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February 1969

AEC RESEARCH AND
DEVELOPMENT REPORT

QUARTERLY REPORT
SPACE ISOTOPE POWER PROGRAM (U)
October-December 1968

Space Isotope Power Department 9520

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SYSTEMS FOR NUCLEAR
AUXILIARY POWER (SNAP) -
ISOTOPIC SNAP PROGRAM C-92a
M-3679 (60th Ed.)

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QUARTERLY REPORT
SPACE ISOTOPE POWER PROGRAM (U)
October-December 1968

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February 1969

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SUMMARY

SNAP 19

Two SNAP 19 generators with increased fuel loading and 2N/3P thermoelectric material have been assembled and tested by the Isotopes Nuclear Division (formerly Martin Marietta). The generators are planned for the Nimbus B-II to be launched in the spring of 1969.

SNAP 27

Program material delivery is nearly complete. The fuel capsule assembly (FCA) fabrication has been completed. After a few remaining fit checks with the generators and GLFC's, the capsules will be stored at Mound Laboratory. The GLFC and FCA which will be flown on the Apollo 10 mission have been tested at qualification and flight environmental levels and satisfactorily passed those tests.

The SNAP 27 system has been reviewed by many representatives of several agencies for the Safety Evaluation Report which the Space Council uses as the basis of its recommendation whether to fly the mission. Several additional tests were completed and the information used to supplement the GE safety report which was completed during the last quarter.

SNAP 29

The SNAP 29 program is being revised by Isotopes Nuclear Division. Authorization was given to build T/E modules with TAGS material for better evaluation of its performance. The demonstration model for December 1969 will be electrically heated; the isotope-fueled model will be available about six months later. Difficulties in producing early models of subsystems has led to several redesigns and variations in processes for manufacturing. A task force was established to report on the feasibility of a burnup design for the isotope heat source. Such a design is believed feasible and the schedule for development might be shorter than for the intact reentry design.

Transit (formerly NAVSAT)

Currently the Navy is planning that this satellite be an improved version of the present Transit system. A Phase I contract has been awarded to TRW to study and recommend an RTG design in 20 weeks. Phase II for development is planned to follow the present contract effort immediately.

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Advanced Development

GGA has demonstrated a life on their mechanical and metallurgical (M&M) bond of over 5000 hours at 500°C. A thermal analysis of the M&M bond indicates that, after failure of the n-type metallurgical bond, the couple output is still about 80 percent of the output before failure.

Hittman's reference capsule design for the Transit program is about 8 inches in diameter and weighs about 10 pounds. Capsule vibration tests are being conducted to the Transit specification; tests to date indicate that the capsule will survive this environment.

On the LRHSC program the first production run of deep-drawn T-111 structural shells was completed; 17 good shells resulted from 18 starting blanks. An additional drawing stage was added to the process to reduce shell thickness to 0.09 inch and 4 of these thinner shells were successfully drawn.

For the Lightweight Capsule program at GGA, a nominal 8-inch-OD capsule has been designed and fabrication procedures are nearly complete. Materials tests are continuing and results to date indicate that the tantalum substrates retain their original ductility through the coating process.

Life testing of the SiGe reference converter at RCA is continuing and, after more than 3690 hours of operation, there is no detectable change in its power output. The computer program for analysis of cascading was rewritten to include transverse heat flow.

At Linde the copper-opacified-quartz system has been operating continuously for about 9300 hours with no apparent change in thermal conductivity.

The attempt to develop a 2200°F bulk insulation at Johns-Manville was unsuccessful and has been discontinued. However, useful information was acquired on the sintering and reactions of powdered Al_2O_3 with various opacifiers.

At TECO the Ta/ ThO_2 samples deteriorated badly after 100-hour tests at 1800°C. The W/ ThO_2 portions of these test samples survived and will therefore be used in the 10,000-hour test.

The four-station TELPS stand and its instrument rack are presently being modified to be used for tests at Sandia.

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1. SPACE ISOTOPE POWER SYSTEM PROJECTS

1.1 SNAP 19

Isotopes
AT(30-1)-3607

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A SNAP 19 power system composed of two "30-watt," 2.7-volt generators mounted end-to-end has been delivered by Isotopes for use on the Nimbus B-II satellite. With this power input the power conditioner (developed by Martin under a previous contract) is expected to deliver about 50 watts of conditioned power at launch and about 46 watts after 1 year in earth orbit.

Compared to the system which was destroyed when the booster malfunctioned during the first launch, this system is modified by two changes--for increased end-of-life power and to lower the rate by which electrical power decreases with time. First, the fuel loading was increased from 570 to 625 thermal watts per generator even though the same vented metallic fuel capsule was used. Second, the thermoelectric material was changed from 2N/2P to 2N/3P.

The Nimbus B-II is scheduled to be launched about April 1.

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1.2 SNAP 27

General Electric
AT(29-2)-2581

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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 (w/o fuel)
Fuel capsule assembly	14.8
Graphite LM fuel cask	25.7
Flight handling tool	0.6

In addition, the SNAP 27 program includes the design and fabrication of ground shipping containers, ground handling tools, electric fuel-capsule simulators, test equipment, and mockups. The prime contractor for the SNAP 27 is the Isotope Power Systems Organization (IPSO), Missile and Space Division, General Electric Company, Valley Forge, Pennsylvania.

The generator assembly, without fuel, will be transported to the moon 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, an astronaut will extract the FCA from the GLFC, using the flight handling tool, and insert the capsule in the generator. He will then deploy the ALSEP system with the SNAP 27 on the lunar surface.

The SNAP 27 program end items, including many items of ground support and checkout equipment in addition to the flight hardware, are tabulated in Table I.

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TABLE I
SNAP 27 Program Hardware

End Item	Use and Quantities		
	Prime Hard- ware	Qualifi- cation Hardware	Mockups and Train- ing Hdwe.
Generator assembly (GA)	5	1	9
GA shipping container	6	1	0
Fuel capsule assembly	5	1	9
Graphite LM fuel cask	5	2	6
Flight handling tool (FHT)	7	1	4
FHT shipping container	6	1	0
Ground handling tool	7	2	0
Electric fuel-capsule simulator	6	0	0
Integrated power unit (IPU) test console	0	2	0
IPU test panels	3 sets	0	0
Spacecraft LM adapter (SLA) transfer cask	5	1	0
SLA handling tool	5	0	0
Port entry trough	2	0	0
Inspection tool	2	0	0
Tether	8	0	0
Ground shipping cask	5	1	1

In addition to the above requirements for hardware, the following milestones are scheduled:

Milestone	Target Date	Complete
First fueling of capsule at Mound performed	September 1967	x
Complete selection of vendors for graphite parts for GLFC	September 1967	x
First flight unit generator (Mod 19) component accepted by AEC	October 1967	x
Auxiliary equipment for first flight unit (Mod 19) component accepted by AEC	November 1967	x
Last flight unit generator component accepted by AEC	February 1968	x

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First complete flight and backup generators delivered to NASA (without GLFC and fuel capsule)	April 1968	x
First fueled capsule transferred to AEC/NASA ALSEP cask assembly acceptance testing program	June 1968	
First qualification cask assembled at GE	June 1968	x
Final Safety Analysis Report (SAR) submitted to AEC	July 1968	x
Last graphite cask assembled at GE	August 1968	
Last generator and flight handling tool delivered to NASA	August 1968	
Addendum to SAR submitted to AEC	September 1968	x
Last graphite cask transferred to AEC/NASA ALSEP cask assembly acceptance testing program	November 1968	
Last fuel capsule transferred to AEC/NASA ALSEP cask assembly acceptance testing program	November 1968	

Fuel-capsule activities at Mound Laboratory ended during this quarter. FCA No. 7 was shipped to GE Vallecitos on September 27, 1968, and the metallography of FCA No. 3 was completed during November.

