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April 1969

AEC RESEARCH AND
DEVELOPMENT REPORT

QUARTERLY REPORT
SPACE ISOTOPE POWER PROGRAM (U)
January-March 1969

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Space Isotope Power Department 9520

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SC 1004-DF (3-67)

SYSTEMS FOR NUCLEAR
AUXILIARY POWER (SNAP)-
ISOTOPIC SNAP PROGRAM
C-92a M-3679 (61st Ed.)

SC-PR-69-237

QUARTERLY REPORT
SPACE ISOTOPE POWER PROGRAM (U)
January-March 1969

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Sandia Laboratories

April 1969

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SUMMARY

SNAP 19

Two SNAP 19 generators were assembled, tested, and integrated with the Nimbus B-II spacecraft at GE Valley Forge. The generators are to be launched from WTR in April 1969. A study of the feasibility of using a modified SNAP 19 generator for other NASA applications has begun.

SNAP 27

The safety review has been completed and recommendations forwarded to the Space Council for permission to fly the SNAP 27 on Apollo 12. The SNAP 27 hardware has been accepted by the AEC pending completion of final qualification testing of the fuel capsule assembly, the graphite LM fuel cask, and the GLFC support structure. A mockup assembly of the FCA and GLFC will be loaded and flown on Apollo 10.

SNAP 29

The SNAP 29 program will end in FY 1969 because of budget reductions. The program plan has been modified to try to complete an electrically heated generator by June 30, 1969. Changes to the design have been necessary because of the short time available for completing this much of the program.

Transit

The RTG end-of-life power requirement was increased from 20 to 30 watts (e). Program milestones were changed to postpone delivery of a fueled RTG to the Navy from July 1970 to March 1971.

Advanced Development

GGA has completed and instrumented the third demonstration generator for performance and life testing. The mechanical-and-metallurgical (M&M) bonded elements have been on an accelerated life test for 6500 hours at 500°C without failing.

Hittman's demonstration heat sources have been subjected to vibration, impact, and plasma tests.

Four more LRHSC capsules were impacted at about 250 feet/sec and all survived the test. On the first creep-rupture test, the capsule ruptured at between 13 and 15 percent strain.

GGA impacted three 8-inch-o.d. capsules, of two configurations, at velocity of about 315 ft/sec. Several 4-inch-o.d. coated spheres were plasma tested to evaluate hafnia and pyrocarbon coatings.

At RCA the SiGe reference converter is still on life test and has completed 6000 hours. Work is continuing on the evaluation of hot shoe materials and SiGe alloys.

Ten 500-gram batches of TPM-217 material have been reacted and analyzed for content at 3M. Thirteen TPM-217 elements have been placed in gradient thermal tests.

At Linde the copper-opacified quartz system has completed the 10,000-hour life test with no change in measured thermal conductivity. A new analytical model incorporating a radiation component for the opacified fillers has been completed.

Johns-Manville has completed all the technical work on its contract. Conductivities are now available for all Min-K formulations and the Glasrock silica foams. Conductivity of Min-K in vacuum at higher temperatures appears to be slightly higher than originally estimated.

Thermo-Electron Corporation has obtained excellent reproducibility of the Ta/ThO₂ system. They have also completed the layer-variation measurements; at lower temperatures relatively small reductions in heat flux resulted from additional layers, but at higher temperatures very significant reductions were observed.

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1. SPACE ISOTOPE POWER SYSTEM PROJECTS

1.1 SNAP 19

Isotopes	V. G. Redmond	505-264-5255
AT(30-1)-3607	R. J. Luikens	505-264-2534

A 50-watt(e), PuO₂ fueled SNAP 19 power system will be launched on about April 10 aboard the Nimbus B-II spacecraft. The power system has been integrated with the spacecraft at GE Valley Forge, and preparations for shipment to WTR are underway.

A study was made by Isotopes of the the feasibility of using a modified SNAP 19 for the "Pioneer" Jupiter fly-by mission. Both a new thermoelectric system and an advanced heat source were considered. Authorization to build and test two reconfigured SNAP 19 generators has been granted. These electrically heated units will be tested to determine whether the new thermoelectric system will help obtain additional power and reduce the drop-off of power with time. The reconfigured SNAP 19's are being considered for use not only on the "Pioneer" Jupiter fly-by but on the "Viking" Mars lander, the "Advanced ALSEP" moon lander, and the remote geological monitor (RGM) experiment.

[REDACTED]

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1.2 SNAP 27

General Electric
AT(29-2)-2581

J. A. Leonard	505-264-2433
A. E. Stephenson	505-264-3830
T. D. Harrison	505-264-3830

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, the 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 Hwde
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

[REDACTED]

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	x
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	x
Addendum to SAR submitted to AEC	September 15, 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	

Thus the major elements of the SNAP 27 program have been completed. A mockup of the system is expected to fly on Apollo 10; the first prime SNAP 27 system is expected to fly on Apollo 12. Sandia continues to provide technical direction to General Electric; to monitor and participate in the testing, acceptance, and shipment of the FCA and GLFC; to supply trained crews to load the FCA and GLFC; to support the operation of loading the FCA and GLFC on the Saturn V at Kennedy Space Center (KSC); and to follow up the Safety Program. Each of these items is discussed below.

