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SNAP 19 RTG FOR VIKING LANDER SYSTEM

First Semiannual Progress Report, January 1—June 30, 1972

August 1972

Energy Systems Division
Teledyne Isotopes
Timonium, Maryland (USA)

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FOR
VIKING LANDER SYSTEM
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AEC CONTRACT NO. AT(29-2)-2960

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FOREWORD

This technical report is the first in a series of semi-annual progress reports to be issued for the SNAP 19 radioisotope thermoelectric generator (RTG) being developed by Teledyne Isotopes, Energy Systems Division, for the Viking Lander System. Two Viking Lander Systems, each employing two SNAP 19 RTG's as the prime electrical power source, will be launched in 1975 and will soft-land on Mars in 1976, approximately one year after launch.

Technical information and progress presented in this first report covers development effort performed during the period January 1, 1972 to June 30, 1972 under AEC Contract No. AT(29-2)-2960. Previous SNAP 19 Viking RTG development effort has been reported in semi-annual progress reports prepared under AEC Contract No. AT(29-2)-2873.

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SUMMARY

During this reporting period, the technical activities associated with the development, design and testing of the SNAP 19 Viking RTG were continued. The major technical efforts include: (1) continued development of a high temperature electrical receptacle-to-generator housing hermetic seal, (2) initiated development of a fuel capsule helium vent system for venting the radioisotope fuel-produced helium external to the generator housing, (3) initiated testing to determine the effect of Mars surface thermal cycling on generator electrical performance and (4) initiated design studies for assembly and test of an Engineering ETG. These and other significant technical efforts performed during this period are listed below under the appropriate task:

1. Task 2 - Design Integration and Systems Engineering

- a. Technical interface coordination was maintained with the AEC, NASA, Martin Marietta Corporation and other agencies participating in the Viking program.
- b. Evaluation of steady state performance data on Viking ETG's S/N 101 and S/N 102 being tested by Martin Marietta Corporation continued.
- c. Evaluation of performance data from Pioneer ETG's S/N 41 and S/N 43, being used in simulated Mars surface thermal cycle testing at Teledyne Isotopes, was initiated.
- d. RTG parametric performance analyses were conducted which resulted in the selection of: (i) a 75% Helium/25% Argon initial generator gas fill, (ii) a helium vent system for piping of the fuel-produced helium external to the thermoelectric converter, and (iii) an increase in capsule

fuel inventory from 675 ± 5 watts(t) to 682 ± 3 watts(t). With the above changes, electrical power output prediction at 0.99 reliability is estimated to be 37 watts(e) at end-of-mission.

- e. Design studies were initiated for the Engineering ETG to be fabricated in December, 1972.
- f. Additional getter optimization studies were conducted and resulted in the selection of a getter configuration/installation which increases end-of-mission electrical power by 1.2 watts(e) over the previous Pioneer-type getter. End-of-mission performance prediction increases to 38 watts(e) at 0.99 reliability.
- g. The SNAP 19 Viking Program Plan (which includes the Reliability Plan) and Product Definition Plan were prepared and submitted to the AEC for approval.
- h. Instrumentation design and evaluation for the RTD, thermistor and pressure transducer were initiated.
- i. The first Viking Reliability Program Review was conducted at Teledyne Isotopes with participation of AEC Reliability and Quality Assurance.

2. Task 4 - ETG/RTG and Component Testing

- a. Thermal cycle testing of Pioneer ETG's S/N 41 and S/N 43 was initiated under simulated Mars surface thermal cycle conditions.
- b. Electrical receptacle-to-generator housing seal development was continued for: (i) diffusion bonded/welded seal, (ii) 100% tin solder seal and (iii) Viton O-ring seal. As a result of these activities, the diffusion bonded/welded seal has been selected for the Viking generator. New development effort on the solder seal approach was terminated in May, 1972, but backup testing of the O-ring seal is continuing.

- c. Requirements for an elevated temperature helium leak check on incoming electrical receptacles were developed and incorporated into quality inspection acceptance criteria.

3. Task 5 - Heat Source Development and Testing

- a. Development of fuel capsule vent system configurations to discharge helium external to thermoelectric converter was initiated. Two configurations were selected and are being evaluated in parallel. One configuration pipes the helium generated during fuel decay directly from the fuel capsule to a generator end cover where it is released to the ambient environment through a controlled leak device. The other configuration is similar to that described above except that the helium is retained in a closed reservoir integral with the generator cover.
- b. The design drawings for two test capsules required for vent system development testing were completed, and two capsules with vent pipe attached were fabricated by Monsanto Research Corporation to these drawings.
- c. The design of the vent system development test hardware for a generator level dynamic test and heat source plasma arc test was initiated. This test hardware will utilize the two test capsules supplied by Monsanto Research Corporation identified in 3.b above.
- d. Characterization studies of controlled leak devices for the vent system were initiated, including evaluation and/or testing of: (i) pressed and sintered platinum frits, (ii) small-bore capillary tubes and (iii) Viton O-rings.

4. Task 6 - Safety Evaluation

- a. The Viking mission, launch vehicle and spacecraft were evaluated to determine major variations in accident environments as compared with the Pioneer mission and vehicles.
- b. In-flight malfunctions resulting in two classes of failure modes were analyzed: (i) Centaur second burn misorientations and the resulting combinations of velocity and flight path angle at an altitude of 400,000 feet and (ii) other Centaur accidents causing orbital capture and, ultimately, orbital decay.
- c. Various preliminary aerophysics and aerothermal studies were conducted to determine the heat source response characteristics.
- d. Updated fuel form and capsule data were used to prepare Viking source term estimates.

5. Task 8 - Quality Engineering

The Quality Program Plan was issued as Part B of the SNAP 19 Viking Product Definition Plan.

I. TASK 2 - DESIGN INTEGRATION AND SYSTEMS ENGINEERING

This task encompasses the basic Engineering activities related to: (1) the design, development, and evaluation of the Viking SNAP 19 RTG, (2) RTG interface definition and control, and (3) technical liaison with the AEC, NASA, MMD, and other participating agencies.

A. TECHNICAL INTERFACE COORDINATION

1. On January 5, 1972, an AEC/Energy Systems Division meeting was held to review updated performance analyses of the Viking RTG having an assumed initial fill gas of 75% Helium/25% Argon and operating at reduced (lower than specification value of 375°F) interplanetary cruise fin root temperatures. This generator concept offered the advantage of maintaining heat source temperatures comparable to those of the SNAP 19 Pioneer RTG. Study inputs were updated to reflect the latest initial power measurements of the SNAP 19 Pioneer flight RTG units. Results of these analyses indicated that the end-of-mission (EOM) power requirement of 35 watts(e) at a probability of 0.99 cannot be satisfied. (See Section I.C for discussion.)
2. On January 13, 1972, a follow-up AEC/Energy Systems Division meeting was held to establish definition of additional parametric performance studies to be conducted during the remainder of January 1972. The results of this study definition investigated the effects of: (a) the helium released from the fuel capsule being vented directly overboard through the generator housing, (b) a generator housing leak comparable to the measured leak of SNAP 19 Pioneer generators (i.e., "controlled leak"), and (c) a reduction in the fin root temperature during

interplanetary cruise to 350°F and 330°F, respectively. All studies were to consider 75% Helium/25% Argon as the initial thermoelectric converter fill gas to maintain heat source temperatures comparable to SNAP 19 Pioneer.

3. On January 21, 1972, a third AEC/Energy Systems Division meeting was held to review results of performance analyses investigating fuel decay helium release being vented directly overboard (external to the generator housing). Results of these analyses indicated a potential 2 watt(e) margin for EOM performance. Beginning-of-life (BOL) strength member temperatures were calculated to be 1510°F which is comparable to the 1485°F value calculated for the SNAP 19 Pioneer RTG. The results of the two cases indicated that EOM performance is not significantly affected by interplanetary cruise fin root temperatures of between 330°F and 350°F. (See Section I.C for discussion.)
4. On January 28, 1972, a fourth AEC/Energy Systems Division meeting was held to review the results of the performance analyses which investigated the effects of a generator housing "controlled leak." The analysis for this concept assumed a generator leak rate comparable to that for the Pioneer RTG Viton O-ring-sealed housing. Results of the performance predictions indicated a potential power margin of 0.6 watts(e) for the 0.99 probability power at EOM.

BOL strength member temperature was calculated to be 1550°F, which is approximately 65°F higher than the comparable SNAP 19 Pioneer temperature. (See Section I.C for discussion.)
5. On February 1, 1972, a technical interface meeting with NASA, Martin Marietta Corporation, AEC and Teledyne Isotopes personnel participating was conducted at Langley Research Center. Results of the SNAP 19 Viking RTG parametric performance/reliability study were updated from those presented at the December 2, 1971 interface meeting held at Teledyne Isotopes. Also the status of the electrical receptacle seal development was reviewed.

6. The basic measurement requirements for the RTG series functional acceptance test recently added to the Viking RTG Specification (Reference I-1) were formulated. The proposed test definition was forwarded to the AEC for review and comment.
7. The SNAP 19 Viking Statement of Work (ALOO Document WSS:JBB(145), dated February 18, 1972) was reviewed and comments prepared in preparation for the early March 1972 contract negotiations. Detail cost estimates for the technical effort defined by the Statement of Work were prepared.
8. A revised mechanical interface drawing (to that shown in Figure 2 of the Viking RTG Specification, Reference I-1) was prepared and forwarded to the AEC reflecting the change in interface dimensions for the proposed weight-reducing HPG-type end cover design.
9. A review of available ETG's which could be utilized for simulated Mars surface thermal cycling testing was performed and recommendations presented to the AEC for review and comment.
10. Teledyne Isotopes' comments on the draft copy of the Viking RTG Specification (Reference I-1) were completed and forwarded to the AEC Site Representative.
11. Technical inputs to the SNAP 19 Viking Program Plan for the contract period 1/1/72 to 9/30/72 were completed. The Program Plan includes the Reliability Program Plan as Addendum 1. Formal submittal of the Program Plan (Reference I-2) to the AEC for approval was accomplished April 19, 1972.
12. A SNAP 19 Viking program review was conducted at Teledyne Isotopes on April 25 and 26, 1972 for Messrs. R. Russell (NASA/LRC), R. Brouns (AEC/LRC) and W. Remini (AEC/SNS). Viking program topics reviewed included:
 - (a) SNAP 19 Viking Program Plan, (b) Viking RTG Specification,
 - (c) receptacle seal development program, (d) capsule vent development program,

(e) thermal cycle testing of Pioneer ETG's S/N 41 and S/N 43, (f) Preliminary Safety Analysis Report (PSAR) outstanding information to be supplied by AEC/ NASA, and (g) pyrotechnic and landing shock requirements and proposed shock tests to be performed on Pioneer RTG S/N 47 and Viking ETG's S/N 101 and S/N 102.

13. A SNAP 19 Viking program review was conducted at Teledyne Isotopes on May 23, 1972 for Messrs. Al Schock and Bernie Raab and Dr. Harry Kling of Fairchild Industries, and Messrs. Vince Redmond and William Ember of the AEC. Topics discussed were: (a) the electrical receptacle diffusion bond development program, (b) the capsule vent development program, and (c) RTG performance predictions.
14. The SNAP 19 Viking Product Definition Plan (Reference I-3) was submitted to the AEC for approval on May 1, 1972. This Plan includes Part A - Engineering and Administration Requirements and Procedures, and Part B - Quality Program Plan.
15. Martin Marietta Corporation, Denver Division, (MMD) test procedure ETG TP06 for the end cap cooler test to be performed at MMD in July and August, 1972, was reviewed by Teledyne Isotopes personnel. Comments on this test outline were forwarded to the AEC Site Representative.
16. A review was conducted at Teledyne Isotopes on June 22, 1972 for the AEC to discuss the getter optimization study results. Tentative approval has been received from the AEC to proceed with the recommended getter installation/ configuration as presented by Teledyne Isotopes. The heat source test specimen for the plasma arc test scheduled for the next reporting period will incorporate the recommendations (as outlined in Section I. E), including

a getter assembly. Also the Engineering ETG, currently in the design phase, will incorporate the recommended optimized getter installation/configuration.

17. The first Reliability Program Review was held in accordance with the Viking Reliability Program Plan (Reference I-2). Formal documentation of the review information will be issued during the next reporting period. It is the AEC's intent to include NASA and possibly MMD in future reviews.
18. Technical inputs to the SNAP 19 Viking Program Work Scope/Cost Estimate for the period Oct. 1, 1972 to Sept. 30, 1975 were initiated.

B. ETG/RTG PERFORMANCE DATA EVALUATION

During the period from January 1, 1972 to June 30, 1972, five generators have been under evaluation to provide data for the Viking mission. These generators include: (1) SNAP 19 Viking ETG's S/N 101 and S/N 102 which were operated and tested at the Martin Marietta Corporation, Denver Division, (MMD), (2) refurbished SNAP 19 Pioneer ETG's S/N 41 and S/N 43 which were operated and tested at Teledyne Isotopes, Energy Systems Division, and (3) SNAP 19 Pioneer RTG S/N 47 which was also operated and tested at Teledyne Isotopes.

ETG's S/N 101 and S/N 102 were developed and fabricated under the Viking program. Generators S/N 41 and S/N 43 were developed, fabricated and fueled under the Pioneer program. After defueling on the Pioneer program, S/N 41 and S/N 43 were transferred to the Viking program by the early part of 1972. Generator S/N 47 was developed, fabricated and fueled under the Pioneer program as a back-up unit for Pioneer F flight units. Following the successful launch of Pioneer F, RTG S/N 47 was transferred to the Viking program in the early part of 1972.

1. Pioneer ETG S/N 41

Generator S/N 41 originated under the Pioneer program first as an ETG and secondly as an RTG. While on the Pioneer program, S/N 41 accumulated 2906 hours of operating time. After defueling, the generator was transferred to the Viking program to become one of the two generators utilized in the Viking Mars Surface Thermal Cycle Test. The generator was refurbished as an ETG and began a series of Viking performance tests in the early part of March, 1972. Table I-1 presents a chronology of performance test conditions experienced by ETG S/N 41 on the Viking program up to the conclusion of this reporting period.

For comparison purposes, the initial manufacturing and thermoelectric laboratory power checks were conducted under Pioneer operating conditions. These operating conditions consist of a 650 watt(t) inventory and a 330°F fin root temperature based on the thermistor measurement. The resulting hot junction temperature was recorded based on a temperature-dependent RTD calibration bias (-20°F bias applied at a 1000°F RTD indication). Table I-2 presents a comparison of the Viking ETG S/N 41 thermoelectric laboratory power check data with the thermal vacuum chamber test data obtained on Pioneer RTG S/N 41 (prior to defueling). This data indicates that the performance of the present refurbished ETG is in excellent agreement with prior RTG performance.

Following the initial power checks, the generator was placed under Viking operating conditions consisting of a 690 watt(t) inventory, and a 330°F fin root temperature (defined as the average of five thermocouples located along fin #3). The hot junction temperature is defined as the RTD indication without any bias.

The first test conducted on ETG S/N 41 under these operating conditions was a load voltage parametric using the Pioneer connector saver harness. The parametric

TABLE I-1

ETG S/N 41 PERFORMANCE TEST CHRONOLOGY

<u>Test Experience</u>	<u>Date</u>
Manufacturing power check with 100% argon gas fill	3/11/72
Manufacturing power check with 75% He/25% Ar gas fill	3/12/72
Thermoelectric laboratory power check with 75% He/ 25% Ar gas fill	3/14/72
Initial load voltage parametric (with connector saver)	3/14/72 to 3/15/72
Initial load voltage parametric (without connector saver)*	3/15/72 to 3/17/72
Steady state performance test under Viking operating conditions	3/17/72 to 5/19/72
Sample and change of generator gas fill	5/19/72
Second load voltage parametric	5/22/72 to 5/25/72
Third load voltage parametric	5/25/72 to 5/26/72
Fourth load voltage parametric	5/30/72 to 5/31/72
Steady state performance checks under reduced fin root temperature**	6/1/72 to 6/20/72
Sample and change of generator gas fill	6/8/72
Performance checks with fin heaters operational	6/20/72 to 6/21/72
Performance check at minimum fin root temperature of thermal cycle***	6/27/72
Performance check at maximum fin root temperature of thermal cycle***	6/27/72
Performance check at 330°F fin root temperature of thermal cycle***	6/29/72 to 6/30/72

*All subsequent testing was performed without connector saver.

**Reduced fin root temperature resulted from removal of fin insulation during installation of fin heating and cooling systems required for thermal cycle test.

***Conducted within the thermal vacuum chamber.

TABLE I-2

S/N 41 TEST DATA COMPARISON
FINAL RTG THERMAL VACUUM VS. FIRST TEST POINT
IN TEST LABORATORY AS REFURBISHED ETG

<u>Program</u>	<u>Pioneer</u>	<u>Viking</u>
Configuration	RTG	ETG
Environment	T/V chamber	Air
Thermal inventory (watts(t))	641	650*
Date	10/4/71	3/12/72
Total operation time (hrs)	2820	3000
Fin root temperature (°F)	333	337
Load voltage	4.214	4.283

Normalized Data**

Power watts(e)	36.7	36.7
Load voltage (volts)	4.214	4.283
Hot junction temperature (°F)	982	983
Instantaneous open circuit voltage (volts)	6.865	6.882
Seebeck coefficient (mv/°F)	11.03	11.04
Internal resistance (ohms)	.304	.303

*Electrical heater input power (equivalent to 641 watts(t) fueled).

**Normalized for 330°F fin root temperature as measured with the thermistor.

was then repeated without the use of the connector saver harness since the connector saver harness will not be utilized during thermal cycle testing. The results of the initial parametric without the connector saver harness are presented in Figure I-1. Following the parametric test, the generator experienced a period of steady state testing under Viking operating conditions and a 4.4 volt load voltage as measured on an external voltage tap. The steady state testing was concluded after 63 days with a sampling of the generator's internal gas fill and a subsequent gas change to assure a 75% Helium/25% Argon gas fill within the generator. The results of this first gas sample are presented in Table I-3. The relatively high nitrogen content reflects the nitrogen permeation through the large Viton O-ring in the outgassing tool.

A second load voltage parametric under Viking operating conditions was conducted after the gas change. The results of this second parametric are also presented in Figure I-1. Figure I-1 serves as a comparison between the results of the initial and the second parametric tests conducted on S/N 41 under Viking operating conditions. The steady state test between the two parametric tests covers ~1650 hours of operation (from ~ 3050 hours to ~ 4700 hours total time) and the differences between the results of the two parametric tests presented in this figure are a function of time only since performance affecting variables such as fin root temperature, power input, and gas fill were held constant.

An examination of the parametric data at a 4.4 volt load voltage indicated that the hot junction temperature had increased 7°F. Comparison with existing SNAP 19 Pioneer generator data shows this increase to be nominal. The power output had decreased 0.36 watts(e) which is in good agreement with a predicted decrease in power output for this time period based on the power degradation model as used in the Viking Parametric Performance Study (Reference I-4). The open circuit voltage increased

FIGURE I-1
VIKING PARAMETRIC TEST RESULTS
SNAP 19 ETG S/N 41
330 °F FIN ROOT TEMPERATURE
690 WATTS THERMAL INVENTORY
75 % HE / 25 % AR GAS FILL
WITHOUT CONNECTOR SAVER

TABLE I-3

RESULTS OF ETG S/N 41 GAS SAMPLE ANALYSIS

	<u>Gas Sample</u>	
	<u>First</u>	<u>Second</u>
Date	May 19, 1972	June 8, 1972
Total Viking Operating Time* (hours)	1680	2165
Time Lapse Since Previous Gas Change (hours)	1607	485
Gas Analysis Results in Mole %		
Nitrogen	4.1	.57
Oxygen	0.034	< .0004
Argon	23.6	28.7
Carbon Dioxide	0.0034	< .001
Hydrogen	0.017	0.002
Helium	71. +	70. +
Carbon Monoxide	0.59	0.074
Methane	0.0006	< .001

*Total heated operating time (including Pioneer operating time) is obtained by adding 2906 hours to this value.