FCA No. 7 was added to the program when it was decided last quarter that FCA No. 3 should be returned to Mound for destructive analysis. The processing of FCA No. 7 at GE Vallecitos was completed and it arrived at GE Valley Forge October 15. This completed the fabrication of SNAP 27 fuel capsules.

Metallography of FCA No. 3 was undertaken to learn whether the nondestructive ultrasonic inspection indicated a deviation from welding specifications or, if the capsule welds met specifications, what was the source of the ultrasonic signals?

The metallographic test plan was reviewed in a meeting at Mound early in the quarter and it was approved shortly thereafter. As part of the plan, Sandia obtained three welded sections for metallographic examination. In general, the findings by both Mound and Sandia were that the discrepancies in FCA No. 3 would not cause the capsule to be rejected per welding specifications. Additional confidence is thereby established in the structural integrity of all the other capsules, since their ultrasonic inspections revealed considerably less severe signals.

In a few of Mound's metallographic sections, intergranular microfissures in the heat-affected zone were identified in the as-polished condition. These might have been the cause for the ultrasonic signals. Sandia also found microfissures in the heat-affected zone in all three of its sample sections. The AEC decided that, since an out-of-spec

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condition had not been identified, the application of more sophisticated techniques by Mound to determine the source of ultrasonic signals should more properly be pursued as an R&D effort.

GE Vallecitos, with the processing of FCA No. 7, completed their work on the SNAP 27 program. Their plasma-coating facility will be left intact until all AEC/NASA combined dynamic testing is completed next April.

FCA No. 2, the flight-backup fuel capsule, was found to have a defective back plate. In spite of the fact that the capsule had earlier passed its generator fit checks, it failed to latch in four of four GLFC's tried. During the week of December 2, the back plate was changed; this change means fit checks with its assigned generators and GLFC's will have to be repeated.

Except for a few other system fit checks between FCA's and generators and GLFC's, the capsules will all be ready for storage at Mound Laboratory after their dynamic acceptance testing.

KSC Support Operations

The responsibility for loading the SNAP 27 FCA aboard the Apollo Saturn V launch vehicle has been assigned to Sandia by the AEC. This entails providing a storage facility for FCA's at Cape Kennedy, fit-checking the FCA with the GLFC and a simulated generator just before loading, loading of the FCA into the GLFC during the launch countdown, and off-loading the FCA in the event a launch is scrubbed.

In this report period hardware and mockups have been assembled at Sandia, to facilitate training of the Sandia loading team, and two procedural documents have been written:

- SM SN27-1 Operational Procedures for SNAP 27 Fuel Capsule Assembly at Cape Kennedy Air Force Station and Kennedy Space Center, 15 November 1968
- SM SN27-1A Receiving Inspection Procedures for SNAP 27 Graphite LM Fuel Cask and SNAP 27 Fuel Capsule Ground Support Equipment, 2 December 1968

Graphite LM Fuel Cask (GLFC)

Purpose and Description

The GLFC has two purposes: It carries the FCA to the moon on the outside of the LM where the FCA can be retrieved for insertion into the generator. Also, in the event of an abort it protects the FCA from the abort environment (explosion, fireball, reentry, etc.) to assure containment of the plutonium dioxide fuel.

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The GLFC comprises two heat shields (see Figure 3 under Drop Test). The primary or outer thermal shield is made of Pyrocarb 406; during normal operation it rejects the heat generated by the FCA, and during reentry following an abort it provides protection against the thermal, ablation, and dynamic force environments. The inner shield is a hollow cylinder of beryllium with walls about 1/2-inch thick; the beryllium is coated with silver, gold, rhodium and Radifrax (an emissivity coating). During normal operation it transmits the heat from the FCA to the outer shield. In an abort, it performs one of two functions, depending on the nature of the abort: In an on-pad explosion it protects the FCA from the heat, fragments, blast impulse, and blast overpressure associated with the explosion; in an abort reentry this shield acts as a thermal capacitance which absorbs the reentry heat to prevent its reaching the FCA.

GLFC Hardware Delivery

M-5 GLFC -- The M-5 mockup cask is part of the SNAP 27 M-5 system which is presently scheduled for use on the LM4 on the Apollo 10 mission (for which no moon landing is planned); the LM4 will be abandoned in orbit, so simulated fuel will be carried and no nuclear safety problems are involved. The M-5 GLFC differs from prime hardware mainly in that the secondary thermal shield is of aluminum instead of beryllium.

All testing of the M-5 qualification unit has been completed. On November 20, NASA, Bendix, GE, AEC, and Sandia completed the Customer Acceptance Review (CAR). The M-5 flight unit with its components also met requirements and the CAR for the flight system was completed on December 3.

Three problems were encountered on the M-5 units during testing. Two of these were associated with the splines--devices inserted between dome and cylinder to prevent rotation of the dome after the mounting structure has burned off during reentry.

The aft spline, which projects about two inches from the GLFC at the top, was bent by the weight of the lanyard. The lanyard had initially been supported as shown in Figure 1 but, at the request of the astronauts, its center loop was later attached to the spline so the astronauts could use the lanyard for tilting the cask and removing this spline. To correct the problem, the AEC initiated design action for a device to support the weight of the lanyard.

The forward spline backed out of its hole (about 1 inch of its 4-inch length). A small amount of cement was applied to hold the spline in place, and similar action will be taken on the flight units.

The forward capsule support moved. Improved procedures for assembling this support were devised and used to correct both the M-5 units and the flight qualification and flight units.

Flight GLFC's -- The flight qualification test unit and three flight GLFC's have been assembled and accepted by Sandia Quality Assurance. The major problem encountered with these units was getting good adherence of the coatings on the secondary thermal shield (Figure 2).

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Figure 1.
SNAP 27 GLFC with FCA
assembled to the Bendix
support structure

Figure 2. SNAP 27 secondary thermal shield

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Poor adherence of the rhodium was cured by adding a gold flash between the silver flash and the rhodium plating, and by controlling the age of the rhodium-plating bath. Peeling of the Radifrax was minimized both by the improvement in the rhodium-plating procedure and by installing an automated control for the Radifrax spraying.

A Qualification Test Readiness Review (QTRR) for the qualification test and a Flight Test Readiness Review (FTRR) for the flight acceptance testing was held at GE during the week of December 2. Sandia, AEC, GE, Bendix, and NASA participated. The results of the QTRR and FTRR assured the agencies concerned that system testing of the FCA, GLFC, and support structure was ready to begin. Qualification testing began December 4 with weight and center of gravity determination and is expected to be completed about the end of February 1969.

Safety Program

Description

The purpose of the safety program is to identify all hazards associated with the use of nuclear fuel in the SNAP 27, to assess the magnitude of the hazards, and to prepare a report on the results of the program. This Safety Report consists of three parts:

The Reference Design Document describes the SNAP 27, the equipment with which it has an interface and the uses to which it will be put.

The Accident Model Document describes the various accidents (aborts, explosions, handling) which could happen to the SNAP 27, the probability of such accidents, and the form and estimated amount of fuel released.

The Safety Analyses Report describes how various amounts and forms (source terms) of released fuel could affect human life.