Technical Direction

During this quarter Sandia issued technical direction on four occasions (in order):

1. Directed GE to finish their studies on the effect of Radifrax chipping from the secondary thermal shield (STS) of the GLFC, to set aside an STS as a standard to evaluate whether chipping will occur in storage, and to improve handling procedures and packaging of the GLFC.
2. Informed the contractor that leak tests already performed on the drop-test FCA were considered adequate for the purpose of the study.
3. Directed that the engineering GLFC be assembled in such a way that it could be used by NASA to check out the support structure.

- [REDACTED]
4. Informed GE that the P-9 GLFC, which was constructed of parts from production spares, will be used for spare parts if any are needed. Otherwise, it will be sent to Albuquerque for surveillance by the Sandia QA organization to determine whether degradation occurs in storage.

Fuel Capsule Assembly

All fuel capsules have been "component accepted" by Sandia. After component acceptance, dynamic acceptance and fit checks are required. The fuel capsules are dynamically tested (vibration and shock) at GE as part of the ALSEP cask assembly (ACA) in a joint NASA/AEC program. ACA testing has been successfully completed on the first three systems. The remaining two ACA's are to be tested and shipped in April.

Unlike the GLFC and all other end items which are delivered to NASA on a DD Form 250 after final acceptance, the fuel capsule never leaves AEC custody. Arrangements have been made to store the fuel capsules at Mound Laboratories until they are shipped to KSC immediately before each Apollo launch. The first capsule, FCA No. 1, was delivered to Mound on March 3.

Qualification testing of the FCA as part of the ACA is also conducted in an integrated NASA/AEC program. The qualification program includes air-soak tests, with and without the pad cooling system, a thermal-vacuum test, vibration and shock tests, and a functional test after all the environmental tests. Flight qualification testing was successfully completed in March.

Graphite LM Fuel Cask

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, the GLFC protects the FCA from the abort environment (explosion, fireball, reentry, etc.) to assure containment of the plutonium dioxide fuel.

The GLFC comprises two heat shields (see Figure 1). 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 thermal 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; during an abort reentry this inner shield acts as a thermal capacitance which absorbs the reentry heat to prevent its reaching the FCA.

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Figure 1. SNAP 27 graphite LM fuel cask beryllium secondary thermal shield incorporated (cutaway view)

Hardware Requirements -- Hardware requirements for the program are as follows:

<u>Unit</u>	<u>Shipping Date</u>
M-5 Qualification	November 20, 1968
M-5 Flight	December 3, 1968
Prime Qualification	
First Prime Flight	February 14, 1969
Backup Prime Flight	March 14, 1969
Second Prime Flight	
Third Prime Flight	
Fourth Prime Flight	

The M-5 is a mockup which does not contain a nuclear fuel capsule; it is expected to fly on Apollo 10. The first prime flight unit is expected to fly on Apollo 12 and the remaining ones, in order, on succeeding Apollo flights.

Fabrication of GLFC's -- Fabrication and Sandia QA acceptance of all required GLFC's was completed this quarter. Shipment is awaiting completion of integrated testing.

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Integrated Testing -- Qualification and acceptance testing of the GLFC, FCA, and Bendix support structure is performed with the three items assembled. Qualification testing consists of exposing the assembly to the operational, thermal, and dynamic environments which it will experience enroute to the moon. Qualification testing was delayed by a need to rework the support structure to meet certain operational requirements.

During testing some Radifrax chipped off the secondary thermal shield and there was also some discoloration of the latch fitting. By a test and analytical program, the amount of chipping that could be tolerated was determined and the observed defects were well below this level. Nevertheless, a coating repair procedure was developed and applied to the damaged shields to preserve the greatest possible margins.

Safety Program

Elements of the Safety Program -- The purposes of the safety program are: to minimize all the hazards to humans associated with the use of nuclear fuel in the SNAP 27; to assess the magnitude of such hazards as exist in terms of probability of releasing fuel, numbers of people exposed to various dose levels, etc; and to determine whether the potential hazards of flying nuclear material are justified. The safety program comprises the following elements:

1. A determination of the environments which might result in the release of the nuclear fuel supply.
2. Design and construction of hardware (the FCA and GLFC) which will survive potentially hazardous environments.
3. An assessment by the contractor of the ability of the hardware to prevent the release of fuel when faced with these environments. This assessment is published by the contractor in the Safety Report.
4. A review of the contractor's safety program by Sandia.
5. An evaluation of the results of the safety program by the Interagency Safety Review Panel comprised of representatives from NASA, DOD, AEC, and HEW, along with appropriate consultants. Their findings are published as the Safety Evaluation Report.
6. Recommendations for flight approval to the Space Council by heads of DOD, AEC and NASA.
7. Further assessment of safety by the Space Council and a recommendation to the President of the United States as to whether flight approval should be given.
8. Flight approval by the President.

Status of the Safety Program -- GE completed the first three items listed above by January 1969. GE's Safety Report was issued July 24, 1968, in three parts:

[REDACTED]

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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.

On September 16, 1968, GE issued Safety Report Supplement No. 1 to describe the results of additional reentry evaluation.

A second supplement was issued January 24, 1969, to update the basic document because probability figures had been received from NASA and additional testing had been done on the response of the GLFC and FCA and its fuel to (1) fragments and overpressure from an SIVB explosion, (2) heating during reentry, and (3) impact with the earth following reentry. Additional studies had also been done on the retention of helium by the plutonium dioxide microspheres. Sandia worked with GE to help evolve the safety assessments, performing tests, performing independent analyses and reviewing GE's work.

