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SNAP 19 TAGS 85/2N
RTG POWER SYSTEMS
THIRD SEMI-ANNUAL PROGRESS REPORT

(July 1, 1970 to December 31, 1970)

INSD-2873-44

January 1971

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AEC CONTRACT NO. AT (29-2)-2873

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FOREWORD

This is the third Semi-Annual Progress Report to be issued for the SNAP 19 TAGS 85/2N RTG being developed for Pioneer F and G missions in 1972 and 1973, respectively, and the Viking mission scheduled for 1975.

Technical information reported herein covers the period July 1, 1970 to November 30, 1970 under AEC Contract AT(29-2)-2873.

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I. SUMMARY

The outstanding achievement of this reporting period was re-design of the heat source capsule support to minimize impact loading on the generator heat shield and converter components during severe dynamic environments of the Pioneer launch. A firm, lasting constraint of the fuel capsule was conceived, implemented, and tested successfully. This enabled fabrication and fueling of the first RTG, S/N 37, with confidence in its ability to withstand qualification level testing.

Other major accomplishments are listed below in outline form for each engineering task.

1. Generator Design and Analysis
 - a. Design of integrally machined handling lugs to facilitate fabrication.
 - b. Modification of inter-module electrical connection to provide strain relief.
 - c. Replacement of safety wiring with bolt retainers to expedite fueling operations.
 - d. RTG design for Viking mission initiated.
 - e. Mass properties prediction updated to include measured component weight and dimensions.
 - f. Component structural analyses performed to validate adequacy of the heat source support.
 - g. Updated reliability and performance evaluation for the Pioneer mission.

- h. Prediction of RTG design performance for the Viking application.
2. Heat Source Development
- a. Receipt of the first two fueled capsules.
 - b. Thermal stress analysis of heat shield during reentry.
 - c. Evaluation of graphite and zirconium oxide materials properties.
 - d. Thermal analysis of hard-mounted fuel capsule design.
 - e. Investigation of alternate heat source components such as the HRD and thermal switch.
 - f. Preparation of test procedures in support of safety evaluation tests.
 - g. Preliminary evaluation of impact tests of heat sources.
3. Generator and Component Testing
- a. Continuation of long term tests of ETG's S/N 26 and S/N 29.
 - b. Performance of load voltage parametric and hot leak tests for ETG's and RTG S/N 37.
 - c. Presentation of cold vibration test series performed in development of fuel capsule support.
 - d. Successful completion of qualification level vibration testing on ETG S/N 36.
 - e. Completion of electrical heater endurance test.
 - f. Evaluation of pressure containment capability of the RTG housing.

- g. Investigation of viton, solder and metal-v seals at the electrical connector.
 - h. Initiation of thermal coating study for Viking mission.
4. Safety Evaluation
- a. Probabilistic analysis of misorientation during third stage burn and micrometeoroid puncture.
 - b. Study of environment exposing heat source and the altitude of heat source release.
 - c. Continuation of aerophysics effort to define the reentry flight path and heating distributions.
 - d. Development of thermal response analyses during reentry.
 - e. Preparation of Safety Analysis Report (SAR) plan and schedule.
5. Auxiliary Ground Equipment
- a. Refurbishment of all fuel capsule shipping containers completed.
 - b. Design and fabrication of RTG shipping containers.
 - c. Modification of RTG handling adapter.
 - d. Design and fabrication of fueling tools.
 - e. Delivery of two ETG power supply consoles.
 - f. Delivery of two portable monitor packages.
 - g. Review of Viking requirements.

II. GENERATOR DESIGN AND ANALYSIS

A. MECHANICAL DESIGN

1. Pioneer Design

This section discusses modifications to the Pioneer generator mechanical design which occurred during this period.

a. Hard mounting of fuel capsule

In order to reduce the impact loading on heat shield and converter components, a revised means of support for the fuel capsule was designed and incorporated into the Pioneer generators. Figure II-1 illustrates the features which replace the previous tantalum felt which relaxed under dynamic environment exposure with a firm, lasting constraint of the capsule. The principal components of the design are (1) the zirconia end pieces which hold the capsule yet provide sufficient thermal impedance to allow tolerable reentry temperatures and (2) the POCO graphite end plugs of the heat shield which contain a breakable section (shear ring) to accommodate excessive expansion of the fuel capsule during reentry.

b. Integrally machined handling lugs

The original method for attaching the RTG handling lugs to the housing body required machining of the lugs as separate pieces and subsequent welding to the housing. However, subsequent chromic acid pickling of the housing assembly divulged pits and/or occlusions in the thin (.080 inch) weld seal rim material adjacent to the lug attachment welds. In order to avoid potential gas leakage and/or structural weakness, the housing design was modified to enable machining the lugs integral with the housing body. This was accomplished within the dimensional constraints imposed by the existing raw stock material by decreasing the handling lug bolt circle from 9.20 inches to

FIGURE II-1. PIONEER HEAT SOURCE

8.875 inches. This change is being effected on all deliverable Pioneer RTG units.

In order to reduce handling time required for interfacing the RTG handling adapter with the generator, threaded titanium inserts have been added to the handling lugs of all RTG units.

c. Modified inter-module electrical connection

In order to preclude circuit damage during environmental exposure, the module interconnecting straps were shortened to provide a flexible joint. The wire consists of untwisted strands to provide further reduction of the flexural stiffness of this joint. Figure II-2 shows the module interconnection detail as revised.

d. Upper cover bolt retainers

As a result of generator fueling practice exercises, it became apparent that the installation of safety wire to the 12 bolts attaching the upper cover to the housing was excessively time-consuming. Therefore, the safety wire was replaced by 12 bolt retainers which are simply dropped in place once the bolts have been torqued and aligned. Figure II-3 illustrates the bolt retainer design.

2. Viking Design Description

Review of existing Pioneer drawings, specifications and procedures was completed, and necessary modifications initiated to reflect the Viking design. Generally, the Pioneer cold end hardware and thermoelectric converter designs were retained with only drawing number changes. The generator housing for Viking will be a new design reflecting the requirements for mechanical and thermal integration with the Viking spacecraft.

FIGURE II-2. MODULE INTERCONNECTION

FIGURE II-3. BOLT RETAINER CONFIGURATION

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II-5

3. Mass Properties

The effort toward determining and controlling the mass properties of a SNAP 19 Pioneer generator consisted of two parallel tasks: (1) utilization of a computer program, LAMP, to predict the mean and variance of generator weight, center of mass, moments of inertia, and products of inertia; and (2) maintenance of a generator weight status.

a. Computer program (LAMP)

The LAMP computer program, which was reported in the Second Semi-Annual Progress Report, INSD-2873-26, was utilized to predict the mass properties of a SNAP 19 Pioneer RTG. Input data, consisting of component weight, distance between component centroid and the geometrical center of the generator, and the moment of inertia of the component about the axes through its centroid and parallel to the generator reference axes, were prepared for the prototype RTG. The reference axes are defined by the mounting plane of the RTG and are illustrated in Fig. II-4. The predicted generator mass properties and the associated three-sigma variances are presented in Table II-1.

b. Weight summary

The current SNAP 19 Pioneer weight prediction based on a combination of measured and calculated weights is shown in Table II-2. Again, the indicated uncertainty is three times the calculated standard deviation.

4. Component Design Studies

a. Thermal expansion analysis

As described previously, the introduction of the hard mount concept for supporting the Pioneer fuel capsule within the heat shield required provisions for accommodating thermal expansion of the fuel capsule relative to the heat shield. Thus, a shear

FIGURE II-4. AXES ORIENTATION

INSD-2873-44

II-7

TABLE II-1

LAMP Mass Properties Summary
(3 σ Var.)

Total Generator Weight:

$$29.18 \pm 0.261 \text{ lbs.}$$

Center of Gravity (measured from mounting plane):

$$\text{X Dimension} = 0.0171 \pm 0.0054 \text{ inches}$$

$$\text{Y Dimension} = 0.00079 \pm 0.0051 \text{ inches}$$

$$\text{Z Dimension} = 5.7270 \pm 0.0184 \text{ inches}$$

Moments of Inertia About the Mounting Plane Axes:

$$I_{xx} = 1187.823 \pm 3.126 \text{ lbs-in.}^2$$

$$I_{yy} = 1189.328 \pm 3.358 \text{ lbs-in.}^2$$

$$I_{zz} = 205.271 \pm 5.750 \text{ lbs-in.}^2$$

TABLE II-2
SNAP 19/Pioneer RTG

<u>Assembly/Component</u>	<u>Weight, lbs.</u>
<u>Container Assembly</u>	8.72 $\pm$ 0.168
Housing Assembly (w/inserts)	5.96*
Upper Cover (w/bolts and washers)	1.22*
Upper Weld Ring	0.15*
Lower Cover (w/bolts and washers)	0.82*
Lower Weld Ring	0.12*
Connector (w/O-ring)	0.11*
Emissive Coating	0.34
<u>Energy Conversion Assembly</u>	4.24 $\pm$ 0.031
Couples	2.86*
Straps and Wiring	0.36*
Insulators (Mica)	0.08*
Insulation	0.86*
Instrumentation	0.02
Magnetic Compensation	0.06
<u>Heat Sink Assembly</u>	3.80 $\pm$ 0.009
Buttons	0.15*
Pistons	0.70*
Module Bars	2.65*
Springs	0.30*
<u>Load Support and Miscellaneous</u>	1.11 $\pm$ 0.015
Upper End Discs	0.55*
Lower End Discs	0.47*
Fiber Insulation	0.02
Solder	0.02
Nameplate, Safety Wire, and Bolt Retainers	0.05
<u>Heat Source</u>	11.31 $\pm$ 0.197
Fuel Capsule	7.72*
Sleeve (long)	0.51*
Heat Shield Body	1.60*
End Plugs	0.85*
ZrO ₂ Rings	0.61*
Thermal Pads	0.02*
Total	29.18 $\pm$ 0.261

*Measured Weight

ring integral with the heat shield end cap was designed to fail under expansion induced loads in excess of 4600 lbs, as arising from pre-load torquing, thermal expansion, and dynamic environments.

Since thermal expansion represented the major factors and also was of greatest uncertainty, an analysis was performed to examine the relative thermal growth/shrinkage of heat source components resulting from the thermal history of the RTG. Conservative assumptions were employed throughout. The fuel capsule was assumed to have an effective length equal to the distance between the two tangency points with the load rings. Relative thermal growth resulting in an interference of the capsule to the support ring and heat shield structure was reacted by the shear strength of the shear ring and end plug threads, axial tension in the heat shield body, and compression in the capsule components. Two cases were examined, one with the clad as the load bearing member and one with the clad "crushed" and the T-111 strength member as the load bearing structure.

Significant results of the analysis are presented in Tables II-3 and II-4. The positive margins of safety in each case considered show that, under the predicted temperature distributions in the period of interest, structural integrity of the heat source components is maintained.

A complete report discussing background and results of this study will be issued during the next report period.

b. Heat source lateral restraint

Additional work was performed during this period to assess the requirements for a modified support system in order to isolate impact loads generated by the heat source from passing through the thermoelectric modules. As reported in the previous period, analyses indicated that these loads could be of such a magnitude as to

TABLE II-3

SNAP 19 Pioneer Heat Shield Resultant Loads for Clad Loading Bearing Case

<u>Condition</u>	<u>RTG Circuit</u>	<u>Total Thermal Growth</u>	<u>Axial Load, lbs.</u>				<u>Margin of Safety</u>
			<u>Thermal</u>	<u>Preload</u>	<u>Dynamic</u>	<u>Total</u>	
Fueling in submarine	S. C.	No gap	0	170	0	170	+26
Air operation (no booties)	Load	.000004" gap	0	0	1560	1560	+ 1.95
Normal BOL operation	Load	.00004" interference	60	170	0	230	+19.0
Shipping container	S. C.	.000211" interference	317	170	small	~ 500	+ 8.2
Operation in spacecraft shroud*	S. C.	.000058" interference	87	170	0	257	+16.9
	Load	.000463" gap	0	0	1560	1560	+ 1.95
Operation in spacecraft shroud**	S. C.	.000537" interference	806	170	0	976	+ 3.71
	Load	.000003" gap	0	0	1560	1560	+ 1.95

*Gas fill of 80% helium 20% argon, resulting from 75% helium release.

**Gas fill of 75% helium 25% argon, resulting from 0% helium release.

TABLE II-4

SNAP 19 Pioneer Heat Shield Resultant Loads for Strength Member Load Bearing Case

<u>Condition</u>	<u>RTG Circuit</u>	<u>Total Thermal Growth</u>	<u>Axial Load, lbs.</u>				<u>Margin of Safety</u>
			<u>Thermal</u>	<u>Preload</u>	<u>Dynamic</u>	<u>Total</u>	
Fueling in submarine	S. C.	No gap	0	170	0	170	+26
Air operation (no booties)	Load	.000369" gap	0	0	1560	1560	+ 1.95
Normal BOL operation	Load	.000807" gap	0	0	0	0	not critical
Shipping container	S. C.	.000416" interference	624	170	small	~ 800	+ 4.75
Operation in spacecraft shroud*	S. C.	.000925" interference	1388	170	0	1558	+ 1.95
	Load	.000172" gap	0	0	1560	1560	+ 1.95
Operation in spacecraft shroud**	S. C.	.000122" interference	1833	170	0	2003	+ 1.30
	Load	.000133" interference	200	170	1560	1930	+ 1.38

*Gas fill of 80% helium 20% argon, resulting from 75% helium release.

**Gas fill of 75% helium 25% argon, resulting from 0% helium release.

result in bottoming of the spring-piston module support system.

A design concept was developed which utilized pre-loaded wedges of Min-K insulation located adjacent to the ends of each module bar and so shimmed as to react a major portion of dynamically induced lateral loads from the heat source directly into the housing wall, thereby bypassing the thermoelectric modules as the primary load transmission path. Bench testing was performed to evaluate the compressive strength of Min-K pieces closely matching the intended configuration. Results indicated a marginal strength capability. Improving the structural capability of these pieces required an increase in dimensions but implementation was severely limited by the lack of available space in the generator. The design concept was held feasible but in need of material and/or configuration improvements.

A second approach briefly explored was the use of a stiffer spring support system either through the use of a new spring design or nesting an additional spring inside of the existing one. Based on availability of stock springs the nesting approach appeared feasible but offered only marginal improvement.