~1% and the internal resistance increased ~3% during the 1580 hours of operation. These changes in thermoelectric parameters are in general agreement with previous SNAP 19 Pioneer ETG's.

Performance data obtained from the third and fourth parametric load voltage tests conducted on ETG S/N 41 are presented in Figures I-2 and I-3. These parametric tests can be compared to the second parametric load voltage test on S/N 41 for an indication of changes in performance due to a reduced fin root temperature and a reduced thermal inventory. The resulting electrical output powers and hot junction temperatures for a 4.4 volt load voltage from the three parametric tests are summarized in Table I-4.

A comparison of the second and fourth parametrics indicates the following:

- a. the 0.78 watt(e) increase in power for the reduced fin root temperature is in good agreement with previous fin root sweep data, and
- b. the associated 28°F decrease in hot junction temperature is in good agreement with the established model for hot junction temperature change as a function of fin root temperature.

A comparison of the second and third Viking parametrics indicates the following:

- a. the 3.4 watt(e) decrease in power for the reduced thermal inventory is in excellent agreement with the established model for power change as a function of thermal inventory change, and
- b. the associated 25°F decrease in hot junction temperature is less than the 35°F expected from the established model for hot junction change as a function of thermal inventory change.

Following the fourth load voltage parametric test, S/N 41 went through a period of preparation, outfitting, and instrumenting for the thermal cycle test to be conducted

FIGURE I-2
VIKING PARAMETRIC TEST RESULTS
SNAP 19 ETG S/N 41
330 °F FIN ROOT TEMPERATURE
655 WATTS THERMAL INVENTORY
75% HE / 25% AR GAS FILL
WITHOUT CONNECTOR SAVER

FIGURE I - 3
VIKING PARAMETRIC TEST RESULTS
SNAP 14 ETG SIN 41
300 °F FIN ROOT TEMPERATURE
690 WATTS THERMAL INVENTORY
75 % HE / 25 % AR GAS FILL
WITHOUT CONNECTOR SAVER

TABLE I-4

POWER OUTPUT AND HOT JUNCTION TEMPERATURE
FROM S/N 41's SECOND, THIRD AND FOURTH VIKING PARAMETRIC TESTS

	<u>Operating Time (hours)</u>	<u>Power Input (watts(t))</u>	<u>Fin Root Temp. (°F)</u>	<u>Power Output (watts(e))*</u>	<u>Hot Junction Temperature (°F) *</u>
Second parametric	4700	690	330	39.46	1065
Third parametric	4750	655	330	36.05	1040
Fourth parametric	4870	690	300	40.24	1037

*At 4.4 volt load voltage.

in the Teledyne Isotopes thermal vacuum chamber as discussed in Section II. A. During the final preparation for the thermal cycle testing, a second sample of the internal gas fill and subsequent gas change was accomplished. Results of the gas analysis of this second sample are also presented in Table I-3. This analysis confirmed the presence of nitrogen due to permeation through the large O-ring utilized with the outgassing tool electrical heater.

Following installation into the thermal vacuum chamber, power checks were performed to establish initial performance data for the minimum point of the thermal cycle (150°F fin root temperature), and the maximum point of the thermal cycle (350°F fin root temperature). A five-day hold at a 330°F fin root temperature was initiated on June 29, 1972 to establish a base performance from which to determine the effect of thermal cycle testing on generator performance. Data from these steady state tests will be compared with similar tests conducted after thermal cycle testing is completed.

Figure I-4 presents a summary of the steady state performance data accumulated during the March to June, 1972 testing period. Total operating time accumulated on the Viking program since refurbishing of S/N 41 was ~2965 hours at the end of this reporting period.

2. Pioneer ETG S/N 43

Generator S/N 43 originated under the Pioneer program first as an ETG and secondly as an RTG. During Pioneer operation, S/N 43 accumulated 2611 hours of operating time, 1579 of which were logged while the generator was in storage on short circuit (hot junction temperature approximately 800°F). After defueling, the generator was transferred to the Viking program to become one of the generators utilized in the Viking Mars Surface Thermal Cycle Test. The generator was refurbished as an ETG and began a series of Viking performance tests in the latter part of April, 1972.

FIGURE I-4
ETG SIN 41 POWER AND HOT JUNCTION TEMPERATURE LIFE DATA
NORMALIZED TO 330 °F FIN ROOT TEMPERATURE, 690 WATT THERMAL INVENTORY
AND 4.4 VOLTS LOAD VOLTAGE
GENERATOR GAS FILL: 75 % HELIUM / 25 % ARGON

Table I-5 presents a chronology of performance test conditions experienced by ETG S/N 43 up to the conclusion of this reporting period.

For comparison purposes, the initial manufacturing and thermoelectric laboratory power checks were conducted under Pioneer operating conditions. These operating conditions consist of a 650 watt(t) inventory and a 330°F fin root temperature based on the thermistor measurement. The resulting hot junction temperature was recorded based on a temperature-dependent RTD calibration bias (-20°F bias applied at a 1000°F RTD indication). Table I-6 presents a comparison of the ETG S/N 43 thermoelectric laboratory power check data with the thermal vacuum chamber test data obtained on Pioneer RTG S/N 43 (prior to storage and subsequent defueling). This data indicates that performance of the present refurbished ETG is in general agreement with prior RTG performance.

Following the initial power checks, the generator was placed under Viking operating conditions consisting of a 690 watt(t) inventory and a 330°F fin root temperature defined as the average of five thermocouples located along fin #3. The hot junction temperature is defined as the RTD indication without any bias.

The first test conducted on ETG S/N 43 under these operating conditions was a load voltage parametric. The results of this initial parametric are presented in Figure I-5. Following the parametric test, the generator experienced a period of steady state testing under Viking operating conditions at a 4.4 volt load voltage as measured on an external voltage tap. The steady state testing was concluded after ~ 19 days with a sampling of the generators internal gas fill and a subsequent gas change to assure 75% Helium/25% Argon gas fill within the generator. The results of the gas sample are presented in Table I-7. The nitrogen content shows the nitrogen permeation through the large Viton O-ring in the outgassing tool.

TABLE I-5

ETG S/N 43 PERFORMANCE TEST CHRONOLOGY

<u>Test Experience</u>	<u>Date</u>
Manufacturing power check with 100% argon gas fill	4/27/72
Manufacturing power check with 75% He/25% Ar gas fill	4/28/72
Thermoelectric laboratory power check with 75% He/ 25% Ar gas fill	5/3/72
Initial load voltage parametric	5/4/72 to 5/11/72
Steady state performance test under Viking operating conditions	5/11/72 to 5/30/72
Sample and change of generator gas fill	5/30/72
Second load voltage parametric	5/30/72 to 6/1/72
Steady state performance checks under reduced fin root temperature*	6/2/72 to 6/20/72
Sample and change of generator gas fill	6/8/72
Performance checks with fin heaters operational	6/20/72 to 6/21/72
Performance check at minimum fin root temperature of thermal cycle**	6/27/72
Performance check at maximum fin root temperature of thermal cycle**	6/27/72
Performance check at 330°F fin root temperature prior to thermal cycle**	6/29/72 to 6/30/72

*Reduced fin root temperature resulted from removal of fin insulation during installation of fin heating and cooling systems required for thermal cycle test.

**Conducted within the thermal vacuum chamber.

TABLE I-6

S/N 43 TEST DATA COMPARISON
FINAL RTG THERMAL VACUUM VS. FIRST TEST POINT
IN TEST LABORATORY AS REFURBISHED ETG

<u>Program</u>	<u>Pioneer</u>	<u>Viking</u>
Configuration	RTG	ETG
Environment	T/V chamber	Air
Thermal inventory (watts(t))	648	650*
Date	10/31/71	5/3/72
Total operating hours	1003	2780
Fin root temperature (°F)	325	325
Load voltage (volts)	4.175	4.297
<u>Normalized Data**</u>		
Power (watts(e))	40.3	39.7
Load voltage (volts)	4.175	4.175
Hot junction temperature (°F)	966	976
Instantaneous open circuit voltage (volts)	6.804	6.898
Seebeck coefficient (mv/°F)	11.19	11.19
Internal resistance (ohms)	.273	.293

*Electrical heater input power (equivalent to 641 watts(t) fueled)

**Normalized for 330°F fin root temperature as measured with the thermistor,
and an equivalent fuel inventory of 648 watts (electrical heater input power
of 657 watts(e)).

FIGURE I-5
VIKING PARAMETRIC TEST RESULTS
SNAP 19 ETG S/N 43

TABLE I-7

RESULTS OF ETG S/N 43 GAS SAMPLE ANALYSIS

	<u>Gas Sample</u>	
	<u>First</u>	<u>Second</u>
Date	May 30, 1972	June 8, 1972
Total Viking Operating Time* (hours)	816	1039
Time Lapse Since Previous Gas Change (hours)	699	223
Gas Analysis Results in Mole %		
Nitrogen	3.6	1.6
Oxygen	0.002	0.016
Argon	26.5	27.5
Carbon Dioxide	0.0058	< .001
Hydrogen	0.016	0.0035
Helium	69. +	70. +
Carbon Monoxide	0.14	0.32
Methane	0.0033	< .001

*Total heated operating time (including Pioneer operating time) is obtained by adding 2611 hours to this value.

A second load voltage parametric under Viking operating conditions was conducted after the gas change. The results of this second parametric are also presented in Figure I-5. Figure I-5 serves as a comparison between the results of the initial and the second parametric tests conducted on S/N 43 under Viking operating conditions. The steady state test between the two parametric tests covers ~560 hours of operation (from ~2890 hours to ~3450 hours total time) and the differences between the results of the two parametric tests presented in this figure are a function of time only since performance affecting variables such as fin root temperature, power input, and gas fill were held constant.

Examination of the parametric data at a 4.4 volt load voltage indicates that the hot junction temperature has increased 7°F, the power output has decreased 0.77 watts(e), the open circuit voltage has increased 1% and the internal resistance has increased ~5%. These changes in performance characteristics are as expected based on the operational history of this generator on the Pioneer program.

Following the second load voltage parametric test, S/N 43 went through a period of preparation, outfitting, and instrumenting for the thermal cycle test to be conducted in the Teledyne Isotopes thermal vacuum chamber. The generator continued to function under Viking operating conditions consisting of a 690 watt(t) inventory, and a 4.4 volt load voltage, but the fin root temperature averaged around 240°F for this period. The reduction in fin root temperature was a result of the uninsulated fin condition which existed during the installation of the fin heating and cooling systems required for the thermal cycle test. The generator also experienced a second sampling of the internal gas fill and subsequent gas change to maintain a 75% Helium/25% Argon gas fill within the generator. The results of the gas sample are also presented in Table I-7. The outfitting period was concluded with power checks while the generator was operating in

air with uninsulated fins and the fin heaters operational. The fin heaters provided an average fin root temperature ranging from 320°F to 330°F for this performance data.

Upon completion of generator outfitting, S/N 43 was operated under a 75% Helium/25% Argon cover gas within the thermal vacuum chamber. The Viking operating conditions consisted of a 690 watt(t) inventory and a 4.4 volt load voltage. The hot junction temperature was defined as the RTD indication without any bias. The fin root temperature was defined as the average of the three thermocouples located along fin #3 adjacent to the module bar. Under these conditions, power checks were made to establish performance data for the minimum point of the thermal cycle (150°F fin root temperature), and the maximum point of the thermal cycle (350°F fin root temperature). A five-day hold at a 330°F fin root temperature was initiated on June 29, 1972. These were the final tests conducted on S/N 43 during this reporting period.

Figure I-6 presents a summary of the steady state performance data accumulated during the April and May, 1972 testing period. Total operating time since refurbishing of S/N 43 was ~1565 hours at the end of this reporting period.

3. Viking ETG's S/N 101 and S/N 102

Viking ETG's S/N 101 and 102 were developed and fabricated at Teledyne Isotopes, Energy Systems Division, during the first half of 1971. Following acceptance testing at Teledyne Isotopes, both generators were shipped to the Martin Marietta Corporation, Denver Division, (MMD) in May 1971. Further testing conducted at the MMD facility included the following tests: (a) Acceptance, (b) Dynamic Impedance, (c) Series Mode - Phase I, and (d) Cruise Mode. These tests were conducted in the second half of 1971.

Initiation of the Series Mode Test - Phase II took place at MMD in the latter part of January, 1972. This steady state endurance test continued until June 22, 1972, at which time both generators were cooled down. The Viking operating conditions imposed

FIGURE I-6

ETG S/N 43 POWER AND HOT JUNCTION TEMPERATURE LIFE DATA
NORMALIZED TO 330 °F FIN ROOT TEMPERATURE, 690 WATT THERMAL INVENTORY
AND 4.4 VOLTS LOAD VOLTAGE
GENERATOR GAS FILL: 75% HELIUM / 25% ARGON

on the generators during this test consisted of a 690 watt(t) inventory, a 330°F fin root temperature (defined as the average of five thermocouples located along fin #3), and a 4.4 volt load voltage (measured on internal voltage taps).

An interim report covering the accumulation, reduction, and normalization of Viking ETG's S/N 101 and S/N 102 steady state test data was issued on March 28, 1972 (Reference I-5). The report covers the data collected at MMD during the period from Acceptance Testing (June 1971) through Series Mode Testing (early March 1972). After the interim report was issued, test data evaluation was conducted on a continuing basis as data became available through the AEC.

Figures I-7 and I-8 present the electrical power output and hot junction temperature profiles during the period from MMD acceptance (June 1971) to the completion of MMD Series Mode Testing (June 22, 1972) for ETG's S/N 101 and S/N 102, respectively. The data presented have been normalized to a 330°F fin root temperature, a 690 watt(t) inventory, and a 4.4 volt load voltage. The reported hot junction temperatures, prior to RTD failure, is the average of the RTD and the alarm thermocouple measurement. After RTD failure, the reported hot junction temperature is 10°F higher than the measured alarm thermocouple reading. (See Section I.G for a discussion of the RTD failure.) The accumulation of data presented in Figures I-7 and I-8 encompasses approximately 4865 hours of MMD testing on S/N 101 and approximately 4920 hours of MMD testing on S/N 102.

Test results of both ETG's indicate that electrical power output is decreasing at a higher rate than anticipated when the units were built. The absence of an expected increase in both the hot junction temperature and open circuit voltage appears to be causing the unexpected power loss since the internal resistance is increasing at the expected rate.

FIGURE I-7

VIKING ETG SIN 101 POWER AND HOT JUNCTION TEMPERATURE LIFE DATA
NORMALIZED TO 330 °F FIN ROOT TEMPERATURE, 690 WATT THERMAL INVENTORY
AND 4.4 VOLTS LOAD VOLTAGE (MEASURED INTERNALLY)

FIGURE I-8

VIKING ETG S/N 102 POWER AND HOT JUNCTION TEMPERATURE LIFE DATA
 NORMALIZED TO 330 °F FIN FOOT TEMPERATURE, 690 WATT THERMAL
 INVENTORY AND 4.4 VOLTS LOAD VOLTAGE (MEASURED INTERNALLY)

The probable cause of the increased power loss is hydrogen generation in the thermoelectric converter, resulting in a decrease in thermal insulation efficiency. Hydrogen generation was noted on early Pioneer ETG's and RTG's employing a thermoelectric converter design and fabrication processing similar to ETG's S/N 101 and S/N 102. The later Pioneer F flight units incorporated a "getter" which, among other gases, "gettered" hydrogen. Also, improved converter outgassing procedures and glove box assembly operations were incorporated to minimize any impurities in the converter cover gas during subsequent operation. These Pioneer design and processing improvements will be incorporated in future Viking generators beginning with the Engineering ETG.

4. Pioneer F Flight Back-up RTG S/N 47

Generator S/N 47 originated under the Pioneer program as a back-up unit for Pioneer F flight units. Under the Pioneer program, S/N 47 accumulated ~2825 hours of operating time, ~140 hours as an ETG and ~2685 hours as an RTG. Following the successful launch of Pioneer F, RTG S/N 47 was transferred to the Viking program.

RTG S/N 47 was received at Teledyne Isotopes from Cape Kennedy on March 15, 1972. Steady state endurance testing was initiated on S/N 47 utilizing existing SNAP 19 Pioneer test procedures. Pioneer operating conditions imposed on the generator consisted of a 325°F fin root temperature and a 4.2 volt load voltage.

On April 10, 1972, a load voltage parametric test was conducted on RTG S/N 47. Normalized results of the parametric test are compared with previous data obtained under the Pioneer program in Figure I-9. The test history of S/N 47 closely approximates that of the Pioneer F flight generators. Loss of efficiency, illustrated by drops in power output and hot junction temperature, suggest expected increases in helium release from the capsule following prolonged RTG storage at low temperatures.

FIGURE I-9

PARAMETRIC TEST RESULTS

SNAP 19 GENERATOR S/N 47

FIN ROCT TEMPERATURE: 330°F

647 WATTS (CAPSULE INVENTORY)

INITIAL GAS FILL: 75% HELIUM / 25% ARGON

Direction by the AEC to return S/N 47 to storage conditions (short circuit electrical load with uninsulated fins) in support of eventual capsule diagnostic for "shelf life" determination was implemented on April 14, 1972. S/N 47 remained under storage endurance test conditions until June 7, 1972, when a final power check under Pioneer operating conditions was conducted. On June 10, 1972, RTG S/N 47 was shipped to Monsanto Research Corporation (MRC) for further testing.

Figure I-10 presents a summary of the steady state performance data accumulated throughout the life of S/N 47. At the time of shipment to MRC, the total fueled operating time (including pre-fueling heated operation) was 4916 hours.

FIGURE E-10
SNAP 19 S/N 47 PERFORMANCE
NORMALIZED TO 136°F FIN ROOT

C. RTG PARAMETRIC PERFORMANCE ANALYSIS

During this reporting period, RTG parametric performance analyses consisted of three studies. During January and February, 1972, a series of performance analyses was performed which investigated the Viking RTG with an initial gas fill of 75% Helium/25% Argon to reduce heat source operating temperatures. This study led to the selection of the vented fuel capsule concept for the Viking RTG. A second study was conducted to establish the acceptance power for the vented Viking RTG. A third study was initiated which updates the performance studies conducted in January and February, 1972.

1. Viking RTG with 75% Helium/25% Argon Initial Fill Gas

These Viking RTG end-of-mission parametric performance analyses extend the analyses performed during the previous reporting period as reported in December, 1971 in "SNAP 19 Viking Parametric Performance Study," INSD-2960-28 (Reference I-4). These results were presented as Addendum A to INSD-2960-28 (Reference I-6). Results of the parametric performance studies led to the selection of a "vented capsule" configuration as the SNAP 19 RTG concept which offered the dual capability of satisfying Viking mission minimum power/reliability requirements and maintaining capsule operating temperatures at the flight safety approved Pioneer levels.