The Safety Report is distributed to interested government agencies including the AEC, DOD, NASA, and HEW. The opinions of these agencies are solicited and, with a combined Safety Evaluation Report, are considered by the Space Council when deciding whether to recommend to the President that the SNAP 27 is safe to fly.

The Safety Report was issued by GE on July 24, 1968. It is being supplemented by several additional documents which do the following:

1. Describe the results of additional reentry analyses. This document, entitled "Supplement No. 1 to SNAP 27 Safety Report, Volume II Accident Model Document, Appendix P," was issued by GE on September 16.
2. Describe the results of fragmentation tests. The tests have been finished and the report is being prepared by GE.

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3. Describe the results of impacting an FCA, with simulated fuel, against granite at 400 feet per second. This test has been completed and the report is being prepared by GE.
4. Describe the results of impacting an FCA into earth at free-fall terminal velocity. This test was completed at Sandia's Tonopah Test Range and a posttest examination of the FCA is in progress at GE. A report on the test will be issued by Sandia.
5. Describe the results of an explosive test. The test has been completed. A report will be issued by Sandia following posttest examination of the material.
6. Amend the source terms and probabilities in the July 24 Safety Report on the basis of information received between July 24 and September 15. This includes event-probability figures from NASA in a document issued September 15.
7. Amend the source-term-and-probabilities document issued September 15 on the basis of new data generated between that date and the completion of the explosive test. These include results of fragmentation, drop, impact, and explosive tests. The document will be issued when the full results of the tests are available.

GLFC/FCA Drop Test

The plan for the drop test was jointly prepared by Sandia and GE. The test article consisted of a flight-model GLFC with an FCA containing simulated fuel and helium at a pressure of 1 atmosphere at 70°F.

Five dummy GLFC's and one engineering evaluation GLFC/FCA were drop tested at the Tonopah Test Range (TTR). The primary objective was to obtain an assessment of FCA damage in a probable impact situation while contained in the GLFC. Secondary objectives were to determine impact velocity and to determine if the subsonic flight characteristics were such that the assembly would assume a particular orientation.

All the drops were made from a C-47 aircraft at an altitude about 12,000 feet above the terrain. The GLFC/FCA was heated, to simulate the reentry heating prediction, and dropped while at a temperature of about 1900°F. Free-fall flight was predominantly in a tumbling mode. Impact was in extremely hard soil and impact velocity for the TTR altitude was determined to be about 295 ft/sec.

Visual examination of the assembly after the test showed delamination of the graphite cylinder and cracking of the beryllium heat shield, but no rupture of the FCA at the center section. Cracks in the capsule did occur at the designed rupture point and in the thin cylindrical section of the backplate mounting flange. No visible rupture of the liners which contain the fuel was observed and there was no loss of the simulated fuel.

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The damage is depicted by Figures 3, 4, 5 and 6. Figure 3 is a cutaway view of the GLFC/FCA with critical parts and instrumentation designated. The thermocouples were used to determine that the assembly was at the proper temperature at the time that it left the C-47. Figure 4 shows the assembly immediately following impact. The GLFC had impacted on its forward dome at an angle of about 25 degrees to the horizontal. The aft dome, not shown in the picture, had separated and was found about 15 feet away. Figure 5 shows the assembly after it had been rotated about 180 degrees from the impact position; breakage and delamination of the graphite is apparent. Figure 6 shows the component parts after disassembly. The only detected damage to the FCA was a crack at the midsection which is designed to be weaker to provide a preferred location which can be burst by helium pressure; the liners which contain the fuel contain filters to permit passage of helium but not fuel to the weak area. Post-mortem of the FCA is in process to determine if damage to the liners occurred.

Figure 3. SNAP 27 GLFC/FCA instrumented for drop test

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Figure 4. SNAP 27 GLFC/FCA following impact from air drop test

Figure 5. SNAP 27 GLFC/FCA rotated 180° to show damage from drop test

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Figure 6. SNAP 27 GLFC/FCA disassembled following air drop test

GLFC/FCA/Support Structure Explosive Test

The effect on the GLFC/FCA assembly of forces generated by an explosion of components of the Saturn V is under investigation. The results of tests to evaluate the effect of fragments were reported in the last quarterly report.

A test to evaluate the effects of explosive overpressure and impulse was conducted at the Sandia shock-tube facility on December 5. The test was jointly planned by Sandia and GE.

The test article consisted of the prototype Bendix support structure, with a pressure plate added to make it equivalent to the flight model; a flight-model GLFC; and an FCA which contained a simulated fuel and had an axial hole bored in it from the aft end to accommodate a Globar heater. The FCA was heated to a temperature of 1300°F until 10 minutes before the test, at which time the power to the heater was cut off.

The test was planned for a static pressure of 600 psig with an impulse of 2.2 psig-seconds. These conditions simulate an explosion of the SIVB with a yield of 25 percent. Estimates of explosive yields as prepared by Sandia (Figure 7) indicate that the probability of a 25 percent yield is low, but that figure was suggested by the Range Safety subpanel of the Interagency Safety Review Panel. The explosion is located on the center line of the SIVB at a distance of 37 feet from the GLFC/FCA. The tank partition which separates the hydrogen from the oxygen is located 43 feet from the GLFC. Actual test conditions were 680 psig and 2.7 psig-seconds.

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Figure 7. Estimates of explosive yields for the SIVB stage as prepared by Sandia

The explosion broke the Bendix support structure loose from its mounting, broke the GLFC/FCA loose from the support structure, and stripped all of the graphite and insulation from the secondary thermal shield. The secondary shield landed about 750 feet from the end of the shock tube. The FCA was jammed in the beryllium shield (see Figure 8). The protection of the shield was essentially intact though a hairline crack ran axially along the beryllium. The latch fitting broke free of the capsule backplate and was free to move along the shield. This exposed a very small area of the FCA at the aft end to the view of the fireball. The result of this exposure in terms of capsule melt is being evaluated. When the simulated FCA is removed from the shield it will be examined to determine if fuel can be released.

Interagency Safety Review Panel

The Interagency Safety Review Panel for the SNAP 27 is comprised of members from the AEC, NASA, DOD, and the Public Health Service of HEW. The panel is divided into five subpanels: Range Safety, Reentry, Meteorological, Oceanographic, and Biomedical.

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Using analyses and test results from GE, Sandia, and the panel members, the subpanels have prepared reports for their areas of responsibility. During the week of December 9, the whole panel met at NASA Headquarters to assemble the reports of the subgroups into the Safety Evaluation Report (see page 14).

Figure 8. SNAP 27 GLFC secondary thermal shield with FCA jammed inside following explosive test

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1.3 SNAP 29

Isotopes
AT(29-2)-2062

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The SNAP 29 program, initiated by the AEC to satisfy possible space mission requirements, was contracted to the Martin Marietta Company in early 1966. During the previous quarter, the Martin Marietta Nuclear Division was purchased by Isotopes, a subsidiary of Teledyne Company and was renamed the Nuclear Systems Division of Isotopes.

The SNAP 29 plans are to use the thermal energy from $^{210}\text{polonium}$ fuel, 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 the excess thermal energy.

General

Isotopes is presently preparing a revised program plan to reflect recent funding and system development changes. This program is expected to be reviewed later this quarter. Basic considerations are the production of an electrically heated demonstration model RTG by December 1969 and an isotope-fueled demonstration model about July 1970. Serious consideration is being given to using a burnup heat source for this program.

Electrical Heat Source

Fabrication and assembly of the first electrical heat source is nearly complete. Effort on this task has been delayed somewhat because of emphasis on the isotopic heat source.