Concurrent with these design studies, preparations were made to perform a static load-deflection test on an actual generator core assembled in a housing. Results of this test, clearly showed that the lateral spring constant of the existing system was much greater than that which had been analytically predicted. The conclusion drawn from this test was that bottoming of the spring-piston combination would not occur during vibration and that further attempts to stiffen the lateral support or provide a structural bypass were not necessary.

c. Electrical connector load analysis

Dynamically induced loads from the RTG/spacecraft power cable and supporting bracket are reacted in part by the power output connector in the RTG housing. On

the basis of dynamic test data and conservative analysis, TRW has provided predicted load data to Teledyne Isotopes for use in evaluating the structural effect on the connector. By superimposing the bending moment and axial load introduced into the connector an analysis of the effect of this environment on the connector was performed. The loads are of such low magnitude as not to result in any structural failures of the connector or its back-up support in the housing. Of prime concern was to determine whether these loads would result in a relaxation of the pre-load at the connector to housing seal interface. The analysis concluded that the connector seal integrity would be maintained by a very substantial margin under these load conditions. Results of the analysis are reported in INSD-PFA-9640.

5. Systems Evaluation Tests

a. RTG shroud evaluation test

In order to protect the RTG emissive coating from damage and discoloration during the welding operation in the fueling chamber, a shroud was devised to cover the generator except for the area being welded. The shroud is made of sheet aluminum and is hexagonal prism in shape with a circular hole in the top which fits over the top of the generator. Slots are provided at the top of each of the six sides to facilitate natural convective cooling and to provide access for tooling. The shroud concept was first tested on SNAP 19 generator S/N 26 to demonstrate practicability and to determine the associated temperature rise. The fin root temperature reached stability at 285°F with a rise of 29°F in 55 minutes. In addition, practice weld tests on a used housing showed that the shroud successfully maintained a clean emissive coated surface. The shroud has now been successfully used in welding RTG units S/N 37 and 38.

b. Helium seal weld test

Two seal plugs (452B5100018-001) and two tubes for the upper cover (452B-5100004-003) were fabricated for the purpose of evaluating adequacy of the final generator weld in a pure helium environment. Two such assemblies were welded in the submarine in 100% helium without difficulty. Prior testing had been performed in 100% argon.

Subsequent to a visual examination which detected no anomalies, the two assemblies were leak checked with helium. No leak was detected on either weld assembly with a machine sensitivity of 2×10^{-10} scc/sec. Metallography was performed on both samples confirming the high quality of the weld. The minimum depth of weld penetration measured was 59 mils. These tests confirmed the ability to successfully seal weld the subject parts in either helium, argon or mixtures of these gases.

c. Heat shield shear ring tests

A total of seven end plug assemblies of the configuration shown on Fig. II-1, with the shear ring machined in the POCO graphite load ring, were tested to determine the apparent shear strength of the load rings of the hard mount heat shield. The test data verified the design for hardmounting the SNAP 19 Pioneer fuel capsule.

The tests included end plug assemblies of the configuration shown on Fig. II-1. These assemblies had previously been cold and hot vibration tested. The average load at failure was 4600 lbs.

d. Frictional tests

(1) Heat shield to thermoelectric modules

A heat shield pull test was conducted to verify the hot shoe/heat shield interface frictional restraining force in the generator longitudinal axis imparted by

the cold end spring system, as first measured on a SNAP 19 Nimbus ATJ heat accumulator block. The SNAP 19 Pioneer cold vibration test fixture (452A4040001-039) was used with a POCO graphite heat shield. The average longitudinal load required to induce motion was 274 lbs. An average of 260 lbs was required to move the ATJ heat accumulator block in the prior test.

(2) Min-K to graphite

A test was conducted to determine the coefficient of friction between Min-K 1301 and graphite, both ATJ and Carb-I-TeX. POCO graphite in slab form was not available in-house, so ATJ was used as its surface texture approximates that of POCO. The test consisted of pulling a loaded Min-K end insulation disc, from generator S/N 35, across the surface of a graphite slab with a spring scale (0-60 lb. pull). The apparent static coefficient of friction of ATJ (or POCO) is 0.35 and Carb-I-TeX is 0.65. The sliding coefficients of friction averaged about 10% less than the static values. Results of this test indicate an additional source for restraining forces to react lateral heat source vibration loads.

B. RELIABILITY AND PERFORMANCE ANALYSIS

1. System and Generator Reliability

a. Generator power regression analysis

Power output vs. time regression analysis was updated for the three SNAP 19 generators (S/N 26, 29, 31) which are presently undergoing life tests. The primary purpose of this analysis is to provide supporting data for determining the degradation of power for the Pioneer and Viking missions. Data have been extrapolated to 30,000 hours. Results of this study are reported in INSD-LLR-3459B.

b. Demonstrated operational reliability

SNAP 19 generators S/N 1 through S/N 37 have accumulated a total of 268,179 generator hours without an identifiable failure. This computes to a demonstrated reliability of 93.0 or greater at a 50% confidence level for the Pioneer mission or 95.2 or greater at a 50% confidence level for Viking. The total number of thermoelectric couple hours accumulated from these generators has increased to approximately 25.4 million. INSD-LLR-3456C presents a detailed discussion of this study.

c. Power variation at beginning of life

Previously established methods for computation of thermoelectric power variance were documented in INSD-LLR-3493. In addition, an improvement on these techniques has been proposed and is being reviewed.

2. Component Reliability

a. Thermoelectric couple production assessment

Continued monitoring and evaluation of the thermoelectric couple production processing and quality control data has been performed during this period. Status and results of this effort are reported in the following documents:

INSD-LLR-3468

INSD-LLR-3469

INSD-LLR-3478

INSD-LLR-3510

INSD-LLR-3452A

b. "O" ring seal reliability

Available test data on Viton "O" ring seal performance under static or non-cyclic operation have been surveyed. Results of this survey have been applied to the determination of a predicted failure probability for the Pioneer and Viking

missions. INSD-LLR-3512 presents the results of this study.

3. Performance Analysis

a. Pioneer Performance

(1) Generator gas analysis

The requirement for lower fuel capsule liner temperatures has led to a recommended RTG initial gas fill of one atmosphere 25% argon/75% helium. This fill, along with 100% helium, was evaluated as a function of time for the parameters shown in Table II-5. A typical result is plotted in Fig. II-5 for the average expected argon leak rate of 5×10^{-6} scc/sec (normalized to the arbitrary conditions of 337°F and 1 atm. Δp) for the in-board RTG.

(2) Fin analysis

In the previous semi-annual, results of a thermal fin analysis using an existing computer program were presented. In order to verify these findings, two other approaches were investigated also; the string method and the average view factor method. Both of these techniques are discussed in SN19-ARL-296 dated Sept. 8, 1970. Results of all techniques are presented in Fig. II-6 in the form of lateral heat rejected per RTG versus fin root temperature for both stacked RTG's and single RTG's. (The string method has no dependence on end effects, i.e., stacking.) The agreement between the methods is considered very good for the approximations involved.

By the use of Fig. II-6 in conjunction with consideration of solar load, end cover heat rejection, and fuel decay, a curve of fin temperature versus time was developed, Fig. II-7. This figure includes the results of a thermal vacuum experiment at NASA/Ames conducted on ETG S/N 35 to evaluate the effect on the in-board RTG of thermal blockage by the support truss and power ribbon.

TABLE II-5

Gas Study Input Parameters

<u>Parameter</u>	<u>Value</u>
Initial Fill Gas	100% Helium; 25% Argon/75% Helium
Helium Release Rate (from fuel)	0, 25, 50, 75 and 100%
Fuel Inventory	650 watts
Initial Pressure	1 atmosphere
Seal Leak Rate*	1×10^{-7} , 5×10^{-6} , 8×10^{-6} , 1×10^{-5} and 1.2×10^{-5} scc/sec
Generator Void Volume	3050 cc
Storage Time/Seal Temperature	9 months/285°F
Flight Time/Seal Temperature	5 years/337°F and 355°F (outboard and inboard RTG's, respectively)

*Expressed in terms of argon at 1 atm. delta pressure and 337°F.

FIGURE II-5

5.0×10^{-6} SCC / SEC GAS CHARACTERISTICS

75% HELIUM INITIAL FILL

INBOARD RTG

FIG. II-6
LATERAL HEAT REJECTION

FIGURE II-7

FIN ROOT TEMPERATURE VERSUS TIME

645 WATTS

INSD-2873-44
II-22

(3) Power

Near the end of the reporting period, the generator fill gas was changed from 75% argon/25% helium (used in ETG's S/N 35 and S/N 36) to 25% argon/75% helium (for S/N 37 and up) in order to lower fuel capsule liner temperatures. Last semi-annual period, power at Jovian encounter was determined for a nominal BOL 330°F fin root temperature for helium initial fills as high as 50%. The performance of the present 75% helium initial fill RTG's is estimated in Fig. II-8 by an extrapolation of the earlier work. Performance is also shown separately for the inboard and outboard RTG's (Beginning-of-mission fin root of 362 and 344°F, respectively).

b. Viking performance

(1) Power

As a result of the recent reduction in allowable heat source operating temperatures, the Pioneer program is using an initial fill gas of 75% helium/25% argon. This initial gas fill reduced the Pioneer operating temperatures to acceptable levels. Attendant reductions in the thermoelectric module hot and cold junction temperatures reduced the electrical power output below the power level obtained with the 100% argon initial gas fill. Since the Viking RTG is assumed to employ the Pioneer program heat source technology, a performance study was conducted to assess the Viking RTG performance utilizing the 75% helium/25% argon initial fill gas in lieu of the 100% argon initially anticipated.

The performance study was conducted utilizing the techniques discussed in the Viking Preliminary Design Data Package (Ref. II-1), and the Second Semi-Annual Progress Report (Ref. II-2) for the 100% argon initial fill gas design. Utilizing the steady state fin root temperature profile vs. time developed in Ref. II-1, the the hot junction temperature and power output vs. time characteristics were developed

Ref. II-1. "Preliminary Design Data Package for Viking RTG, " INSD-2873-10, May 1970.

Ref. II-2. "SNAP 19 TAGS 85/2N RTG Power Systems Second Semi-Annual Progress Report, " January 8, 1970 to June 30, 1970, INSD-2873-26.

FIGURE II-8
ENCOUNTER POWER
0.995 PROBABILITY
100% HELIUM RELEASE
 645 ± 5 WATTS

as a function of helium release rate. Figure II-9 shows the nominal hot junction temperature behavior in time for various helium release rates from the fuel.

Results of the nominal performance studies were the bases for performing parameter variation analyses described in Ref. II-1 and II-2. All other assumptions of the referenced analyses were retained for this study. The cumulative power distribution calculated using the Monte Carlo analysis technique was combined with the catastrophic generator probability to predict the reliability-power distribution. Figure II-10 shows the results of this study for the trapezoidal helium release distribution utilized in Ref. II-1. These results show a mean power for the Mars surface day environment of 35.1 watts(e). The power at a predicted reliability of 0.99 is 33.0 watts, two watts below the Viking design goal of 35.0 watts.

In a further study of the reliability-power distribution, the helium release rate from the fuel was assumed to be 100%. Results of the reliability-power distribution are shown in Fig. II-11.

Table II-6 presents a summary of the Viking reliability-power distribution for the two assumptions on helium release rate. Also shown for comparison purposes are the results of the 100% argon initial fill gas study of Ref. II-1. This table indicates that the 100% argon initial fill gas is the only design of those studied which satisfies Viking power output design criteria.

(2) Heat source temperature

Results of the above performance study show the penalty imposed by the Pioneer design heat source. Therefore, two alternate approaches were considered for the Viking RTG: (1) the use of a Pioneer heat source modified with a helium retention device (HRD), and (2) a Pioneer heat source with an HRD and a thermal switch replacing the pyrolytic graphite sleeves. Both the HRD and thermal switch

FIGURE II-9

VIKING RTG HOT JUNCTION TEMPERATURE PROFILE

FUEL INVENTORY = 675 WATTS

INITIAL FIN ROOT TEMPERATURE = 330 °F

INITIAL FILL GAS = 75 % HELIUM / 25 % ARGON

STORAGE
AND
PRE-LAUNCH

INTERPLANETARY
CRUISE

MARS
ORBIT
MARS
SURFACE
(DAYTIME)

FIGURE II-10

VIKING LANDER RTG

RELIABILITY - POWER DISTRIBUTION

INITIAL FILL GAS - 25% ARGON / 75% HELIUM AT 14 PSIA

NOMINAL FUEL INVENTORY - 675 WATTS
17 MONTHS AFTER LAUNCH (EOM)

PERCENT HELIUM RELEASE FROM FUEL
TRAPEZOIDAL DISTRIBUTION

MARS SURFACE DAY

RELIABILITY

1.0

0.9

0.8

0.7

0.6

29

30

31

32

33

34

35

36

POWER (WATTS)

FIGURE II-11
VIKING LANDER RTG
RELIABILITY - POWER DISTRIBUTION
INITIAL FILL GAS - 25% ARGON / 75% HELIUM AT 14 PSIA

NOMINAL FUEL INVENTORY - 675 WATTS
17 MONTHS AFTER LAUNCH (EOM)

100% HELIUM RELEASE FROM FUEL
MARS SURFACE DAY

TABLE II-6

Summary of Reliability-Power Distributions
(Mars Surface Day)

Probability	Power Output (watts)		
	100% Argon	25% Argon - 75% Helium	
	Traezoidal	Trapezoidal	100%
99.8	35.2	32.8	32.4
99.0	35.5	33.0	32.6
95.0	36.0	33.5	32.9
90.0	36.4	33.8	33.2
50.0	38.0	35.1	34.2

technologies are considered feasible because of development time available prior to Viking RTG deliveries.

A preliminary steady state thermal analysis was performed on each of these modified heat source configurations. In each design, the generator was considered to have an initial fill gas of 100% argon and to have helium retained within the fuel capsule. The existing three-dimensional thermal model of the Pioneer heat source was used, but approximations in the calculations were required because of the longer Viking fuel capsule which accommodates an extra fuel puck to achieve a nominal 675 watts(t) thermal inventory. The heat source operational steady state temperature distribution was calculated as a function of average heat shield temperatures at the beginning-of-life.

Results of the analysis are summarized in Figs. II-12 and II-13. Figure II-12 shows the heat source temperature distribution for the HRD in combination with the pyrolytic graphite sleeves. It is apparent that the 900°C liner temperature is exceeded for all heat shield temperatures above 875°F. Therefore, pyrolytic graphite sleeves in combination with an HRD exceed the present Pioneer heat source temperature constraints. Figure II-13 shows the calculated heat source temperatures for the thermal switch and HRD combination. For this configuration, 900°C liner temperatures are exceeded for heat shield temperatures in excess of 1080°F which is very near the heat shield operating point for the Viking RTG at beginning-of-life (the expected value is 1100 to 1125°F). Therefore, the HRD and thermal switch combination yields marginal heat source configuration for the Viking mission with present temperature constraints. Additional heat source temperature capability is desirable to provide added temperature margin.