A total of six cases were analyzed to investigate the effects of:

- a. a change in the generator gas fill from 100% Argon to 75% Helium/25% Argon to reduce heat source temperatures to levels consistent with the SNAP 19 Pioneer heat source temperatures.

- b. a reduction in the interplanetary cruise mode fin root temperature to reflect measured fin root temperatures during Martin Marietta Corporation's Cruise Mode Test.
- c. changes in the management of the helium gas evolving from the RTG fuel capsule to investigate the potential improvement of end-of-mission electrical power output.

End-of-mission (EOM) electrical performance and beginning-of-life (BOL) heat source temperatures were determined for each of the six cases using analytical techniques discussed in Reference I-4. Analysis input parameters were based on the modified study (page 91 through Page 101 of Reference I-4) and were updated to reflect the latest Pioneer RTG performance where applicable. Table I-8 defines the input parameters for the six cases investigated.

The results of this study are summarized in Table I-9. The conclusions are shown below.

1. A 100% Argon fill generator offers 0.5 watt(e) margin in power output but causes an increase in strength member temperature of 550°F above safety approved Pioneer temperatures. (This conclusion is a restatement of the conclusion of Reference I-4.)
2. Changing the initial gas fill from 100% Argon to 75% Helium/25% Argon offers Pioneer level heat source temperatures, but end-of-mission power is 1 watt(e) less than required by the Viking mission when the helium generated by the fuel capsule is released directly into the sealed thermo-electric converter.

TABLE I-8

SNAP 19 VIKING RTG CONFIGURATION INPUTS

	CASE IDENTIFICATION					
	I	II	A-III	A-IV	B-III	B-IV
Fuel Inventory, watts(t)	682 ±3					
Initial Gas Fill	75% He/25% Ar					
Gas Management	Welded Gen.		Capsule Vented		Controlled Leak	
Leak Rate, scc of Ar/sec atm	1×10^{-7}				$7.3 \times 10^{-6*}$	
Leak Rate Standard Deviation, scc of Ar/sec at 1 atm	0				$1.8 \times 10^{-6*}$	
Time for RTG Acceptance, months	3		1			
Fuel Capsule Gas Fill	75% He/25% Ar		100% He		75% He/25% Ar	
Helium Release into T/E Converter, %	100		0		100	
Initial Power Distribution	S/N 43 - S/N 48					
Nominal BOL Power, watts(e)	43.18					
Standard Deviation on BOL Power	0.4506		0.389			
Cruise Average Fin Root Temperature, °F	350	330	350	330	350	330
Mars Surface Average Fin Root Temperature, °F	340	330				
EOM Catastrophic Reliability Apportionment	.9977					
EOM Operational Reliability Apportionment	.9923					

*Viton O-ring seal leak is temperature sensitive with a 337°F reference point.

TABLE I-9

SNAP 19 VIKING PERFORMANCE PREDICTIONS

	CASE IDENTIFICATION					
	I	II	A-III	A-IV	B-III	B-IV
Nominal Initial Power, watts (e)*	43.18					
Nominal EOM Power, watts (e)	35.1	35.4	37.9	38.0	36.9	36.8
EOM Power at 0.99 Probability, watts (e)	34.1	34.4	37.0	37.1	35.6	35.6
EOM Required Power at 0.99 Probability, watts (e)	35.0					
EOM Power Margin, watts (e)	-0.9	-0.6	+2.0	+2.1	+0.6	+0.6
Calculated BOL Temperature Distribution, ° F						
Hot Junction	1018					
Heat Shield	1068					
Clad	1495		1475		1495	
Strength Member	1550		1510		1550	
Liner	1615		1548		1615	
Inner Liner	1675		1580		1675	
Fuel Surface	1750		1617		1750	

* Initial power distribution includes SNAP 19 Pioneer generators S/N 43 - S/N 48.

3. A 75% Helium/25% Argon fill generator with fuel capsule generated helium vented directly overboard (external to the thermoelectric converter) offers a potential 2 watt(e) end-of-mission power margin with heat source temperatures comparable to Pioneer.
4. As a backup to the overboard venting concept, a 75% Helium/25% Argon fill generator which has a controlled housing leak is described where the fuel capsule generated helium is released directly into the thermoelectric converter. This leak is based on the Pioneer connector Viton seal leak rate. Heat source temperatures are comparable to Pioneer heat source temperatures and a potential end-of-mission power margin of 0.5 watt(e) is indicated.
5. End-of-mission performance is not significantly affected by variations of interplanetary cruise fin root temperatures between 330°F and 350°F.

The potential 2 watt(e) EOM power margin indicated for the vented capsule concept, while maintaining RTG heat source temperatures comparable to those of the SNAP 19 Pioneer, is the basis for the selection of this concept for the SNAP 19 Viking configuration. Development of the vented capsule RTG configuration is now being pursued with the intent of providing this modified configuration in the set of prototype RTG's scheduled for delivery to AEC/NASA in October 1973.

Additional characteristics of the vented capsule SNAP 19 Viking RTG are shown in Figures I-11 through I-13. Figure I-11 shows the two fin root temperature profiles utilized in the RTG analysis. Figures I-12 and I-13 show the resultant hot junction temperature as a function of time and parametric in helium release rate from the fuel capsule. For the vented capsule design, the zero percent helium release rate represents the expected hot junction temperature profile. The parameters

FIGURE I-11
VIKING RTG FIN ROOT TEMPERATURE PROFILE
REDUCED INTERPLANETARY CRUISE FIN ROOT TEMPERATURE
CASES A-III, A-IV, B-III AND B-IV

STORAGE AND PRE-LAUNCH	INTERPLANETARY CRUISE	MARS ORBIT	MARS SURFACE (AVG)
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FIGURE I-12
VIKING RTG HOT JUNCTION TEMPERATURE PROFILE
REDUCED INTERPLANETARY CRUISE FIN FOOT TEMPERATURE
ONE MONTH ACCEPTANCE - CASE A-III
(CAPSULE VENTED TO SPACE)

INITIAL GAS FILL OF 25% Ar / 75% He ~ 1.0 ATM
 682 ± 3 WATTS THERMAL INVENTORY
 LEAK RATE = 1.0×10^{-7} SCC Ar / SEC ATM

FIGURE I-13
VIKING RTG HOT JUNCTION TEMPERATURE PROFILE
REDUCED INTERPLANETARY CRUISE FIN ROOT TEMPERATURE
ONE MONTH ACCEPTANCE - CASE A-IV
(CAPSULE VENTED TO SPACE)

INITIAL GAS FILL OF 25% Ar / 75% He ~ 1.0 ATM
 682 ± 3 WATTS THERMAL INVENTORY
 LEAK RATE = 1.0×10^{-7} SCC Ar / SEC ATM

presented for Mars surface operation are steady state parameters associated with a 330°F fin root temperature and do not reflect expected thermal cycling.

2. Acceptance Power for Vented Viking RTG

An analysis of the effect of a specific measured initial power on the predicted EOM electrical power was conducted to establish a minimum level of acceptance power. A minimum level of acceptance power eliminates the lowest performing RTG's at acceptance and provides assurance that the EOM electrical power will meet mission requirements.

To evaluate the effects of specific measured initial power on the expected EOM electrical power, the helium-vented Viking RTG concept was examined parametrically for nominal initial (measured at acceptance) electrical powers of 40 to 43 watts(e). A measurement uncertainty of $3\sigma = 0.2$ watts(e) was assumed to apply about the measured power. A cruise mode fin root temperature of 350°F and the associated generator characteristics shown in Figures I-11 and I-12 were utilized in the analysis.

The results of the minimum acceptance power study are presented in Figure I-14 where the nominal and 0.99 EOM electrical powers are plotted as a function of specific measured initial power. Figure I-14 shows that any measured initial power above 40.2 watts(e) will produce an EOM 0.99 probability electrical power equal to or greater than the 35.0 watt(e) EOM Viking requirement. Based on experimental performance to date, a minimum acceptance power of 40.2 watts(e) would essentially eliminate the risk of fabricating an unacceptable RTG (an RTG which produces a power less than the minimum acceptance power). Unfortunately, a minimum acceptance power of 40.2 watts(e) leaves no margin for the uncertainties in a prediction of EOM power (such as the effect of Mars surface thermal cycling, the uncertainties of the RTG environments, or the uncertainties of future changes in generator mission life effects).

FIGURE I-14
END-OF-MISSION PERFORMANCE OF SPECIFIC POWER
GENERATOR

FUEL INVENTORY = 682 WATTS (t)
 ACCEPTANCE POWER MEASUREMENT UNCERTAINTY $3\sigma = .2$ WATTS (e)
 0% HELIUM RELEASE RATE
 (CAPSULE VENTED OVERBOARD)
 INITIAL GAS FILL = 75% He - 25% Ar, ~ 1.0 ATM
 CRUISE AVERAGE FIN ROOT TEMPERATURE = 350°F
 LEAK RATE = 1.0×10^7 SCC AT/SEC ATM

Increasing the acceptance value above 40.2 watts(e) provides margin in the life effects at the increased risk of producing a generator which will not satisfy the acceptance power. For the expected Viking RTG population ($P_{\text{mean}} = 43.18$ watts(e) and $\sigma = .389$ watts(e)), the acceptance power can be increased as high as 42.0 watts(e) with only a 0.25 percent chance of an RTG not satisfying the acceptance power. An acceptance power of 42 watts(e) would accommodate an increase of approximately 1.8 watts in life effects but would allow only a small reduction in the RTG population initial power distribution without greatly increasing the chance of having a generator with less than acceptable power. Selection of an acceptance power of 41.0 watts(e) provides a tradeoff of the two considerations. An acceptance power of 41.0 watts(e) provides an 0.8 watts(e) margin for life effects and provides for a 1.0 to 1.2 watts(e) decrease in the initial power of the RTG population. Therefore, an acceptance power of 41.0 watts(e) has been selected for the vented SNAP 19 Viking RTG.

3. Parametric Performance Update

An update of the performance analyses discussed above has been initiated. This study updates previous analysis by including effects of: (a) a 360°F interplanetary cruise mode fin root temperature, (b) heat losses associated with the vented fuel capsule, (c) heat losses from the optimized getter configuration and (d) the RTG housing temperature distribution for various phases of the Viking mission. A 360°F cruise mode fin root temperature and a 375°F fin root temperature during the Mars orbit checkout phase of the mission are presently defined as the RTG fin root temperature instead of the 350°F utilized in the analyses discussed in Section I.C.1. Heat loss calculations are performed in Task 5 (Chapter III) for the vented capsule design. These heat losses have been factored into the RTG performance analysis. Heat losses associated with the optimized getter (discussed in Section I.E) are being integrated into the analysis. The reduced

heat losses of the optimized getter will increase the initial RTG power output and hot junction temperature.

Reference I-7 presented the Integrating Contractor calculation for the RTG housing temperature distribution during various phases of the mission. Results of this analysis are being utilized to update the expected hot junction temperature for each phase of the Viking mission. An updated EOM performance analysis will be issued during the next reporting period.

D. ETG/RTG DESIGN

1. Refurbishment of SNAP 19 Pioneer Generators S/N 41 and S/N 43

On the SNAP 19 Pioneer program, RTG's S/N 41 and S/N 43 were defueled at Monsanto Research Corporation (MRC) for shelf life studies. Generator S/N 41 was subsequently shipped to Teledyne Isotopes and placed in storage; generator S/N 43 remained at MRC in storage. After an evaluation of available generators to perform the Mars Surface Thermal Cycle Test, both generators were transferred to the Viking program for use in the cycle test. Generator S/N 43 was subsequently delivered to Teledyne Isotopes on March 30, 1972.

A procedure was written and released (Teledyne Isotopes drawing 452A6000311) defining the necessary refurbishment for Pioneer generators S/N 41 and S/N 43 as ETG's. SNAP 19 Pioneer outgassing tools (Teledyne Isotopes drawing 452B5140001) were utilized as the electrical heat source for each of these generators. This outgassing tool is sealed to the generator housing utilizing a Viton O-ring. Since the tool was designed for short-term use during RTG assembly and fueling, this seal configuration is not backed up with welded seal rings as utilized on Viking ETG's 101 and 102. This large O-ring is, therefore, subject to gas permeation as discussed in Section I.B of this report.

Refurbishment also consisted of installation of a new getter assembly and new Min-K parts in the fueling end of the generator, and reworking the lower end cover to accommodate the current outgassing technique. After completion of generator assembly, the generators were cold leak checked, re-outgassed and tested at steady state conditions to evaluate performance prior to initiation of thermal cycle testing. Details of these steady state tests are contained in the Section I.B and II.A discussion.

Following the development of the thermal control system as discussed in Section II. A, drawings were issued which defined: (a) the strip heater installation along the ETG fin root, (b) the cooling plate installation on the ETG fin tips, and (c) fan shroud and mounting provisions in the thermal vacuum chamber.

2. Engineering ETG Design Studies

Design effort was initiated for an engineering model ETG by reviewing ETG S/N 101 and 102 detail drawings to assure their compliance with the latest Pioneer detail drawing data. During this reporting period, thermoelectric module assembly detail drawings have been reviewed and updated, and design investigation of alternate methods for attaching the upper and lower covers to the housing assembly was initiated and completed.

The previously planned Viking end cover installation/seal configurations are as shown in Figures I-15 and I-16. The top end cover (fueling end) shown in Figure I-15 is retained by twelve titanium alloy bolts which thread into stainless steel inserts in the MgTh housing body. The inserts are threaded and locked in the MgTh body. After torquing of the bolts, individual lock plates are placed over each bolt head to prevent loss of torque due to loosening during dynamic environments. This configuration is similar to that of the Pioneer smaller diameter lower cover (non-fueling end on Pioneer).

Figure I-16 shows the Viking bottom end cover (spacecraft mounting end) which employs an HPG-type shear weld. The incorporation of the HPG-type cover at the lower end and relocation of the smaller diameter cover to the upper end resulted in a 1.2 pound generator weight decrease over the Pioneer configured covers. In generator assembly operations, the thermoelectric core assembly is inserted from the bottom of the housing since the "scallop" for the threaded inserts at the top end cause interference.

FIGURE I-15
TOP COVER BOLTED

FIGURE I-16
BOTTOM COVER WELDED

SCALE: 2/1

In generator design and assembly/fabrication studies performed during this period, several desirable features not provided by the previously planned end cover configurations became evident. To assure electrical receptacle hermetic seal integrity prior to final welding in the generator housing, and to eliminate all soldering operations in the glove box line, it is desirable to solder all wires to the diffusion bonded electrical receptacle assembly and perform Quality checks prior to welding the receptacle assembly into the housing. Then, after the core assembly is inserted into the housing in the glove box line, the wire pigtailed on the receptacle will be crimped to the ends of the thermoelectric circuit using the same size crimps and techniques as presently used on crimps between modules. Elimination of the difficult task of soldering the wires to the receptacle in the glove box line will assure more reproducible solder joints and greater quality control.

The electrical receptacle is located at the lower end of the generator with a configuration as shown in Figure I-17. If the wires have been soldered to the receptacle prior to the time of thermoelectric core insertion from the bottom, the wires will cause interference during core insertion unless the receptacle mounting arrangement in the housing is modified (at a weight penalty) to provide wire bundle space during core insertion. If the core is inserted from the upper end, interference is eliminated.

End cover closures with similar welds at the top and bottom of the generator will facilitate the implementation of automated welding. The seal-weld type closure will be the simplest to automate since it does not require filler weld rod.

Figures I-18 and I-19 illustrate the present end cover installation/seal designs which will permit implementation of the desired design features discussed above. An HPG-type cover is retained by a threaded ring at its outer periphery instead of by a shear weld. The mechanical loading will be taken by shear in the ring

FIGURE I - 17

DIFFUSION BOND INSTALLATION

IN HOUSING

FIGURE I-18
TOP COVER THREADED RING

FIGURE I-19
BOTTOM COVER THREADED RING

SCALE: 2/1

threads instead of the shear weld. The seal will be provided by non-loadbearing seal-welds similar in geometry to the present Pioneer seal-weld configuration. With the configuration illustrated, the upper and lower cover weld lips, threaded rings, seal rings, and seal-weld diameters are identical to facilitate automatic welding. The weight of this configuration will be approximately 0.2 pounds lighter than the configuration employing a bolted top cover and HPG-type lower cover.

A summary of study conclusions is presented in Table I-10. Incorporation of the end cover modifications in the Engineering ETG will verify design adequacy and mechanical feasibility. The planned pressure test of the lower end cover mockup, including a diffusion bonded receptacle, would include the recommended cover configuration.

3. Heat Pipe Design Feasibility Study

A limited design feasibility study for the application of a heat pipe radiator system to the Viking generator was performed. Two generator concepts were evaluated:

Concept #1, Straight Fin Radiator, Figure I-20

Concept #2, Conical Fin Radiator, Figure I-21

The heat pipes are slanted at a 30° angle to the horizontal plane due to potential lander orientation on the Martian surface. One key to the successful application of a heat pipe radiator is the development of a suitable means of attaching the evaporator end of the heat pipes to the generator housing. In the cases studied, it is assumed that 100% tin solder would be used for bonding the copper heat pipes to the copper-plated MgTh housing.

TABLE I-10

SUMMARY OF END COVER CHANGE ADVANTAGES

1. Simplifies generator assembly procedures in that all soldering operations in glove box line are eliminated.
2. Permits retention of Pioneer-type seal welds (non-load bearing, same welding parameters, same repair capability).
3. Facilitates implementing automatic welding in that no filler rod is required and both end cover welds are identical and on same diameter.
4. Shear area of ring threads will result in increased load bearing capability.

FIGURE I-20

FIGURE I-21

An analytical effort in support of the heat pipe design effort was performed. The potential advantages of a heat pipe heat rejection system when applied to the SNAP 19 Viking generator configuration were investigated. Two configurations were evolved as depicted in Figures I-20 and I-21, but only one design was analyzed due to the brief duration of the study. The design analyzed, as shown in Figure I-20, is nearly identical to the straight conduction fin design of the present Viking generator. The straight conduction fin design consists of 6 tapered fins, 10.44 inches high and 8.25 inches wide, and is capable of rejecting 592 watts to a 100°F sink temperature at an average fin root temperature of 330°F (an additional ~40 watts is rejected from the top cover).

Copper-water heat pipes (1/4 inch OD, 10 mil wall) were selected for the system studied because, when compared to other applicable container-fluid combinations (see Table I-11) for this temperature range, they offer the following advantages: (a) long term compatibility, (b) highest heat transport capability, (c) copper-water both exhibit high thermal conductivity - therefore, low heat pipe temperature drops, and (d) moderately low vapor pressure (wall thickness to retain pressure is less than 4 mils). Other transport fluid-container material combinations could be considered, but the relatively low thermal conductivity of other applicable fluids would make a detailed analysis necessary before any significant weight saving could be predicted. It can be shown that the weights of the heat pipes alone could be reduced by up to 50% over the copper-water system, but the heat pipes represent only 10 to 20% of the total heat rejection system weight for even the relatively heavy copper-water system. Therefore, the reduced heat pipe weights can be negated by the requirement for more fin area if the temperature drops due to lower fluid thermal conductivity are larger.