Heat-Rejection System

Isotopes is having perhaps more than normal "start-up" difficulties with the diffusion-bonding fixture to bond the nickel heat pipes to the aluminum radiator panel. The schedule for the manufacturing checkout test, in which 10 heat pipes are to be diffusion-bonded to the radiator panel, has slipped from mid-October, 1968, to early 1969. This test will not be performed until an adequate amount of experimentation has been done to select a combination of pressure, temperature, and time which results in a good diffusion bond.

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Thermal Control Subsystem

Fabrication of the structural parts of the thermal-control shutters is complete and they have been accepted by the Isotopes quality group. The insulation is now being added to complete the assembly. One NaK reservoir for this subsystem has passed leak testing without any deviations.

During the fabrication process, the titanium honeycomb strength members were successfully brazed to the frames, but it was discovered after brazing that the frames had not first been straightened. As a consequence, the brazed assemblies were out of tolerance by about 0.03 inch and this would not allow the shutters to close. Straightening after brazing was impossible and an investigation of the matter by Isotopes resulted in a decision to provide a groove in the shutter insulation which allows enough clearance for the shutters to avoid one another as they rotate between the open and closed positions. This change will not appreciably affect the degree of thermal control and has now become a permanent part of the design. To insure that sufficient clearance is provided on future units, the tolerances on the individual piece parts of the shutter assembly will be changed.

The reliability predictions and available test records for the thermal control subsystem have been reviewed by R. E. Smith, Div. 1642. Questionable items of Isotopes reliability predictions and materials choices have been discussed with their reliability and engineering people, and a joint reply to our questions is being prepared.

RTG Housing Structure

The end frames, support frames, and shutter beams of the RTG structure have been fabricated and some parts have already undergone quality inspection. Two support-beam assemblies (W-beams) showed hairline cracks on the edges after welding. These beams are made of Rene 41 and a literature search by Isotopes indicated that a possible cause of cracking was the 2050°F heat treatment before welding. One source recommended a maximum heat-treatment temperature of $1975 \pm 25^\circ\text{F}$ for severely constrained welded assemblies.

Although this was proposed by Isotopes as the probable cause, discussions with metallurgical people at Sandia indicated that there could be many reasons for the cracks developing and the real reason could only be ascertained by metallographic analysis. Literature on Rene 41 at Sandia showed also that the type of welded joint used in the design was not highly recommended, strain-age hardening could be a factor, and other, more minor causes are possible.

Before this additional information could be discussed with Isotopes and a logical approach decided on, the cracks were machined out on the two parts. On one of them only minor machining was required, but on the second it was necessary to go completely through the face plate (in one of the three areas machined) before the crack was eliminated. It was decided not to use the second part.

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Since the parts containing cracks were made of material heat-treated to 2050°F, Isotopes originally planned to fabricate two samples using material treated at 1975°F and, if no cracks appeared, assume the problem was solved and make two new W-beams of material heat treated at the lower temperature. Sandia felt that an effort to duplicate the cracking with the original materials would be more helpful, since there would then be samples for metallographic examination to determine the exact cause.

After some discussion it was decided to make one sample from each type of material, one to duplicate the cracks and the other to help decide whether the heat treatment before welding could be the problem. The samples were prepared, with quality checks at each step, and no cracks developed in either one nor have any appeared after about 4 weeks of storage. Therefore, the results of the sample welding are inconclusive, but metallographic work on the samples is now in progress in a final attempt to determine the cause of the cracking.

Certain corrective action will be taken on the drawings, hopefully to prevent a recurrence of this situation on future assemblies. The heat treatment of the material will be changed to $1975 \pm 25^\circ\text{F}$ as recommended in the literature and, on the supposition that the cracks may have been caused by an edge effect because the welder lingered too long on the end of the part, a tab for machining off will be added to allow the welder to continue on without stopping at the edge. Isotopes engineering is also requiring electron-beam welding in all of these areas to reduce the probability of cracking. These actions are all steps in the right direction, but it has not been absolutely established that they will correct the situation.

A stress check by Isotopes indicated that the areas where the cracks have been machined out are still adequate in strength and the Sandia stress analyst agrees that they should be strong enough. It was therefore decided that both of the first assemblies could be used. However, when the second one was removed from storage, after about 6 weeks, a fourth crack had appeared in an area where none had been before. This means that residual stresses of some kind have been set up in the material which could cause additional cracks at a later date. The new crack has also been machined out and it is still intended to use this part. However, all of these parts are now being kept under close surveillance and any propagation of cracks from the machined-out areas may result in their rejection and the manufacture of new assemblies.

T/E Elements

Battelle-Columbus will perform the measurements to characterize Isotopes TAGS-85 thermoelectric elements. This will involve measuring Seebeck coefficient, electrical resistivity, and thermal conductivity in the general temperature range from room temperature to 450°C. Thermal conductivity will be determined by measuring the material's density, specific heat, and thermal diffusivity.

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T/E Modules

Sandia made an evaluation of the SNAP 29 hot-plate brazed module which developed cracks during production brazing at Isotopes. Three samples sectioned from the cracked area of the module were examined by Isotopes and the cracks appeared to contain braze material and several reaction zones. Three other samples from the same area were sent to Sandia.

The specimens delivered to Sandia were first inspected by ultrasonics and x-ray; neither revealed any new information. They were then sectioned, mounted, and polished in preparation for metallographic and microprobe analysis. Optical metallography showed the original Haynes-25 interface was still well defined and that there was a reaction zone of about 7 mils adjacent to that interface. This was followed by another zone of about 3 mils and then by what was apparently beryllium. The cracking which occurred during the braze cycle was revealed in cross section D as intergranular penetration. Both the cracking and the diffusion-reaction zones are illustrated in Figure 9. A Filar eyepiece was used to determine the thickness of each zone and that the original thickness of the Haynes-25 was unchanged by the process.

The microprobe evaluation revealed that the major constituents of the Haynes-25 had diffused into the 7-mil zone. The material in the cracks through the Haynes was identified as silver and copper, the major constituents of the braze alloy. However, silver and copper were not present in the 7-mil zone to any appreciable extent but were restricted mainly to the 3-mil zone, with diffusion tending toward the beryllium. The presence or absence of beryllium in the different zones was not definitely determined because Sandia's microprobe is not capable of identifying very light elements. However, the backscattered electron scan, see Figure 10, indicated the presence of a light element in the 7-mil zone (heavy elements leave a bright trace and light elements leave a dark trace). Knowing the elements involved, it may be assumed that beryllium is present in this zone, but a small sample was extracted from the 7-mil zone for analysis by x-ray diffraction. The results indicated the presence of Be_2Cr with probably Be_2M and M being the major elements in the Haynes-25.

Attempts were made to construct a model to explain the reason(s) for the cracking as well as the complete diffusion process. An analysis of the thermal map of the panel versus time did not support a theory requiring significant differences in heating and cooling. Another model looked at residual stress due to lattice volume changes during the formation of the Be_2M . Residual stresses in the Haynes sheet may have contributed to crack formation.

The following conclusions have been drawn from this investigation:

Why or how the silver-copper braze alloy penetrated the grain boundaries of the Haynes-25 is still not known.

The original braze interface was displaced by about 7 mils through a diffusion mechanism (the silver-copper braze alloy is 7 mils away from the Haynes-25, exists as a distinct zone, and shows no evidence of wetting the Haynes-25).