The Interagency Safety Review Panel began its evaluation in February 1968 when representatives from NASA/Ames started a study of potential reentry environments. The membership of the panel expanded so that by September 1968 there were five subgroups: Range Safety, Reentry, Meteorological, Oceanographic, and Biomedical. The membership of these groups includes personnel from every major NASA facility, the AEC, and DOD. In addition there are consultants from HEW, Aerospace Corporation, TRW, Sandia, and the Naval Ordnance Laboratory. About 100 experts from many different disciplines considered the GE reports plus analyses and tests of their own to provide input to the panel.

As an example of its activities, the panel investigated the effect if boxes from the instrument unit (IU) of the Saturn V were propelled by an explosion into the GLFC. The postulated explosion was one of about 10% yield starting on the outer surface of the SIVB near the interface between the liquid oxygen and liquid hydrogen tanks. An ad hoc fragmentation committee with members from Sandia, Aerospace, TRW, Marshall Space Flight Center, KSC, NASA Headquarters, and NASA/Lewis met at Sandia on February 18 and 19, 1969, to establish the parameters for a test. On February 20, the test was performed at Sandia's sled facility. An instrument box from the IU, 9 x 12 x 15 inches and weighing 34 pounds, was impacted at 700 ft/sec into a secondary thermal shield containing a simulated capsule. The long diagonal of the box was parallel to the direction of motion and perpendicular to the long axis of the capsule. A catch box failed to contain the test articles after impact. The shield was broken, the capsule was broken in two, and each half had a hole gouged in it. It is not known whether this damage occurred at the time of first impact or on impact with the sled, the track, or the ground. Sandia's Aerospace Nuclear Safety Department estimated fuel spillage at 20% per second with 20% of the fuel remaining in the capsule.

The Safety Evaluation Report was issued on February 28, 1969. It postulates only two accidents from which lung burdens in excess of 0.016 microcurie might result. The 0.016-microcurie level is the upper

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limit of exposure to plutonium for radiation workers, derived from guidelines established by the International Commission on Radiological Protection.

The first such accident would occur on the pad. An abort resulting in a very high-yield explosion could produce fragments which might open the FCA and spill half the fuel into the fireball, resulting in 10,000 curies of vapor. There would also have to be an on-shore wind and neutral or unstable atmospheric conditions. The probability of exposing people to lung burdens in excess of 0.016 microcurie from this incident is on the order of 10^{-6} .

The second accident would result from the GLFC/FCA impacting earth after an abort. If it is postulated that the FCA has been substantially degraded by reentry heat or the explosion environment, that 10% of the microspheres have been reduced to less than 3 microns in diameter, and that the FCA breaches upon impact, the probability of exposing people to lung burdens in excess of 0.016 microcurie is on the order of 10^{-3} .

The last three steps in the program, recommendations by agency heads, action by the Space Council, and a decision on safety approval by the President, are expected in late March or early April 1969.

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.

During this report period additional time was spent on training at Sandia, using our mockup of the IU section. All training so far has been with interim training hardware; the qualification test hardware will be assigned to Sandia for training purposes as soon as the test program is complete.

The D2/M5 flight test mockup, which consists of a GLFC, support structure, and dummy FCA, will be flown aboard LM 4 on the Apollo 10 mission. The fuel capsule loading will be done during the countdown exactly as if the capsule were real. The flight hardware was shipped to KSC in December 1968; the tools needed during the on-pad loading operation were fit-checked with the flight hardware at KSC in February; and all remaining ground-support equipment for the D2/M5 flight will be shipped to the Sandia building by the end of March. The KSC countdown procedure for fuel capsule loading has been revised and approved for use on Apollo 10.

During the week of February 10 all members of the Sandia loading team completed their training at KSC for launch-pad access during Apollo launches. Also, they were permitted by NASA to tour the Apollo 10 launch vehicle.

KSC support requirements for vehicles, security arrangements, and communications have been reviewed with the AEC and forwarded to NASA. The requirements are those which are needed by Sandia for movement to the launch pad.

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1.3 SNAP 29

Isotopes
AT(29-2)-2062

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E. F. Johnson	505-264-2970
F. L. McFarling	505-264-2138

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 summer of 1968, the Martin-Marietta Nuclear Division was purchased by Isotopes, a subsidiary of the Teledyne Company, and was renamed the Nuclear Systems Division of Isotopes.

The SNAP 29 plans are to convert thermal energy from ^{210}Po polonium fuel 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 submitted a cost proposal and program plan to cover the present funding and schedule requirements for the SNAP 29 but, early in this quarter, the decision was made to end the program by June 30, 1969, because of budget reductions. This announcement required extensive changes in the basic program requirements. Isotopes is now proposing to furnish an electrically heated generator based on the present design by the end of June. This generator will then be available for performance testing after June 30, if any funds are available. Several additional tasks are also planned such as a solid propellant burn test, vehicle integration studies, and additional fuel studies.

Electrical Heat Source

Fabrication of the electrical heat source is complete and it is presently being instrumented.

Heat-Rejection System

Isotopes had difficulty diffusion bonding heat pipes to the radiator panel. Consequently, they have resorted to a rigid epoxy bond for this interface and two radiator panels have already been fabricated using this method.