FIGURE II-12 VIKING HEAT SOURCE TEMPERATURES AT B.O.L.
(PIONEER GEOMETRY WITH HRD AND 650W INVENTORY)
PYROLYTIC GRAPHITE SLEEVE
ARGON COVER GAS

FIGURE II-13 VIKING HEAT SOURCE TEMPERATURES AT B.O.L.
 (PIONEER GEOMETRY WITH H.R.D. AND 650W INVENTORY)
 THERMAL SWITCH SLEEVE
 ARGON COVER GAS

(3) Transient thermal behavior

Two preliminary simplified transient thermal models were developed for the Viking RTG and ETG. These thermal models were developed for use in determining generator response to a time-varying fin root temperature. A single, lumped-node model was developed for use when the fin root temperature changes less than 0.2°F per minute. Table II-7 indicates the thermal properties at the single-node model. This model assumes that the gradients within the generator remain constant throughout the transient response.

The second model, which is used for fin root temperature changes greater than 0.2°F per minute, contains five-nodes. Figure II-14 is a presentation of the five node model. Values of thermal properties and interconnecting resistances are presented in Table II-7 for the RTG and ETG at a beginning-of-life condition. Note that three values of thermal resistance are given for the thermoelectric module (R_2), corresponding to generator operation on short circuit, nominal load voltage and open circuit. Interconnections with boundary nodes of T_1 , T_2 and T_3 are dependent on the generator environment and are not given here. This model also makes the simplifying assumption that the thermal gradients within the generator are temperature independent. The five-node model is presently being compared to transient TAGS-85/2N generator tests conducted by NASA Goddard, NASA Langley and JPL.

FIGURE II-14

Five Node Transient Thermal Model

TABLE II-7

TYPICAL MASS AND THERMAL PROPERTIES FOR
FIVE NODE AND SINGLE NODE THERMAL MODELS
UNDER BOL CONDITIONS

FIVE NODE MODEL

Node	Thermal Capacity (Watts/°F)	Internal Heat Source (Watts)	Interconnecting Thermal Resistance (°F/Watt)
1- Container and Heat Sink Assemblies	1.139		$R_1 = 0.0918$
2- Cold End Energy Conversion Assembly	0.1046	$P_o = -44$	R_2 Short Circuit = 0.8281 R_2 Open Circuit = 1.1797 R_2 Load = 0.9844
3- Hot End Energy Conversion Assembly	0.0967		$R_3 = 0.0781$
4- Heat Shield	RTG=.3302 ETG=.2420		$R_4 = 0.8047$
5- Heat Source	RTG=.1537 ETG=.1892	$Q_o = 675$	

Single Node Model

Internal Heat Source ($Q_o - P_o$)

Short Circuit	=	675 watts
Open Circuit	=	675 watts
Load	=	631 watts
Heat Capacity		
RTG	=	1.8242 W/°F
ETG	=	1.7715 W/°F

Above nominal values of thermal resistance are subject to % Helium Generation by fuel, gas leak rate, and time.

III. HEAT SOURCE DEVELOPMENT

A. HEAT SOURCE DESIGN

Figure III-1 delineates the various components of the Pioneer heat source. Since the last reporting period, the capsule-heat shield interface was redesigned to provide greater structural capability during a launch vibration environment. In the present design, the fuel capsule is rigidly supported between the two graphite end plugs of the heat shield. In order to accommodate the hemispherical ends of the capsule and the inside configuration of the end plugs, capsule support rings of zirconia are used.

Since the thermal expansion coefficients for the T-111 capsule strength member and the POCO graphite heat shield are practically identical, no significant additional axial loads resulting from differential thermal expansion should occur until beyond the time of peak heating during atmospheric reentry. At this time, the graphite heat shield is cooling more rapidly than the strength member. In order to accommodate increased axial loading without catastrophic failure of the heat shield, the heat shield end plugs have built-in shear rings for local relief when the axial load reaches approximately 4600 pounds. It is important to note that the tensile capability of the heat shield barrel is about an order of magnitude above this level or about 30,000 lbs.

The discs of tantalum felt and the PG support sleeves were introduced to provide additional thermal protection during reentry.

1. Fuel Capsule Status

To date, two Pioneer fueled capsules have been fabricated and received at INSD. The nominal power level is 645 watts (thermal). In each case the capsules have required seventeen fuel discs rather than the designed eighteen discs. This

FIGURE III-1. PIONEER HEAT SOURCE

occurred because the fuel power density has been about 3.3 - 3.4 watts/cc which is greater than the specification of 3.2 watts/cc (minimum). Thus, elimination of a fuel disc and filling the void with tantalum shims has been implemented.

The weights of the two capsules, PF-1 and PF-2 are 7.72 pounds each. For additional capsule design data, reference is made to MRC specification 1-14447, "Pioneer Fueled Capsule Assembly Specification" and INSD document 452B5120502, "Pioneer RTG Fueled Capsule Specification."

There have been no significant design changes affecting either the heat shield barrel (6.5" in length x 3.5" across the hexagon flats) or the three layered capsule, except for the fuel change from SSC (Solid Solution Cermet) to PMC (Plutonium Molybdenum Cermet).

2. Heat Shield Stress Evaluation

The thermal stress analysis of the Pioneer heat shield was continued during the past reporting period. To date approximately sixteen reentry trajectories have been evaluated to determine the stresses as a function of time as a result of aerothermal heating. The trajectories examined may be defined by the following limits:

$$-16^{\circ} \leq \gamma_i \leq -6^{\circ}$$

$$30,000 \leq V_i \leq 4,000$$

where γ_i and V_i are the path angle and velocity respectively at 400,000 feet.

As was done in the preliminary stress analysis report, a thick-walled circular cylinder was used as the analytical model for the hexagonal cross-section and the model was treated as a plane strain case. The temperatures applied to the analysis were supplied from the output of the Thermal Analyzer Program (TAP-3) which facilitates the evaluation of transient and steady state heat transfer.

Since graphite is a very brittle material with little plastic deformation capability, the calculated radial, circumferential and axial stresses are evaluated by the maximum principal stress criteria. A Mises or Tresca criterion is not justified.

The most critical stress is in the circumferential or hoop direction. This stress is given as,

$$\sigma_{\theta} = \frac{E \alpha}{r^2 (1 - \nu)} \left[\frac{r^2 + a^2}{b^2 - a^2} \int_a^b Tr \, dr + \int_a^r Tr \, dr - Tr^2 \right] + \frac{E}{2(1 - \nu)} \left(\frac{r}{b^2 - a^2} \right) \left(3 - \frac{b^2 + a^2}{r^2} - \frac{a^2 b^2}{r^4} \right) C$$

where 'a' and 'b' are the inside and outer radii. C is a function of the circumferential temperature distributions at the inner and outer surfaces as represented by Fourier expansions. T represents the radial temperature gradient through the wall and its form for application is a polynomial as a function of average surface and mid-plane temperatures.

The stresses were evaluated as a function of trajectory time and compared directly with POCO graphite ultimate strength data such that a minimum ultimate strength to calculated stress ratio was obtained for each trajectory. A presentation of these results is shown in Fig. III-2. All cases assume side-on-stable reentry orientation.

B. MATERIALS

1. Compliant System

The revised design utilizes an approximate 3 W/O magnesia stabilized zirconium oxide (ZrO_2) refractory with a melting point $\sim 4500^\circ F$. This composition is normally

FIGURE III-2
STRESS RATIO (SIDE-ON-STABLE)

monoclinic between room temperatures and $\sim 1500^{\circ}\text{F}$ with a density of $\sim 5.6 \text{ gm/cc}$. Above $\sim 1500^{\circ}\text{F}$, the monoclinic form inverts to the tetragonal form with a density of $\sim 6.1 \text{ gm/cc}$, the transition temperature shifting downward with added impurities. The thermal conductivity of ZrO_2 is the lowest of all common oxides with the possible exception of amorphous silver at low temperatures, and there is less change in conductivity with temperature than with all other oxides. Zirconia is reported to be stable in vacuum, in contact with Pt/Rh at 2000°F or in contact with carbon to 4170°F . The measured vapor pressures (ATM) of ZrO_2 and MgO at 3150°F are $\sim 10^{-6}$ and $\sim 5 \times 10^{-6}$ torr respectively. Chemical analysis and the following property measurements have been determined by Battelle Memorial Institute on sample hardware details:

- a. Compressive strength,
- b. Thermal diffusivity
- c. Linear thermal expansion.

2. Graphite Heat Shield Components

As of November 30, twelve pyrolytic sleeve assemblies have been received and conditionally accepted pending tests to be conducted at Los Alamos Scientific Laboratories (LASL). Pfizer Inc., the supplier, has recently completed mechanical property measurements, i.e., flexure and compressive strength, for thin substrate nucleated pyrolytic graphite plate material which is deposited in an equivalent manner as the PG tube material. All results exceed INSD's Material Specification (MS150-001) requirements. In addition, Pfizer performed immersion density measurements on randomly selected PG tube material which resulted in densities of 2.188 gm/cc or greater. The ash determinations which are performed by Crobaugh Testing Laboratories in Cleveland, Ohio also meet with the acceptance criteria. Other tests for,

i.e., nodules, delaminations and general material characteristics have indicated acceptable hardware. Tensile strength measurements on PG plate material are currently being performed at Southern Research Institute under contractual direction by Pfizer. This data shall be forwarded to INSD by Pfizer as soon as the work is completed.

C. THERMAL ANALYSIS

1. Steady State

a. Parallel heat source study

Under the parallel heat source study, three heat source configurations differing from the February 1970 baseline design (with compliant pad and cup) were studied:

- (1) HRD in clad,
- (2) HRD in clad and replacement of PG sleeve with a thermal switch sleeve, and
- (3) HRD in clad and replacement of PG sleeve, compliant pad and cup with a "shell" of thermal switch material.

Steady state calculations were performed using the LIMP digital computer program. The thermal model used is that shown in Fig. III-3 with modifications being made for the thermal switch sleeve and "shell" configurations. Steady state operational temperatures of the heat source components are presented in Table III-1 for BOL, launch and vacuum (generator seal failure).

In all cases, argon is the initial cover gas outside the HRD and helium, inside. Nine months later, at launch, the mixture outside is 80% argon/20% helium, while

FIGURE III-3
THERMAL MODEL NODAL MAP - SNAP 19/PIONEER HEAT SOURCE

TABLE III-1

SNAP 19 Heat Source Component Temperatures (°F)

<u>Component</u>	<u>HRD - PG Sleeve</u>			<u>HRD - Switch Sleeve</u>			<u>HRD - Shell¹</u>		
	<u>BOL²</u>	<u>Launch³</u>	<u>Vacuum⁴</u>	<u>BOL</u>	<u>Launch</u>	<u>Vacuum</u>	<u>BOL</u>	<u>Launch</u>	<u>Vacuum</u>
O. Poco	1115	1085	1300	1125	1090	1310	1105	1070	1300
I. Poco	1120	1090	1305	1130	1095	1320	1110	1075	1305
O. Sleeve	1145	1105	1625	1625	1115	1615	1130	1085	1575
I. Sleeve	1375	1315	2295	1200	1150	1650	1150	1110	1605
Clad	1665	1575	2455	1525	1445	1955	1375	1300	1840
Strength Member	1710	1620	2490	1575	1490	2000	1410	1335	1880
Liner	1750	1660	2520	1620	1530	2040	1450	1375	1915
Fuel Surface	1765	1680	2530	1635	1550	2055	1465	1395	1930
Fuel Centerline	1860	1775	2625	1730	1645	2160	1550	1475	2025

¹Replacement of PG sleeve, compliant pads and cups with "shell" of thermal switch material.

²Beginning of life, initial argon cover gas

³After 9 months storage with 75% helium release

$$T_{\text{fin root}} = 330^{\circ}\text{F}, \quad Q_{\text{Inv}} = 650 \text{ W(t)}$$

⁴Generator seal failure, helium retained in capsule

inside the gas is still 100% helium.

Use of the HRD in the capsule offers a significant reduction in temperature of the internal capsule members when argon is employed as the generator cover gas (liner temperature would be 200°F with an HRD). The thermal switch material has a higher conductance than either the pyrolytic graphite and the tantalum felt compliant pad thereby also allowing the capsule to operate at lower temperatures. In addition, use of the single member thermal switch over the three piece pyrolytic graphite sleeve is especially valuable in the event of a generator seal failure. Table III-1 shows the additional thermal advantage gained by combining the thermal switch with the HRD.

b. Hardmounted fuel capsule design

(1) Design evaluation

Design changes incorporated in the heat source for the purpose of hard-mounting the fuel capsule required thermal analyses of the redesigned configuration (Fig. III-4). Analyses were performed from beginning of life (BOL) where the generator gas fill is .75 helium/.25 argon, to launch where the gas fill is 0.80 helium/0.20 argon (assuming a 75% helium release and a nine months' storage). In addition, the SNAP 19/Pioneer safety studies require calculations of the heat source temperatures in the event of:

- (a) generator seal failure while in earth orbit,
- (b) release of the heat source from the RTG while in earth orbit.

Initially, several heat source configurations were evaluated:

- (a) POCO load ring and pyrolytic graphite (PG) sleeve
- (b) POCO load ring and thermal switch (TS) sleeve

FIGURE T-4
SNAP 19 PIONEER HEAT SOURCE

(c) ZrO_2 load ring and pyrolytic graphite sleeve

(d) ZrO_2 load ring and thermal switch sleeve

Maximum (hot spot) temperatures of the individual heat source components are presented in Table III-2 for the four configurations at both BOL and launch, for a thermal inventory of 660 watts. Predicted liner temperatures for all cases were within the design criterion of 1650°F (900°C).

From a steady state viewpoint, the POCO graphite load ring permitted the lowest capsule temperatures because of its high thermal conductivity ($\sim 34 \text{ BTU/hr-ft-}^\circ\text{F}$ at 1000°F), but this high conductivity caused melting of the clad during reentry. Therefore, the selected design incorporated a ZrO_2 load ring (thermal conductivity is approximately $1.1 \text{ BTU/hr-ft-}^\circ\text{F}$ at 1000°F) with a PG sleeve.

(2) Heat source prelaunch temperature history

With the present hardmounted fuel capsule design (ZrO_2 load ring, PG sleeve), a torque is applied to the end plug during fueling of the generator. Differing expansion coefficients of the capsule, load ring and heat shield, however, create a varying load as the generator environment changes from the conditions at fueling and final assembly. To assure that an excessive loading is not applied to the integral shear ring between BOL and launch, it was necessary to calculate heat source operating temperatures at several times during this period to enable evaluation of relative differential thermal expansion.