TABLE I-11

CANDIDATE FLUIDS FOR SNAP 19 VIKING HEAT PIPE

HEAT REJECTION SYSTEM

TRANSPORT FLUID	PV(PSIA) @ 275°F	PV@ 375°F	LIQUID TRANSPORT NL @ 275°F	PEAK NL PEAK IV	FREEZE POINT (°F)	THERMAL COND. FLUID BTU/FT ² -HR. °F	CONTAINER MATERIALS	WICK MATERIALS	ADVANTAGES/DISADVANTAGES; COMMENTS
Water	46	185	1.6 x 10 ¹⁰	300°F 510°F	+32	0.4	Cu, ss, Ni*	Cu, ss, Ni*	Highest transport factors Highest thermal conductivity Operating near peak NL *Must be oxidized thoroughly.
Methanol (CH ₃ OH) (Methyl Alcohol)	140	500	1.75 x 10 ¹⁰	265°F 345°F	-144	0.13	Al, ss	ss, Al**	Commonly called wood alcohol is basically a solvent spectrophotometric grade require **AL wick may be used if structurally adequate.
Ethylene Glycol (C ₂ H ₆ O ₂)	1.5	12	1.17 x 10 ¹⁰	540°F	+3.5 +8	0.15	Al, Cu, ss	ss, Cu, Al	Commonly used as anti-freeze Initial decomposition at 330°F spq.= 1.113
Ethyl Alcohol (C ₂ H ₅ OH) (Ethanol)	97	352	8.5 x 10 ⁹ at 85°F	F	-179	0.11	Al, ss	Al,** ss	Also called Ethanol & Methyl carbanol. Must be anhydrous(200 proof) TCR = 469°F spg =.789
Freon 11	235	540	4.3 x 10 ⁹	70°F 220°F	-126	0.050 (R.T.)	Most Metals except +	Most Metals except +	+ IF H ₂ O present, Al, Mg & Zn can be affected. Critical Temp = 388°F
Freon 112	49	147			+79	0.040 (R.T.)	Most Metals except +	Most Metals except +	Lowest pressure Freon (Tcr = 532°F, High Freeze Point
Dowtherme	4.5	17.7	5 x 10 ⁹		-7	0.065	Most Metals except #	Most Metals except #	#Not compatible with aluminum - Must keep H ₂ O out
Glycerol (C ₃ H ₈ O ₃)	0.04	0.58			+63	0.164			Antifreeze constituent
Acetone (CH ₃) ₂ CO			9 x 10 ⁹		-138	0.096			Solvent (Tcr = 455°F) spg = .791
Carbon Tetrachloride CCL ₄					-9.5	0.095			Solvent, degreaser, cleaner spg = 1.594
Ortho-Dichloro Benzene o-C ₆ H ₄ Cl ₂	4	20			+1	0.11			

Many design options are offered by the use of a heat pipe system by varying the fin width, fin thickness, and the number of heat pipes per fin. Several examples are shown in Table I-12. These options include lower heat rejection system weight, smaller system envelope, altered system envelope, increased power output because of lower heat rejection temperatures, reduction in thermoelectric material degradation because of lower hot junction temperatures or various combinations of the above. Despite the conservative weight analysis used in this study, it is predicted that the heat pipe system studied could be designed to weigh nearly 50% less than the straight conduction fin design of approximately 5 pounds and also exhibit superior performance by reducing the fin root temperature 35°F within the same overall envelope. Structural analyses are, however, required to verify the adequacy of the thinner (heat pipe stiffened) fins.

The Viking heat pipe investigation was terminated due to the relatively small EOM power increase (approximately 1 watt(e) with present Viking constraints on envelope and fuel inventory).

TABLE I-12

COMPARISON OF HEAT PIPE H/R SYSTEMS WITH STRAIGHT CONDUCTION FIN DESIGN

(All Configurations - 6 Fins, 6.44" Housing Dia.)

<u>DESIGN</u>	<u>FIN HEIGHT (IN)</u>	<u>FIN WIDTH (IN)</u>	<u>FIN THICKNESS (IN)</u>	<u>NO. OF HEAT PIPES</u>	<u>Q*REJ. (WATTS)</u>	<u>FIN ROOT(°F) TEMP.</u>	<u>H/R SYSTEM WT.(LBS.)</u>
Conduction Fin	10.44	8.25	0.25 to 0.03	None	592	330	5.3
Heat Pipe	10.44	8.25	0.050	3	592	330	3.43
Heat Pipe	10.44	8.25	0.025	4	592	315	2.96
Heat Pipe	10.44	8.25	0.050	6	592	296	4.03
Heat Pipe	10.44	8.25	0.025	6	592	298	3.36
Heat Pipe	10.44	12.9	0.025	3	592	280	3.48
Heat Pipe	10.44	9.75	0.025	6	592	280	3.7
Heat Pipe	10.44	12.26	0.050	3	592	280	4.38
Heat Pipe	10.44	9.55	0.050	6	592	280	4.45
Heat Pipe	10.44	10.7	0.050	4	592	280	4.27

* Sink Temperature = 100°F
E = 0.83

E. GETTER OPTIMIZATION STUDIES

Design evaluation and analytical studies were performed with regard to improvement of the Viking ETG/RTG getter configuration with the intention of reducing the parasitic heat losses associated with the current Pioneer design. This effort considered changes to the getter assembly configuration and location within the generator assembly. Design layouts were evaluated with regard to getter effectiveness, thermal losses, nuclear safety and mechanical feasibility.

1. Thermal/Electrical Studies

Table I-13 summarizes the effect of a single getter assembly on generator electrical performance as determined for all Pioneer generators employing the current getter design. Also included in this tabulation is the effect of a getter as determined for the HPG generator. The effect on electrical performance was determined to range between 0.6 and 0.9 watt (e), and averaged approximately 0.8 watt (e) per getter assembly or 1.6 watts(e) per generator for both getter assemblies.

The ground rules for the optimization study were that (a) the thermoelectric modules, including the RTD location, would not be altered, (b) the getter would operate in contact with the heat shield unless getter effectiveness studies dictated otherwise, (c) the getter would not be placed in the heat source structural support path provided by the Min-K at the ends of the heat source and (d) the Pioneer getter materials would be retained (70 to 80% dense zirconium in palladium housing).

Figure I-22 shows the preliminary designs evaluated in detail using nominal 1050°F heat shield and 300°F housing boundary temperatures. Results of the thermal analyses performed for these configurations indicated that only by "nesting" the getter around the heat shield and reducing the getter size could a significant decrease in thermal losses be realized. Also, the getter temperature for all configurations was

TABLE I - 13

GETTER EFFECT ON ELECTRICAL POWER OUTPUT

1	2	3	4	5	6	7	8
<u>Generator S/N</u>	<u>Number of Getter Assemblies in ETG Prior to Fueling</u>	<u>Number of Getter Assemblies in RTG After Fueling</u>	<u>ETG Power Before Fueling (watts)</u>	<u>Corrected* ETG Power Before Fueling (watts)</u>	<u>RTG Power After Fueling (watts)</u>	<u>Power Loss ** Due to One Getter Assembly (watts)</u>	<u>Fuel Inventory (watts)</u>
41	0	2	38.0	38.9	37.3	0.8	641
42	1	2	39.1	40.0	39.4	0.6	645
43	1	2	40.1	41.0	40.1	0.9	648
44	1	2	41.0	41.9	41.0	0.9	649
45	1	2	39.9	40.8	40.0	0.8	646
46	1	2	39.3	40.7	40.1	0.6	647
47	1	2	39.7	40.6	39.7	0.9	647
48	1	2	40.1	41.0	40.4	<u>0.6</u>	649
					Pioneer Avg.	0.8	
HPG	1					0.8	

* Correction of 0.9 watt added to Column 4 power for the effect of outgassing tool.

** Calculated as (Column 5 - Column 6)/(Column 3 - Column 2).

FIGURE I - 22
PRELIMINARY GETTER CONFIGURATIONS

(CONSTANT 1050°F HEAT SHIELD WITH
 300°F HOUSING AND END COVER)

PIONEER GETTER
 (13 W(t), 1.3 W(e))*

1047**

GETTER IN NOTCHED HEAT SHIELD
 (8 W(t), 0.8 W(e))*

1048**

FLAT RING GETTER
 (15 W(t), 1.5 W(e))*

1045**

**SHORTENED GETTER IN
 NOTCHED HEAT SHIELD**

(4 W(t), 0.4 W(e))* 1049**

* THERMAL LOSS INCREASE AND ELECTRICAL POWER
 DECREASE FROM "NO GETTER" CONFIGURATION

** GETTER OPERATING TEMPERATURE

within 5°F of the adjacent heat shield temperature.

Figures I-23 and I-24 show the proposed optimized getter installation which analytically results in a decrease in thermal losses of 13 watts and an increase in generator electrical power output of 1.3 watts at beginning-of-life. This increase will be 1.2 watts (e) at end-of-mission. (The Viking "hot case" Mars day heat shield and housing temperature distributions were assumed since these are "worst case" power output conditions.) This increase is significant considering the capsule helium venting system is being developed for approximately 2 watts (e) power increase at end-of-mission (see Section III. B).

2. Getter Effectiveness Studies

In the proposed getter configuration the quantity of zirconium getter material is 65% of the Pioneer configuration. As shown in Figure I-25, based on what are considered conservative assumptions for the quantity of water remaining in the generator after outgassing considering present glove box assembly operations, 65% of the Pioneer quantity will still provide more than a factor of four overcapacity considering all O_2 and H_2 in the water is gettered by the zirconium. Figure I-26 shows that for hydrogen/zirconium atom ratios of from less than 0.1 to 1.3, the equilibrium pressure of hydrogen is approximately constant in the getter operating temperature range (500 to 600°C). Thus, the reduction in getter quantity will not have a significant influence on hydrogen partial pressure in the generator and the capsule shelf life capability will not be altered (storage will be at approximately 500°C getter temperature).

Studies performed concerning location of the getter for optimum operational temperature indicated that the present Pioneer location (adjacent to heat shield) should be retained. Results of a literature survey and review of Pioneer testing (Figure I-27 and I-28) performed in 1971 in support of the Pioneer F program indicate that a temperature

FIGURE I-23

VIKING OPTIMIZED GETTER CONFIGURATION

(MARS HOT DAY PREDICTED HEAT SHIELD,
HOUSING AND END COVER TEMPERATURES)

HEAT LOSS COMPARED TO PIONEER GETTER: -13.2WATTS THERMAL

AVERAGE HEAT SHIELD TEMPERATURE: 1070°F

AVERAGE FIN ROOT TEMPERATURE: 330°F

GETTER OPERATING TEMPERATURE: 1066°F

FIGURE I - 25

GETTER DESIGN

A. ADSORBED MOISTURE REMAINING AFTER OUTGASSING

1. Total H_2O in air-exposed Min-K ~ 2%
2. Total mass of Min-K in generator = 850 gm
3. Assume 90% of adsorbed H_2O is removed by outgassing
4. Remaining adsorbed H_2O in generator is
 $0.02 \times 0.10 \times 850 = 1.7 \text{ gms}$

B. WATER OF HYDRATION

1. 5% of Min-K is asbestos
2. 2% of asbestos is water of hydration
3. Total water of hydration in generator is
 $0.02 \times 0.05 \times 850 = 0.85 \text{ gm}$

C. TOTAL H_2O IN GENERATOR AFTER OUTGASSING

$$0.85 + 1.70 = 2.55 \text{ gms}$$

D. AMOUNT OF Zr REQUIRED TO CONSUME THE REMAINING H_2O IN GENERATOR (2.55 gms)

$$32.3 \text{ gms } (ZrH + ZrO_2)$$

$$29.4 \text{ gms } (ZrX_{1.3})$$

E. TOTAL Zr IN GENERATOR GETTER CONFIGURATION

About 200 gms

Excess factor is 6.2 (ZrH and ZrO_2)

Excess factor is 6.8 ($ZrX_{1.3}$)

FIGURE I-26

FIGURE I-27

FIGURE I-28

of 450°C (842°F) is required for diffusion of any oxide surface layer formed on the zirconium into the material to assure an unreacted surface for reaction with hydrogen. If no oxygen surface effects were postulated, the getter could be operated at approximately 300°C (572°F) for maximum effectiveness.

In the tests represented by Figures I-27 and I-28, portions of a zirconium getter ring were first oxidized with a quantity of oxygen representing proportionally the quantity of water (2.55 gms) shown in Figure I-25. The getters were then exposed to a proportional quantity of hydrogen. Only when the getter temperature exceeded 450°C did significant reaction with hydrogen begin. Figure I-27 represents the quantity of getter in the Pioneer generators while Figure I-28 represents one-half that getter quantity.

Table I-14 summarizes the conclusions in evaluating getter operating temperature. To assure retention of getter effectiveness as determined by gas analysis performed on Pioneer RTG's S/N 41 and 43 (Table I-15) and calculated getter efficiency based on getter chemical analysis (Table I-16), the getter temperature will remain at essentially the heat shield operating temperature.

3. Structural Considerations

Shortening the heat shield by approximately 0.4 inch at each end will reduce end plug engagement from 13 to 9 threads. The load rating per thread in shear is approximately 1000 pounds. As shown in Table I-17, reducing the load rating of the end plug threads to 9000 pounds still provides a safety factor of two over the shear ring load relief mechanism in the heat shield assembly.

4. Nuclear Safety Considerations

As shown in Figure I-23, the proposed getter installation necessitates shortening of the Viking heat shield body approximately 0.4 inch at each end. Overall

TABLE I - 14

OPTIMUM H₂ ABSORPTION TEMPERATURE RANGE FOR RTG USE

1. OPTIMUM H₂-GETTERING TEMPERATURE OF ACTIVATED Zr IS 300°C
IF NO O₂ IS PRESENT (GULDNER & WOOTEN)
2. IF O₂ IS PRESENT, A PROTECTIVE FILM FORMS BELOW ABOUT 450°C (MILLER)
3. WHEN Zr IS EXPOSED TO WATER VAPOR AT 700 TO 800°C, FREE H₂ IS PRODUCED.
(GULDEN & WOOTEN)

CONCLUSION: OPTIMUM TEMPERATURE RANGE FOR Zr GETTER IN RTG IS
500 TO 600°C.

TABLE I - 15

GAS ANALYSIS, VOL OR MOL%

RTG S/N	SAMPLE NO.	H ₂	H ₂ O	N ₂	O ₂	CO ₂
41	MRC 4	0.1	0.1	ND	-	-
	6	0.1	0.1	0.1	-	-
	LASL 5	.004*	ND	ND	-	.004 - .005
	7	.004"	ND	ND	-	.004 - .005
	ACCUMULATOR	.0055	-	0.71	0.13	.0096
43	MRC 4	ND	**	ND	ND	ND
	6	ND	**	.01	ND	ND
	LASL ***5	.0007	**	.0096	ND	ND
	7	.0008	**	.0083	ND	ND
	ACCUMULATOR	ND	**	.049	.0097	.0014

*+ 0.002%

**NONE REPORTED

***+ 50% OF VALUE

TABLE I - 16

GETTER EFFICIENCY, BASED ON LASL GAS ANALYSIS

S/N 41	INCREASE IN WEIGHT DUE TO H ₂	= .025%
	VOL OF H ₂ OCCLUDED	= 539 CC (STP)
	0.004 V/O x 3000 CC (VOL OF RTG)	= 0.12 CC (STP)
	539/539.12 x 100	= 99.98 %
S/N 43	INCREASE IN WEIGHT DUE TO H ₂	= 0.032 %
	VOL OF H ₂ OCCLUDED	= 700 CC (STP)
	0.001 V/O x 300 CC (VOL OF RTG)	= 0.03 CC (STP)
	700/700.03 x 100	= 99.996%

TABLE I - 17

HEAT SOURCE COMPONENT

ALLOWABLE LOADS

Shear ring	4,600 lbs
Capsule strength member (compression yield)	50,000 lbs
Heat shield body (tension)	31,000 lbs
Present end plug threads (shear)	13,000 lbs
Proposed end plug threads (shear)	9,000 lbs

length across end caps will remain the same at 6.712 inches. The heat source recess (See Figure I-29) resulting when the heat source end plugs are installed is designed to permit the getter ring to separate from the heat shield body during generator reentry breakup for all cases except stable, end-on reentry. In this instance the getter ring could be held to the heat shield by dynamic forces. The molten products of the getter could impinge on the graphite body of the heat shield as they are swept away by the reentry air stream. The meltdown will be rapid and the molten products (palladium and zirconium) are only in contact with the heat shield for a short period of time producing negligible material reactions as with other heat sources employing complete encapsulation of the heat source (Transit and Multi-Hundred Watt).

The increase in ballistic coefficient of the getter-recessed heat shield is approximately two percent, which yields a very small increase in the total reentry heating. Local heating distributions around the recessed area will be perturbed, but are not expected to be magnified to any significant extent, since the original configuration exhibited a sharp 90° corner which in itself yielded a high local heat flux. Reattachment of the shock layer exists for the original heat shield and is not expected to increase for the recessed configuration. Ablation of the sharp corners will also be minimal based on previous plasma-arc tests results on the Pioneer program.

Thermal stress during reentry is dependent on the difference in temperature between the inside and outside of the heat shield body at any given point on the body. The proposed design does not configure the heat source to the extent that the temperature difference will be greater than the present design, thus thermal stress-to-strength ratios should not change.

5. Conclusions

By incorporating the proposed getter configuration/installation in the Engineering

FIGURE I - 29

*SIDE VIEW-PROPOSED VIKING HEAT
SHIELD ASSEMBLY*

ETG scheduled to be fabricated by the end of CY 1972, verification of the conclusions on getter effectiveness as stated above can be achieved before delivery of the prototype RTG's in October 1973. The fallback position is, of course, to return to the present Pioneer design.

With regard to nuclear safety, additional analyses will be performed to validate the engineering judgements presented herein. Additionally, incorporation of the proposed modification (including installation of a getter ring on the test specimen in the development test plasma-arc test planned for August 1972 will provide supporting test data for the modifications.

F. RELIABILITY

1. Program Plan and AEC Review

The Reliability Program Plan was patterned after AEC Specification SNS-3, dated October 1971, titled "Reliability Program Requirements for AEC Space Nuclear Systems" and documented as a separate Addendum to the SNAP 19 Viking Program Plan (Reference I-2). It was scoped to cover the reliability activity through the end of the program, and thus would not require a rewrite for each program phase. The applicability of any specific task and the schedule for the task were set forth in the overall SNAP 19 Viking Program Plan.

The first AEC/ESD Reliability Program Review was conducted with participation of AEC Reliability and Quality Assurance. Future reliability program reviews will include representation from NASA and possibly the Integrating Contractor.

The primary reliability effort during the reporting period was directed towards analyses of the designs proposed for the Viking RTG over and above the baseline Pioneer F and Viking First Set of ETG's, S/N 101 and 102. The designs having the greatest impact on the capability of meeting performance are reported herein. They include the addition of a capsule vent system, the change to diffusion bond for the electrical power receptacle. A reliability demonstration test program, associated with the assessment of these designs, was also formalized.

2. Capsule Venting System

A fuel capsule venting system (see Section III. B) is under development for the Viking RTG to isolate the capsule cover gas generated by fuel decay from the thermoelectric converter fill gas of 75% Helium/25% Argon. The isolation of these gases provides an additional two watts of electrical power at end-of-mission. Two approaches

are being evaluated; one approach uses a Controlled Leak Device (CLD) which allows helium to vent directly to space at a rate that maintains pressure in the capsule; the other approach retains the gas generated in a reservoir integral with the generator cover.