Thermoelectric Modules

Two piston-type test modules, S/N 003 and S/N 005, and the one 90-couple 2N/TAGS module were placed back on power test to get a better comparison of the performance of these types. Test fixtures for the piston-type modules had been reworked to improve the insulation fit around the electric heaters and reduce the ΔT across the hot plate assembly; in the original tests these two modules did not have the benefit of this better insulation as the 2N/TAGS module had. Other purposes for the retest were:

To determine if the power output of the two 2N/3P modules would be improved (from 104 and 105 watts) with a smaller ΔT of $\sim 50^\circ\text{F}$ instead of $\sim 100^\circ\text{F}$ across the hot plate surface.

To see if the 2N/TAGS module, after having cooled down, would again reach its 109-watt output level.

To determine the power output of all three modules when the T/E cold-side temperature was increased to 375°F . This is thought to be nearer the actual system operating temperature for the heat-pipe, diaphragm-module design.

The coolant water loop failed and all three modules were so overheated that the cold-side temperatures reached about 850°F , hot enough to damage the cold-side circuitry. This damage to the last remaining SNAP 29 program test modules was a serious setback in efforts to get actual performance data for use in comparing couple designs.

Twenty 2N/TAGS couples from the several lots of SNAP 29 qualified units have been placed on long-term test. Results of these tests are reported in Table II. Units S/N's 02, 04 and 05 have undergone three simulated heat-up and cool-down cycles.

TABLE II

Tests of 2N/TAGS Couples

<u>Unit</u>	<u>T_h/T_c ($^\circ\text{F}$)</u>	<u>Time (hrs)</u>	<u>Output (watts)</u>	<u>Unit</u>	<u>T_h/T_c ($^\circ\text{F}$)</u>	<u>Time (hrs)</u>	<u>Output (watts)</u>
02	1050/350	2	1.64	05	1050/350	2	1.63
	1050/350	169	1.63		1050/350	165	1.59
	1050/375	218	1.50		1050/375	312	1.42
	Thermal Cycle				Thermal Cycle		
	1050/375	~ 1	1.40		1050/375	~ 1	1.33
	1050/375	~ 2	1.37		1050/375	~ 2	1.36
	1050/375	~ 3	1.38		1050/375	~ 3	1.37
	1050/375	600	1.41		1050/375	688	1.37
	1050/375	861	1.37		1050/375	837	1.35
04	1050/350	2	1.54	07	1050/350	2	1.62
	1050/350	166	1.56		1050/350	118	1.58
	1050/375	379	1.44		1050/375	263	1.51
	Thermal Cycles				1050/375	358	1.49
	1050/375	~ 1	1.43		1050/375	692	1.45
	1050/375	~ 2	1.42	10	1050/350	2	1.63
	1050/375	~ 3	1.43		1050/350	164	1.62
	1050/375	602	1.47		1050/375	306	1.48
	1050/375	860	1.44		1050/375	503	1.48
					1050/375	742	1.48

<u>Unit</u>	<u>T_h/T_c</u> <u>(°F)</u>	<u>Time</u> <u>(hrs)</u>	<u>Output</u> <u>(watts)</u>	<u>Unit</u>	<u>T_h/T_c</u> <u>(°F)</u>	<u>Time</u> <u>(hrs)</u>	<u>Output</u> <u>(watts)</u>
12	1050/350	2	1.51	23	1050/350	2	1.66
	1050/350	92	1.52		1050/350	70	1.59
	1050/375	169	1.43		1050/375	265	1.49
	1050/425	503	1.30		1075/375	662	1.60
	1050/425	675	1.31	25	1050/350	0	1.61
15	1050/350	2	1.68		1050/350	69	1.60
	1050/350	92	1.63		1050/375	260	1.49
	1050/375	482	1.53		1050/375	503	1.48
	1045/375	676	1.46	28	1050/350	2	1.50
18	1050/350	2	1.62		1050/350	51	1.50
	1050/350	67	1.62		1050/370	145	1.47
	1050/375	214	1.50		1075/375	165	1.41
	1050/N=439	672	1.29		1077/376	191	1.39
	1050/P=374	672	1.29	29	1050/350	2	1.57
20	1050/350	2	1.66		1050/350	69	1.54
	1050/350	50	1.67		1073/375	120	1.51
	1050/375	97	1.56		1073/375	169	1.48
	1050/375	263	1.53	16	1050/350	2	1.50
	1050/375	669	1.44		1050/350	92	1.49
22	1050/350	2	1.61		1078/375	262	1.62
	1050/350	75	1.60	32	1025/375	2	1.24
	1050/375	261	1.39		1025/375	77	1.26
	1073/375	505	1.44	33	1025/375	2	1.43
					1025/375	191	1.43
35	1030/375	2	1.28	38	1030/375	2	1.30

The TAGS-85 thermoelectric property measurement work at Battelle Memorial Institute, Columbus, Ohio, was started in January 1969 and is scheduled for completion by March 1969. Seebeck voltages and resistivity measurements have been completed along with density and specific heat determinations. Difficulty with the laser apparatus has caused a delay in measuring the material's thermal diffusivity and calculating thermal conductivity.

Isotopes completed one complete temperature cycle of the Haynes 25/beryllium ΔT test module. Testing ended during the second heat-up and cool-down cycle when a short to ground occurred in the heater circuit. The ΔT between the T/E element cold cap and the inside of the nickel heat pipes was 16°F which was near the predicted value of 15°F.