The times of interest and the respective temperature of the RTG fin root and heat source heat shield are presented in Table III-3. Predicted heat source component temperatures are presented in Fig. III-5 as a function of average heat shield temperature at BOL. The band for each component represents the thermal gradient through that member. Internal temperatures at launch will be slightly lower than at

TABLE III-2

SNAP 19/Pioneer Heat Source Temperatures⁽¹⁾
Hardmounted Fuel Capsule Design
Fuel Inventory = 660w
Fin Root Temperature = 330°F

<u>Component</u>	<u>POCO Support Ring</u>				<u>ZrO₂ Support Ring</u>			
	<u>Pyrolytic Graphite Sleeve</u>		<u>Thermal Switch Sleeve</u>		<u>Pyrolytic Graphite Sleeve</u>		<u>Thermal Switch Sleeve</u>	
	<u>BOL</u>	<u>Launch</u>	<u>BOL</u>	<u>Launch</u>	<u>BOL</u>	<u>Launch</u>	<u>BOL</u>	<u>Launch</u>
Heat Shield ⁽²⁾	1000	1000	1000	1000	1000	1000	1000	1000
End Plug ⁽²⁾	1020	1020	1000	1000	1020	1020	990	990
Load Ring ⁽²⁾	1100	1100	1070	1070	1150	1150	1100	1090
Sleeve Outer Surface	1000	1000	1020	1020	1010	1010	1040	1040
Sleeve Inner Surface	1160	1160	1050	1050	1250	1230	1070	1070
Clad	1310	1290	1210	1200	1470	1440	1340	1320
Strength Member	1370	1350	1280	1270	1510	1480	1370	1350
Liner	1440	1420	1360	1340	1570	1540	1440	1410
Fuel Surface	1480	1450	1390	1370	1600	1560	1480	1440
Fuel Centerline	1560	1530	1480	1460	1700	1660	1590	1530

⁽¹⁾Maximum (hot spot) temperature (°F)

⁽²⁾Average temperature

TABLE III-3

Selected Pioneer RTG Temperatures - Fueling to Launch

<u>Condition</u>	<u>Circuit</u>	<u>Temperature (°F)</u>		
		<u>Fin Root</u>	<u>Hot Junction</u>	<u>Heat Shield</u>
Fueling in submarine	S. C.	250-300	755-800	825-870
Normal Operation (BOL)	Load	340-360	940-960	1010-1030
Air Operation (no booties)	Load	250	860	930
Shipping Container	S. C.	250	760	830
Operation in Spacecraft Shroud (.8 He-.2 Ar.)	S. C.	~160	675	745
	Load	~160	775	845

FIGURE III-5 PIONEER HEAT SOURCE SENSITIVITY
TO HEAT SHIELD SURFACE TEMPERATURE

BOL and the estimated reductions are shown at the bottom of the figure.

(3) Pioneer selected design

Following a reduction of fuel inventory to a maximum of 650w, the heat source thermal model was revised to incorporate updated thermal properties (for PMC fuel) and newly calculated internal gap dimensions. Steady state operational temperatures in vacuum were calculated and are presented as a function of heat shield temperature in Fig. III-6. The heat shield surface temperatures of the two points of interest, generator operating with internal vacuum and heat source viewing infinite sink in a vacuum, were calculated to be 1285°F and 775°F, respectively.

Thus, the predicted steady state operating temperatures of the selected Pioneer SNAP 19 heat source design are within the design criterion of 1650°F (900°C).

2. Reentry

a. Parallel heat source study

Of the three configurations evaluated in Section III. C. 1, only that with the thermal switch sleeve and HRD was analyzed for reentry. Reentry temperatures were predicted using the TAP-3 digital computer program. The thermal model is described in Fig. III-3. The heat flux distribution during the side-on, flat leading edge reentry attitude is based on the Langley test data for the SNAP 19 heat source. The initial reentry conditions studied, flight path angle (γ_i) and velocity (v_i) and the peak heat source component temperatures are presented in Table III-4.

It is apparent that, over the range of initial reentry conditions considered, the clad remained below the melt temperature of 3400°F.

b. Reentry tests

Four SNAP 19 heat source configurations were tested to determine hypersonic

FIGURE III-6

PIONEER HEAT SOURCE SENSITIVITY
TO HEAT SHIELD SURFACE TEMPERATURE
VACUUM OPERATION
FUEL INVENTORY = 650W

TABLE III-4

Peak Heat Source Reentry Temperatures
Compliant Pad Heat Source Design with Thermal
Switch Sleeve and HRD Fuel Inventory = 650w(t)

Initial Path Angle (Degrees)	Initial Velocity at 400,000 ft. (ft/sec)	Peak Temperature (°F)				
		Heat Shield Surface	Sleeve Outer Surface	Sleeve Inner Surface	Clad	Strength Member
-0.056	24,390	4020	3930	2600	2600	2570
-6.0	30,000	5340	5030	2150	2260	2130
-16.0	30,000	6000	5040	1990	1950	1870
-5.5	36,000	5770	5500	2520	2660	2520
-6.0	36,000	6080	5730	2420	2600	2430
-16.0	36,000	7400	6050	2050	2070	1950
-8.0	44,000	8680	7630	2560	3160	2790

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continuum convective heating distributions at various attitudes and Reynolds numbers. The tests were performed at NASA/Langley, between June 12 and 18, 1970 with the angle of pitch varied from 0° to 90° (end-on to side-on, respectively), the angle of roll varied from 0° to 30° (edge-leading to flat-leading, respectively), and a Mach number of six (6). In addition, a spherical model was tested as a check on the phase-change paint measurement technique. Phase-change paint was used to obtain the aerodynamic heating distribution over the four heat source configurations (unablated, uniformly ablated, end ablated, and asymmetrically ablated) and the sphere. The nominal Reynolds number per foot was 3×10^6 . In addition some tests were made at Reynolds number per foot of 1×10^6 to 8×10^6 . This range of Reynolds number was done to check on transitional and turbulent boundary layers along the longitudinal, flat side of the heat source in the sweep attitude.

The tests were conducted in NASA/Langley's 20-inch Hypersonic Tunnel (Mach 6). Forty-one tests were made. Each configuration was sprayed with a discrete melting temperature paint. Two cameras (looking in from the side and top) were used to record the history of the melt contour of the paint. A film reader was used to determine the location and the time of the melt contour. Knowing the time, location of the melt contour, melt temperature of the paint, thermodynamic properties (density, conductivity and specific heat) of the plastic test model, initial temperature of model, and tunnel conditions (total pressure and temperature of the free stream), the local heat transfer coefficients were calculated. Results of the tests are reported in SN19-RHA-255, "Aeroheating Distribution Tests Conducted at NASA/Langley."

D. TESTS IN SUPPORT OF SAFETY EVALUATION

1. Test Procedures

The following test procedures were written and released:

- a. Vibration testing (Dwg. 452B5120400),
- b. Low density force and moment wind tunnel test of the heat source (Dwg. 452B5120406),
- c. Continuum - flow heat transfer wind tunnel test of the heat source (Dwg. 452B5120410),
- d. Safety tests of the calibration heat source (Dwg. 452B5120410),
- e. Revisions to overpressure testing of generators (Dwg. 452B5120411A and 452B5120412),
- f. Hot impact testing, Phase II (Dwg. 452B5120412),
- g. Solid propellant fire test (Dwg. 452B5120413),
- h. Fragmentation test (Dwg. 452B5120414),
- i. Plasma arc reentry simulation test (Dwg. 452B5120416),
- j. Liquid propellant fire test (Dwg. 452B5120417),
- k. Hot drop test (Dwg. 452B5120418),
- l. Post-test evaluation of safety test specimen (Dwg. 452B5120420).

The test conditions for overpressure and fragmentation tests as stated in the above documents reflected a failure-bracketing philosophy. This approach was later changed to one of testing for maximum realistic and nominal launch abort conditions as calculations for these conditions were received from NASA/Lewis and Sandia. In addition, thermal preconditioning was dropped from all test procedures.

2. Test Specimens

The six launch abort sequential test specimens; two simulated generators, three heat sources and one bare capsule; including capsules P9, P12, P13, P15, P17 and P19 were fabricated and shipped to Sandia. In addition, most of the components for the generator and heat source that will be used in the vibration test were fabricated and/or gathered together in preparation for final assembly.

3. Test Equipment

An electric furnace for preheating plasma arc test specimens was designed, fabricated and calibrated.

A specification for a water-cooled calorimeter (for plasma arc testing) was written and the calorimeter was ordered from Thermogage, Inc. The vendor designed, built and fabricated the calorimeter and INSD thoroughly inspected it and shipped it to NASA/MSFC.

4. Test Results

The first series of hot impact tests was conducted in July and August. Three heat sources were preheated to approximately 2400°F and impacted against granite at about 325 feet per second. No simulated fuel was released in any test. In the 0° (end-on) test the three layers of the capsule remained intact and the 22-1/2° and 45° tests the clad was ruptured but the strength member and the liner apparently remained intact.

A summary of the launch abort sequential tests that have been conducted to date is presented in Fig. III-7. No fuel simulant was dispersed outside the capsule. However, during the fragmentation tests of P12 and P17, the capsule clad was breached and during the solid propellant direct contact fire test all three layers of the P19 and P12 capsules were breached. Consideration is being given to rerunning:

FIGURE III-7
 SNAP 19 PIONEER SAFETY TEST PROGRAM
 LAUNCH ABORT SEQUENTIAL TESTS

= Test date

(1) the edge-on fragmentation test because the fragment velocity was only 1/3 of the intended velocity, and (2) the solid prepellant direct contact fire test on a bare capsule because the presence of liquid copper during this test may have contributed to breaching the capsule.

E. ALTERNATE PROGRAM

In August 1970, two existing AEC development programs were accelerated in an attempt to qualify a Helium Retention Device (HRD) and a Thermal Switch Sleeve (TSS) for the SNAP 19 Pioneer Heat Source. Both products were being developed by Hittman Associates Inc., (HAI), Columbia, Md. Isotopes Nuclear Systems Division (INSD) provided system requirements in the form of drawings and specifications, and detailed operational and safety analysis of the two products within the framework of the Pioneer Mission. In addition, INSD sub-contracted to Weiner Associates Inc., (WAI), Baltimore, Md. to critique the two product development programs and to supplement part of the INSD safety analysis.

Although significant progress was made in each product area during August and September, not all of the performance characteristics were demonstrated to the extent required for flight hardware acceptance by the decision date of Oct. 8, 1970. As of this date, capsule hardware was committed at Monsanto Research Corp., (MRC) for SNAP 19 capsule fueling in order to meet the Pioneer schedules for generator delivery. Since that time the two development programs at HAI have been reduced to a low level effort.

In general, one major design philosophy for a radioisotope heat source for aerospace application is to minimize both normal operating temperatures and maximum reentry temperatures of the fuel capsule within the heat shield. These design

goals are not necessarily compatible. For example, a thermal insulator which limits the amount of heat reaching the capsule during a possible reentry also tends to restrict heat transfer during normal operation thus increasing capsule operating temperatures.

During the SNAP 19 heat source design and development program, it became apparent that the normal operating temperatures of the SNAP 19 heat source were higher than allowable for acceptable fuel and capsule liner oxidation compatibility. An analysis was initiated to identify design options for lowering the fuel capsule temperatures within the SNAP 19 heat shield.

Three options were available:

- (1) The substitution of a thermal switch sleeve for the existing pyrolytic graphite (PG) sleeves in the heat shield. Since the TSS maintained a high thermal conductivity at operational temperatures compared with the low conductivity of the pyrolytic sleeves, lower capsule operating temperatures could be achieved. During reentry, the TSS would change its effective thermal conductivity through vaporization of its copper impregnant, to yield conductivities slightly lower than the PG. Maximum reentry temperatures would thus be approximately equivalent for the two sleeve concepts with the advantage of lower capsule operating temperatures for the thermal switch.
- (2) Incorporation of a helium retention device in the capsule clad. The SNAP 19 was initially designed to operate with an argon cover gas within the sealed generator. Since the capsule clad and strength member were not sealed, argon would occupy the gaps between capsule components thus yielding a high thermal resistance. Incorporation

of the HRD would exclude argon from the capsule allowing helium from the radioactive decay process to occupy the gaps. This significantly improved heat transfer across the capsule gaps and thus lowered the normal operating temperatures.

- (3) Substitution of helium or helium-argon mixtures for the argon generator fill gas. This change improves all gap conduction paths within the generator thus lowering all system temperatures. Unfortunately this gas fill technique also increased parasitic heat losses which reduced generator performance. However, actual fabrication of SSC fuel showed higher fuel power density that had been anticipated and increased heat loss tolerable.

IV. SAFETY EVALUATION

Effort on this task was largely devoted to evaluating accident situations arising from the launch vehicle safety study Ref. IV-1 and IV-2). Probability results were expanded upon in detail for two cases: the effects of vehicular misorientation at third stage ignition, and the probability of micrometeoroid puncture of the RTG for an orbital-capture abort. In addition, certain reentry trajectories were studied for situations in which spacecraft and RTG's in turn, shield the heat source until relatively deep penetration in the atmosphere. Thermal analyses were updated to incorporate design changes and improvements in representation of heat transport.

Other activities during the period concerned definition of the contents of the Safety Analysis Report (SAR) and a schedule for its completion. Acquisition of supporting data and preparation of a model for predicting conversion of fuel to inhalable form were two of the SAR items initiated.

A. FAILURE MODES, EFFECTS, AND PROBABILITIES

In this section are presented the results of the third stage misorientation study and estimates of micrometeoroid puncture probabilities for orbital capture situations.

1. TE 364-4 Misorientation

The consequences of vehicle misalignment during the TE 364-4 burn are being studied in detail. Monte Carlo analysis is used to determine the reentry or escape statistics and to map the resultant velocity-angle (V, γ) reentry probabilities at the 400,000 ft. altitude.

An instantaneous thrust model is used. Given an initial altitude, velocity and flight path angle, the thrust probability density is assumed uniformly distributed

over all or part of the inner sphere about the impulse point. The unit thrust vector is defined by the polar and azimuth angles, θ and ϕ , of the sphere (see Fig. IV-1). The magnitude of the impulse velocity is equal to a fraction of the velocity imparted by the TE 364-4 burn. The equations of motion are then solved to determine the resultant velocity, V_1 , and flight path angle, γ_1 , at the 400,000 ft. altitude, and the occurrence of reentry.

Typical results are shown in Fig. IV-2. For this case, misalignment directions were chosen over the entire unit sphere. The energy referred to in this figure is the escape energy ($E = 0$ at escape velocity). The summary of orbital conditions shows that the first five correspond to trajectories which yield reentry in a relatively short time. Condition 6, orbital decay, corresponds to those trajectories with perigees greater than 400,000 ft but energy less than escape energy and, hence, will result in reentry. Including orbital decay, the total reentry probability is 0.5411 (sum of probabilities for the first six conditions).