Figure I-30 presents the results of the reliability comparison (trade-off) between the two approaches based on failure mode, effects and criticality analyses. The reservoir approach is preferred since no single failure points were identified which would create a category one failure (catastrophic loss of electrical power). The advantage of this system is nullified by the limited amount of test data on fuel capsule clad creep at operating temperature; a high reliability for pressure containment cannot be verified. The controlled leak approach has a number of single failure points of low probability for producing a category one failure. However, ingress of air (during storage) and nitrogen (during operation in the sterilization canister) may compromise safety through embrittlement of the capsule strength member.

The data available or expected to become available during the program does not appear to be sufficient to assure the required reliability or safety criteria.

3. Electrical Receptacle and Diffusion Bond Analysis

A diffusion bond technique for mounting and sealing the electrical power receptacle to the generator housing is under development (see Section II.B). This technique differs from the Pioneer program which used a Viton O-ring and jam nut combination, and from earlier Viking ETG's which used a solder seal in combination with a jam nut. In all cases, the receptacle was basically a Deutsch Company DBA 54H-16-26PN. The Pioneer approach, using the Viton O-ring, is retained as a backup design to the diffusion bond.

Failure mode, effects and criticality analyses, development tests and operational

FIGURE I - 30

RELIABILITY COMPARISON OF CAPSULE VENTING SYSTEMS

(SUMMARY OF FMECA RESULTS)

Item	Function	Mode	Effect	Consequence/Criticality
Controlled Venting System				
Capsule, vent tube and fitting subsystem	Isolates helium generated by fuel decay from T/E converter gas.	Leak	Capsule helium gas mixes with T/E converter gas.	Category 2 failure - loss of 2 watts(e) .
		Blockage		
Fitting/cover subsystem			Leak	T/E converter gas released to space.
Controlled Leak Device (CLD)	Releases capsule gas to space at 10 ⁻⁵ scc/sec rate.	Excessive leak	Partial or total loss of capsule gas.	Safety consequence.
		Blocked	Capsule gas mixes with T/E converter gas .	Category 2 failure.
Reservoir Venting System				
Capsule, vent tube and fitting subsystem	Isolates capsule gas from T/E converter gas	Leak	Capsule helium gas mixes with T/E converter gas.	Category 2 failure. Dome provides redundancy with fitting/cover subsystem.
		Blockage		
Fitting/cover subsystem		Leak		
Dome	Stores capsule generated helium	Leak	Partial or total loss of capsule gas.	Safety consequence.

experience show the diffusion bond and Viton O-ring approaches to be feasible. However, their reliability will be verified by the reliability demonstration test described below. These same analyses and tests show that the electrical receptacle used on the Pioneer F experienced leaks at the glass insert-to-shell seal at 200°C (392°F). Deutsch modified the design by changing the stainless steel shell material from a 321 to a 20CB3 type. No failures have been observed in qualification and engineering tests performed by Deutsch, and in elevated temperature acceptance tests performed by Teledyne Isotopes subsequent to that change. The Deutsch receptacle with the 20CB3 shell material is being used for Pioneer G and will be utilized for Viking generators.

No analytical or test data are available to assure that this modified Deutsch receptacle will provide the required reliability at the higher (~40°F) environment of the Viking cruise mode and thermal cycling during Mars surface operation. Therefore, a program to qualify the Deutsch receptacle to the Viking environment requirements has been initiated. In addition, a back up program has also been instituted to obtain alternate sources. ITT Cannon, Gulton Industries and Physical Sciences are tooled and can furnish an interchangeable unit to the same specification, NAS 1599. Plans are being formulated to evaluate one or more of these designs.

4. Component Reliability Demonstration Test Criteria

A reliability demonstration test will be applied to three component subsystems: a) electrical receptacle diffusion bond and welds, b) electrical receptacle Viton O-ring seal and c) capsule vent tube/controlled leak device bonds and welds. The approach provides for a life test simulating, as nearly as practical, the Viking RTG mission profile followed by a thermal cycle test to failure. The assessment of the results of the tests will be based on the Reliability Safety Margin technique using the equation

$$SM = \frac{\bar{X} - RB}{\sigma}$$

where SM = Safety Margin

$\bar{X}$ = mean of the number of cycles to failure.

σ = standard deviation associated with the mean, normal distribution assumed.

RB = 360 cycles (representative of 90 days on the Martian surface).

Having computed the safety margin, SM, the demonstrated reliability may be determined directly from the normal Probability Function with correction to 50% confidence level.

This confidence level is the basis for design of Viking tests and assessment of reliability.

These tests are designed to provide data for reliability assessment of the electrical receptacle glass-pin-shell seal, various welds of similar and dissimilar materials, diffusion bonds, Viton O-ring, etc. Thus, demonstration of the reliability of a number of potential single failure points will be obtained.

G. INSTRUMENTATION DESIGN AND EVALUATION

The instrumentation design effort consists of evaluation of integral generator sensors. Integral generator instrumentation, by definition, comprises performance sensors mounted integral with the generator as well as instrumentation components associated with these sensors.

1. Improved RTD

The SNAP 19 Viking generator hot junction temperature sensor is a platinum wire-wound Resistance Temperature Detector (RTD) designed to measure temperature over the range from 0°F to 1300°F. One RTD is installed in each generator. The principal goals of this task were to:

- (a) improve the configuration design of the sensing coil element assembly of the RTD by providing better protection against possible chemical attack with progressive long-term operation of the generator,
- (b) improve the hermetic seal integrity of the entire RTD configuration, and
- (c) improve the test and quality assurance program for the RTD unit during its manufacturing process.

a. RTD failure history

Two RTD failures occurred in SNAP 19 Viking generators in March, 1972, one in ETG S/N 101 and the other in ETG S/N 102. Both failures took place after about 2800 hours of RTD operation. The failure mode in both cases was an open circuit condition in the RTD circuit inside the generator. No diagnostic efforts could be undertaken up to date to analyze the exact cause of the RTD failure in either case since both generators are still operational in long-term field test set-ups.

Similar RTD failures were experienced with the same model RTD in 1971 in SNAP 19 Pioneer generators after over 5000 hours of continuous operations. In all these cases (Pioneer and Viking generator RTD failures) the same symptoms appeared in the RTD performance characteristics indicating imminent breakdown just prior to the actual failure event caused by an open circuit RTD condition. In one of these failure cases, namely SNAP 19 Pioneer RTG S/N 37 with RTD S/N-H-319, the RTD was retrieved from the generator, dissected and analyzed. Here, the open circuit failure mode was traced to multiple breaks in 5 loops of the 0.0006 inch diameter platinum sensing coil wire (see Reference I-8).

The purpose of the improved RTD design effort is to formulate a better RTD design assuring long-term reliability based on experiences gained from the RTD diagnostic task initiated during the Pioneer program. These efforts were conducted jointly by engineering personnel of Teledyne Isotopes and Rosemount Engineering Company (REC), the RTD vendor.

b. Difference between old and new design RTD models

In the following, the previously used RTD, designated by Teledyne Isotopes Specification CCI-74N7 and REC model 118YB, will be described as the "old" design and the new improved RTD, REC model 132FG, will be described as the "new" design. Reference is made to Figure I-31 illustrating the RTD configuration. The salient features of the new design over the old one will be:

(i) Sensing coil configuration

Wire diameter:

Old design = 0.0006 inch diameter

New design = 0.001 inch diameter

FIGURE I-31

NOMENCLATURE OF RTD CONFIGURATION MODEL 118YB
 (Old RTD Design)

A larger diameter sensing coil wire will afford a better structural design of the coil and allow a larger magnitude of measurement current through the RTD without self-heating. Whereas the old design could have had as few as 2 platinum grains across the wire cross section, the larger diameter will guarantee a larger number of platinum grains.

Element encapsulation stages :

Old design = 1 stage

New design = 3 stages and a getter shield

In the old design, the two sensing coils (electrically in series) were mounted inside a hermetically sealed 304 SS coil housing. In the new design, a single coil will be encapsulated with high-purity alumina by a flame-spray technique. Then the unit will be encapsulated again within a closed platinum cylinder. This cylinder will serve as a barrier or getter for the platinum coil, inside the cylinder, against any possible chemical attack. Thereafter, the assembly will be encapsulated again inside a hermetically sealed coil housing constructed of inconel.

Coil arrangement:

Old design = 2 coil windings, freestanding, cemented

New design = 1 coil winding, wound on mandrel, no cement

In the old design, the two sensing coils were freestanding coil loops cemented to a 304 SS base plate. In the new design, one single coil will be bifilar-wound on a high-purity alumina mandrel which in turn will be anchored inside the aforementioned platinum cylinder (about 0.007 inch O.D.). No cement will be applied. This technique is employed by the vendor successfully in heavy-duty commercial and military RTD models.

(ii) RTD barrel configuration and hermetic seal integrity

With the generator hot junction at 1050°F (and the RTD sensing coil at the same temperature) the RTD barrel is in a temperature zone of about 470°F inside the SNAP 19 generator.

RTD hermetic seal:

Old design temperature rating = 700°F maximum allowable

New design temperature rating = 1000°F maximum allowable

In the old design, the hermetic seal of the RTD barrel consisted of a fused glass composition. In the new design, the entire barrel assembly will be replaced with a 1000°F rated, proven and commercially available feedthrough header.

(iii) Improved RTD testing and quality assurance provisions

Numerous intermediate inspection steps were added during the new design RTD manufacturing process to enhance quality assurance. The steps include among others:

- radiographic inspections at different assembly points during the manufacturing process of the RTD;
- a 48-hour heat soak aging process at 1100°F prior to final calibration and leak testing;
- additional procedures for testing the hermetic integrity of the total RTD configuration;
- insulation resistance measurements at room temperature and at 1100°F between RTD internal circuit and RTD housing at 100 V DC.

c. RTD resistance versus temperature

A comparison of the temperature/resistance relationship between the old RTD coil design, model 118YB, and the new design, model 132FG, presented in Table I-18, shows no significant difference in calibration data over the temperature range from 70°F to 1100°F. It should be noted, however, that the listed resistance values are for the RTD sensing elements only, and do not include the RTD lead wire loop resistances.

d. Planned RTD effort during next period

A number of the new design RTD's, model 132 FG, will be ordered and will be tested at Teledyne Isotopes to verify the improved design configuration. These tests will include long-term RTD performance runs in 100% H₂ atmosphere at 1000°F with reference RTD's in 100% helium atmosphere at the same temperature level.

2. Thermistor

The SNAP 19 Viking generator fin root temperature sensor is a glass-encapsulated bead thermistor designed to measure temperature over the range from 70°F to 500°F. Each generator is instrumented with one fin root temperature thermistor which is installed inside the generator housing.

TABLE I-18

COMPARISON OF OLD AND NEW RTD DESIGN SENSING
COIL CALIBRATION DATA

<u>Temperature</u> <u>(°F)</u>	<u>Old Design</u> <u>118 YB</u> <u>in ohms</u>	<u>New Design</u> <u>132 FG</u> <u>in ohms</u>
0	92.66	93.11
32	99.60	100.00
70	108.06	108.51
100	114.61	115.06
200	136.22	136.63
300	157.48	157.88
400	178.38	178.68
500	198.94	199.14
600	219.15	219.24
700	239.00	238.97
800	258.51	258.32
900	277.67	277.31
1000	296.48	295.93
1050	305.75	305.10
1075	310.35	309.65
1100	314.93	314.18
1200	333.04	332.06
1300	350.80	349.57
1400	368.21	366.70
1500	385.26	383.47

a. Evaluation objectives

The purpose of this task is to evaluate different models of commercially available glass-encapsulated bead thermistors from different vendors which exhibit higher measurement sensitivity than the presently used thermistor model. One of these could be selected as a possible replacement candidate for the presently used thermistor. Reference is made to Table I-19 which lists typical temperature versus resistance calibration data of the presently used generator thermistor. Figure I-32 illustrates the thermistor calibration curve obtained from the data of Table I-19. The curve in Figure I-32 was purposely plotted with a linear/linear scale to illustrate more distinctly the shape of this curve as well as its varying slope over the operational temperature range of the generator.

By definition, the sensitivity of a transducer is the ratio of the change in transducer output to a change in the value of the measurand. In the case of a thermistor, the thermistor sensitivity is the ratio of the change in the thermistor resistance in ohms to a unit change of temperature (1°F) at any given temperature point. This ratio can be expressed as a percentage of the thermistor resistance change in ohms with respect to the nominal thermistor resistance value at the temperature point under consideration.

Although the aim of this study is to determine the availability of a replacement candidate with higher sensitivity over the 150°F to 380°F temperature band, other characteristics of importance for this candidate must also be considered. These are:

- (i) thermistor calibration stability under low level nuclear radiation over long-term service,
- (ii) reliability proven by previous performance under conditions similar to the internal generator environment,
- (iii) the size constraint of the thermistor assembly,

TABLE I-19

PRESENTLY USED SNAP 19 VIKING GENERATOR THERMISTOR CALIBRATION TABULATION

Teledyne Isotopes Spec. CCI-92N4

Victory Engineering Corp. TX-1737

R at 77°F=1,500,000 ohms nominal

Sensitivity at 350°F = 1.41%/°F

 $\Delta R/1^\circ\text{F}$ at 350°F = 83 ohms

SNAP 19 GENERATOR NOMINAL THERMISTOR CONVERSION TABLE, STANDARD HOUSING TEMPERATURE

(°F, ohms)

°F	- 0 -	- 1 -	- 2 -	- 3 -	- 4 -	- 5 -	- 6 -	- 7 -	- 8 -	- 9 -
80	1432.91K	1391.12K	1350.70K	1311.59K	1273.75K	1237.14K	1201.71K	1167.42K	1134.22K	1102.09K
90	1070.97K	1040.45K	1011.67K	983.42K	956.05K	929.54K	903.85K	878.97K	854.85K	831.48K
100	808.83K	786.87K	765.58K	744.94K	724.93K	705.52K	686.70K	668.45K	650.74K	633.56K
110	616.84K	600.72K	585.02K	569.79K	555.01K	540.66K	526.72K	513.20K	500.09K	487.31K
120	474.92K	462.89K	451.20K	439.85K	428.82K	418.10K	407.69K	397.57K	387.73K	378.17K
130	368.88K	359.84K	351.06K	342.52K	334.21K	326.13K	318.28K	310.64K	303.20K	295.97K
140	288.94K	282.09K	275.43K	268.94K	262.63K	256.49K	250.51K	244.69K	239.03K	233.51K
150	228.14K	222.91K	217.81K	212.85K	208.01K	203.30K	198.72K	194.25K	189.89K	185.65K
160	181.51K	177.48K	173.55K	169.72K	165.99K	162.35K	158.80K	155.34K	151.97K	148.68K
170	145.47K	142.34K	139.26K	136.31K	133.40K	130.57K	127.80K	125.02K	122.30K	119.65K
180	117.07K	114.55K	112.09K	109.69K	107.35K	105.07K	102.85K	100.67K	98.55K	96.48K
190	94.46K	92.49K	90.57K	88.69K	86.85K	85.06K	83.31K	81.61K	79.94K	78.31K
200	76.72K	75.17K	73.65K	72.17K	70.72K	69.30K	67.92K	66.57K	65.25K	63.96K
210	62.70K	61.46K	60.26K	59.07K	57.90K	56.76K	55.64K	54.55K	53.49K	52.44K
220	51.43K	50.43K	49.46K	48.50K	47.57K	46.66K	45.77K	44.90K	44.05K	43.21K
230	42.40K	41.60K	40.82K	40.06K	39.31K	38.58K	37.86K	37.16K	36.48K	35.81K
240	35.15K	34.51K	33.88K	33.26K	32.66K	32.07K	31.49K	30.92K	30.37K	29.82K
250	29.28K	28.76K	28.24K	27.74K	27.24K	26.76K	26.29K	25.82K	25.37K	24.92K
260	24.48K	24.06K	23.64K	23.23K	22.82K	22.43K	22.04K	21.66K	21.29K	20.93K
270	20.57K	20.22K	19.88K	19.54K	19.21K	18.89K	18.57K	18.26K	17.96K	17.66K
280	17.37K	17.04K	16.80K	16.52K	16.25K	15.98K	15.72K	15.46K	15.21K	14.96K
290	14.72K	14.48K	14.25K	14.02K	13.79K	13.57K	13.35K	13.14K	12.93K	12.73K
300	12.53K	12.33K	12.14K	11.94K	11.76K	11.57K	11.39K	11.22K	11.04K	10.87K
310	10705	10540	10379	10220	10064	9911	9761	9613	9468	9325
320	9185	9046	8909	8775	8643	8513	8386	8261	8138	8017
330	7898	7782	7667	7554	7444	7335	7228	7123	7019	6917
340	6818	6719	6623	6528	6434	6343	6252	6164	6076	5991
350	5906	5823	5741	5661	5582	5504	5428	5353	5279	5207
360	5135	5055	4996	4928	4861	4795	4730	4666	4603	4541
370	4481	4421	4362	4304	4247	4190	4135	4081	4027	3974
380	3922	3871	3821	3771	3722	3674	3627	3580	3534	3489
390	3444	3400	3357	3314	3271	3229	3188	3147	3107	3068
400	3029	2990	2953	2916	2879	2843	2807	2772	2738	2704
410	2670	2637	2605	2573	2541	2510	2479	2449	2419	2390
420	2361	2333	2304	2277	2249	2223	2196	2170	2144	2118
430	2093	2068	2044	2020	1996	1973	1950	1927	1904	1882
440	1860	1839	1817	1796	1776	1755	1735	1715	1696	1676
450	1657	1639	1620	1602	1584	1566	1548	1531	1514	1497

FIGURE I-32

SNAP 19 GENERATOR THERMISTOR

VICTORY ENGR. CORP. MOD TX-1731/TELEDYNE ISOTOPIES CCI-92N4

RESISTANCE VERSUS TEMPERATURE

RESISTANCE SCALE EACH LINE = 100,000 OHMS

TEMPERATURE SCALE EACH LINE = 2 °F

- (iv) the vendor's capability to reproduce the selected model with interchangeability tolerances when manufactured in different batches at different times.
- b. Thermistor sensitivity

Table I-20 lists a comparison of the sensitivity of candidate thermistors versus the sensitivity of the presently used thermistor in steps of 50°F over the temperature range from 80°F to 550°F. The results indicate that none of the thermistor sensitivities is significantly higher over the 150°F to 380°F temperature range than that of the presently used generator thermistor, model TX-1737.

- c. Planned thermistor effort during next period

Additional thermistor evaluations will be conducted to finalize this effort during the next reporting period with the decision to either retain the presently used thermistor model or to replace it with a candidate with higher sensitivity characteristics.

3. Generator Pressure Transducer

A pressure transducer is contemplated as additional SNAP 19 Viking generator instrumentation. This transducer will be installed inside the generator, and its function will consist of monitoring the absolute internal pressure of the hermetically sealed generator housing. Basically, this function is a static pressure measurement of the inert fill gas. Depending on the selected type of transducer, the monitored signal output will be forwarded directly or preconditioned with a signal conditioning unit for further data processing by the telemetry system of the Spacecraft Integrator.

- a. Evaluation objective

The purpose of this task is to undertake a state-of-the-art survey, select and test suitable candidate pressure transducers for generator application.