Another Haynes 25/beryllium braze operation was performed by Isotopes on a hot- and cold-plate assembly. The hot plate was satisfactorily brazed but the cold-plate braze failed in the same way as the previous hot plate, i.e., there were small cracks in the 0.012-inch

Haynes 25 sheet through which braze material penetrated. At this time a task force committee was formed at Isotopes to review the status of the SNAP 29 T/E module subsystem, with particular emphasis on this problem of sheet cracking. As a result of the task force investigation, and in the interim period before replacement materials could be received, several immediate steps were taken: The sheets of Haynes 25 were selectively graded on the basis of macroscopic surface examination, and only the best 2D-finish sheets were chosen for program hardware; none of the 2D-finish material was used until it had been reannealed in vacuum or inert gas to correct residual effects of stretching and, possibly, insufficient annealing by the supplier; and only bright, annealed, 0.012-inch sheets were used for the diaphragm components. (Even before the task force was set up, all 0.012-inch-thick Haynes 25 sheets next to the beryllium had been replaced with 0.024-inch sheets.)

As previously mentioned, after Isotopes experienced several problems in diffusion bonding heat pipes to the radiator panels, the change was made to a high-temperature adhesive bond. In addition, Isotopes plans to use an RTV silicone rubber to bond the heat pipe evaporator section into the thermoelectric module. Using a silicone material as the bonding agent will increase the cold-junction temperature of the T/E to an estimated 385 to 400°F.

Status of Hardware

Diaphragm module S/N 1 has been fabricated and instrumented; its heat-pipe panel is undergoing final checkout. The mating of module and panel was expected to be done by mid-March. Diaphragm module S/N 2 and its heat-pipe panel were scheduled for completion in mid-March. Assembly of this module and heat-pipe panel was scheduled for completion by the last week of the same month. Module S/N 3 is in the process of having the cold end of the couples bonded to the sprayed-on electrical circuitry.

Thermal Control Subsystem

Fabrication and assembly of the thermal control subsystem has been completed for the engineering model, which will be delivered. It will not be possible to complete testing and evaluate any problems disclosed before the end of the present contract.

RTG Housing Structure

The structure has been assembled and disassembled several times and is ready to have the modules inserted as soon as they are ready. There are still problems with welding techniques which have not been solved; some analyses have been made of them and some corrective action taken in the specifications, but no proof of the effectiveness of these has been or will be furnished. No vibration test of the structure will be made before the contract expires. The effort at this control point is considered to be complete so far as the engineering model is concerned.

1.4 Transit (formerly NAVSAT)

TRW
AT(29-2)-2617

D. L. Krenz 505-264-4041
R. J. Luikens 505-264-2534
V. G. Redmond 505-264-5255

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 Transit satellites. Design constraints for the Transit RTG now include a 30-watt power output at the end of a life (EOL) of 5 years, and an intact-through-impact fuel capsule.

A major modification was made when, based on the Navy's power requirements for the modified Transit satellite, the RTG power requirement was increased from 20 to 30 watts at EOL. Thus, during the Phase I study phase, TRW had to reevaluate candidate thermoelectric conversion systems. Major changes were necessary in the Phase II program milestones. Revised, they are as follows:

<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 Phase II preliminary program plan	April 8, 1969
Design-review Meeting	April 8, 1969
Selection of RTG design--including fuel capsule, heat source, fuel form, and converter--by AEC	April 18, 1969
Freeze RTG/satellite interface	June 15, 1969
Submission of preliminary safety analysis report (PSAR)	July 1, 1969
Heat source specification to Mound	December 1, 1969
Submission of up-dated PSAR	January 15, 1970
Deliver 1st electrically heated RTG	March 1, 1970
Deliver 2nd electrically heated RTG	June 1, 1970
Receive ground-test heat source	October 15, 1970
Complete safety test and analysis	October 15, 1970
Start ground test of fueled RTG	November 1, 1970
Submission of final safety analysis report	January 15, 1971

<u>Milestone</u>	<u>Date</u>
Final fueled RTG environmental qualification	December 15, 1970
Receive 1st flight heat source	January 15, 1971
Deliver 1st fueled RTG to APL	March 31, 1971
Receive 2nd flight heat source	April 15, 1971
Deliver backup fueled RTG to APL	June 15, 1971

During the Phase I study, TRW reassessed the plutonium fuel form, T/E converter, and heat source technologies in view of these revised milestones.

After reviewing the existing literature and reports covering the status of various AEC-funded programs on plutonium fuel forms, T/E converters, and heat source technology, TRW sent a list of detailed questions to the appropriate contractors and made visits to their locations to discuss these questions. Also, tours were made of the contractors' test and manufacturing facilities. Those visited were:

Los Alamos Scientific Laboratory
 Battelle Memorial Institute
 Hittman Associates
 Westinghouse Astronuclear Laboratory
 General Electric, MSD
 Mound Laboratories
 RCA
 Sanders Nuclear
 3M
 Atomic International
 Gulf General Atomics
 Sandia Laboratories

Although no trip was made to Isotopes, Inc., a meeting with Isotopes staff representatives was held at TRW.

A design-review report was being prepared by TRW for submission to the AEC on March 24, 1969. This report evaluates the various fuel forms, T/E converters, and heat source technologies in view of the Transit RTG program requirements, as specified by the AEC. An evaluation team has been formulated at Sandia to review the TRW design-review report.