Figure IV-3 relates the misalignment angles θ , ϕ to the resultant reentry conditions V_1 , γ_1 . The hover and skip boundary used in the analysis are shown. In this model, the resultant velocity is a function of the polar angle θ , only. The misalignment angles θ , ϕ are related to the pitch and yaw angles, p and y , by the transformations

$$\begin{aligned}\theta &= \cos^{-1} (\cos p \cos y) \\ \phi &= \tan^{-1} \left(\frac{\tan y}{\sin p} \right) \quad \text{for } p \text{ positive} \\ \phi &= \pi - \tan^{-1} \left(\frac{\tan y}{\sin p} \right) \quad \text{for } p \text{ negative}\end{aligned}$$

A check of results for trajectory No. 3 with proven Convair results (Ref. IV-3) over all pitch and yaw angles leading to reentry shows differences in $\left| \gamma_1 \right|$ of 2°

Figure IV-1. Definition of Thrust Direction for Misorientation Conditions.

V, GAMMA STATISTICS FOR PIONEER MISORIENTATIONS
V, GAMMA STATES AT 400,000 FT ALTITUDE - - - INSTANT THRUST APPROXIMATION

TRAJECTORY NUMBER 3
INITIAL ALTITUDE 672,000 FT. INITIAL VELOCITY 34,414 FT./SEC.
INITIAL FLIGHT PATH ANGLE 4.55 DEG. IMPULSE VELOCITY 12,468 FT./SEC.

GAMMA	VELOCITY (KFT/SEC)																			
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
20-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21-22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22-23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24-25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26-27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27-28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28-29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31-32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32-33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33-34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34-35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35-36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36-37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37-38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38-39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39-40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40-41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41-42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42-43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43-44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SUB-ORBITAL RE-ENTRY COUNT 920
PROMPT SUPER-ORBITAL RE-ENTRY, ENERGY LT 0 2979
PROMPT SUPER-ORBITAL RE-ENTRY, ENERGY GT 0 594
MULTI-ORBIT, E LT 0 (BELOW HOVER BOUNDARY) 244
MULTI-ORBIT, E GT 0 (BELOW HOVER BOUNDARY) 58
ORBITAL DECAY 616
SKIP ESCAPE (BELOW SKIP BOUNDARY) 218
ESCAPE (FORWARD MISORIENTATIONS) 4371
TOTAL 10000

Figure IV-2. Probability Density for Speeds (V) and Flight Path Angle (γ_1)
at 400,000 ft. Altitude

Figure IV-3. Functional Dependence of Speed (V) and Flight Path Angle (γ_1) on Misorientation Angles (θ, ϕ)
(Full, instantaneous thrust assumed for third stage)

or less and velocity less than 400 ft/sec. Differences are solely attributable to the instantaneous thrust approximation.

2. Meteoroid Penetration - Earth Orbital Aborts

Flight conditions such as non-ignition of the TE 364-4 stage, thrust termination, or misorientation, may place the spacecraft in earth orbit. Analyses have been performed at the Sandia Corp. indicating the relationship between vehicle configuration (resulting from the postulated abort) and orbital lifetime. The results are tabulated in Table IV-1.

The calculations indicate lifetimes in the range of 2 to 40 years. For relatively long orbital lifetimes there is increased likelihood of micrometeoroid puncture of the RTG, loss of the fill gas and significant increase in heat source temperatures prior to reentry.

A model was constructed to estimate the probability of micrometeoroid puncture as a function of orbital lifetime. The model employs a NASA environmental specification (Ref. IV-4) at IAU, an assumed log normal density describing uncertainty in the environment, and Poisson hit statistics. A simple model of the generator is employed along with a penetration model which estimates the effect of uncertainty in the penetration law as a function of impact speed and meteoroid mass.

Results obtained with this model show a range of probabilities from about 0.01 to 0.07 for lifetimes ranging from 5 to 40 years.

B. REENTRY ENVIRONMENTAL ANALYSIS

This section contains results of work defining environments in which the heat source would be exposed for certain types of reentry. Realistic initial conditions were derived from a consideration of the effects of spacecraft and RTG during reentry.

TABLE IV-1

Relationship between Vehicle Configuration and
Orbital Lifetime*

<u>Vehicle Configuration</u>	Estimated Orbital Lifetime (years)		
	<u>Random Tumbling</u>	<u>Side- on</u>	<u>End- on</u>
Pioneer heat source	27.8	18.1	47.2
Generator	11.8	5.8	41.6
Spacecraft (RTG's stowed)	4.3	5.9	2.7
Spacecraft (unburned TE 364-4 attached, RTG's stowed)	19.9	23.5	15.3
Spacecraft (empty TE 364-4 attached, RTG's stowed)	4.9	5.8	3.8

*Calculated for Centaur MECO nominal conditions:

Initial perigee radius = 84.9 nautical miles

Initial perigee velocity = 34,569.2 feet/second

Initial eccentricity = 0.817

Heating distributions about the heat source, and reference stagnation heat fluxes for selected velocity and flight path angle combinations at an altitude of 400,000 ft. were investigated. Potential flight test conditions were evaluated and the environment resulting from multi-revolution, orbital decay was examined. Finally, a status of tests designed to provide aerophysics characteristics of the heat source is provided.

1. Initial Conditions

The influence of Pioneer spacecraft and RTG breakup on thermal response of the heat source was evaluated (Ref. IV-5 and IV-6). Conditions for RTG release were furnished by TRW (Ref. IV-7) for four abort cases. The RTG was assumed to fail and expose the heat source when the equivalent of 12,000 BTU/ft² at the heat source stagnation point is experienced. This criteria is consistent with the results of SNAP 19/Nimbus studies and tests.

The results of this study showed that peak clad temperatures are reduced by about 360°F if a realistic structure breakup is assumed. However, thermal stresses in the heat shield were shown to increase. A comparison of the heat source reentry temperature histories assuming release at 400K and 216K foot altitudes is shown in Table IV-2.

2. Aerophysics

a. Aerodynamic heating distribution over the unablated SNAP 19 IIHS

(1) Side-on, flat-leading attitude

(a) Two-dimensional

The two-dimensional hypersonic continuum convective heating distribution over the unablated heat source in side-on, flat-leading attitude is presented in Fig. IV-4. Between stations 0 and 2, the test data from the NASA/Langley

TABLE IV-2

Summary of Peak Temperatures (°F)

<u>Component</u>	<u>400K Release Alt.</u>	<u>216K Release Alt.</u>	<u>ΔT</u>
Heat shield - OD	7984	7513	471
Heat shield - ID	6426	5808	618
Clad	3366	3003	363
Strength member	2884	2669	215
Liner	2648	2552	96

test (Ref. IV-8) were used. Between stations 2 and 3, the distribution was estimated by the utilization of the normalized distribution over the end surface along line 0-4 (see sketch in Fig. IV-4). Between stations 3 and 4, the distribution was estimated by cylinder wake data (Ref. IV-9).

(b) Three-dimensional

The axis system used in three-dimensional heating distribution analysis over the IHS is shown in Fig. IV-5. Over the leading 0° sweep, 60° sweep, and end surfaces, the NASA/Langley test results were used to estimate heating distributions. The same methods that were used to estimate the two-dimensional distributions over the 120° - and 180° -sweep surfaces were used for the three-dimensional distribution. The three-dimensional distributions over the leading, 60° -sweep, 120° -sweep, 180° -sweep, and end surfaces are shown in Figs. IV-6 thru IV-10, respectively.

(2) End-on attitude

The average heating distribution over the end surface of the unablated IHS in end-on attitude is shown in Fig. IV-11. Figure IV-12 presents the average heating distribution over the longitudinal surfaces. The distributions over the leading end surface and about 25% of the leading part of the longitudinal surface were estimated from the NASA/Langley test data. The curve was extrapolated over the remaining part of the longitudinal surface. These distributions over the unablated IHS in end-on attitude are discussed in more detail in a Teledyne-Isotopes memorandum (Ref. IV-10).

b. Velocity-flight path angle parametrics

Various reentry trajectories were used in a digital trajectory analysis code (digital program UB088) for a constant ballistic coefficient of 50 psf to determine

FIGURE IV-4 TWO-DIMENSIONAL HEATING DISTRIBUTION OVER THE UNHEATED SHARP 19 IIHS IN SIDE-ON, FLAT-LEADING ATTITUDE ($\alpha = 90^\circ$, $\phi = 30^\circ$).

$\dot{q}_{s,HS,R_N=1} \sim$ STAGNATION POINT HEATING RATE TO A HEMISPHERE WHOSE $R_N = 1$ FT.

x/D - NONDIMENSIONAL LATERAL SURFACE DISTANCE MEASURED FROM GEOMETRIC CENTER ON LEADING SURFACE.

FIGURE IV-5 LATERAL AND LONGITUDINAL SURFACE STATION NOMENCLATURE
FOR THE UNARLATED SNAP 19 ITHS IN SIDE-ON, FLAT-LEADING
ATTITUDE ($\alpha = 90^\circ$, $\phi = 30^\circ$).

FIGURE IV-6 CARFET PLOT OF CONVECTIVE HEATING DISTRIBUTION VS VARIOUS LATERAL AND LONGITUDINAL STATIONS OF THE LEADING SURFACE FOR THE UNHEATED SNAP DITHIS IN SIDE-ON, FLAT-LEADING ATTITUDE ($\alpha = 90^\circ$; $\phi = 30^\circ$).

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FIGURE IV-7a CARPET PLOT OF CONVECTIVE HEATING DISTRIBUTION VS VARIOUS LATERAL AND LONGITUDINAL STATIONS OF THE 60°-SWEEP SURFACE FOR THE UNBLUNTED SNAP 19 IHS IN SIDE-ON, FLAT-LEADING ATTITUDE ($\alpha = 90^\circ, \phi = 30^\circ$).

$$(b) 0.635 \leq s/b \leq 0.90$$

FIGURE IV-7c (CONCLUDED)

(c) $0.90 \leq s/b \leq 1.5$

FIGURE IV-8 CARPET PLOT OF CONVECTIVE HEATING DISTRIBUTION VS VARIOUS LATERAL AND LONGITUDINAL STATIONS OF THE 120° SWEEP SURFACE FOR THE UNRELATED SNAP 19 IIHS IN SIDE-ON, FLAT-LEADING ATTITUDE ($\alpha = 90^\circ$, $\phi = 30^\circ$).

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FIGURE IV-9 THREE DIMENSIONAL CONVECTIVE HEATING DISTRIBUTION
IN LATERAL DIRECTION AT VARIOUS LONGITUDINAL STATIONS
ON THE 130° SWEEP SURFACE OF THE UNRELATED SNAP 19
IHS IN SIDE ON, FLAT-LEADING ATTITUDE ($\alpha = 90^\circ$, $\phi = 30^\circ$).

$$\dot{q}_{SHSRN} = 1/2 / \dot{q}_{SHSRN} = 1'' = 1.72$$

s/b - NONDIMENSIONAL LATERAL SURFACE DISTANCE MEASURED
FROM GEOMETRIC CENTER ON LEADING SURFACE.

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FIGURE IV-10a THREE DIMENSIONAL CONVECTIVE HEATING DISTRIBUTION ALONG VARIOUS PARALLEL LATERAL SURFACE STATIONS (PARALLEL TO THE VELOCITY VECTOR) OVER THE END SURFACE OF THE UNBLATED SNAP 19 ITHS IN SIDE-ON, FLAT-LEADING, ATTITUDE ($\alpha = 90^\circ, \phi = 30^\circ$).

$$\dot{q}_{s, ITHS, R_n} = b/2 / \dot{q}_{s, HS, R_n} = 1' = 1.72$$

◇ VALUE ALONG $s/l = 0.5$ BETWEEN $s/b = 1.5$ & 2.5 ON 120° -SWEEP SURFACE.

s'/b ORIGIN IS LOCATED ALONG LONGITUDINAL STATION $s/l = 0.5$ BETWEEN LATERAL STATIONS $s/b = 0$ & 1.5 .

(a) LATERAL SURFACE STATIONS $0 \leq s/b \leq 0.5$

s'/b - NONDIMENSIONAL LATERAL SURFACE DISTANCE ACROSS THE END OF ITHS MEASURED FROM LEADING EDGE OR CORNER OF END SURFACE.

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FIGURE IV-10b (CONTINUED)

◇ VALUE ALONG $s/r=0.5$ BETWEEN $s/b=1.5$ & 2.5 ON 120° -SWEEP SURFACE.

(b) LATERAL SURFACE STATION $s/b=0.55$

s/b -NONDIMENSIONAL LATERAL SURFACE DISTANCE ACROSS THE END SURFACE OF IHS MEASURED FROM LONGITUDINAL STATION $s/r=0.5$ FOR NOTED LATERAL STATION.

FIGURE IV-10c (CONTINUED)

◇ VALUE ALONG $s/l = 0.5$ BETWEEN $s/b = 1.5$ & 2.5 ON 120° -SWEEP SURFACE.

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FIGURE IV-10d (CONTINUED)

◇ VALUE ALONG $S/L=0.5$ BETWEEN $S/b=1.5$ & 2.5 ON 120° -SWEEP SURFACE.

S'/b -NONDIMENSIONAL LATERAL SURFACE DISTANCE ACROSS THE END SURFACE OF IHS MEASURED FROM LONGITUDINAL STATION $S/L=0.5$ FOR NOTED LATERAL STATION.

FIGURE IV-10e (CONTINUED)

◇ VALUE ALONG $s/l = 0.5$ BETWEEN $s/b = 1.5$ & 2.5 ON 120° -SWEEP SURFACE.

s/b - NONDIMENSIONAL LATERAL SURFACE DISTANCE ACROSS THE ENL SURFACE OF IHS MEASURED FROM LONGITUDINAL STATION $s/l = 0.5$ FOR NOTED LATERAL STATION.

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FIGURE IV-10f (CONCLUDED)

◇ VALUE ALONG $s/l=0.5$ BETWEEN $s/b=1.5$ & 2.5 ON 120° -SWEEP SURFACE.

(i) LATERAL SURFACE STATION $s/b=1.0$

(j) LATERAL SURFACE STATION $s/b=1.2$

s/b -NONDIMENSIONAL LATERAL SURFACE DISTANCE ACROSS THE END SURFACE OF IHS MEASURED FROM LONGITUDINAL STATION $s/l=0.5$ FOR NOTED LATERAL STATION.

FIGURE IV-11 AVERAGE CONVECTIVE HEATING DISTRIBUTION
OVER THE END SURFACE OF THE UNRELATED
SNAP 19 IIHS IN END-ON ATTITUDE ($\alpha=0^\circ, \phi=-$).

$$\frac{\dot{q}_{S,IIHS,R_0=0.157}}{\dot{q}_{S,HS,R_0=1}} = 1.425 \text{ (THEORETICAL)}$$

s/R - NONDIMENSIONAL SURFACE DISTANCE MEASURED
FROM CENTER OF END SURFACE.