TABLE I-20

THERMISTOR SENSITIVITY COMPARISON TABULATION

TEMPERATURE (°F)	(1) 1.5 MΩ Thermistor	(2) 4.5MΩ Thermistor	(3) 5MΩ Thermistor	(4) 12MΩ Thermistor	(5) 0.1MΩ Thermistor	(6) 0.5MΩ Thermistor	(7) 1 MΩ Thermistor	(8) 2MΩ Thermistor	(9) 5MΩ Thermistor	(10) 1.5MΩ Thermistor	(11) 6.25MΩ Thermistor
80	2.92	2.93	2.93	3.38	2.40	2.69	2.76	3.08	3.20	2.53	2.53
100	2.72	2.73	2.73	3.14	2.24	2.50	2.57	2.86	2.98	2.36	2.36
150	2.29	2.46	2.44	2.56	1.91	2.17	2.23	2.42	2.52	1.99	1.99
200	2.02	2.10	2.11	2.28	1.67	1.87	1.95	2.14	2.28	1.74	1.73
250	1.78	1.82	1.90	1.92	1.48	1.65	1.69	1.93	2.04	1.44	1.44
300	1.60	1.59	1.52	1.75	1.25	1.49	1.54	1.75	1.74	1.26	1.26
350	1.41	1.52	1.50	1.57	1.06	1.31	1.36	1.49	1.54	1.08	1.12
400	1.29	1.32	1.37	1.43	0.98	1.26	1.24	1.35	1.40	1.08	1.05
450	1.09	1.19	1.20	1.28	0.80	0.99	1.12	1.24	1.24	0.94	0.95
500	1.06	1.07	1.11	1.22	0.83	1.04	1.01	1.18	1.16	0.92	0.94
550	0.76	0.97	-	-	0.61	-	-	0.89	0.99	-	-

- (1) Victory Engineering Corporation Model TX-1737 (present thermistor)
 (2) Victory Engineering Corporation Model
 (3) Victory Engineering Corporation Model 65A5
 (4) Victory Engineering Corporation Model 71A20 and 71A2
 (5) N. L. Industries Model 1-H-104
 (6) N. L. Industries Model 81-B-504
 (7) N. L. Industries Model 81-B-105
 (8) Gulton Industries Model 62PK
 (9) Gulton Industries Model 65PL
 (10) Fenwall Electronics Model GA62J2
 (11) Fenwall Electronics Model GA66J1

NOTE: a. The thermistor sensitivity is presented as percentage change in resistance per 1°F with respect to the nominal thermistor resistance at listed temperature.
 b. Thermistor resistance values in column headings are at 77°F.

An intensive vendor survey and state-of-the-art investigation was conducted in three phases during this period. Firstly, preliminary discussions were held with twenty-four pressure transducer vendors whose instruments were used previously either on spacecraft or in nuclear reactor applications or in other high temperature applications. Cognizant engineers of some of these vendor's customers (government agencies and industry) were contacted with the vendor's permission and interviewed about their pressure transducer experiences. Secondly, detailed meetings with technical personnel from eleven vendors were held at Teledyne Isotopes facilities to discuss the generator application in all facets. Thirdly, as a result from the previous activities, a specification for a generator pressure transducer system was drafted and forwarded as RFQ to twenty-seven interested pressure transducer vendors.

b. Generator pressure transducer discussion

The most important characteristic required of the generator internal pressure transducer is long-term calibration stability and operational reliability (3 years storage, 5 years operational life expectancy) at a rated temperature of 450°F. The transducer configuration must be capable of withstanding the effects of low-level nuclear radiation, the internal generator environment and the dynamic environment of spacecraft mission profiles. The following types of pressure transducers were investigated: potentiometric, strain gage, linear variable differential transformer (LVDT), variable reluctance, variable inductance, variable impedance or eddy-current, variable piezo-electric and piezo-resistive and variable capacitance. Some of the advantages and disadvantages of these different types of pressure transducers are listed in Table I-21.

TABLE I-21 PRELIMINARY GENERATOR PRESSURE TRANSDUCER EVALUATION

Functional Requirement	Potentiometric	Strain Gage	LVDT	Reluctance	Eddy Current	Piezo Electric	Capacitive
Temperature Rating (450°F required)	500°F	600°F	900°F	850°F	1000°F	Not Suitable	Not Suitable
Temperature Rating Proven by Vendor	No	No	No	Yes	Yes	--	--
Used Previously on Spacecraft	Yes	Yes	Yes	Yes	No	Yes	Unknown
Used Previously in Nuclear Reactor	Yes	Yes	Yes	Yes	No	--	--
Sliding Contacts & Moving Parts	Yes	No	No	No	No	No	No
Special Signal Conditioning Unit Required	No	No	Yes	Yes	Yes	Yes	Yes
Number of Lead Wires Required	3 or possibly 2	4	3	3	3	4	4
Sensitivity	Acceptable	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite
Resolution	Good	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite
Linearity	Excellent	Acceptable	Good	Good	Excellent	--	--
Hysteresis	Acceptable	Acceptable	Good	Good	Excellent	--	--
Repeatability	Good	Good	Good	Good	Excellent	--	--
Static Error Band 70°F - 450°F Proven by Vendor	No	No	No	No	Verified Excellent	--	--
Calibration Stability Proven by Vendor	No	No	No	No	Verified for 7 months		
Size, Weight & Volume Constraint	None	None	None	None	None	--	Yes
EMI Operating A.C. Frequency	None(DC)	None(DC)	2 to 5 Khz	2 to 10Khz	1Mhz	--	--
Power Demand	1/4 watt	milliwatts	1/2-2 watts	1/2-2 watts	1.4 watts	--	--
Vendors Contacted	5	11	5	5	1	4	1

c. Planned pressure transducer effort during next period

Proposals received from responsive vendors will be evaluated and pressure transducer candidate(s) for generator application will be selected and testing initiated. The test program will consist of screening tests for long-term life performance at steady state rated temperature, thermal cycling, pressure cycling and calibration stability determinations.

II. TASK 4 - ETG/RTG AND COMPONENT TESTING

This task encompasses the Engineering test activities related to: (1) acceptance and qualification level testing of ETG/RTG systems, (2) ETG/RTG system level development/verification testing, and (3) component level development/verification testing. Also included in this task is any support effort required for the design, analysis and fabrication of test fixtures, tooling and instrumentation related to the test activity. Evaluation of the test results is performed under Task 2.

Since no Viking ETG/RTG systems were built during this reporting period, no system level acceptance and qualification level testing was performed. However, system level development/verification testing using available Pioneer-type ETG's, was performed as defined herein. Component level development/verification testing was limited to the electrical receptacle seal.

A. THERMAL CYCLE TESTING OF PIONEER GENERATORS S/N 41 AND S/N 43

The purpose of this test is to determine the effect of generator thermal cycling, due to the Martian environment, on generator performance. Martin Marietta Corporation, Denver Division, (MMD) has calculated the RTG temperatures during the maximum hot and cold conditions on Mars and presented the results in Reference I-7. The MMD recommended thermal cycle profile was transmitted to Teledyne Isotopes in a letter R. C. Brouns to V. G. Redmond (Reference II-1) which presented the calculated temperature history in the area of the electrical receptacle and the recommended test temperature. The period of a cycle is six hours and the test duration is 90 days for a total of 360 cycles.

Two defueled SNAP 19 Pioneer generators, S/N 41 and S/N 43, have been transferred to the SNAP 19 Viking program for the thermal cycle test. Both generators

will be operating at Viking conditions, 690 watts (e) electrical heater input and a 4.4 volt load voltage.

1. Test Design

Unlike the Viking generators, each of which will have welded end covers and a diffusion bonded/welded electrical receptacle, generators S/N 41 and S/N 43 are equipped with Viton O-rings in one end cover (electrically heated configuration using an outgassing tool) and at the electrical receptacle. The possibility of a Viton seal failure exists due to the thermal cycle effects, therefore, it is necessary to test the generators in an environment identical to the generator internal gas fill. This will assure that foreign gases will not diffuse into the systems and cause a performance characteristic other than that due to thermal cycling. The Teledyne Isotopes horizontal thermal vacuum chamber was chosen to provide the containment of the desired gas environment. Maximum utilization of the test cables developed for the Viking thermal vacuum test was also possible. To control the thermal cycle, the concept chosen was one in which the generator is cooled to the Mars cold condition with water-cooled plates attached to the fins and then heated to the Mars hot condition with strip heaters attached to the fin roots. The cooling system (an open system) was designed to cool continuously using tap water. The heaters would be energized by a cam-actuated proportional controller to control the fin root temperature profile as a function of time. In addition, a fan was necessary to provide sufficient cooling for the Mars cold condition.

2. Procedure Development

To evaluate the chosen thermal control system, a thermal mockup of an ETG was constructed using a discarded Pioneer test housing. The housing, similar to the S/N 41 generator design (short fins), was outfitted with an electrical heater mounted internally to simulate the heat source. A fin cooling assembly consisting of: a) inlet

and outlet manifolds located above the generators, b) 1" wide x 0.25" thick plates attached along the length of each fin at the tip and c) interconnecting tubing, was fabricated using copper components interconnected by brazing. The cooling assembly was installed on the test housing by clamping the plates to the fin tips. After initial testing (in air) with 690 watts (e) internal heater power, the fin-to-cooling plate thermal interface was improved by removing the emissive coating from the fins, adding a thermal conductance compound, and straightening the fin tips by rigidly supporting the tips with 1" x 1" aluminum angle members.

Several water flow rates were evaluated with the optimum flow resulting in a 165°F fin root temperature, the objective being 150°F. Since the operational temperature inside the chamber would be higher due to heating of the gas environment, the use of a fan was added to the system to obtain the desired cold case. By directing the fan air stream over the lower end of the mockup, an average fin root temperature of 133°F was obtained.

Evaluation of the fin heaters followed. Chromalox strip heaters (250 W, 1" wide x 8" long) were affixed to the fins close to the fin root. Various input power levels were evaluated with the cooling system activated. Severe fin root thermal gradients were witnessed during these test. It was found that the heating element power density was not uniform over the reported heated length. Attempts to dampen the gradient by brazing a copper plate to the heater surface were unsuccessful. A new fin heater was designed using a 7-inch cartridge-type heater inserted into a pre-drilled 0.5" thick copper bar. The resulting fin root temperature gradient was much closer to that which is obtained when the fin insulation pads are installed. Average fin root temperatures in excess of 360°F were obtained in the area of the module bar with the objective being 350°F.

The ETG thermal mockup with heater and cooling assemblies was then transferred into the test chamber. A Barber Coleman cam-actuated proportional wave controller was introduced into the test setup. A cam was cut and installed in the controller which would permit the controller to vary the power as a function of time and a measured temperature on the test housing. The fan was connected to a temperature switch-activated relay. Quartz lamps were installed in the chamber to simulate the thermal input of a second generator. After pumpdown, the chamber was backfilled with 75% Helium/25% Argon. The cooling system and the power controller were activated. Adjustments were made to the cam and fan activating temperature switch until the desired response of the fin root temperature was obtained. All test control parameters were recorded. During this time the second proportional controller and most other test equipment were checked out using the thermal mockup.

Concurrent with the above equipment evaluation, the test procedure (452 A6000406, Mars Surface Thermal Cycle Test) was written. Data obtained during the thermal mock-up tests were used in defining the detailed steps of the procedure.

3. S/N 41 and S/N 43 Preliminary Testing

Following generator refurbishment, a series of preliminary performance tests was conducted to characterize initial generator performance. These tests were conducted in the thermoelectric laboratory in an air environment and are discussed in Section I. B (see Tables I-1 and I-5).

4. Thermal Cycle Test Preparations and Installations

After completion of all preliminary testing on the ETG's, the generators were prepared for installation into the test chamber. The emissive coating near the fin root of one side of each fin was removed to enhance conduction of heat from the heater elements to the fin root. Two holes were drilled in each fin to permit attachment of the heaters to the fin root. The emissive coating at the fin-to-cooling plate interface

was removed and thermally conductive grease was applied to this interface to improve heat transfer into the cooling plates. The fin cooling plates were clamped to one side of each fin. Figure II-1 shows the final location of the heaters and fin cooling plates on generator S/N 41.

The chamber penetration wiring was checked for contact resistance and continuity. A life test of the constant voltage load banks was conducted to confirm stability. Chamber seal integrity was verified with the use of a helium leak detector. Alarm systems were verified to indicate generator hot junction and fin root overtemperature, generator open circuit condition, water coolant leakage and loss of coolant flow. A transfer of all generator electrical connections was made to route all power and instrumentation signals through the chamber penetrations. A power check was then performed to assure adequacy of the electrical and instrumentation interfaces.

The generators were installed on the chamber support railing on June 16, 1972 as shown in Figure II-2. A shroud assembly, containing the cooling fan, was located below each generator. The generator coolant lines were connected to the chamber fluid penetration ports. The chamber door was closed and the chamber evacuated and backfilled with 75% Helium/25% Argon gas. A final leak check was performed on the coolant loop before flow was initiated.

Figure II-3 shows the control and monitoring equipment layout. The proportional cam controllers are located on the left side of the bench. (The shaped cam conforming to the thermal cycle requirement can be seen installed on each controller.) The right side of the bench contains the generator power input and monitoring consoles with various instruments connected for obtaining generator functional parameters. The lower portion of the bench contains each generator's transistorized load bank, over-temperature alarm circuits and temperature recorder. Fin root temperatures are monitored continuously with strip chart recorders (not shown in Figure II-3).

Fig. II-1 ETG S/N 41 - Fin Root Heaters and Water Coolant Assembly Installation

Fig. II-2 ETG's S/N 41 and S/N 43 - Installed in Test Chamber

Fig. II-3 Control and Monitoring Equipment - Mars Surface Thermal Cycle Test

5. Thermal Cycle Startup and Initial Results

The hot and cold cycle points were verified by rotating the cam to the maximum and minimum temperature points. Both proportional controllers were then activated and the systems permitted to operate for several cycles to evaluate overall test system performance. Generator response and performance characteristics during these initial cycles is presented in Figures II-4 and II-5 for ETG's S/N 41 and S/N 43, respectively. The fin root temperature response satisfied the test criteria. These figures also show the hot junction temperature and the electrical power output (at 4.4 volts) during the thermal cycles. The hot junction temperature response is seen to lag the fin root temperature profile, causing the swings in electrical power output. Power output varies approximately 12 to 13 watts (e) during various portions of the cycle, reaching a peak at 47 to 49 watts (e). Both ETGs were then placed on a five-day steady state test at Viking operating conditions beginning June 29. At the conclusion of the steady state test, an E-I parametric will be performed, followed by the ninety days of thermal cycling (360 total cycles).

B. ELECTRICAL RECEPTACLE SEAL DEVELOPMENT

1. Diffusion Bond Seal

a. Background and requirements

Diffusion bonding is the technique being employed to join an electrical receptacle, the shell material being 20CB-3 stainless steel, to the SNAP 19 Viking generator housing fabricated from magnesium thorium (alloy HM21A-T5). The technique provides for the electrical receptacle to be TIG welded to the nickel-201 detail of a Ni/MgTh (alloy HM21A-T8) diffusion bonded and machined subassembly, bench tested and subsequently welded (MgTh/MgTh) into the generator housing. Figure II-6 shows a sketch of the arrangement of the details forming the electrical receptacle assembly.

The requirement for this development was a direct result of the Viking mission design criteria to maintain a constant inert cover gas within the generator housing to sustain predicted power performance throughout the mission. Prior experience with Viton O-ring seals ascertained initial helium leak rates in the order of 10^{-5} scc Helium/sec (at one atmosphere ΔP) at operating temperatures from 320 to 370°F, and with Viton seals of Parker Company compound 77-545, thermal degradation at Viking seal operating temperatures results in higher leak rates due to compression set. At the present time, the operating conditions of the Viking mission require that the electrical receptacle and joints withstand a maximum temperature of 370°F and maximum thermal cycle temperature limits of 150-370°F (capable of 360 thermal cycles and remain leak-tight ($\leq 5 \times 10^{-7}$ scc Helium/sec at one atmosphere ΔP) for a period of twenty-six months).

Figure II-6. Electrical Receptacle Assembly

b. Evaluation and R & D activities

Application of diffusion bonding as a joining technique was considered to accomplish the electrical penetration seal because the metallurgical incompatibilities of stainless steel and the MgTh metal alloy posed numerous problems for joining by common welding or brazing procedures. A theoretical and experimental evaluation was conducted on several metal couple systems (e.g., MgTh/Au/Ag/stainless, MgTh/Ag/stainless and MgTh/Ni) to ascertain the most likely candidate to achieve Viking mission requirements and program schedule constraints. The metal couple systems selected for evaluation were made primarily on the basis of their tendency towards the formation of solid solutions and stable bonds in accordance with such factors as the physical and chemical properties of the metals at elevated temperatures. Also, design configurations and facility requirements were considered.

Pressure, temperature and time are the three major processing parameters which must be carefully controlled in diffusion bonding to assure sound joints. Application of pressures provides intimate contact of surfaces to be diffusion bonded. Pressures must be high enough to negate surface asperities on the joint surfaces by bringing interfaces within atomic distances. On the other hand, pressure cannot be so high as to cause undesirable deformation, whereby subsequent fabrication requirements cannot be met.

Temperature serves mainly to accelerate atom movement and aid surface movement. Too low a temperature will restrain atom movement and interface yielding. Naturally, too high a temperature could produce undesirable results and/or effects to the metal system to be joined, such as melting, extensive deformation, degradation of material properties, deleterious phase formations and high sublimation rates. For both metallurgical and schedule considerations, the time at temperature is kept to a

minimum. A bare minimum of atom movement across the joint is highly desirable because the strongest joints are usually formed with a minimum degree of diffusion. Excessive diffusion can lead to voids (Kirkendall effect) or to the formation of brittle intermetallic phases, especially in the case of dissimilar metal joints. Other variables such as atmosphere, flatness, surface finish and cleanliness are also important to bond strength and quality. During this investigation, it was found that pressures of 10^{-4} torr or less were suitable.

Because the metal systems under investigation (specifically HM21A-T8) deformed readily under the imposed contact pressure and temperature, special attention was not required of surface finish and flatness tolerances beyond that which could be achieved with normal engineering and fabrication practices. Atomically clean surfaces are desirable for bonding; however, it was found that proper control of variables such as atmosphere and removal of tenacious oxide films just prior to diffusion bonding resulted in sound metallurgical joints.

Results of the theoretical and experimental evaluation of the candidate metal couple systems ascertained the superior attributes of the Ni-201/MgTh (HM21A-T8) system. (A typical Ni/MgTh metal couple system is shown in Figure II-7. The other systems evaluated were compromised by requirements for: (1) electrolytic coatings on the MgTh alloy where adherency of the coatings left much to be desired, and (2) excessively high bonding temperatures resulting in metallurgical and facility perturbations and/or formation of brittle phases which would be deleterious in meeting with the operating conditions anticipated for the Viking mission.

c. Development activities

The development phase of the study experimentally established the diffusion bond parameters for the candidate metal couple system, Ni/MgTh. As previously stated, pressure is a principal process variable and must be controlled to promote

NICKEL to MgTh diffusion bond, Run #7.
725°F/7000 psi/20hrs
Diffusion zone 0.00024".