On April 8, 1969, TRW will present a recommended Transit RTG design to the AEC for their consideration. Following the TRW presentation, Sandia will present the results of their report review and evaluate the TRW-recommended RTG design.

By April 19, 1969, the AEC will direct TRW to proceed with the design and development of a specific RTG for the Transit satellite.

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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. Alternating washers of p- and n-type lead telluride (Figure 2) are electrically insulated from one another by mica disks. 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 2. Tubular module used in Westinghouse compact converter

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TEM-1 S/N 1, the first module fabricated for this program, has accrued over 31,000 hours on test at $T_h = 1000^\circ\text{F}$. Recent data indicate that it is continuing to operate in a stable manner with less than 3% efficiency degradation during the past 2 years of testing.

Data from the first two modules incorporating a two-piece inner conductor ring, to insure isolation of p- and n-type T/E materials, indicate that the circuit efficiency is unchanged after 500 hours of operation at $T_h = 1100^\circ\text{F}$.

Attempts to decrease the weld shrinkage, which is thought to cause distortion of the mica at the outer conductor rings in the end couples, are continuing. The efforts so far include reducing the weld volume at the outer-clad/retainer-ring joint and fabricating samples for investigation of TIG and EB welding processes.

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 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 .

The third demonstration generator, GC03, has been fabricated and instrumented and is ready for performance and life testing. This converter has eight GC02-type panels and two panels with M&M bonds and laser-welded cold caps.

An outgassing from one batch of aluminum-opacified paper used in the foil insulation was identified as zinc. Precautions have been taken by both the contractor and vendor to assure the cleanliness of opacified paper.

A thermal analysis of an Isotec system operating in space environment has shown that uneven solar heating of the radiator does not perturb the hot-junction temperature by more than 2°C .

M&M-bonded n elements have been on an accelerated life test for 6500 hours at 500°C without any failing.

Most of the contractor's efforts during this quarter were spent gathering and reporting information for the Transit review.

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, made up of Haynes-188 capsules, silica insulation, and graphite reentry protection, have been subjected to vibration, impact, and plasma testing. In general, they survived the Scout launch vibration environment and impact on granite at the terminal velocities anticipated after reentry. The four impact tests were as follows:

<u>Wall Thickness (in.)</u>	<u>Impact Velocity (ft/sec)</u>	<u>Impact Temperature (°F)</u>	<u>Results</u>
0.045	305	1790	Inconclusive*
0.055	306	1808	Intact
0.045	315	1680	Intact**
0.035	315	1802	Small crack in shell

*Capsule did not remain in catcher. Capsule breached.

**A small crack about 1/8-inch long occurred because of holder interference.

The simulated-reentry plasma test was inconclusive since the specimen rotation fixture failed. The capsule did burn through after rotation stopped but the heat source was not designed to survive a non-spinning reentry.

The silver-silica thermal switch effort is continuing with work directed toward determining the impregnability of various silica foams, the material properties of these foams, and applicability of the thermal switch to spherical and cylindrical heat sources.

2.2.2 Large Radioisotope Heat Source Capsule Program (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 about 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.

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During this reporting period four more capsules were impacted. Two had the standard 127-mil-thick walls while the other two had 100-mil-thick structural shells. The planned impact was 300 ft/sec at 1200°F but the capsules actually impacted at 260 and 250 ft/sec because of difficulties with the sabot holding each. All four capsules readily survived impact. To get rid of the sabot, AI has constructed a new impact gun barrel with its own capital, and also improved the instrumentation. Upcoming tests should yield much better results.

The creep tests are continuing and at one time during the quarter there were four creep rigs in operation. The creep-rupture ended at 3500 hours when the capsule ruptured at between 13 and 15% strain and an internal pressure of 4970 psi. The failure could be described as catastrophic as about a 2-inch hole opened in the side. However, the significant point in this test was the very high strain reached before failure; it had been expected that the strain to rupture would be in the range of 7 to 10%. The rupture was very ductile in nature with about a 50% wall-thickness reduction in the area of the rupture. Complete metallurgical evaluation is presently underway. Other creep tests performed included the first "A" capsule configuration, and a "B" capsule crept to 5% strain. Tests presently in progress include A-2 (1480 hours), B-4 (170 hours), and B-6 which is scheduled for 1% strain in 8800 hours and 5% strain in 13,800 hours. Analytical evaluation of the creep results is underway as is a thorough posttest metallurgical and chemical examination of the shells.

The major problem experienced in the program to date is the galling which occurs during the shrink-fit assembly of the "fueled" sub-assembly into the structural shell. Friction tests were performed at Sandia to determine the benefit of an alumina coating on the Ta 10W liner to be inserted in the T-111 structural shell. The results were very encouraging; however, the first attempt to make this assembly using an alumina coating was unsuccessful. Significantly, though, no damage occurred to either the liner assembly or the structural shell. Other parameters, such as a thermal mapping of the open end, are being investigated and another attempt will soon be made.

Principal meetings which were held include the Transit application briefing and a meeting with Mound personnel on the piece parts for prototype fueling. No new topical reports have been released, although one on piece-part fabrication is being prepared, and AI's only publications have been the normal monthlies and the quarterly.