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$$\dot{Q}_{S,INS} / \dot{Q}_{S,HS,R_{H=1}} = 1.425 \text{ (THEORETICAL)}$$

resulting environments. A rotating oblate earth model was considered with U.S. Standard Atmosphere 1962. The initial conditions at 400K feet were:

- a. $V_I = 25,690 \text{ fps}$ and $\gamma_I = -0.1^\circ$ with $-180^\circ \leq \psi_I \leq 0^\circ$, $\Delta \psi_I = -30^\circ$
- b. $V_I = 40,000 \text{ fps}$ and $\psi_I = 0^\circ$ (due east) with $-8^\circ \leq \gamma_I \leq -5^\circ$, $\Delta \gamma_I = -1^\circ$
- c. $V_I = 44,000 \text{ fps}$ and $\psi_I = 0^\circ$ with $-7^\circ \leq \gamma_I \leq -5^\circ$, $\Delta \gamma_I = -1^\circ$
- d. $V_I = 48,000 \text{ fps}$ and $\psi_I = 0^\circ$ with $-8^\circ \leq \gamma_I \leq -5^\circ$, $\Delta \gamma_I = -1^\circ$

where V_I , γ_I and ψ_I are inertial velocity, flight path angle, and heading, respectively. Study of these trajectories provides analysis of the region in $V-\gamma$ space where aerodynamic heating is expected to be maximized. Additionally, heading angle variations were explored to determine resulting variations in heating rate distributions.

c. Athena-H test analysis

Two Athena H reentry trajectories were made for the unablated IHS in side-on, flat-leading and tumble-spin attitudes. The initial conditions were:

- altitude = 290,000 feet,
- inertial velocity = 21,600 fps,
- inertial flight path angle = -19.9° , and
- inertial heading = -90° (due south)

These calculations were performed to determine the worth of launching a simulated Pioneer heat source.

d. Multi-revolution study

A 260,000 ft. perigee trajectory (Ref. IV-11) was chosen to define the parameters for a plasma arc test simulating the multi-orbit environment. This trajectory was selected because of its length (seven atmospheric passes) and compatibility with heating rate ($\dot{q}^* = 181 \text{ BTU/ft}^2\text{-sec}$) capability of the plasma arc. Figure IV-13 contains the histories of the following trajectory parameters for each atmospheric pass:

- a. Altitude
- b. Relative velocity
- c. Inertial flight path angle
- d. Heating rate ($\dot{q}^*$)
- e. Total heat ($\dot{q}$)
- f. Stagnation pressure
- g. Stagnation enthalpy

Figure IV-14 contains some time quantities as a function of each pass for this multi-orbit trajectory.

The average cooling rate histories to the hexagonal body and the hexagonal ends are shown in Fig. IV-15. These rates were calculated from $M = 1.8$ (501 seconds from 400,000 feet) to impact.

3. Aerophysics Test Status

- a. NASA/Ames supersonic force and moment tests

Force and moment data obtained from supersonic wind tunnel tests were reduced and applied to six degree-of-freedom analyses. Evaluation of the reentry motion of the SNAP 19/Pioneer heat source is proceeding.

*Convective, stagnation heat rate or flux related to a sphere at one foot radius.

FIGURE IV-13a. HISTORIES OF VARIOUS TRAJECTORY PARAMETERS FROM SANDIA'S 260 KFT. PERIGEE MULTI-ORBIT TRAJECTORY (SEVEN ATMOSPHERIC PASSES) OF THE UNARMED SNAP 19 IHS IN SIDE-ON, FLAT-LEADING ATTITUDE.

FIGURE IV-13b (CONTINUED)

(b) RELATIVE VELOCITY

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FIGURE IV-13c (CONTINUED)

(C) INERTIAL FLIGHT PATH ANGLE

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FIGURE IV-13d (CONTINUED)

(d) HEATING RATE ($\dot{Q}_{C,S,H,S,R_N=1''}$)

FIGURE IV-13e (CONTINUED)

(2) TOTAL HEAT ($Q_{C,S,H,S,R_1=1''$)

FIGURE IV-13f (CONTINUED)

(f) STAGNATION PRESSURE

FIGURE IV-13g (CONCLUDED)

(9) STAGNATION ENTHALPY

FIGURE IV-14. VARIOUS TIME QUANTITIES AS A FUNCTION OF THE NUMBER OF PASS FOR SANDIA'S 260KFT. PERIGEE MULTI-ORBIT TRAJECTORY OF THE UNABLATED SNAP 19 ITHS IN SIDE-ON, FLAT-LEADING ATTITUDE.

ORBITAL DECAY, $\Delta t_{in} = 52.8$ MIN.

HEXAGONAL BODY

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b. NASA/Langley low density force and moment tests

Preliminary low density aerodynamic force and moment data were received in October 1970. In addition to the test program outlined in the Second Semi-Annual Progress Report, four additional models were constructed and tested to obtain low density rolling moment data. These models represented the unablated hexagonal heat source and the heat source with one flat ablated. The latter duplicated the one configuration tested at NASA/Ames. These data are being used to establish the aerodynamic coefficients in the transitional flow regime.

c. NASA/Langley heating distribution tests

The heating distribution data obtained in the NASA/Langley 20-inch Mach 6 hypersonic wind tunnel were received in August 1970. The data for the unablated configuration are being reduced to obtain heating rates around the hexagonal heat source in various orientations to the velocity vector.

d. Proposed plasma arc test

The results of drop tests of heat sources having various amounts of recession were described in the Second Semi-Annual Progress Report. These tests indicated that the terminal velocity of the heat source was very sensitive to the specific radius geometry of the recessed edges. The need for a plasma arc test of the heat source in a spinning mode, in order to experimentally determine the recession geometry, was outlined in INSD Memo SN19-MIH-328.

C. REENTRY THERMAL RESPONSE ANALYSIS

Descriptions of recent changes made to the transient heat transfer model used in reentry analyses are provided in this section. An evaluation of the accuracy of the model was performed and results of a limited parametric study are presented.

1. Model Development

a. Graphite oxidation

Equations were derived (Ref. IV-12) to predict the oxidation of graphite at moderate wall temperatures (1000-3000°F). Assuming the reaction rate constants for the oxygen-graphite reaction are known, it is anticipated that this effort can be utilized to predict, more accurately, surface recession during the terminal phase of reentry and during multi-orbit reentries.

b. Graphite sublimation

Equations were developed (Ref. IV-13) to account for the sublimation of graphite. These equations were subsequently incorporated into SNAP 19/Pioneer aerothermal analyses.

c. Accuracy of thermal model

A study was made to evaluate sources of error in computational methods used to predict temperatures during reentry (Ref. IV-14). It was determined that current methods underestimate peak capsule temperature by about 30°F.

Heat source temperatures were computed for an orbital decay reentry, side-stable reentry mode to compare with similar results obtained by the Sandia Corp. The trajectory, TTB B, was furnished by Sandia Corp. Two release altitudes, 300,000 ft. and 400,000 ft, were assumed. Teledyne Isotopes results, summarized in Table IV-3, for peak clad temperatures are smaller by about 200°F than corresponding calculations performed at Sandia Corp. Also evident is the significant temperature increase at the clad.

2. Restricted Parametric Analyses

Heat source temperatures were computed for five superorbital reentry cases. Each case assumed a stable reentry mode. Results are summarized in Table IV-4.

TABLE IV-3

Summary of Results

<u>Location</u>	<u>Temperature (°F)</u>			
	<u>Maximum</u>		<u>Impact</u>	
	<u>Release</u>	<u>Release</u>	<u>Release</u>	<u>Release</u>
	<u>Alt.</u>	<u>Alt.</u>	<u>Alt.</u>	<u>Alt.</u>
	<u>400K ft.</u>	<u>300K ft.</u>	<u>400K ft.</u>	<u>300K ft.</u>
Heat shield - outer surface	3906	3893	984	938
Heat shield - inner surface	3783	3758	1010	960
Sleeve - outer surface	3732	3701	1130	1074
Sleeve - inner surface	3020	2844	2081	1918
Clad	2918	2693	2336	2182
Strength member	2869	2629	2418	2257
Liner	2837	2585	2497	2331
Fuel	2816	2564	2663	2475
Fuel centerline	2789	2554	2725	2525

<u>Element</u>	<u>Surface Recession (in.)</u>	
	<u>Release</u>	<u>Release</u>
	<u>Alt.</u>	<u>Alt.</u>
	<u>400K ft.</u>	<u>300K ft.</u>
251	.111	.104
110	.122	.115
252	.073	.069
253	.069	.066
254	.085	.082
255	.068	.066
256	.009	.009
257	.001	-
258	-	-
259	-	-

TABLE IV-4

Summary of Results

<u>Run</u>	<u>Initial Velocity (fps)</u>	<u>Initial Path Angle (deg.)</u>	<u>Temperature (°F) Peak Values</u>			<u>Strength Member @ Impact</u>	<u>Stag. Pt. Surface Recession (in.)</u>	<u>Comments</u>
			<u>Heat Shield @ Stag. Pt.</u>	<u>Clad</u>	<u>Strength Member</u>			
100	36,000	-6	5651	2974	2763	2202	0.123	2-D Model
101	42,000	-6.5	6032	3222	3020	2314	0.216	2-D Model
102	42,000	-12	6615	2513	2338	1982	0.168	2-D Model
113	36,000	-16	6383	2318	2001	1787	0.076	3-D Model
114	36,000	-16	6398	2252	1950	--	0.080	3-D Model
$K_{HS} = .75 K_{POCO}$								

These cases were the first in a series of reentry analyses for which the thermal model has been updated to account for sublimation of graphite. It is apparent that, as a result of including sublimation effects, peak surface temperatures were reduced considerably.

D. SAFETY ANALYSIS

Objectives during this reporting period included detailed planning and scheduling of the Pioneer SAR, acquisition of necessary supporting information from outside sources, and safety analysis.

1. SAR Plan and Schedule

Draft copies of an appropriate "SNAP Safety Plan Document for Pioneer F and G" were issued on 30 August 1970 as INSD-2873-2. A meeting was held subsequently on 22 October 1970 to review the scope of work, establish formats for the three SAR volumes, and to establish completion dates on each report section. The final section is set for completion on 14 May 1971.

2. Acquisition of Supporting Information

Information requirements for SAR preparation were reviewed carefully and documented as "Supporting Information Requirements for SNAP 19 Pioneer F/G Safety Analysis Report," 16 September 1970, INSD-TMO-9612. This document was updated on 20 October 1970 as SN19-TMO-313. A substantial number of items were still outstanding as of 30 November 1970. The subject memo will be updated as needed until a final disposition has been determined on each information item.

Attendance at the AEC Safety Evaluation Techniques Symposium, 30 Sept. and 1 Oct. 1970, at Los Alamos, provided some information on Pioneer analysis models. A draft was received on one of the topics: "Meteorological Data Summary and

Transport of Atmospheric Contaminants at Kennedy Space Center," NUS-728, and constructive comments were submitted.

Information available at INSD on PMC fuel properties was compiled and documented 29 Sept. 1970 as INSD-TMO-9618.

3. PMC Reentry Response Analysis

A semi-empirical model of PMC fuel response to reentry was formulated, based on Sandia arc tunnel tests of microspheres and bulk fuel. Details are in INSD-TMO-9650, to be issued in December 1970 as a section of SAR Vol. III, Chapter 2 (Fuel Response to Environment).

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V. GENERATOR AND COMPONENT TESTING

A. GENERATOR TESTING

1. Test Chronology

A matrix of generator activities is presented in Table V-1. As shown, four generators remain on test at the conclusion of the reporting period. S/N 26 is the Isotopes Generator used for general performance evaluations, with 13700 hours accrued. S/N 29 helium filled endurance generator has 10200 heated hours. The Pioneer prototype generator S/N 37 was fueled in November, 1970 and is scheduled for environmental qualification testing during December. S/N 38 was awaiting fueling at the end of the reporting period. Two SNAP 19 ETG's (S/N 35 R and S/N 36) were delivered to NASA/Ames during July and October, respectively. Of these, S/N 36 successfully completed Pioneer vibration, acceptance and qualification levels. The principal results of specific tests are presented below.

2. Fueling

Fueling of the first Pioneer type SNAP 19 generator was completed on 19 November 1970. The actual fueling was preceded by extensive personnel training and equipment checkout sessions to assure a safe and efficient operation. The fueling was accomplished in a specially designed glove box within the fueling laboratory with the generator output on short circuit. Following placement of the capsule quality assurance measurements, and thermal stabilization, the generator upper cover was secured and seal welded. A successful leak check completed the fueling operation.

3. Load Voltage Parametric Tests

The results of parametric tests performed on SNAP 19 generators S/N 26,

TABLE V-1

Generator Test Chronologies (7/1/70 thru 11/30/70)

Generator S/N	29	35R	36	37	38
Complete Outgassing		7/1/70	9/17/70	11/15/70	11/25/70
Mfg. Power Check (argon)		7/1/70	9/17/70	11/15/70	11/25/70
Cooldown		7/2/70			11/25/70
Gas Exchange (75% He)				11/17/70	11/30/70
Heatup		7/3/70			
Fueling				11/19/70	
Hot Gas Leakage Tests		7/4/70	9/18/70	11/20/70	
Parametric Tests	7/9/70	7/3/70	9/18/70	11/21/70	
Radiation Survey				11/24/70	
Cooldown		7/4/70	9/20/70		
Heatup		7/8/70	9/23/70		
Start Vibration Tests (Accept. Lvl)			9/24/70		
Cooldown		7/9/70	9/25/70		
Heatup			9/28/70		
Qual. Level Vibration			9/28/70		
Cooldown			9/29/70		
Heatup			9/30/70		
Hot Gas Leakage Tests			10/1/70		
Parametric Tests*	10/14/70		10/2/70		
Cooldown			10/2/70		
Disposition**	On test	Deliv. NASA Ames 7/70	Deliv. NASA Ames 10/70	On test	On test

*Parametric Tests on S/N 26 -10/14/70.

**S/N 26 is on test.

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29, 35, 36 and 37 are presented in Figs. V-1 through V-5. All tests were conducted with fin root temperatures around 330°F and data were normalized to exactly 330°F. The thermal input of ETG's is corrected for net thermal losses associated with heater installation so that a radioisotope equivalent inventory is indicated for each. Gas fills are argon, helium, or mixtures of the two gases, as shown on the graphs.

4. Hot Argon/Helium Leakage Tests

The results of argon/helium leakage tests performed on three generators in vacuum are summarized in Table V-2. It should be noted that although generator S/N 37 was tested in the RTG configuration of one viton-sealed penetration, a viton-sealed close-off valve was temporarily installed which may have added to the leakage measurement. Subsequent RTG's (after S/N 38) will have this ~~valve~~ removed during the fueling process. However, these tests do indicate that the leakage anticipated from a single viton O-ring seal at the connector is in the 0.4 to 0.7×10^{-5} scc/sec of argon range.