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Figure 9. Sample D, as-polished, 88X. Illustrates zones observed on all specimens, also typical cracking in the Haynes-25 and horizontal cracks in adjacent diffusion zone. From the bottom: mount, Haynes-25, 7-mil zone, 3-mil zone, beryllium (vertical line left by microprobe scan).

Figure 10. Microprobe backscattered electron scan of sample D, 175X. Illustrates zones, cracks, and braze alloy "feeding" the cracks.

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The 7-mil reaction zone appears to be a brittle intermetallic combination of beryllium with most of the elements in the Haynes-25.

There is little evidence of a good braze joint between the beryllium and the Haynes-25.

In summary, the evaluation did not reveal the reason for the cracks in the Haynes-25 skin of one brazed module. However, the evidence seems to point to the fact that the molten braze alloy followed the cracks but did not contribute to their formation: (a) all cracks observed penetrated the total thickness of the Haynes-25 sheet; (b) cracks were not observed in the Haynes sheet on the opposite side of the module; (c) there was no evidence of braze-alloy/Haynes interaction; and (d) the braze alloy and the braze "feed" channels were displaced through the 7-mil reaction zone. The braze joint has reaction zones similar to those encountered during braze development. However, it seems that some conclusions made during braze development were erroneous with regard to the location of the Haynes-25 interface and the elements diffusing into it.

A compilation of the microprobe and metallographic study photographs made at Sandia are included in an appendix to this report.

AGE

Present plans are to delay this task both until funding has improved and until progress has been made toward developing a better definition of the isotopic heat source.

Isotopic Heat Source

For this report period, all design effort on the heat source stopped and was diverted to assist the Task Force organized by AEC/SNS (see below).

Safety

The release of polonium from a SNAP 29 is easily detectable at 50,000 feet (or at other altitudes significant to the program). Ground release, of course, presents a severe hazard. In the report "SNAP 29 Task Force Final Report," SC-M-68-772, which defines the burnup capsule design (in lieu of an intact one), effort has been made to pursue these and other problems.

Intense planning has proceeded on a test of the burnup capsule in the launch-abort environment. United Technology Corporation's propellant 3001, developed for the Titan III D, may have a sustained flame temperature, in air, of from 3200 to 5000°F for as long as 5 minutes. Several conditions might result in this extreme environment where the capsule could melt and release polonium.

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SNAP 29 Task Force

The SNAP 29 Task Force was established to arrive at a burnup heat source design and to define the tests required to develop the design. The task force members were:

James Jacobs, Chairman	Sandia
Karl Kershner	Mound Laboratory
Dean Ruwe	Isotopes

The task force drew upon the staffs from the members' respective organizations to fulfill the assigned objectives. The results, discussed briefly here, are given in detail in the SNAP 29 Task Force Final Report, Sandia's document SC-M-68-772 (Monsanto Research Corporation's MLM 1571, Isotopes' INSD-2062-4002).

As illustrated in Figures 11 and 12, the burnup heat source uses 13 cylindrical fuel elements. These are 1.2 inches in diameter by 30 inches long and are stacked in a flat vertical array held together by an outer frame. Approximate over-all dimensions including the frame are: length, 32 inches; height, 20 inches; and thickness, 1.2 inches. Each fuel element consists of an outer cylindrical heat shield containing two capsules, one at each end. A hollow spacer is used between the fuel capsules, both to provide the proper capsule location with respect to the T/E modules and to provide a degree of impact protection for possible end-on impact. The thermal inventory is identical to that of a corresponding intact heat source, and the component operating temperatures will be nearly the same. The burnup heat source will weigh about 105 pounds, whereas the intact heat source was calculated to be close to 90 pounds.

Only minor changes in the existing RTG housing will be required to accommodate the burnup heat source. Once these changes are made, and when both heat sources have reached operational status, it is expected the intact and burnup heat sources can be used interchangeably to provide the greatest flexibility in terms of mission planning and nuclear safety.

Based on the reference mission, design criteria, and mission environments established by the task force, the following conclusions and recommendations were made.

Conclusions -- It is feasible to build a burnup heat source for the SNAP 29 system. The design discussed in this report is technically sound and represents a low-risk development effort.

The setting of higher priorities and the hiring of additional people at Mound Laboratory would permit completion of the work by March 1970. With present resources and priorities, the program will be completed by June 1970.

Based on the presently defined launch-pad-abort conditions, the burnup heat source design recommended by the task force will not survive the solid-propellant-abort environment. To design a heat source which would survive this environment and still burn up on reentry is, if possible at all, a very difficult task and would require extensive development.

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Figure 11. SNAP 29 burnup heat source

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Figure 12. Fuel element

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The burnup heat source is interchangeable with the existing intact heat source design.

The proposed design should serve as the baseline design for the SNAP 29 program. Continued design, analyses, scheduling, and procurement efforts are expected to result in modifications and improvements.

Recommendations -- Conduct tests on solid propellant to determine the environment associated with this fuel during launch-pad aborts.

Determine the feasibility of leaving the heat source in orbit.

Establish Isotopes/Mound interface drawings requiring formal signoff by both.

Additional technical contacts should be established at the working level between Isotopes, Sandia, and Mound.

Conduct fuel-liner compatibility tests at the temperatures and for the time defined by the launch-pad-abort environments.

Establish a shrapnel model for the Titan launch vehicle.

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1.4 Transit

TRW
AT(29-2)-2617

D. L. Krenz 505-264-4041

The objectives of this program are to design, develop, fabricate, qualify, and deliver two plutonium-fueled RTG's to the Navy for use on the operational Transit (formerly NAVSAT) satellites. Design constraints for the Transit RTG include 20 watts power output at the end of a 5-year life and an intact-through-impact fuel capsule.

TRW was selected as the AEC's Transit RTG systems contractor. Phase I of the two-phase program, started December 9, 1968, will be a 20-week study to evaluate plutonium fuel forms, heat sources, and thermoelectric converters. It will culminate in an evaluation report and a TRW-recommended Transit RTG design.

<u>Milestone</u>	<u>Date</u>
Program start	December 9, 1968
Submission of Phase I program plan	January 1, 1969
Submission of design-review package to AEC	March 24, 1969
Submission of preliminary Phase II program plan	April 8, 1969
Design-review meeting at AEC Hqs.	April 8, 1969

Phase II of the Transit RTG program will begin immediately after approval by the AEC of the RTG design. Programmatic milestones for Phase II are as follows:

<u>Milestone</u>	<u>Date</u>
Selection of RTG design by AEC	April 18, 1969
Freeze RTG/satellite interface	April 25, 1969
Submission of preliminary Safety Analysis Report	July 1, 1969
Deliver 1st electrically heated RTG	July 15, 1969
Deliver 2nd electrically heated RTG	October 1, 1969
Complete safety tests and analyses	February 15, 1970
Start ground test of fueled RTG	April 1, 1970
Submission of final Safety Analysis Report	May 15, 1970

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Final RTG environmental qualification	May 15, 1970
Deliver 1st fueled, flight-qualified RTG to Navy	July 31, 1970
Deliver 2nd fueled, flight-qualified RTG to Navy	September 30, 1970

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The TRW project organization is shown below:

Hittman Associates, as a subcontractor, will assist TRW in the areas of nuclear safety and fuel form/heat source evaluation.

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2. SPACE ISOTOPE POWER ADVANCED DEVELOPMENT

2.1 Thermoelectric (T/E) Converters

2.1.1 Compact Converter

Westinghouse
AT(29-2)-2638

W. W. Joseph 505-264-2138

The Westinghouse converter uses lead-telluride (PbTe) thermocouples to convert thermal energy to electric energy (Figure 13). Alternating washers of p- and n-type lead telluride are electrically connected in series at their hot and cold junctions by 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.

