynes-25 capsules which had not been aged showed no indication of failure when impacted against granite in the velocity range of 360 to 560 feet per second with the capsule temperature at a nominal 500°F. Nonaged Haynes-25/Ta-10W capsules impacted against granite in the velocity range of 360 to 460 with the capsule at nominal 500°F showed no indication of failure.

Haynes-25/Haynes-25 capsules aged at 1500°F for 1000 hours were impacted against granite as follows:

<u>Capsule Number</u>	<u>Impact Velocity (ft/sec)</u>	<u>Impact Temperature (°F)</u>	<u>Result</u>
PR-8	606	520	Failed
PR-9	374	500	Failed
PR-12	304	500	Inner liner failed, outer shell did not fail
PR-11	340	500	Failed

Haynes-25/Ta-10W capsules aged at 1800°F for 1000 hours were impacted against granite as follows:

<u>Capsule Number</u>	<u>Impact Velocity (ft/sec)</u>	<u>Impact Temperature (°F)</u>	<u>Result</u>
PR-110	470	490	Failed
PR-112	356	500	Failed
PR-111	337	500	Failed

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A Haynes-25 shell, creep tested at Westinghouse, reached 1 percent strain at 432 hours. The predicted creep was 1 percent strain at 500 hours, based on wall thickness of 0.034 inch and outside diameter of 2.005 inches. The capsule failed in the heat-affected area of the weld at about 500 hours. The creep at that time was 2-1/2 percent strain.

The contract has been modified to make a parametric study of an optimum spherical capsule design for a given application, and to make an analytical comparison of this capsule with other capsule shapes and designs. This program is in the early stages of study.

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2.7 Lightweight Thermoelectric Generator

General Atomic
AT(29-2)-2241

H. J. Gerwin, 505-264-1751

The principal objective of the ISOTEC program is to develop lightweight, long-life, reliable, bonded lead-telluride thermoelectric converter designs for general application to space missions. AEC funding of the General Atomic thermoelectric program began in April 1963.

The basic design employs 2n and 3p material supplied by 3M, which is pressed and sintered to 0.165-inch-long elements. Nickel end caps are bonded to the n-elements and iron end caps are bonded to the p-elements. Thin silver conductors are welded to these caps for heat collectors and radiators. Vacuum insulation is used in this unsealed system which operates at a hot junction temperature of 400°C.

The 450° and 500°C accelerated testing program is continuing; however, no conclusive results are yet available. Lifetimes of the n-element hot junction bonds are erratic. Consequently, most of the elements currently fabricated for testing have been isothermally aged to improve the stability of the metal phases formed during bonding. Trace impurities in the nickel cap have been identified as to their effect on the bond reaction and as-bonded strengths. Manganese, in the nickel cap, has improved both the bond reaction and strength so that new modules going on test will be used to measure the effect on lifetime in gradient conditions at 450° and 500°C hot junctions.

A design review for a 30-watt converter was held on September 8 at Sandia. Thermal analyses using view factor and temperature distribution plotting codes had been performed on two converter configurations--with cylindrical and spherical heat sources; these different shapes had little effect on junction temperature distribution. The decision was made to develop a flat octagonal converter configuration with identical 14 x 5.5 inch panels on the sides and on the top and bottom planes. Trapezoidal areas of the top and bottom planes will not have thermoelectrics; however, the calculated power (beginning-of-life) is 30 watts with an efficiency of 4.25 percent at junction temperatures of 145° and 400°C. New tooling must be ordered and parts fabricated for the first converter, to be tested about April 1968.

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2.8 Large Radioisotope Heat Source Capsule (LRHSC)

Atomics International
AT(29-2)-2338

J. Jacobs, 505-264-3762

The over-all goal of the LRHSC program is to develop, in part, the technology required reliably to design radioisotope capsules capable of operating in the space environment for extended periods of time at temperatures of approximately 2000°F. The program includes processing development and the generation of engineering materials data required to attain the main objective. Additionally, the data obtained from the program will be used to verify the currently used design approaches, to determine the applicability of materials data derived from tab and coupon tests, and to define the design margins which would exist for high-temperature capsules intended for flight systems.

A contract for the LRHSC program has been awarded to Atomics International (AI). A letter contract was initiated for 90 days to allow more time to negotiate the definitive contract. The program manager at AI is Mr. W. V. Botts.

The scope-of-work for the definitive contract has been completed. The work for FY68 was curtailed somewhat because of the limitation on funds available.

The design of the reference capsule has been completed and approved. The drawings defining this capsule were released on August 15, 1967, which was the first planned milestone date. The design of the reference capsule is shown in Figures 13 and 14.

Figure 13. LRHSC structural assembly

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Figure 14. LRHSC fueled subassembly

The required material specifications have been written, reviewed, and approved. The total material requirements for the program have been determined. AEC/SAO will procure the platinum and rhodium and supply the material to AI as government-furnished material. Only the cost of fabricating the Pt-Rh alloy will be charged to the program. The complete program requirements for tantalum alloys will be purchased this year to get the desired number of heats of material. National Research Corporation, the low bidder, was selected to supply the tantalum alloys.