5. Cold Vibration Test Series

As discussed in Section V.A.4 of INSD-2873-26 (Second Semi-Annual Report), vibration testing of Pioneer generators revealed the need for design modification to assure compatibility of the generator with the established Pioneer vibration input levels. Testing of ETG units S/N 33 and 35 resulted in the removal of the "getter" component from the design configuration. In addition, a cold (room temperature) vibration test was performed on a rebuilt version of S/N 35 utilizing a "dummy" capsule configuration comprised of fuel simulant, liner, strength member and clad. As discussed in the previous semi-annual report, results of this cold vibration test indicated that the tantalum felt compliance pad was not sufficient to support the capsule.

The figure consists of four vertically stacked line graphs sharing a common x-axis representing Load Voltage in Volts, ranging from 2.4 to 3.0. Two data series are plotted in each graph: a solid line for 9390 hours (5 June 1970) and a dashed line for 12550 hours (14 Oct 1970).

- Hot Junction Temperature (°F):** The y-axis ranges from 1020 to 1080. Both temperatures increase with load voltage, with the 9390-hour temperature consistently higher than the 12550-hour temperature.
- Cold Junction Temperature (°F):** The y-axis ranges from 370 to 390. Both temperatures are relatively stable, with the 9390-hour temperature slightly higher than the 12550-hour temperature.
- Internal Resistance (ohm):** The y-axis ranges from 0.14 to 0.18. Both resistances are relatively constant, with the 9390-hour resistance slightly higher than the 12550-hour resistance.
- Open Circuit Voltage (volts):** The y-axis ranges from 4.6 to 5.2. Both voltages increase with load voltage, with the 9390-hour voltage consistently higher than the 12550-hour voltage.
- Net Power Output (watts):** The y-axis ranges from 34 to 39. Both power outputs increase with load voltage, with the 9390-hour power output consistently higher than the 12550-hour power output.

FIGURE II-2
SNAP 19 GENERATOR S/N 29
PARAMETRIC TEST RESULTS
FIN ROOT TEMPERATURE: 330°F
675 WATTS (EQUIVALENT FUELED)
HELIUM FILLED

FORM 10-00000 K&E LANCING UNIT
© 1970 K&E LANCING UNIT
20180

FIGURE IV-3
SNAP 19 GENERATOR S/N 35
PARAMETRIC TEST RESULTS
FIN ROOT TEMPERATURE : 330 °F
640 WATTS (EQUIVALENT FUELED)
FILL GAS: 75 % ARGON/25 % HELIUM

FORM 9000000 28100
K-1
REVISION 10-67

FIGURE II-4
SNAP 19 GENERATOR S/N 36
PARAMETRIC TEST RESULTS
FIN ROOT TEMPERATURE: 330 °F
640 WATTS (EQUIVALENT FUELED)
FILL GAS: 75% ARGON/25% HELIUM

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FIGURE V-5
SNAP 19 GENERATOR SIN 37
PARAMETRIC TEST RESULTS
FIN ROOT TEMPERATURE: 330 °F
644 WATTS (CAPSULE INVENTORY)
FILL GAS: 75% HELIUM/25% ARGON

TABLE V-2

Results of SNAP 19 Argon/Helium Leak Tests at
337°F Fin Root Temperature

<u>Generator S/N</u>	<u>Test Date</u>	<u>Heated Hours</u>	<u>Leak Rate x 10⁻⁵ scc/sec. atm.</u>	<u>Pressurization Gas</u>
35* (rebuilt)	7/4/70	45	0.8 argon 2.7 helium	75% argon/25% helium
36*	9/18/70	40	1.5 argon 5.8 helium	75% argon/25% helium
36*	10/1/70	185	1.2 argon 5.2 helium	75% argon/25% helium
37	11/20/70	120	0.7 argon 2.1 helium	25% argon/75% helium

*These generators contain two viton-sealed connector mountings.

It was further concluded that this lack of support permitted the capsule free motion within the heat shield and that the resultant impact loads were the main cause of the broken couples and displaced buttons observed during diagnostic disassembly of this test unit.

In order to verify these results, cold vibration test #2 was performed. This test featured a solid carbon steel simulated heat source mass to duplicate the effect of a configuration which replaced the compliant tantalum felt support with an essentially solid capsule support system. Instrumentation consisted of two accelerometers mounted on the simulated heat source and the continuous recording of module electrical circuit continuity during all phases of dynamic testing. Results of this test verified that by eliminating the "loose" capsule support system, damage to the thermopile and the electrical continuity of the system could be avoided.

Cold vibration test #3 attempted to explore an alternate solution to the problem which consisted of retaining the tantalum compliant pad and simulating the effect of crushing the capsule clad down upon the strength member. While some heat source pyrolytic graphite sleeve damage resulted from this test, it was unique to the technique of simulating the support condition and the post-test examination showed no thermoelectric module damage. A further consideration of the capsule clad crushing approach indicated that, while this technique might offer a feasible solution, related development of a clad crushing technique and coordination with the fuel capsule supplier could impose schedule restrictions incompatible with established program milestones. Also, the compressed tantalum pad yielded insufficient thermal impedance.

The alternate solution then, was to develop and test what has now evolved into the hard mount design configuration for supporting the capsule. A series of four

additional cold vibration tests and one electrically heated vibration test supported this development effort and verified the final design.

Table V-3 summarizes the complete cold vibration test series. A complete report detailing the background, description and diagnostic results of these tests will be issued during the next reporting period.

6. Generator S/N 36 Vibration

ETG S/N 36, a welded generator incorporating the Pioneer prototype hard-mount design feature, was successfully tested to both acceptance and qualification levels for Pioneer applications. Table V-4 documents vibration test levels. Performance was unaltered by these tests, and structural integrity to withstand these levels of dynamic loading was demonstrated.

The levels in Table V-4 reflect two major changes from earlier levels (Ref. Table V-3 of Second Semi-Annual) on the Pioneer program. First, the amplitude (g's) in the S/C thrust axis for 25-50 Hz was reduced approximately 50% based on recent spacecraft vibration tests at TRW. Secondly, the random vibration levels were increased to effectively incorporate acoustic energy. Some slight increases were also made in the sinusoidal spectrum to accommodate acoustic energy input.

7. Endurance Tests

The endurance tests of argon-filled generator S/N 26 and helium-filled generator S/N 29 are continuing and power performance is shown in Figs. V-7 and V-8.

S/N 26 is being held in an argon atmosphere at a hot junction temperature of 1020°F. The internal pressure has increased from 8.2 psia to 9.7 psia during the reporting period which indicates the expected in-leakage of argon from the one-atmosphere generator ambient environment. Power output has decreased at a linear rate of 0.34 watts/1000 hours during the period.

TABLE V-3

Cold Vibration Test History

<u>Test No.</u>	<u>Capsule</u>	<u>Capsule Support</u>	<u>Sleeve</u>	<u>End Plug</u>	<u>Accelerometer and Circuit Continuity</u>	<u>Modules</u>	<u>Remarks</u>
1	Sandia Capsule	Compliant Pad	Yes (Pyrolytic)	Carb-I-Tex	No	(5) from Orig. ETG S/N 35 (1) new	Sleeve cracked during test. Some broken couples loose buttons.
2	Solid Mass	Not Applicable	No	Carbon Stl.	Yes (in End Plugs)	(2) New (4) Used	Modules intact; circuit continuity unchanged.
3	Sandia Capsule with center clad removed	Compliant Pad Highly Compressed	Yes (Pyrolytic)	Carb-I-Tex	Yes	(2) New (4) Used	End clad pushed down on strength member; moved further during test; sleeve chipped. Modules intact; circuit continuity unchanged.
4	Same as in Test 3	Hard Mount	Yes (ATJ)	ATJ	Yes	Same as in Test 3	Hard mount test with end plugs relieved on end to assure side contact on capsule. Modules intact; circuit continuity unchanged.
5	Serial #P27 capsule	Hard Mount	Yes (ATJ)	ATJ	Yes	(2) New (4) Used	Same as Test 4 except for capsule. Modules intact; circuit continuity unchanged.
6	Serial #P27 capsule	Hard mount with shear ring	Yes (ATJ)	Carb-I-Tex	Yes	Same as in Test 5	Modules intact, circuit continuity unchanged, hard mount design intact.
7	Serial #P23 capsule	Modified hard mount with shear ring	Yes (ATJ)	POCO Q1	No	Same as in Test 5	Modified hard mount design integral end plug/shear ring ZrO ₂ capsule support ring. Mechanical test only. Hard mount design intact.

TABLE V-4

Vibration Levels for Pioneer Applications

I. Sinusoidal Vibration Levels

<u>Axis</u>	<u>Frequency Range (Hz)</u>	<u>Accept. Accel. (g's)</u>	<u>Qual. Accel. (g's)</u>
Normal to generator cylinder and parallel to fin (S/C thrust axis)	5-25	8.0*	12.0*
	25-50	18.0*	27.0*
	50-100	6.0	9.0
	100-200	1.5	2.3
<u>Axes</u>			
Normal to generator cylinder and normal to fin (S/C Lateral 1)	5-22	13.0*	20.0*
	22-100	12.0*	18.0*
	100-200	2.0	3.0
Axial, parallel to axis of generator (S/C Lateral 2)			
Sweep Rate (octave/min)		4	2

*or within 0.4 inch double amplitude displacement.

II. Random Vibration Levels

	<u>Frequency Range (Hz)</u>	<u>PSD (g²/Hz)</u>	<u>Accel. g (rms)</u>
Qualification level All three axes at 4.0 min/axis	20-50	0.40 at 50 Hz with 12 db/octave roll off below 50 Hz	
	50-75	0.40	11.5
	75-200	Smooth roll off (approx. 6 db/octave) from 0.4 at 75 Hz to 0.056 at 200 Hz	
	200-2000	0.056	
Acceptance level All three axes at 2.0 min/axis	20-50	0.179 at 50 Hz with 12 db/octave roll off below 50 Hz	
	50-75	0.179	7.7
	75-200	Smooth roll off (approx. 6 db/octave) from 0.179 at 75 Hz to 0.025 at 200 Hz	
	200-2000	0.025	

FIGURE V-7
SNAP 19 TAGS GENERATOR S/N 26 PERFORMANCE
ELECTRICALLY HEATED - ARGON FILL GAS - 2.85 LOAD VOLTS
POWER OUTPUT NORMALIZED TO 330 °F ON FIN ROOT
POWER INPUT = 668 WATTS (640 WATTS EQUIVALENT FUELED)

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FIGURE V-8
SNAP 19 TAGS GENERATOR SIN 29 PERFORMANCE
ELECTRICALLY HEATED - HELIUM FILL GAS - 2.85 LOAD VOLTS
POWER OUTPUT NORMALIZED TO 330 °F ON FIN ROOT
POWER INPUT - 705 WATTS (e) (675 WATTS EQUIVALENT FUELED)

S/N 29 is operated in a helium environment at a hot junction temperature of approximately 980°F. The rate of power depreciation since June 1970 has been 0.15 watts/1000 hours. The internal pressure of S/N 29 is constant at 1.0 atmosphere.

B. COMPONENT TESTING

1. Heater Evaluation Test

A test was performed to evaluate the SNAP 19 electrical heater element life when operating at the high temperatures anticipated in prototype and flight generators filled with one atmosphere argon. The test was performed with a SNAP 19 heater block placed within an argon filled bell jar. Power input to the heater block was 650 watts with heater block surface temperature near 1800°F. Test duration was 2908 hours with no heater element failures. This test will be reported next period in INSD-2873-41, "Heater Evaluation Test."

2. Pyrolytic Sleeve Test

Because of the large differential thermal expansion between pyrolytic graphite and POCO AXF-Q1 graphite, analysis predicts that the gap between the sleeve and heat shield body at room temperature assembly increases by 5 mils at operating temperature, i.e., 1000°F on the heat shield body. A test was conducted to evaluate the thermal effect of this gap. An electrical heat source was assembled and all critical dimensions were measured before and after the test. The heat source was heated in two different environments, 100% argon and 75% helium/25% argon, and temperatures of the heat shield body, pyrolytic sleeve, and heater block were recorded after stability was achieved at operating temperature and nominal power input. Data reduction has not been completed, but preliminary indications are that

measured and predicted temperatures agree closely.

3. Hydrostatic Test of Generator Housing/End Covers

Hydrostatic testing of a complete housing/end cover assembly (bolted covers and weld sealed closures) was performed during this period. The test specimen was as defined in 452A4040002 and the test procedure performed in accordance with 452A4040404. Testing was conducted in three basic phases as follows:

- Phase 1. Incremental pressure increase to 180 psig (design pressure) followed by helium leak check.
- Phase 2. Incremental pressure increase to 270 psig (1.5 x design pressure) followed by helium leak check.
- Phase 3. Incremental pressure increase to failure.

All pressure testing was conducted at a housing/end cover temperature of 330°F. Instrumentation consisted of thermocouples, strain gages (temperature compensated), and dial gages for measuring end cover deformations. The pressure medium was oil. Since a major percentage of the design pressure of 180 psig is mechanically induced (165 psi) by the Min-K end plug, the use of a fluid to simulate total internal pressure introduced a degree of conservatism to this test.

The leak checks performed after Phases 1 and 2 indicated no damage to the seal integrity of the upper and lower cover welds. While the strain gage data were somewhat erratic, reasonable agreement with analytically predicted data was obtained from some gages. Similarly, dial gage readings of load-deflection relationships for the instrumented upper cover compared well with predicted values.

Limited instrumentation data were recorded during Phase 3 pressurization to failure. Failure (inability to increase internal pressure) was encountered at an internal pressure slightly in excess of 370 psi. Post test inspection showed that

some of the end cover bolts had developed sufficient tensile loads to pull the threaded titanium inserts from the housing end boss. As this occurred, the seal weld ring picked up increasing amounts of load and was drawn down over the bolt heads until the seal ring material was actually penetrated by the bolt heads, thereby causing loss of seal capability. This mode of failure was non-catastrophic in the sense that no explosion or shrapnel resulted.

Based on a demonstrated failure pressure of 370 psig, and a design pressure of 180 psig, a margin of safety of +1.05 exists on the structural design of the upper end cover. Since the test specimen consisted of actual housing and upper and lower cover assemblies, it can be stated that this structural margin of safety on pressure containment applies to the entire RTG housing assembly.

A hydrostatic test report will be issued during the next reporting period.

4. Connector Seal Tests

a. Pioneer connector/O-ring testing

A test program was initiated last period to investigate the performance of the Pioneer selected 0.076-inch diameter Viton connector O-ring in conjunction with the Deutsch 26-pin receptacle. The test consisted basically of five deep thermal cycles (2-1/4 hr period) from room temperature to 400°F followed by a 98-day soak at 350°F with additional thermal cycles to room temperature for cold leak testing. Three test samples were used in the investigation.