Figure 13. Tubular module used in Westinghouse compact converter

A major effort during this reporting period has been directed toward establishing high-temperature-degradation rates for tubular modules employing solid tungsten inner conductor rings and TEGS-2P thermoelectric material. Data have been accumulated which indicate that tungsten inner conductor rings substantially reduce degradation rates for average hot-clad temperatures up to 1200°F. However, the problem of performance degradation above 1000°F requires additional effort.

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Destructive examination of tubular modules tested at hot-clad temperatures $\geq 1200^{\circ}\text{F}$ has been in process. The primary mode of power degradation of nonferrous conductor ring modules has been identified as n-type T/E material contamination. Ample evidence has been obtained that the p-type PbTe is the source of the contamination, although the exact diffusion species has not been identified. Concurrently, data show that the use of tungsten conductor rings has eliminated the problem of p-type PbTe contamination caused by iron conductor rings.

2.1.2 Lightweight T/E Generator

Gulf General Atomic
AT(29-2)-2564

I. G. Waddoups 505-264-4107

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

The basic design employs 2N and 3P material supplied by 3M Company, 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-foil insulation is used in this unsealed system which operates at a hot-junction temperature of 400°C .

Data have been accumulated which indicate improvement of the element bond life; bonds made with the new batch of nickel have lasted longer. The mechanical and metallurgical (M&M) bond has demonstrated a life of over 5000 hours at 500°C which is higher than any other bond to date. A thermal analysis of an M&M bond indicates that the couple output after metallurgical bond failure, but with mechanical bond intact, is 80 percent of the output before failure.

Investigations of 5- and 10-mil vapor-deposited SiO_2 radiator coatings have been abandoned for adhesive-bonded 3- or 8-mil-thick by 1-inch-square SiO_2 mirrors. Analysis indicates that a slight performance improvement could be obtained by using an aluminum converter radiator, but no changes are presently planned.

Recent calculations indicate that 8 percent efficiency can be obtained from a PbTe/GeSi cascaded system operating at a hot-junction temperature of 800°C .

The second converter built, GC02, is being life tested and has run for 2000 hours without apparent degradation. The third converter, GC03, will be completed in January 1969.

Converter GC01 has been operated in nitrogen to determine operating temperatures in air. The maximum temperature recorded was 202°C . Modules have been operated in air for 800 hours at 250°C without any observable degradation.

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A mockup converter incorporating structural design changes was vibration tested to the Transit requirements and experienced "g" levels above those which can be survived by live T/E panels. Mechanical isolators are being procured in an attempt to alleviate this problem.

Two heat sources capable of surviving the vibration tests and subsequent life testing have been fabricated.

Additional work is being conducted on laser welding, bismuth telluride material, radiation vulnerability, reliability, and engineering analysis.

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2.2 Capsules

2.2.1 Advanced Spherical Capsule

Hittman Associates
AT(29-2)-2475

I. G. Waddoups 505-264-4107

The demonstration heat sources for impact and plasma testing are nearly complete and will be tested early in January 1969. These heat sources are 9.3 inches in diameter and weigh about 11 pounds. The capsule's inner and outer shells of Haynes-188 retain the fuel simulant between them. The impact capsules use tungsten-molybdenum and the plasma capsule uses zirconia as the fuel simulant. The capsule is enclosed in an 0.55-inch-thick, silica-foam shell which is in turn enclosed in an 0.1-inch-thick ATJ graphite shell. Compliance members of nickel felt will be used as necessary.

The design has been refined since the design selection for the demonstration heat sources. The primary design Transit heat source is similar to the demonstration model in construction but weighs about 10 pounds and is approximately 8 inches in diameter.

Tests are being conducted to determine how this type of heat source withstands the Transit vibration specifications. Tests to date indicate this is possible using the nickel-felt compliance members and it can probably pass the tests without them.

Impact tests have been conducted on seventeen 2-inch shells, five 4-inch shells and three 8-inch demonstration capsules. The 2- and 4-inch-shell data were used to lend credence to Hittman's impact-survivability-correlation technique; the data were in general agreement with results predicted by the technique. The three 8-inch, Haynes-188 capsules were impacted at velocities ranging from 278 to 330 ft/sec and temperatures ranging from 820 to 1800°F as follows:

Velocity (ft/sec)	Temperature (°F)	Results
306	820	No crack
278	1800	Crack from secondary impact (very little, if any, fuel loss)
330	1800	Crack 1/3 of way through primary container (no fuel loss)

Thermal conductivity measurements are being made on plain and silver-impregnated ceramic foams.

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2.2.2 Large Radioisotope Heat Source Capsule (LRHSC)

Atomics International
AT(29-2)-2338

D. R. Johnson

505-264-6638

The over-all goal of the LRHSC program is to develop, in part, the technology required 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 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.

Very significant progress was made in the fabrication area during this quarter. Specifically, the first production run of deep-drawn T-111 structural shells was completed; 17 good shells resulted from 18 starting blanks. It is believed that either a minor change in the anneal point or the introduction of one more intermediate anneal, or both, will allow production of large quantities of structural shells with negligible losses. Another major accomplishment was the successful drawing of 4 of these shells through another die which reduced the wall thickness from 0.127 to 0.090 inch. These shells will be used in both the creep and impact tasks. All liner piece parts and structural end caps have been completed, machined, and inspected. Also the deep drawing process for the platinum-rhodium shells has been qualified, as has the coining and spinning process for the platinum-rhodium end caps. Four of these shells have been successfully fabricated to support "C" capsule assembly.

In the assembly area, all welds have been completely developed, including the final closure on the platinum-rhodium. The first standard "C" capsule has been successfully fabricated and assembled, and this is to be followed by assembly of the "C" capsules for creep testing. The "B" capsule assembly (structural shell only) is well qualified and the structural welds are proved and repeatable. Assembly of the "A" capsule was delayed by severe galling during insertion of the simulated fueled assembly into the structural shell. Program requirements call for a shrink-fit assembly in the EB weld chamber. The problem is mainly due to the inherent characteristics of the tantalum alloys involved. The problem is significant, but methods are being explored for successful assembly without leaving a gap between shells. Meanwhile, assembly of "A" capsules to support the creep and impact test programs is being accomplished by opening up clearances and assembling by hand operation.

The creep program is continuing with two "B" capsule tests well in progress. Capsule B-5 is scheduled for creep to 5 percent strain while capsule B-7 will be tested to rupture, which should occur during the month of January. Capsule B-6 is scheduled for a 10,000-hour test which has just started. A rig is ready for the initial "A" creep capsule test pending successful assembly.

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Initial impact tests were conducted late in the quarter at a velocity of 250 ± 10 ft/sec and a temperature between 1200 and 1300°F. Planned for end-on, it was found that the sabots used for size compatibility with the gun barrel available caused an in-flight torque resulting in impact angles of 10 degrees for one capsule and 30 degrees for the other. Neither capsule was ruptured nor did the structural or internal shells show any signs of cracking. Both had been plasma-arc sprayed with alumina and they were heated in a helium atmosphere before impact. Other tests are planned at higher velocities and reduced wall thickness.