2.2.3 Lightweight Capsule

Gulf General Atomic
AT(29-2)-2588

I. G. Waddoups 505-264-4107

Three nominal 8-inch-o.d. refractory capsules were impacted as follows:

<u>Design</u>	<u>Impact Velocity (ft/sec)</u>	<u>Impact Temperature (°F)</u>	<u>Results</u>
A	316	481	Several cracks
B	315	462	Inner capsule intact
B	315	526	Inner capsule intact

Design A had the fuel simulant peripherally loaded and design B had the fuel simulant loaded in a 4-inch-o.d. sphere held centrally in the 8-inch sphere. The outer shell was 0.02-inch-thick tantalum in all cases. The inner 4-inch capsules were 0.02-inch T-111 enclosed in 0.01-inch platinum. One of the 4-inch capsules had an additional layer of 0.005-inch tantalum over the platinum. The platinum was breeched in both cases but the inner T-111 shells were intact.

Several 4-inch-o.d. coated spheres were plasma tested to evaluate hafnia and pyrocarbon coatings. Four hafnia-coated and 4 pyrocarbon-coated spheres were submitted to a $230 \text{ Btu/ft}^2/\text{sec}$ pulse for 30 seconds to determine the thermal shock characteristics of the coatings. The coatings exhibiting the best adherence to the substrate were 0.01-inch hafnia and 0.045-inch pyrocarbon. All of the coatings prevented capsule melting whereas the uncoated capsules tested did melt. The thicker pyrocarbon coating showed no appreciable deterioration. Three other capsules with hafnia coatings were submitted to a simulated reentry pulse. All of the hafnia coatings tested to date have lost adherence to the substrate at the stagnation point. Preliminary evaluation indicates that the coatings over a CVD tungsten layer prevent contamination of the T-111 during reentry. One of the hafnia-coated spheres tested for 30 seconds was subsequently submitted to the reentry pulse which resulted in a burned-through capsule.

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.

Material samples of 63.5-, 70-, and 80-percent-silicon SiGe and SiMo continue to be evaluated by use of isothermal tests at temperatures ranging from 900 to 1200°C. Tests are being carried out both in air and in vacuum to determine weight changes as well as changes in thermoelectric properties.

The hot pressing of both SiMo and SiGe alloys has been very successful. This method is currently being used in preparing most of the samples for evaluation of bonding, material composition, etc. The advantages and risks of using hot pressing exclusively (that is, dropping zone leveling of SiGe and vacuum casting of SiMo) in further development are currently under consideration.

The inability to obtain acceptable SiC shoes from the vendor (delivery is currently nearly 6 months late) is preventing any significant evaluation of this potential shoe material. The vapor-deposition techniques for coating graphite shoes with SiC appear to be approaching optimum. Several types of graphite are currently being evaluated for this use.

The coefficients of thermal expansion as a function of temperature from 100 to 1100°C have been determined for SiGe alloys with compositions ranging from 63 to 100% silicon as well as the standard SiMo alloy. Similar measurements are being made on graphite under consideration for use as shoe materials.

Evaluations are underway to determine the optimum means of attaching the air-vac cold stack to the converter radiator. A number of variations of the bolted attachment are under consideration.

A variety of couple configurations continue to be used in couples made for mechanical and performance testing. Vibration testing (cold)

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of couples during this quarter indicated the reference design couple to be quite rugged; it survived 40 g's, the limit of the tester equipment. Testing of the frame couple, designed to achieve very large I/A, indicated much lower limits; cracks in the T/E legs occurred at levels from 5 to 20 g's.

The status of performance testing on modules and converters to date may be summarized as follows:

Reference design converter, constant power input: Time on test ~6000 hours, average $T_h \sim 975^\circ\text{C}$, power output -25.4 watts, power decrease from 1500-hour point 2.7%.

Min-K insulated converter, constant power input: Time on test ~7500 hours, average $T_h \sim 1000^\circ\text{C}$, power output -4.75 watts, power decrease from completion of performance mapping (at ~2000 hours) <2%.

Intermediate-flux, high-temperature module: After 30 hours of operation at 1150°C the module was shut down because of severe shrinkage of the Min-K 2020 insulation. The module insulation was replaced with Dynaquartz. After 500 hours at 1150°C this insulation appears stable.

Linde foil insulation converter: All couples in this converter have been replaced (a number of the original couples were broken during converter assembly) with couples of a new cold stack configuration which allows electrical connections to be made after individual couples have been inserted through the insulation. The performance mapping of the converter was started this quarter.

SNAP-17A modules: The times on test range from 36,000 to 40,000 hours and all modules are operating at 90 to 100% of their respective 500-hour power levels.

The parametric analyses of cascaded converters is continuing. Analyses of all variations to be considered with a fixed Isotec cold stage have been completed. Analyses to determine effects of changing the cold stage configuration have 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.

Effective March 1, 1969, the testing of the SNAP-17A type modules will continue under Contract AT(29-2)-2510. Their status was therefore reported under that section.

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 by testing modules.

Ten 500-gram batches of TPM-217 have been reacted and analyzed for material content. It has been determined by x-ray diffraction and atomic absorption techniques that the content of the 10 batches varies by a maximum of ± 0.3 w/o. Trace impurities as determined by emission spectroscopy have been kept below 100 ppm (average was less than 20 ppm).