Results of the test are shown in Table V-5. Although two failures were observed at the end of the test (one of the O-rings resealed upon reheating), the results are not directly applicable to an RTG because of the complete cooldown to room temperature, i.e., this test series resulted in considerable overtest. The now-apparent explanation for these failures is as follows: at temperatures

TABLE V-5

Viton O-Ring Test Summary

<u>Chronological Event</u>	<u>Leak Rate (scc/sec)x 10⁶</u>					
	<u>Fixture #1</u>		<u>Fixture #2</u>		<u>Fixture #3</u>	
	<u>Argon</u>	<u>Helium</u>	<u>Argon</u>	<u>Helium</u>	<u>Argon</u>	<u>Helium</u>
Leak at room temperature	--	.32	--	.16	--	.13
Leak at approx. 325°F	11	35	6.8	12	2.3	8.2
Five cycles (room temperature to 400°F)						
Leak at approx. 325°F	7.3	33	5.4	14	2.9	9.4
Leak at room temperature	--	.88	--	.28	--	.60
30-day soak at approx. 350°F						
Leak at room temperature	--	.35	--	.59	--	.48
Leak at approx. 330°F	8.6	38	3.7	19	.75	35
68-day soak at approx 350°F						
Leak at room temperature	--	gross	--	gross	--	0.056
Leak at approx. 350°F	--	gross	--	20	--	--

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approaching 400°F, Viton undergoes 100% compression set in 500-1000 hours; upon cycling to a lower temperature, contraction of the elastomer (expansion coefficient is about 10 times that of steel receptacle), results in a leak.

The condition of most concern for Pioneer would be at launch when a cycle down to about 170°F fin root temperature (~155°F seal temperature) is expected. By this time, compression set will probably be complete. However, the same elastomer and launch temperature were used with complete success for the four RTG's launched under the Nimbus program. Therefore, the increases in leak observed on two of the three recent test samples appear attributable to the fact that they were cycled completely down to room temperature.

b. Viking connector seal studies

Mission requirements for the Viking program indicate a change in the generator electrical connector seal from the Viton seal used on the Pioneer program is desirable because of the higher seal operating temperature and cycling conditions encountered during the Viking mission. The objective of this study is to develop a seal capable of withstanding a minimum of 100 thermal cycles between 150 and 400°F while maintaining a leak rate of 10^{-7} scc/sec of helium or lower. Sealing methods to be evaluated include soft soldering and metal seals.

(1) Soft solder studies

Connector shells to be utilized on Viking are fabricated from stainless steel while the generator housing is HM21A magnesium-thorium alloy. Since these materials will not easily solder directly, it is necessary to copper plate both components. Plating was done by an outside vendor, Furniture City Plating Company of Grand Rapids, Michigan. Since it would be impractical to send a generator housing to the vendor for plating the small area where the connector seal is located, two

different methods for welding a small boss (which can be readily plated) to the generator housing are being investigated. One design employs a fillet weld and the other seal weld similar to that used at the end covers of the generator. The first design is simpler to fabricate but requires more heat in welding to the housing. Each design will be evaluated as to (1) ease of welding, (2) leak tightness, (3) warpage in the seal area, and (4) condition of copper plate in the seal area after welding.

Soldering the connector requires an evaluation of the hermetic seal in the connector itself. This seal must be leaktight after withstanding the solder melt temperature and cycling between 150-400°F during the life of the generator. Connectors from two vendors are being evaluated under the above conditions and a connector will be selected based on these tests.

Two solders being investigated in this study are 100% tin and 95% tin/5% antimony. Both solders melt at about 450°F. Kester 817 flux will be used with both solders. Soldered connectors will be leak tested after cycling between 150 and 400°F in air a minimum of 100 times. A leak rate of 10^{-7} or better after cycling is desired. Solder joints will also be heated and cycled under a vacuum of at least 10^{-6} torr for a minimum period of two weeks to determine the effect of this environment upon joint integrity.

Preliminary tests with 100% tin solder indicate that it may be necessary to install a transition metal between the stainless connector and the magnesium-thorium boss. It is suspected that because of the difference in thermal expansions, the solder joint is being compromised. Brass is being investigated as a transition metal.

(2) Metal V-seal test

Metal V-seals appear to be an attractive alternate for sealing the electrical connector since they offer an order of magnitude decrease in leak rate, necessitate minimal generator design modification, and permit continuous operation at temperatures approaching 400°F. Two months of thermal cycling tests with over 600 cycles from 140°F to 400°F over a two-hour period were conducted on three gold-plated inconel electrical connector V-seals installed in test fixtures. Leak checks were conducted before, during, and after the thermal cycling. Helium leak rates at operating temperature, i.e., 330°F, were about 3×10^{-7} scc/sec. No degradation of the seal was noted after 5 and 88 cycles, but leak rates increased by 2-5 orders of magnitude between 88 and 600 cycles. The cause of the leaks appears to be a compression set failure of the magnesium-thorium seat, which can probably be corrected by plating with a harder metal, such as nickel or copper.

Detailed test data can be found in INSD-PFA-9634, "SNAP 19 Metal V-Seal Test Evaluation."

5. Viking Thermal Coating Study

Although the thermal control coating presently in use on the SNAP 19 Pioneer generator housing has a satisfactory α_s/ϵ ratio, an emissive coating which will have an α_s/ϵ ratio equal to or lower than the coating presently in use and which is easily repairable, non-porous and offers improved resistance to sand abrasion is desirable. The present investigation is to evaluate various commercially available pigments and binders for possible application to the Viking generators. Since the pigment (ZrO_2) in the present SNAP 19 coating produces an acceptable α_s/ϵ ratio, this pigment will be the primary one investigated in this study. In order to minimize the number of coatings investigated, screening tests were

conducted to eliminate unsatisfactory coatings. The screening tests consisted of heating coated coupons a minimum of 2-weeks at 400°F in air to determine if the coating would spall or change color, heating to 400°F in a vacuum of 10^{-6} torr or better a minimum of two weeks to determine weight loss and color change and a room temperature qualitative abrasion test. Other factors considered included method and ease of application, ease of cleaning, and degree of porosity.

a. Coupon preparation

Test coupons were prepared from 90-mill HM21A-T8 magnesium-thorium alloy. Coupon configurations were one-inch diameter discs and one-inch by three-inch rectangles. Four coupons of each configuration were coated for the various planned tests. One set (disc and rectangle) was to be used for α_s and ϵ measurements, one set for the air test at 400°F, one set for the vacuum test at 400°F and the remaining set for a control.

Coupon surfaces were grit blasted with Al_2O_3 to roughen the surface for better coating adhesion. Initially, two different size grits were used, 120 and 47 mesh, but a decision was made early in the program to standardize with 47 grit as it was believed that a rougher surface would be more advantageous for coating adhesion and thermal properties. After grit blasting, the coupons were chemically cleaned per PS 0300005, Cleaning and Deoxidizing Magnesium Alloys. Cleaned coupons were bagged in plastic to prevent surface contamination prior to coating.

b. Coupon coating

Several methods for applying coatings were investigated: brushing, dipping, and spraying. Brushing and spraying are the preferred application methods--brushing when the coating is too viscous to be sprayed. Operator technique was found to be a major factor in obtaining uniformly coated coupons.

Coating investigated included:

- (1) Sherwin-Williams Fluoroclad 1900 paint--a fluorocarbon resin
- (2) Dow 17 conversion coating
- (3) Ceramite E.G. -- a proprietary ceramic coating
- (4) The standard Teledyne Isotopes coating-- ZrO_2 pigment in water glass binder
- (5) Dow Corning 806A resin plus ZrO_2 --a silicone resin (binder-pigment ratio 3:2)
- (6) Dow 17 conversion coating plus DC 806A with ZrO_2 (binder-pigment ratio 3:2)
- (7) DC 806A plus BaSO_4 pigment (binder-pigment ratio 3:5)
- (8) Fluoroclad 1900 plus ZrO_2 (binder-pigment ratio 9:1)
- (9) Five different General Electric RTV formulations

Additional coatings are being investigated in an effort to obtain a coating which will satisfy the thermal and mechanical properties described earlier. Emphasis has been on coatings which are resilient as opposed to hard and ceramic coatings as the former are more resistant to sand abrasion.

c. Coupon testing

All of the coatings investigated except for the five G.E. RTV formulations appeared to adhere satisfactorily to the magnesium substrate and in no instance was spalling or flaking observed during cycling between 150-400°F. The acceptance coatings were measured for α_s and ϵ and the results are tabulated in Table V-6.

The air and vacuum tests are underway and results have not yet been tabulated. Preliminary tests indicate that Fluoroclad 1900 provides the most resistance against sand abrasion of the coatings presently under test.

TABLE V-6

Measurements of Acceptance Coatings

<u>Coating</u>	<u>Solar Absorptivity * α_s</u>	<u>Emissivity* ϵ</u>
Teledyne Isotopes	.335	0.995
Ceramite	.290	0.840
Fluoroclad 1900	.378	0.665
DC 806A-ZrO ₂	.357	0.915
Dow 17	.865	0.865
Dow 17 plus DC 806A-ZrO ₂	.435	0.905
Fluoroclad 1900 plus ZrO ₂	NA**	NA
DC 806A-BaSO ₄	NA	NA

*Measurements were made at approx. 130°F

**NA - Results not available at this date---measurements are being made.

VI. RTG INTERFACE ACTIVITIES

A. PIONEER MISSION

Interface activities during this reporting period included two interface meetings at which INSD was represented and a Heat Source Design Update at which INSD presented the Pioneer heat source design configuration. Splinter meetings were held subsequent to this meeting to discuss specific areas of interest with customer and user agency representatives.

B. VIKING MISSION

During this reporting period three interface meetings were attended (two at NASA/Langley and one at Martin Marietta Corporation, Denver Division (MMD)) and the Viking Lander System (VLS) to Radioisotope Thermoelectric Generator (RTG) Interface Requirements Document, ID 3703151 was reviewed. The meetings at NASA/Langley were concerned primarily with review and comment on the VLS/RTG interface document. This document is the agreement between NASA and MMD on the VLS/RTG interface, and requirements therein will be reflected in the AEC and Teledyne Isotopes agreements.

The meeting at MMD was concerned primarily with resolving in detail the technical interface requirements for the First Set ETG (two units) scheduled for delivery in May 1971. Items discussed included: (1) the generator housing configuration (wall thickness and mounting hole dimensions), (2) the generator handling tool, (3) the generator transient electrical performance characteristics with changes in load voltage and fin root temperature, (4) the electrical ground equipment to be supplied with the First Set ETG, and (5) thermal control techniques for the VLS.

VII. AUXILIARY GROUND EQUIPMENT (AGE)

The AGE for the Pioneer/Viking programs will make maximum use of existing SNAP 19 AGE design drawings and fabricated hardware. Progress during this period is reported in this section.

A. MECHANICAL AGE

1. Pioneer Capsule Shipping Container

All capsule shipping containers have been refurbished for use on the Pioneer program. In order to provide added assurance of gas containment in transit and storage, the primary container has been modified to accommodate a sealed can which now contains the capsule. Application for DOT transportation permit was completed, submitted, and approved in this reporting period.

2. Pioneer RTG Shipping Container

Design and fabrication of the RTG shipping containers was performed during this period. Each shipping container is capable of transporting RTG units either singly or in pairs. The container configuration consists basically of a support base and a removable protective cage for enclosing the RTG(s). The support base has provisions for shock mounting the generator support structure and electrical interface connections for in-transit or storage monitoring equipment. Application for DOT transportation permit was completed, submitted, and approved in this reporting period.

3. Pioneer ETG Shipping Container

Fabrication of ETG shipping containers was completed in this reporting period.

4. Pioneer RTG Handling Adaptor

Design modifications were completed this period. These change included: (a) reducing the bolt hole circle diameter to conform with the reduced pattern on the generator resulting from the change in RTG handling lug configuration and (b) redesign of the handling tool interface flange to reduce weight and provide improved access to the generator attachment bolt holes.

5. Pioneer Heat Source Handling Tool

Modifications to the heat source handling tool were accomplished in order to improve the handling characteristics of this unit and to comply with the introduction of longer pyrolytic graphite sleeves in the heat source. The combined handle/vacuum hose connecting tube was fitted with a right angle bend and the suction head was shortened to enable complete insertion of the tool head into the heat shield.

6. Pioneer Miscellaneous Generator Fueling Tools

Engineering and fabrication was completed on the following tools for use in the RTG fueling generator:

- (a) Modified spanner wrench for heat shield end plug torquing.
- (b) Emergency heat source handling tool.
- (c) Emergency heat source removal tool.
- (d) End cover bolt alignment tool.
- (e) Generator weld shroud.
- (f) Sleeve restraint ring insertion tool.
- (g) Capsule height check tool.
- (h) Thermal shroud for capsule.

7. Viking Mechanical AGE

Design of a generator handling tool has been initiated. The tool will permit vertical lifting of the generator and handling with an overhead crane. Any auxiliary tooling required for installation of the generator on the Viking spacecraft will be designed and fabricated by the Viking Lander Capsule integrating contractor.

Other mechanical AGE such as the ETG shipping container and fin thermal insulation pads will be basically the same design as employed for Pioneer.

B. ELECTRICAL AGE

1. Pioneer ETG Power Supply Consoles

During this period, three ETG power supply consoles were assembled, tested and calibrated. Two of the consoles were delivered.

The testing of the ETG power supply consoles includes a 100-hour cumulative burn-in period at operational settings for generator heater power to ascertain the reliability of each console assembly.

Preparation of a detailed operations manual for the ETG power supply consoles and their applications with different ETG systems set-ups was completed. Manuals were furnished with each power supply.

A load test unit for checkout and calibration of the ETG power supply was fabricated and delivered with the first power supply console. The purpose of this load test unit is to verify operational readiness of the console in the field after shipment.

Each ETG power supply console, which can supply controlled heater power to two generators simultaneously, was provided with interface cables for generators with push-pull type connectors as well as interface cables for generators with

bayonet-lock type connectors.

2. Pioneer PMP Unit

Four PMP units (portable monitor package) were fabricated during this period. Of these, three were tested and calibrated. Two units were delivered.

A detailed operations manual for the PMP units and their applications with RTG's, ETG's and RTG and ETG systems set-ups was completed. Manuals were furnished with each delivered unit.

Each PMP unit, which is capable of monitoring the performance parameters of two generators, was provided with interface cables for generators with push-pull type connectors, for generators with bayonet-lock type connectors and for usage in combination with the aforementioned ETG power supply console.

3. Viking Electrical AGE

Review of the existing Pioneer electrical AGE design drawings, specifications and procedures for the ETG power supply, portable monitor package and load test unit has been initiated. No extensive modification of these units for Viking is anticipated. Design of the interconnecting cabling required for the electrical AGE has been initiated and coordinated with Martin Marietta Corporation, Denver Division.