2.2.3 Lightweight Capsule

Gulf General Atomic
AT(29-2)-2588

I. G. Waddoups 505-264-4107

A nominal 8-inch-OD capsule has been designed and fabrication procedures are near completion. Three capsules will be fabricated and impact tested during the next quarter. Two designs are being considered. One has peripherally loaded fuel and the other retains the fuel in a smaller sphere (approximately 3-inch OD) which, in turn, is retained by spacers inside the nominal 8-inch outer shell. The outer shell of tantalum or T-111 is CVD coated with tungsten and then covered with a reentry coating. HfO₂ and pyrocarbon coatings are being evaluated by applying them to 4-inch-OD spheres which will be plasma tested.

Basic materials data are being taken to determine the effect of the coatings on the substrate. All tests to date indicate that the tantalum substrates do not lose their original ductility through processing.

Capsules with 0.02- and 0.04-inch wall thicknesses of pressed and sintered tantalum were dropped from a helicopter on rocky soil to measure impact resistance. The 0.02-inch-wall capsule developed a small crack. Further tests will be impacted on granite.

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2.3 Thermoelectrics

2.3.1 SiGe T/E Materials and Module Development

RCA
AT(29-2)-2510

W. F. Windle 505-264-4942

The primary objective of this program is the development of highly reliable, long-lived, and reproducible silicon-germanium thermoelectrics capable of operating in anticipated environments with hot-junction temperatures of 1000°C or higher. A long-range program to establish the basic technology for optimized and predictable T/E conversion devices is planned.

The work will be carried out in three main areas. First, the materials program will include the optimization of the present silicon-molybdenum hot shoe material and bonds; the development of new, improved hot shoe materials and bonds for improved T/E performance and stability; and the development of higher silicon content SiGe exhibiting improved thermoelectric properties. Second, the Air-Vac Module Development program is for the optimization of thermocouple and module configurations for a variety of performance criteria and environmental extremes. Finally, the Cascade Converter Development program will examine analytically, in depth, the performance of a variety of cascaded T/E converters and include the fabrication and initial testing of SiGe stages for cascaded converters.

Optimizing the SiMo alloy used for hot shoes is proceeding very well. The hot shoe yield from the cast alloy has increased from about 50 percent early in the program to better than 70 percent at the present time.

The hot pressing of both SiMo and SiGe alloys has been quite successful, but optimization of these processes has not been completed. Densities of better than 99 percent have been achieved on both n and p types of SiMo and SiGe (both 63.5 percent and 80 percent Si alloys). The current hot-pressed material shows thermoelectric properties comparable to the vacuum-cast and zone-leveled alloys, and with significantly higher strength.

The effort on alternate hot shoe materials has been concentrated on SiC and SiC-coated graphite but was delayed about two months by late delivery of these hot shoes from the vendor. The first attempts at vapor-deposition of SiC coating on SX-4 graphite shoes have been completed and the results are very encouraging. Reasonably uniform, crack-free coatings were achieved, and refinement of this process is proceeding.

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Isothermal testing at temperatures up to 1100°C is continuing on couples representing the various SiGe alloys and hot shoe materials. In order to evaluate the benefits of using foil insulation on SiGe converters, a 5-watt (18-couple) converter was designed and fabrication attempted; this would have allowed direct comparison with a 5-watt converter which was tested with dynaquartz insulation, then reinsulated with Min-K 2020, and which is currently on long-term test. During fabrication, either when the insulation was put in place by Linde or during the brazing of the couples to the radiator mounting plate, a number of couples were broken. Only two of the six 3-couple strings remained intact. The partial converter with only the six couples (remaining holes in foil filled with Min-K 2020) was tested over a range of temperatures. Although the nature of the test precludes the exact comparison which had been hoped for, it appears that the total heat loss through the foil is about 30 to 40 percent of the heat loss through the Min-K 2020 insulation on the 5-watt converter.

Life testing of the reference converter and the 5-watt, Min-K-insulated converter is continuing. The total time on these converters as of December 11 was 3693 and 5372 hours respectively with no detectable change in power output since the initial performance mapping at 1000 hours.

After the initial parametric analyses for cascading Air-Vac with Isotec were completed, without the inclusion of transverse heat flow, the computer program was rewritten to account for the transverse heat flow in the hot and cold plates of both stages. Analyses with this improved program have just started.

2.3.2 T/E 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 the SNAP 17A SiGe, Air-Vac modules. The cascade work showed the feasibility of cascading Air-Vac SiGe with sealed PbTe module T/E's. 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 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 34,000 to 38,000 hours and presently are operating at 90 to 100 percent of their respective 500-hour power levels.

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2.3.3 TPM-217 Development Program

3M Company
AT(29-2)-2473

G. H. Whiting

505-264-4942

The objective of this program is to characterize accurately the TPM-217 thermoelectric material through a well-organized basic materials study. The scope of work requires that the T/E properties be determined and statistically analyzed, the mechanical and chemical properties studied, and the long-term performance and stability characteristics determined through tests of 10-couple modules.

A life test of an 0.243-inch-diameter, 0.4-inch-long element has completed 2100 hours of operation in a 500°C temperature gradient. The element is operating with a constant load, interrupted only momentarily to obtain open circuit voltage. The element has shown no degradation in this period of testing. The actual performance appears to be somewhat better than predicted by Seebeck, resistivity, and thermal-conductivity data.

The attempt to explain all the Seebeck, resistivity, and thermal conductivity curves in terms of the energy band gap, the effective mass of the holes and electrons, the energy dependence of the scattering length, the collision times for electrons and holes, and the lattice thermal conductivity was continued during this period. Low-temperature resistivity has been found to fit very well a $T^{-1.67}$ temperature dependence, in good agreement with a zero scattering parameter. Through this analysis the energy band gap and the ratio of electron mobility to total mobility has been determined.

2.3.4 T/E Test Methods

R. M. White
C. F. Joerg

505-264-4107
505-264-6767

The four-station TELPS stand and its instrument rack are presently being modified. It was necessary to make a number of new parts for the ingradient performance fixture. New heater controls for both the hot and cold blocks are now operable. All the parts of one performance fixture were cleaned in carbon tetrachloride and this fixture is now being reassembled with new thermocouples and heating elements. A computer code has been written to determine the values of Seebeck coefficient, resistivity, and thermal conductivity, given typical input values expected from the TELPS device. While this code must be modified to process actual electrical signals, the present code has been helpful in determining the theoretical parametric performance of the device.

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Two reports have been prepared for publication. The first, "The Determination to the Elevated Temperature Seebeck Coefficients of Common Thermocouple Materials Referenced to Platinum," has been distributed and the second, "A Computer Technique to Determine the Seebeck Coefficient of Thermoelectric Materials in a Changing Temperature Gradient," has been approved and sent to printing.

A study to determine the electrical resistivity of cylindrical T/E elements using a nonlinear, point-contact technique continues. The first results from the computer code indicate the feasibility of the technique. Actual device-testing hardware has been constructed and awaits checkout. The nonlinear technique is ideally suited to elevated temperature resistivity readings and to acceptance testing of T/E elements.

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2.4 Thermal Insulation

Introduction

Three contracts are underway for the development of thermal insulation for radioisotopic thermoelectric and thermionic generators. Johns-Manville is evaluating and developing bulk fibrous types of insulation materials for use in the 400 to 1800°F temperature range. The Linde Division of Union Carbide is developing vacuum-foil insulation systems for use from 400 to 1800°F. Thermo Electron Corporation is developing vacuum-foil insulation systems for use in the range from 1800 to 3100°F. All three companies have completed an 18-month Phase I period. Each company is now doing a Phase II follow-on program. The Phase I activities started in mid-FY 1966.