Design of the fabrication tooling for the reference design has been initiated. Alternate techniques for fabricating the structural shell are being investigated.

The coating development program on the alumina coating has been initiated. Both chemical vapor deposition and plasma-sprayed coatings are being investigated.

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2.9 Thermionic Research Program

E. L. Burgess, 505-264-2178

The purpose of this program is to investigate, experimentally, the adsorption of various alkali and alkaline-earth vapors on different substrated materials. The program consists of measuring the change in work function of the substrate as a function of the adsorbate vapor pressure, the degree of coverage of the substrate by the adsorbate, and the substrate surface temperature. In order to check the validity of the measuring technique, the well known tungsten-cesium system was chosen for initial studies.

The tube to be used in the adsorption studies was received the first of September. (Delivery had been expected in early July; the delay was due to some fabrication problems.) When the tube was connected to the vacuum system for processing, a leak was detected at one of the electrodes. This leak has been repaired and a vacuum of approximately 5×10^{-8} torr obtained.

The work function of the bare tungsten filament will be measured before the cesium is distilled into the tube. To measure the work function accurately, it is necessary to know the surface temperature to a high degree of accuracy. Since the filament is only 5-mils diameter, it is not possible to use a thermocouple, and an optical pyrometer cannot be used because the filament is not visible in the test configuration. The temperature will be calculated from the known filament current. A mockup of the test configuration was constructed with a small viewing hole for an optical pyrometer and the temperature of the filament in this simulated test was measured as a function of filament current. These measurements agreed with the calculated temperatures within a few percent. It is felt that temperature can be measured by this scheme accurately enough to yield good work function measurements; however, careful error analysis will be performed.

2.10 Thermoelectric Research

J. A. Corll, 505-264-6923

In the temperature range for efficient thermoelectric energy conversion devices, the accurate measurement of thermal conductivity by conventional techniques is hindered by two inherent features: radiation losses and the inaccuracies associated with a temperature difference measurement. The fourth order temperature dependence of thermal radiation renders the heat flow equations insoluble for most geometries. Conventional techniques attempt to overcome this difficulty by shielding the sample with matching temperatures to minimize radiation losses. Although not so evidently a source of error, the accurate measurement of temperature differences by conventional techniques may be even more difficult. In most arrangements two thermocouples are involved, one at the higher temperature (T_H) and one at the lower temperature (T_C). A 0.1 percent uncertainty in the calibration of these thermocouples at 800°K will introduce an 8 percent uncertainty in measurement of a 20°K temperature difference ($T_H - T_C$). This uncertainty does not include the perturbation introduced by the attachment and presence of the thermocouples.

It is believed that the apparatus and techniques presently being developed will circumvent both of these major difficulties and permit more accurate measurements of thermal conductivity above 700°K. Instead of trying to minimize the radiation losses the inherent radiation is used as part of the desired heat flow, resulting in the determination of the surface emissivity as a by-product of the conductivity measurement. Furthermore, only one thermocouple is used and, to minimize the uncertainty in temperature difference determination and eliminate perturbations, it is not attached to the samples.

The apparatus consists of an arrangement of axial heating of a right circular cylinder sample whose length is long compared to its diameter. The heat flow is radial from the axial heater, through the sample to the outer surface of the sample where it radiates to the walls of the chamber. The chamber is evacuated to eliminate heat conduction and/or convection and the walls are kept at 77°K by a surrounding liquid nitrogen bath. The single thermocouple is mounted on the axis, inside the heater.

Since the sample is long compared to its diameter and symmetric about the center plane, the heat flow will be strictly radial in the center plane and the temperature of the inner surface of the sample will be at the temperature of the thermocouple when steady state conditions are reached. In the center plane, the amount of heat flowing through the sample per unit length will be equal to the power generated by the heater per unit length. The heat radiated by the outer surface of the sample per unit area is a function of temperature only and the heat flowing in the center plane is transferred to the walls of the chamber solely by radiation.

By recording the power generated in the heater versus the temperature of the thermocouple for steady state heat flow and a given diameter of the sample, and then reducing the diameter of the sample and repeating these measurements, sufficient information is obtained to solve for the thermal conductivity and emissivity as a function of temperature.

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The design and acquisition of the major components of this apparatus and the supporting monitoring devices were completed during this quarter. The many minor modifications associated with a new device are being made and techniques developed for the sample-heater-thermocouple fabrication and assembly.

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Attn: G. A. Newby, Asst. Director
Space Nuclear Systems,
SEPO

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Director of Space Nuclear Systems
Space Electric Power Office
Washington, D.C. 20545
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Washington, D.C. 20545
Attn: W. A. Yingling

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