Thirteen TPM-217 elements have been placed in gradient thermal tests. Of the thirteen, one is operating between the temperature limits of 800 and 300°C, four are operating between 700 and 280°C, four are operating between 600 and 260°C and four are operating between 500 and 210°C. The one element operating at a hot-junction temperature of 800°C has been on test for about 5000 hours and shows no change in performance.

The Seebeck coefficient, electrical resistivity and thermal conductivity of TPM-217 have been determined; Figure 3 shows the figure of merit as a function of temperature.

Figure 3. TPM-217 figure of merit as function of temperature

2.4 Thermal Insulation

Introduction

Three contracts are under way 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; the Phase I activities started in mid-FY 1966. Each company is now doing a Phase II follow-on program.

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 insulation by conducting long-term, continuous tests at maximum operating temperature. The copper-opacified quartz system has completed the 10,000-hour test. The apparent thermal conductivity remains unchanged from the original measurement of 15.45×10^{-3} Btu/hr-ft-°F between 1220 and 415°F. Performance deterioration after 10,000 hours as predicted by free-vaporization analysis was estimated, before testing, at 10 to 20%. That such deterioration was not experienced indicates the analysis was conservative.

The nickel-opacified, multilayer system has now been on test for 3600 hours. The apparent thermal conductivity of this system is about 7.85×10^{-3} Btu/hr-ft-°F between 1485 and 577°F. This remains at a level about 3% higher than the original value because of thermal etching of the surface. The molybdenum-quartz system, a substitute for the Ni-quartz system at higher temperatures, will begin test on April 1.

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. More thermal conductivity data have been obtained on the nickel-astroquartz system at the higher loads. Plans have been made to retest some of the aluminum multilayer systems to upgrade the data generated early in the program. Also, the flat plate tester will be used to test the molybdenum system at temperatures up to 2500°F. The completed Nickel data are as follows:

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	0.10	120	1.31
1515	230	0.10	120	2.27
540	110	1.0	132	2.15
1533	230	6.0	132	2.66
549	111	6.0	142	2.22
1544	272	6.0	142	4.64
536	139	15.0	152	3.87
1543	310	15.0	152	5.53

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. The new analytical model incorporating a radiation component for the opacified fillers has been completed and is operational. Test hardware and a sample fixture have been completed to test an actual penetration. An Isotec panel with elements and fillers will be used in the initial tests to check the analytical program.

2.4.2 1800°F Bulk Insulation

Johns-Manville
AT(29-2)-2661

D. J. Mottern 505-264-6638

The technical portion of the Phase II work is completed. After completion of the final report this contract will be closed out. Data are now available for all the Min-K formulations and the Glasrock silica foam.

Evaluation of Min-K Formulations

Thermal conductivity data on Min-K 2020 has been measured in vacuum and air at mean temperatures up to 1600°F after 2000 hours at 1600°F in vacuum. These data are given below.

<u>Atmosphere</u>	<u>Mean Temp (°F)</u>	<u>Thermal Conductivity (Btu/hr-ft-°F)</u>
Air (1 atm)	500	0.0178
	846	0.0208
	1202	0.0254
	1600	0.03
Vacuum (10 ⁻⁵ Torr)	500	0.01
	850	0.0176
	1250	0.03
Vacuum (2 x 10 ⁻⁴ Torr)	1600	0.0455

As one can see, the conductivity in vacuum is higher than in air above 1200°F. This appears to be a problem in experimental measurement rather than of the insulation itself; an attempt will be made by Johns-Manville to modify their equipment to get more meaningful readings. It is doubtful that the Min-K conductivity data at elevated temperatures will be available for the final report.

Load-Bearing Insulation

The objective of this task was to develop the best bulk insulation with load-bearing capabilities. An evaluation of the load-bearing characteristics of unopacified Glasrock silica foam was completed. This product at 25 to 30 lb/ft³ density should not be used above 200-psi loading for extended periods since it will result in a permanent set. The thermal conductivity determination has not been completed but will be included in the final report. The thermal conductivity of unopacified Glasrock 25 is as follows:

<u>Mean Temperature (°F)</u>	<u>Thermal Conductivity (Btu/hr-ft-°F)</u>
303	0.085
399	0.09
519	0.97
633	0.105
856	0.118
913	0.121
1120	0.133
1228	0.14
1589	0.161

2.4.3 High-Temperature Insulation

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Task 2 - Spray Coating and Layer Variation Measurements

The reproducibility tests have been completed and the heat flux through 4 of the 6 Ta-ThO₂ test samples varied by less than 0.016 watt/cm² at 1700°C. The layer variation measurements are nearing completion. The 40, 80, 120, 160, and 200 layer Ta-ThO₂ insulation samples have been evaluated between 700 and 1800°C. At the lower temperatures (700 to 900°C) there were relatively small reductions in heat flux for added layers of insulation; in the 1600 to 1800°C range the reductions were very significant. The 160- to 200-layer samples were able to limit the heat flux to less than 0.01 watt/cm².

Task 5 - Edge Heat Losses

The second series of edge loss tests involving the concentric-cup corner assembly have been completed. At 1700°C a 35% reduction in edge losses, to about 0.6 watt/cm², was realized. This was attributed primarily to reduction of the thermal losses through the butt joint.

Task 6 - Lower Temperature Applications

The 6- and 12-inch-long, 40-layer samples of Al-ZrO₂, Cu-ZrO₂, SS-ZrO₂, and Ni-ZrO₂ have all been tested. The results, pending analysis, will be reported in the next quarterly.

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