2.4.1 1800°F Foil Insulation

Linde
AT(30-1)-3632

D. J. Mottern 505-264-6638

Long-Term Thermal Conductivity Tests

The objective of this task was to obtain preliminary indications of the long-term stability of multilayer insulations by conducting long-term, continuous tests at maximum operating temperature. The copper-opacified-quartz system has been in continuous operation for about 9,300 of a scheduled 10,000 hours with no apparent change in thermal conductivity. Conductivity remains at 15.45×10^{-3} Btu/hr-ft-°F between 1220 and 415°F. The nickel-opacified-quartz, multilayered system has been on test for 1400 hours with an apparent thermal conductivity of 7.63×10^{-3} Btu/hr-ft-°F between 1485 and 577°F. Current efforts in the 1800°F multilayer system have been directed toward two potential systems--molybdenum and nickel. Problems have been encountered at 1800°F with the nickel system. The conductivity increases with time at temperature because of thermal etching of the surface which results in emissivity changes. Both the nickel and molybdenum undergo considerably reduced surface deterioration when used with high-purity Astroquartz.

Flat-Plate Tests

The objectives of this task are to develop a means of obtaining accurate thermal-conductivity data for multilayer insulations and to correlate these data over a range of temperatures (to 1800°F) and at various layer densities. Apparent thermal conductivity data have been obtained on a nickel/Astroquartz multilayer sample through a temperature range of 500 to 1500°F and at mechanical loadings of 0.04, 0.1 and 1.0 psi. Typical data are shown at the top of the next page.

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Temp. (°F)		Load (psi)	Density (layer/in.)	K x 10 ³ (Btu/hr-ft-°F)
T _h	T _c			
549	90	0.04	108	0.25
1533	220	0.04	108	1.23
540	104	0.1	120	1.31
1515	230	0.1	120	2.27
540	110	1.0	132	2.15
1533	273	1.0	132	2.66

Penetration

The objective of this study was to determine the effect of the presence of a penetration through an insulation panel on the insulation thermal performance and to develop an analytical model for all types of penetrations. Efforts are complete on reformulating the filled-gap analytical model to reflect the actual performance characteristics of the opacified fillers.

2.4.2 1800°F Bulk Insulation

Johns-Manville
AT(30-1)-3633

D. J. Mottern 505-264-6638

Phase II work is nearly completed. Development of a 2200°F bulk insulation was not successful but provided useful information on the sintering and reactions of powdered Al₂O₃ with various opacifiers. A lower temperature application of Al₂O₃ may be possible but was not pursued under this phase.

Load-Bearing Insulation for 400 to 1800°F Service

The objective of this task was to develop the best bulk insulation with load-bearing capabilities. A foamed silica product called Glasrock was selected for 1800°F service because of its more favorable properties, but conductivity of the titania-opacified Glasrock specimens was not reproducible from batch to batch. Considerably more effort would be required to establish the reason for lack of reproducibility as well as the manufacturing process and quality control requirements necessary to achieve consistently the strong, low-conductivity product. For this reason further work with opacified Glasrock was halted.

In lieu of an evaluation of the opacified product for load-bearing capability, a similar program was undertaken for 25 and 30 lb/ft³ un-opacified Glasrock foam silica. These tests were conducted at an 1800°F hot face on 2 x 2 x 1-inch specimens. The test time depended upon the ability of the specimen to carry the load without permanently deforming, as well as the fatality rate of the heating units. The results are summarized in Table II.

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TABLE II
Permanent Set of Unopacified Glasrock

Constant Load (psi)	Test Time (hr)	Average Permanent Set (inch)	
		As Tested	After Scraping
500	3/4 to 24	0.02	0.03
400	164 to 271	0.02	0.027
300	336 to 504	0.014	0.018

In all instances where permanent deformation occurred, a thin layer of silica powder was found on the surface of the specimen. This was a result of crushing of the cellular structure, considered undesirable since it would indicate a significant reduction in applied load had the test been conducted on a constant-deflection rather than a constant-load basis. Thus, permanent set was determined both with and without this thin layer of silica powder on the surface of the specimen. Since this product is rigid, rather than resilient like Min-K, a permanent set of more than several thousandths of an inch was considered a failure.

Tests are currently in progress at the 200-psi level for both 25 and 30 lb/ft³ material. In some cases, the tests are being conducted cold since heater replacements were not readily available. A comparison of hot versus cold testing at the 300-psi level indicated that the hot specimens were slightly stronger than the cold specimens, although considerably more tests would have been necessary to establish this statistically. It was sufficient, however, to determine that cold testing would not show the product to be significantly better than under the hot conditions.

2.4.3 High-Temperature Insulation

TECo
AT(30-1)-3634

D. J. Mottern 505-264-6638

Spray Coating

The objective of this task was to optimize the spray coating of the refractory oxide particles onto the foils. Testing continues to determine the optimum coating density of W/ThO₂. Sample No. 42 had a coating density of 0.0104 mg/cm² which, when viewed under the microscope, appeared to be too light a coating. A heavier spray coating, 0.0683 mg/cm², was applied to sample 43 and an improvement of about 50 percent was measured. A final test sample will be prepared with a coating density of about 0.12 mg/cm².

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Cylindrical Insulation

The purpose of this task was to develop and test a multifoil cylindrical insulation under loaded and unloaded conditions. Thermal expansion of the cylindrical samples during heating is placing compressive pressures on the insulation which affect test results. Testing will continue using a Mo heater block with a Mo sleeve over the outermost layers. It was observed that the minimum heat flux can be achieved with a layer spacing of 4 mils/layer.

Edge Heat Losses

The first series of tests were performed on the 38-layer, concentric-cup corner assembly. The performance did not appear to be as good as with tapered corners and was comparable to the overlap and slit-cup corners.

Low-Temperature Applications

The objective of this task was to examine lower temperature multifoil insulations using oxide particles. Several new low-temperature samples have been fabricated. Forty layer samples of Al/ZrO₂, Cu/ZrO₂, Ni/ZrO₂, and stainless steel/ZrO₂ have been fabricated and tested. These data have not been reduced, so will be reported in the next quarterly.

Life Tests

After 100 hours at 1800°C the Ta/ThO₂ samples deteriorated badly; this material tended to shrivel and excessive bonding was noted between layers. The W/ThO₂ portions of these samples survived very well. These tests indicated that 1800°C is too hot for Ta insulation, and only W/ThO₂ will be used on the 10,000-hour insulation test systems.

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APPENDIX

Compendium of Photomicrographs,
Metallography and Microprobe

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Microprobe Sample D-1, 175X
(Figures A-1 through A-8)

Figure A-1. Backscattered electron scan

Figure A-2. Same scan as Figure A-1 with longer exposure

Figure A-3. Silver scan

Figure A-4. Copper scan

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Figure A-5. Cobalt scan

Figure A-6. Chromium scan

Figure A-7. Nickel scan

Figure A-8. Tungsten scan

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Microprobe Sample D-2, 175X
(Figures A-9 through A-15)

Figure A-9. Backscattered electrons

Figure A-10. Silver scan

Figure A-11. Copper scan

Figure A-12. Cobalt scan

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Figure A-13. Chromium scan

Figure A-14. Tungsten scan

Figure A-15. Nickel scan

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Metallography (Figures A-16 through A-21)

Figure A-16. Sample F, 35X, 12-mil side, typical, as-polished

Figure A-17. Sample F, 35X, 30-mil side, typical, as-polished

Figure A-18. Sample D-1, 175X

Figure A-19. Sample D-1, 262X

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Figure A-20. Sample D-2, 175X

Figure A-21. Sample D-2, 262X

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