NL-19751
I-469

As Polished

Magn. 350X
3 Mar. 72

TELEDYNE ISOTOPES

Fig. II - Typical Nickel to Mg·Th Diffusion Bond

interfacial atomic bonding and predict the amount of deformation. The exact amount of deformation is mainly a function of the metal(s) properties as influenced by thermal conditioning. The room temperature (RT) mechanical properties of HM21A, the effect on the RT properties by heating the alloy to elevated temperature for short and long times and data at elevated temperature per required exposure times/temperatures were evaluated. As a result of the initial experiment, it was concluded that sufficient pressure would be exerted to cause creep deformation at the joint interface during applied heat and pressure. A review of the creep data and subsequent evaluation ascertained the percentage of extension (deformation) as a function of pressure, temperature and time. Mechanical properties for the Ni played no role in reaching an optimum pressure because the MgTh alloy is the weaker member of the Ni/MgTh system. It is worthy to note that a high purity (99% minimum) low carbon Ni (Ni-201) was selected to diminish potentially embrittling phases resulting from impurities and avoid embrittlement due to graphite precipitates upon exposure to bonding temperatures above 600°F. The principal mechanical property of the HM21A-T8 joint configuration evaluated to establish bonding pressures was the compressive yield strength. An engineering evaluation of the data presented tentatively established a mechanical loading pressure of 6000 psi and a temperature of 700°F for bonding times up to 100 hours. The essential element provided by the creep data is the knowledge of maximum metal movement during the first hour at temperature and the requirement to adjust the applied loading force.

A parametric study was performed to determine the effects of time and temperature on the width of the diffusion zone for the Ni/MgTh. The investigation strived for the highest pressure possible to negate any surface asperities and to achieve a 100% bond without excessive deformation. Ni and MgTh pieces, having a surface area of

approximately one square inch, were cleaned with 600-grit silicon carbide paper and rinsed with denatured ethyl alcohol. Immediately after cleaning (approximately within a thirty minute time period) the specimens were placed in the load application and support block which was designed so that a controlled load could be applied as illustrated in Figure II-8. After the furnace chamber was assembled, the gaseous pressure was reduced to the 10^{-4} torr range and heated slowly to facilitate outgassing. A load of approximately 1000 lbs. per square inch of joint area was applied to the specimens prior to heating. When the specimens reached the temperature under investigation, the desired applied load was initiated and adjusted intermittently over the first and last two to four hours at temperature. Gaseous pressures in the order of 10^{-5} to 10^{-6} torr range were achieved during the bonding operation. The temperature loading pressure, and time parameters investigated and the results of this study are presented in Table II-1.

d. Results

The preliminary bonding studies showed that the Ni/MgTh bimetal couple system was obtainable and provided consistently good joints. Systematic fabrication techniques and procedures were developed and proof-loading tensile and shear tests indicated that the Ni/MgTh diffusion bonded joint possesses an average RT ultimate tensile strength of 3020 psi and an average RT shear strength of 2430 psi. The tensile test fixture designed and fabricated for these tests is shown in Figure II-9.

Experience gained during the Pioneer program indicated that critical mechanical loads experienced by the electrical receptacle would be those caused by handling, i. e., installation and removal of electrical connectors. Therefore, for the purpose of structural analysis, it was assumed that similar conditions will exist for Viking and that the dynamically induced loads will not exceed the handling loads.

Figure II-8. Cross Sectional View of Bonding Assembly Fixture

TABLE II-1

PARAMETRIC STUDY OF THE NICKEL/MAGNESIUM THORIUM COUPLE SYSTEM

<u>Run No. / Pot No.</u>	<u>Temperature (°F)</u>	<u>Pressure (PSI)</u>	<u>Time (Hrs.)</u>	<u>Width of Diffusion Zone (inches)</u>	<u>Deformation* (inches)</u>	<u>Remarks</u>
1/2	650 700	5000 4000	11.5 5.0	.0001	0 to .003	
2/2	700	5250	20	.0002	.002	
3/2	750-775	5250	20	.0004	.065	
4/2	720-725	6000	18.5	.00026	.004	
5/2	700	6000	64	.00036	.005	
6/2	700-705	6000	20	.00022	.010	Overpressure indicated
7/2	725	7000	20	.00024	.053	
8/2	675-705 705-72-	6500 6500	18 3.5	.00018	.004	
9/2	715-725	6500	21.5	.00022	.002	Underpressure indicated

*Amount of MgTh displacement due to nickel penetration under load.

Fig. II - Tensile Testing Facility with Diffusion Bonded Specimen Insitu

An analysis was performed to estimate simultaneously induced diffusion bond shear and tensile stresses resulting from handling loads. The indicated peak tensile and shear stresses were 418 psi and 211 psi, respectively. Since these stresses do not account for such concurrently acting secondary effects as thermal stresses, residual stresses induced by fabrication processes, or local stress peaking effects which occur commonly at the edges of stressed, bonded interfaces, a factor of 5 is assumed in order to account for these unknowns. Hence, a minimum tensile and shear strength of 2100 psi and 1050 psi was the goal to exceed.

e. Fabrication control

The next stage in the development was concerned with the design of the details to be diffusion bonded and the control of the fabrication process to produce hardware of consistent quality by a tightly controlled procedure. As previously mentioned, pressure, temperature and time are the three major processing parameters which must be carefully controlled in diffusion bonding to assure sound joints. Regulated power, proper thermocouple installation and temperature monitoring proved highly successful in the control of the bonding temperature. To assure a control of bonding pressure during unattended operation, a hydraulic accumulator pressure regulating system for the hydraulic clamping system on the assembly fixture (Figure II-8) was designed and fabricated. This system is employed to control three separate bonding fixtures simultaneously. The fabricated facility installation is shown in Figure II-10.

Configured hardware for the receptacle seal subassembly has been successfully fabricated by diffusion bonding of the Ni-201 to MgTh (alloy HM21A-T8) and subsequent machining of the bonded metals to the present Viking drawing specifications. Weld parameters for joining an electrical receptacle (shell material being of 20CB-3 stainless steel) to the bonded subassembly have been developed. To achieve greater

Fig. II - Diffusion Bonding Facility

reliability in the welded joint and predict maximum temperatures imposed on the receptacle (glass-to-metal seal), the weld was completely automated. Dummy receptacles (no glass-to-metal seal) were successfully welded into diffusion bonded subassemblies, resulting in non detectable ($\leq 10^{-9}$ scc Helium/sec) leak rates for the entire assembly. The maximum temperature imparted on the dummy receptacles during welding was 190°F (with reference to room temperature (72°F), a ΔT of 118°F).

A preliminary weld schedule and joint configuration to join the MgTh member of the diffusion bonded subassembly into test fixtures (to permit thermal aging and cycle testing) and SNAP 19 Viking generator housings, all of which are fabricated from MgTh alloy, have been established. At the present time, a fully automated DCSP TIG welding technique has been incorporated. The maximum temperature recorded on the MgTh detail of the bonded assembly was 328°F; the maximum temperature of the dummy receptacle was 225°F. It is important to note that the electrical receptacles are rated by the vendor to be leak-tight ($\leq 10^{-8}$ scc Helium/sec) for continuous operation at 392°F. Weld development is continuing with the emphasis on live electrical receptacles (glass-to-metal seal) to verify the adequacy of all weld parameters and joint configurations.

f. Status of production activities

As of this date, seventeen diffusion bonded and machined electrical receptacle subassemblies have been successfully fabricated. Nine subassemblies have had dummy receptacles (no glass-to-metal seal) successfully welded into them, resulting in non detectable ($\leq 10^{-9}$ scc helium/sec) leak rates for the entire assembly. The remaining eight are designated for reliability testing, whereby, electrical receptacles (with glass-to-metal seals) will be installed by automatic TIG welding. Seven assemblies (diffusion bonded subassembly plus the welded dummy receptacle) have been successfully welded (MgTh/MgTh) into test fixtures to conduct required environmental testing. All of the seven welded/assembled test fixtures show no detectable leak ($< 10^{-9}$ scc helium/sec).

2. Solder Seal

Solder seal development effort accomplished prior to the assembly of ETG's S/N 101 and S/N 102 in late 1970 and early 1971 led to a receptacle seal design and bonding procedure which permitted soldering electrical receptacles into the generator housing and cover. Figure II-11 shows the receptacle seal configuration developed from these early studies and utilized in the fabrication of ETG's S/N 101 and S/N 102. The electrical receptacle is a copper-plated Deutsch 26-pin, jam nut-type with an O-ring groove and 321 stainless steel body (Deutsch Part No. DBA54H-16-26PN). The seal ring is a machined magnesium thorium (alloy HM21A-T8), copper-plated ring which is seal-welded into the housing. 100% tin solder washers were utilized in combination with Nokorode flux. The copper screens and brass thermal compensator are machined into washers and tinned with 100% tin to fill all pores. An installation procedure was written (Teledyne Isotopes drawing 452A6000308) which defined the details of the solder sealed electrical receptacle installation.

Since the fabrication of ETG's S/N 101 and S/N 102 in March-April 1971, significant solder seal development effort consisted of: (a) defining the test parameters for life simulation testing, (b) assembly of test fixtures, (c) preliminary evaluation of ETG's S/N 101 and S/N 102 solder seal configuration, (d) qualification test specimen evaluation, (e) alternate receptacle plating vendor investigations, (f) alternate magnesium thorium plating vendor investigations, and (g) process improvements. Subsections a through d present the development effort from early 1971 to December 31, 1971 and include current test data on solder seals fabricated during that period. Subsection e is primarily concerned with effort during this reporting period.

FIGURE II-11
VIKING ETG 101 & 102 SOLDER
RECEPTACLE SEAL CONFIGURATION

On May 26, 1972, an AEC directive was received which requested termination of all new solder seal effort. The directive authorized continued effort on on-going tests.

a. Definition of test parameters

Solder seal development test parameters were defined to simulate the conditions the receptacle seal will experience in actual generator operation during the Viking mission. The receptacle seal assemblies were aged at 375°F for a minimum of 1000 hours followed by thermal cycling between 150°F and 375°F (three-hour cycle period). Table II-2 summarizes the temperature characteristics of a typical thermal cycle realized during the test program. Thermal cycling was continued until failure (defined as a leak rate greater than 5×10^{-7} scc Helium/sec atm) or until 1000 cycles were accumulated. Following 1000 successful cycles, the receptacles were returned to steady state aging at a temperature of 375°F. Leak checks were performed on a weekly basis at operating temperature. A controlled gas (or vacuum) environment was provided on one face of the receptacle to simulate mission environments.

b. Test fixture design

To test the receptacle seal assemblies under the simulated mission environments, a control console, a test manifold, and test boxes for individual seals were designed and assembled. The console permitted operating the test specimens at steady state temperature or under cyclic conditions. The test manifold permitted the test specimens to be exposed to air on one face and to a controlled environment (argon cover gas or vacuum) on the manifold face of the test specimen. (Receptacles were mounted in the test box to expose the "bayonet-coupled" face to the vacuum environment and the other face to the argon environment.) Leak checking of individual test specimens at operating temperature was accomplished by attaching a helium leak detector to the test manifold.

TABLE II-2
TYPICAL RECEPTACLE SEAL SPECIMEN
THERMAL CYCLE CHARACTERISTICS

Temperature Cycle	150°F to 375°F to 150°F
Heatup Cycle	
Max. Rate (First 15 Min.)	~ 325°F/Hr.
Total Time	~ 100 Min.
Cooldown Cycle	
Max. Rate (First 15 Min.)	~ 325°F/Hr.
Total Time	~ 80 Min.
Total Time < 200°F	~ 30 Min.
Total Time > 350°F	~ 30 Min.
Total Cycle Time	~ 3 Hrs.

NOTE: Values based on Sample Nos. 42 and 44

Two cartridge heaters were attached to each test box and the temperature of the receptacle seal was regulated by the test console controlling the electrical power input to the cartridge heaters.

c. Preliminary evaluation of ETG's S/N 101 and S/N 102 solder seal configuration

Concurrent with selection of the receptacle seal configuration for ETG's S/N 101 and S/N 102, solder seal specimens No. 37 and No. 38 were assembled using copper-plated electrical receptacles which had been utilized in previous solder seal tests. These specimens were assembled to obtain early test data on the ETG configuration.

Solder seals Nos. 37 and 38 were fabricated per the procedure utilized on ETG's S/N 101 and S/N 102. Tables II-3 and II-4 summarize the test specimens Nos. 37 and 38 (as well as subsequent test specimens), configurations and test results. These units were aged 1000 hours at 375°F with no leakage at the solder joint. After the 1000 hour aging period, the receptacles were placed on a thermal cycle from 150°-375°-150°F (3-hour cycle time). Both seals exceeded 400 thermal cycles before failure occurred. Seal No. 37 showed a leak after 421 thermal cycles which increased gradually until at 575 cycles the leak rate exceeded 10^{-5} scc Helium/sec atm. Seal No. 38 showed a leak after 414 thermal cycles which gradually increased to $>10^{-5}$ scc Helium/sec atm by 448 cycles.

Both seals were sectioned and metallographically examined. Numerous voids were visible in the solder near the screens and in the receptacle O-ring groove. A grey phase was present between the solder and the copper plate and appeared quite brittle as many cracks were present. The leakage path appeared to be in the grey phase in the solder near the stainless body of the receptacle. The copper plating on both the stainless steel and HM21A-T8 was sound with no blisters, separations or voids.

TABLE II-3

SOLDER SEAL CONFIGURATION SUMMARY

<u>Spec. No.</u>	<u>Recpt. Part No.</u>	<u>Date Fab.</u>	<u>Recpt. O-ring Groove</u>	<u>Flux Used</u>	<u>Tin Plated Compon.</u>	<u>Atmosp. Control During Soldering</u>	<u>Date Aging Initiated</u>	<u>Date Thermal Cycle Initiated</u>	<u>Date Aging Initiated</u>	<u>Test Manifold Environment</u>
37	DBA54H-16- 26PN	5-28-71	Yes	Yes	No	Argon purge	6-2-71	7-16-71		Vacuum
38	"	5-28-71	Yes	Yes	No	Argon purge	6-9-71	7-29-71		Vacuum
39	"	7-13-71	Yes	Yes	Yes	Argon purge	7-21-71	9-7-71		Argon
40	"	7-13-71	Yes	Yes	Yes	Argon purge	7-21-71	9-7-71		Vacuum
41	"	9-13-71	Yes	Yes	Yes	Argon purge	9-28-71	11-12-71	4-18-72	Vacuum
42	"	9-14-71	Yes	Yes	Yes	Argon purge	9-29-71	11-17-71		Vacuum
43	"	9-15-71	Yes	Yes	Yes	Argon purge	9-29-71	11-18-71	4-18-72	Argon
44	"	9-16-71	Yes	Yes	Yes	Argon purge	9-30-71	11-18-71		Argon
45	"	9-21-71	Yes	Yes	Yes	Argon purge	10-12-71	11-24-71	4-18-72	Argon
46	"	9-21-71	Yes	Yes	Yes	Argon purge	10-12-71	11-24-71	4-18-72	Vacuum
47	" *	9-22-71	Yes	Yes	Yes	Argon purge	10-13-71	11-24-71		Vacuum
48	" *	9-23-71	Yes	Yes	Yes	Argon purge	10-14-71	11-29-71		Argon
51	78026-16- 26PN	12-8-71	No	Yes	Yes	Argon purge	12-10-71	1-24-72	5-31-72	Vacuum
52	"	12-8-71	No	Yes	Yes	Argon purge	12-10-71	1-24-72		Argon
54	"	2-24-72	No	No	Yes	Closed argon system	3-6-72	4-18-72		Vacuum
55	"	3-1-72	No	No	Yes	"	3-7-72	4-18-72		Vacuum
56	"	3-1-72	No	No	Yes	"	3-7-72	4-18-72		Vacuum

*Alternate vendor plated receptacle.

TABLE II-4
SOLDER SEAL DEVELOPMENT TEST RESULTS*

<u>Spec. No.</u>	<u>Seal Configuration</u>	<u>Hours Aged at 375°F</u>	<u>No. of Thermal Cycles 150-375- 150°F</u>	<u>Additional Hours of Aging at 375°F</u>	<u>Date of Last Leak Check</u>	<u>Leak Rate at 350°F (std cc He/sec atm)</u>	<u>Status as of 6/26/72</u>
37	ETG 101 and 102 welded into MgTh test box	1050	421		9-17-71	$> 10^{-5}$ not measured	Test terminated.
38	"	1185	414		9-17-71	$> 10^{-5}$ not measured	Test terminated.
39	Same as 37 except tin plated details	1032	361		10-21-71	4.7×10^{-3} at room temperature	Test terminated.
40	"	1032	197		9-28-71	$> 10^{-5}$ not measured	Test terminated/overheated
41	"	1032	1186	1486	6-19-72	8.4×10^{-8}	On test.
42	"	1176	948		3-13-72	5.4×10^{-10}	Test terminated/sectioned.
43	"	1200	1216	1636	6-26-72	1.9×10^{-6}	On test.
44	"	1176	798		2-29-72	1.3×10^{-3}	Test terminated.
45	"	1030	1169	1636	6-26-72	3.8×10^{-7}	On test.
46	"	1030	1211	1633	6-26-72	2.5×10^{-8}	On test.
47	Same as 39 except alt. receptacle plating	1030	810		2-29-72	7.1×10^{-4}	Test terminated.
48	"	816	636		2-2-72	8.8×10^{-4}	Test terminated.
51	Nickel plated receptacle	1015	1100	530	6-23-72	1.0×10^{-6}	On test.
52	"	1015	364		3-6-72	1.7×10^{-3}	Test terminated.
54	"	1032	606		6-26-72	1.8×10^{-10}	On test.
55	"	1007	678		6-26-72	1.8×10^{-10}	On test.
56	"	1007	524		6-26-72	1.8×10^{-10}	On test.

*Data as of June 26, 1972.

d. Qualification test specimens

Because of the necessity for reaching a decision for ETG's S/N 101 and S/N 102 in early 1971, little test data was available which could be used for reliability studies. The available test data was obtained from repetitive thermal cycling tests and did not reflect extended thermal aging effects at the maximum seal operating temperature (340 to 360°F). To provide the data base for solder seal qualification and reliability predictions, 10 solder sealed receptacle test specimens were assembled and tested.

The receptacles utilized in the first eight of the ten test specimens were rejected by Teledyne Isotopes quality inspection after copper plating due to corrosion of the electrical feedthrough pins. The corrosion was attributed to plating solution leakage through the masking during the plating operation. Since the solder seal is not influenced by the receptacle feedthroughs, the rejected receptacles were utilized strictly as a solder seal test rather than an "all up" configuration test which would include receptacle evaluation. Subsequent heatup of these receptacle specimens indicated leaks in the receptacle glass-to-metal seal area.

After the receptacle glass-to-metal seal leakage problem was observed, two receptacles were sent to an alternate plating vendor (Almag Chemical Corporation) to evaluate their plating capability. The two receptacles were rejected by Teledyne Isotopes quality inspection after plating due to a lack of plating thickness certification. However, no evidence of feedthrough pin corrosion was apparent and the receptacles were utilized in the test program.

Specimens Nos. 39 to 48 utilized an "improved" fabrication technique, namely tin plating of all component surfaces. Tin plating provides continuous surface coverage and minimized oxidation of mating surfaces during soldering. All seal rings, screens and brass washers were tin plated by Furniture City Plating. Receptacles Nos. 39 to 46

were also plated by Furniture City, but receptacles Nos. 47 and 48 were plated by Almag Chemical Corporation to evaluate an alternate plating vendor. All receptacles had an O-ring groove which required hand-filling by heating the receptacle in an inert atmosphere. The tin plating made filling of the O-ring groove easier and also facilitated filling of the openings in the copper screens.

Upon initial heatup of all ten of these test specimens, the glass-to-metal seal of these receptacles indicated leaks. At the time of initial heatup the leaks were attributed to the corroded pins. However, later work on both the Pioneer and Viking programs defined the leakage as a basic problem with the receptacle as discussed in Section II.B.4 of this report. To continue the test program, a vacuum sealant was placed in the receptacle glass feedthrough area to seal the receptacle leak.

Tables II-3 and II-4 summarize the test specimen configurations and test results of these ten units (specimen Nos. 39 through 48). Also included in this table is the receptacle environment on the manifold face of the receptacle.

Seal No. 39 was leak-tight through 1032 hours of thermal aging and 361 thermal cycles. It gradually increased in leak rate until at 435 cycles the leak rate was 4.7×10^{-3} scc Helium/sec atm at room temperature.

Seal No. 40 was leak-tight through thermal aging and up to 197 thermal cycles at which time the seal was accidentally overheated and the solder joint melted.

Seal No. 41 was leak-tight through 1032 hours of thermal aging, 1186 thermal cycles and 1486 additional hours of thermal aging. As of June 30, 1972, this specimen remains on test.

Seal No. 42 was leak-tight through 1176 hours of thermal aging and 948 thermal cycles. Although the seal was still leak-tight, the solder joint was sectioned to determine if it differed significantly from leaking solder joints. No detectable differences were noted

between leaking and non-leaking solder joints.

Seal No. 43 remains on test after 1200 hours of thermal aging, 1216 thermal cycles and 1636 additional hours of thermal aging as of June 26, 1972. Although the indicated leak rate is 1.9×10^{-6} scc Helium/sec atm, it is suspected that the leak is in the receptacle glass-to-metal seal. Efforts are underway to determine precisely the source of leakage.

Seal No. 44 was leak-tight after 1176 hours of thermal aging and 164 thermal cycles. After 164 cycles the leak increased and the test was continued to determine how rapidly the leak would increase. The leak rate at 164 cycles was 6.6×10^{-8} scc Helium/sec atm and by 517 cycles had increased to 1.3×10^{-3} scc Helium/sec atm. At 798 cycles, the test was terminated with the leak rate remaining at 1.3×10^{-3} scc Helium/sec atm.

Specimen Nos. 45 and 46 remain on test as of June 30, 1972. They both have exceeded 1000 hours of thermal aging, 1100 thermal cycles and 1600 additional hours of thermal aging without leaking greater than 5×10^{-7} scc Helium/sec atm.

Seal Nos. 47 and 48 had receptacles plated by Almag Chemical Corporation as part of an effort to evaluate an alternate plating vendor. Seal No. 47 was leak-tight through 1030 hours of thermal aging and 90 thermal cycles. Leakage was occurring through the receptacle glass-to-metal seal and was very difficult to eliminate. The leak increased to 2×10^{-4} scc Helium/sec atm by 138 cycles and remained at this level until 810 cycles at which time the test was terminated.

Seal No. 48 was leak-tight for 816 hours of thermal aging. The aging was continued to 1104 hours at which time the leak rate was 1.6×10^{-5} scc Helium/sec atm. The seal was then thermally cycled 636 times and had a leak rate of 8.8×10^{-4} scc Helium/sec atm.

The results from these two seals indicate that the Almag plating was not as good as that of Furniture City since both seals failed prematurely.

e. Solder seal improvement studies

Because of the variability in solder seal life encountered during the qualification testing, additional studies were conducted in an effort to produce more reliable and consistent solder seals. Areas of further investigation are discussed below:

(i) Receptacle plating

As a result of the receptacle feedthrough pin corrosion problems discussed above, alternate methods of preparing the receptacle surface for the soldering operation were considered. One method, which was discussed above, was to send the Deutsch (Part No. DBA 54H-16-26PN) receptacle to a second copper plating vendor. Resultant test data was not encouraging. Purchasing five modified receptacles from Deutsch was also accomplished; the modified receptacle was a Deutsch development receptacle (Part No. 78026-16-26PN) which had the same configuration as the DBA54H-16-26PN receptacle except the flange did not contain the O-ring groove. The receptacle shell was plated by Deutsch prior to shipment with a tin plate over a nickel plate. These five receptacles were subsequently utilized in the process improvement test specimens discussed below. No receptacle leaks were detected in this group of receptacles.

(ii) Magnesium thorium plating

Plating of the magnesium thorium seal ring with the copper and tin in some cases resulted in severe corrosion of the seal rings around the electrode contacts. In one case, 20 machined seal rings were rejected after plating. In alternate plating vendor investigations, two machined magnesium thorium seal rings were sent to Almag Chemical Corporation for plating. Visual examination of the seal rings after plating indicated that the plating was

not uniform in thickness or appearance. Metallographic examination showed corrosion pits between the plating and the base metal. No further efforts to plate magnesium thorium were conducted by this vendor. A third vendor (Jamaica Electroplating Corporation) was investigated for plating the seal rings. Sample pieces were plated by the vendor and evaluated by Teledyne Isotopes and found to be satisfactory. However, when seven machined seal rings were sent to Jamaica for plating, only three of the parts were returned and all three contained large blisters. The copper plate was delaminated from the MgTh substrate and was extremely uneven in thickness due to folds and convolutions in the plate. Because of the non-uniformity and lack of adherence, the seal rings were unacceptable.

Furniture City Manufacturing was contacted to discuss the corrosion problem mentioned above. A decision was made to send over-size seal rings to be plated so that any corroded material would be machined off in a subsequent operation. Twenty rings were plated successfully and machined in-house to the required dimensions.

(iii) Improved soldering environment

During the assembly of all solder seals up to No. 52, the glove box atmosphere was maintained by having a continuous argon purge through the box. While tinning and soldering components, in many instances discoloration occurred on the copper plate or at the pretinned surface. Oxygen and moisture impurities in the atmosphere caused oxidation on the solder surfaces. Moisture and oxygen measurements made during the argon purge were on the order of 175 parts per million (ppm) and 580 ppm, respectively.

The glove box was disassembled, thoroughly cleaned and reworked to eliminate leaks which were occurring at the glove box ports and at the window. New gloves were installed, and plumbing was incorporated to permit connecting a Dri-Train system (oxygen and water gettering system) to the glove box. The Dri-Train is a closed system which continuously circulates and purifies the atmosphere passing through it. Other valving was added to permit connecting oxygen and water analyzers. The new moisture and oxygen levels after reworking the glove box were 1-2 ppm and 25-45 ppm, respectively. Three solder seals, Nos. 54, 55 and 56 were fabricated in the clean atmosphere, and surfaces which had tarnished during previous solder operations remained bright and clean.

(iv) Reduce or eliminate solder flux

Since flux is used in soldering to remove surface oxides, the cleaning up of the glove box atmosphere as discussed above could minimize or eliminate the need for flux. Elimination of flux is desirable because the flux tends to become entrapped in the molten solder forming bubbles or pockets. When the solder solidifies, the flux is entrapped in the joint and in the case of a very thin joint may even cause a leak. Solder tests in the clean glove box showed that it was possible to solder without flux and so solder seals Nos. 54, 55 and 56 were assembled without flux. (After the solder had melted, a minimum of flux was used on the exterior surface of the receptacle flange - not in the joint - to obtain a uniform wetting at the flange periphery.)

(v) Fabrication of composite screen-washer-screen

Voids observed in sectioned solder seals which had failed were believed to be partially due to the stacking of individual screens and the brass washer during seal assembly. Studies were made for a composite screen/washer assembly to be installed as a single unit at the final solder operation. Samples were prepared and sectioned and void areas were shown to be reduced. A preliminary procedure was written for preparation of the composites. No seals were fabricated using the composite thermal compensator due to termination of the solder seal effort.

(vi) Modified receptacle plating

Five additional solder sealed electrical receptacle specimens were fabricated and tested (Nos. 51, 52, 54, 55, and 56). The receptacles used in these test specimens were the nickel/tin plated Deutsch (Part No. 78026-16-26PN) receptacles which do not have an O-ring groove. Table II-3 summarizes the configuration of these receptacles indicating the various improvements incorporated into each specimen. Table II-4 summarizes the test status at the end of this reporting period for each of the specimens.

As of June 30, 1972, seal No. 51 was still on test after aging 1015 hours, 1100 thermal cycles and 530 additional aging hours. Between 453 and 530 hours of aging the leak rate has increased to 1.0×10^{-6} scc Helium/sec atm.

Seal No. 52 was aged 1015 hours and was leak-tight after 108 thermal cycles. After 108 cycles a leak developed. Further testing indicated a leak of

1.7×10^{-3} scc Helium/sec atm after 364 total cycles at which time the test was terminated.

The major factors suspected in causing the variability in leak tightness for the 12 preceding solder seals (10 qualification seals plus Nos. 51 and 52) were use of flux in the assembly of the seals and the fact that the argon atmosphere in the assembly box contained relatively high amounts of oxygen and moisture.

Seal Nos. 54, 55 and 56 were soldered after the glove box had been reworked to provide the Dri-Train system which recirculated and purified the atmosphere. No flux was used in the assembly of these receptacles except for a minimum amount on the exterior of the receptacle flange. All three seals remained on test as of June 30, 1972 and were leak-tight after 1000 hours of thermal aging and more than 500 thermal cycles.

3. Viton O-ring Seal

a. Background data

Viton V747-75 is a low compression set fluorocarbon sealing compound resulting from four years of development effort by Parker Seal Company. This compound incorporates Parker Seal's proprietary compounding techniques with recent improvements in DuPont Viton to provide a seal compound which reduces compression set in O-rings at high temperatures (up to 400°F) more than 50% over the Parker Seal Company 77-545 compound. In discussions with technical advisors of Parker Seal Company and DuPont, the nuclear radiation resistance, permeability and vacuum service characteristics of Viton V747-75 are identical to or better than that of Viton 77-545. Parker Seal states that Viton 77-545 is presently being phased out and will be replaced across their entire seal line with the improved Viton V747-75 compound.

Testing of Viton V747-75 seal compound was initiated at Teledyne Isotopes in September, 1971 on the SNAP 19 Pioneer program to evaluate its permeability and elevated temperature operational stability relative to the Viton 77-545 seal compound used for the Pioneer F RTG electrical receptacle O-ring seal. The test parameters, by necessity, were conservative in terms of the nominal Pioneer mission receptacle seal operating temperature (300 to 320°F) to provide early data on which to base a comparison of the seal compounds. However, the test parameters were in the range of the Viking electrical receptacle seal maximum operating temperature (340 to 360°F).

Evaluation of the V747-75 Viton O-ring compound was initiated on the Viking program during this reporting period. The testing on the V747-75 which was initiated on the Pioneer program in September, 1971 was transferred to the Viking program in January, 1972 and has been expanded to include additional Viking-oriented testing based on the promising results of the initial Pioneer tests. Viton had been rejected as a

potential seal material in early SNAP 19 Viking design studies because of the known compression set characteristics of the 77-545 compound at the relatively high Viking seal operating temperature.

b. Test fixture description

Each seal test fixture consists of a sealed chamber containing helium gas at one atmosphere on one side of the seals. The unsealed side of the receptacle is exposed to ambient air, vacuum or carbon dioxide, depending on the test phase. Figure II-12 depicts the test fixture which contains four receptacles sealed with Viton O-rings. The fixtures are fabricated from MgTh and incorporate Viton O-rings to seal the Deutsch Company DBA54H-16-26PN electrical receptacles.

c. Test results

(i) Test Fixtures 1 and 2

Test Fixtures 1 and 2 (testing of which was initiated on the Pioneer program) were heated in September, 1971 and leak rates determined for each seal at room temperature, 140°F, 250°F and the specified soak temperatures of 400°F and 360°F, respectively. The significant result of the heat-up data was that the helium leak rates (and hence permeability) of the 77-545 and V747-75 Viton O-ring compounds are virtually identical within the data spread. Test Fixtures 1 and 2 were each assembled with two O-rings of each compound (77-545 and V747-55). Desired soak temperatures were attained on both fixtures by September 14, 1971 (Fixtures 1 (400°F) and 2 (360°F)).

Figure II-12. Viton Seal Fixture Assembly

In Fixture 1, both 77-545 seals had failed at the end of the initial one-month soak at 400°F. The leak rates of the two Viton V747-75 seals in the same fixture exhibited virtually stable leak rates and maintained their sealing capability upon scheduled thermal cycling down to 140°F. The leak rates of the two 77-545 and two V747-75 Viton seals in the fixture operating at 360°F remained virtually unchanged during the initial one-month soak period and survived scheduled thermal cycling down to 140°F (see Figures II-13 through II-16). However, one 77-545 Viton seal failed in Fixture 2 after approximately 2000 hours of testing during the 360°F soak.

Figures II-13 through II-16 present the results of testing on Fixtures 1 and 2 to date. The fixtures were cycled once monthly down to 140°F to evaluate compression set characteristics of the 400°F and 360°F soak temperatures. To date no V747-75 O-rings have failed; three out of four of the 77-545 O-rings have failed. The four V747-75 and one 77-545 (soaked at 360°F) Viton seals continue to exhibit stable permeation characteristics through 7000 hours of testing. In May, 1972, the decision was made to terminate thermal cycling and maintain the constant soak temperature on these fixtures to more closely simulate a Pioneer-type mission. At a later date, thermal cycling will again be initiated for purpose of further Viking mission-oriented evaluation.

(ii) Test Fixtures 3 and 4

A total of four additional test fixtures (16 seals/receptacles) will be placed on test for Viking qualification/reliability testing. During this period two of these fixtures (Fixtures 3 and 4) were placed on test.

In February 1972, Fixture 3, containing four Viton (compound V747-75) O-ring sealed Deutsch Company electrical receptacles, was placed on thermal aging test at 370°F. After approximately two weeks at temperature, two of the four seals/receptacles were leaking in excess of 10^{-4} scc Helium/sec atm. Leakage was traced to the glass-to-metal seal in the receptacle pin area and is not attributed to the Viton O-ring; testing was

FIGURE II-13

FIGURE II-14

FIGURE II-15

FIGURE II-16

terminated. In April, 1972 this fixture was reassembled using new O-rings. In addition, another test fixture (Fixture 4) containing four Viton (compound V747-75) O-ring sealed receptacles, was assembled. Both fixtures were placed on test in May, 1972. The receptacles in these two fixtures were subjected to a thermal acceptance test (at 392°F) prior to installation to demonstrate hermetic seal capability. This thermal acceptance test will be utilized for incoming inspection of all electrical receptacles to be utilized in the receptacle seal development and reliability demonstration tests as well as Viking ETG's and RTG's (see Section II.B.4 for receptacle acceptance discussion).

Figures II-17 and II-18 present the data to date for Fixtures 3 and 4. The helium leak rate has remained essentially constant during the 370°F soak. These two fixtures, and the two to be placed on test during the next reporting period, will be subjected to thermal soaking at 370°F and then thermal cycling between 150°F and 370°F to simulate the Viking mission receptacle seal temperature profile.

4. ETG/RTG Electrical Receptacle Testing and Evaluation

A continuing electrical receptacle test and evaluation effort was conducted during this reporting period. A related investigation of the receptacle elevated temperature glass-to-metal seal leakage was conducted on the Pioneer program in support of the Pioneer G flight RTG's. A summary of those efforts is presented in this report to provide background information on developments leading to a change in the electrical receptacle shell material. Procurement of the modified receptacles was accomplished on the Viking program for both the O-ring seal and the weld flange (diffusion bonded) electrical receptacles. An investigation into procuring backup electrical receptacles was initiated. A discussion of each effort is included below.

FIGURE II-17

FIGURE II-18

a. Background data

Deutsch Electronic electrical receptacles (Part Number DBA54H-16-26 PN to specification NAS 1599) were used in Viking ETG's S/N 101 and S/N 102, Viking solder seal development testing and seventeen Pioneer ETG's and RTG's including Pioneer F flight RTG's. These receptacles were subjected to an ambient temperature acceptance leak test at $< 10^{-7}$ scc Helium/sec atm. On the Pioneer program, the receptacles were subsequently tested in the generator (after installation with a Viton O-ring) at ambient and 330°F to a sensitivity of 10^{-5} scc Helium/sec atm. Permeation through the O-ring, being several orders of magnitude higher than the typical receptacle glass-to-metal seal leak, precluded distinguishing variation in the relatively small leak contributed by the glass-to-metal seal. The indication of excessive leakage above 350°F on the Viking solder seal development program resulted in an effort to re-evaluate the receptacle capabilities for elevated temperature application. (Reference was made in this report covering the solder seal development (Section II. B. 2) as to excessive leakage ($> 5 \times 10^{-7}$ scc Helium/sec atm noted through the glass-to-metal seal of some electrical receptacles tested at operating temperatures in excess of 350°F.)

Teledyne Isotopes instituted an elevated temperature receptacle seal acceptance leak test on the Pioneer program for receiving inspection using a receptacle leak test fixture (Teledyne Isotopes drawing 452B5140038) specifically designed for that purpose. The test was performed using Teledyne Isotopes procedure 452B5100310. A total of 21 receptacles were tested with the 321 stainless steel shell. This shell material reflects the Deutsch design used on all SNAP 19 Viking and Pioneer receptacles prior to the Spring of 1972. The receptacles were from four different "lots." (Lot number indicates week and year of fabrication, e. g., "lot" 7204 means the fourth week of 1972.) Only 4 of 20 units passed the criterion of $< 10^{-7}$ scc Helium/sec atm to 392°F. One receptacle tested to only 353°F was leak-tight. These results are shown in Table II-5.

TABLE II-5

PIONEER RECEPTACLE LEAK TEST RESULTS

Deutsch Receptacle - DBA54H-16-26PN (321 shell material)

<u>Lot</u>	<u>Results *</u>		<u>Maximum Temp. (°F)</u>
	<u>Ambient Temp.</u>	<u>Elevated Temp.</u>	
7204	S	S	353
	S	S	398
	S	F	346
	S	F	390
7133	S	S	396
	S	S	398
7108	S	S	398
	S	F	383
	S	F	380
	S	F	379
	S	F	375
7136	S	F	381
	S	F	367
	S	F	305
	S	F	276
	S	F	235
	S	F	380
	S	F	371
	S	F	336
	S	F	377
7128	S	F	390

*S = Success

F = Failure ($>10^{-8}$ scc Helium/sec atm at room temperature; $>10^{-7}$ scc Helium/sec atm at elevated temperatures).

Deutsch Electronics tested 44 receptacles with the identical insert arrangement (shell size 16, 26 pins) from various lots as much as two years old. They experienced ~20% failures (leak $> 10^{-8}$ scc Helium/sec atm) at 400°F, substantiating that the receptacle glass-to-metal seal was suspect at elevated temperatures. The time at temperature was much shorter in the Deutsch test, and may be the cause of the lower failure rate.

b. Corrective action

To correct the elevated temperature leakage problem, Deutsch changed the shell material from 321 stainless steel to a 20CB-3 stainless steel purportedly to obtain a better coefficient of thermal expansion match between the glass insert and shell material. Deutsch tested 24 receptacles with the identical insert arrangement except 20CB-3 was substituted for 321 shell material. All samples were leak-tight ($< 10^{-8}$ scc Helium/scc atm) at 400°F.

Deutsch revealed that Teledyne Isotopes application of hermetic sealed receptacles at temperatures above 350°F was unique. Thus, they had little data to increase Teledyne Isotopes' understanding of the failure mechanisms and knowledge of the temperature design margin. Nevertheless, the results of tests by Deutsch and subsequent testing (discussed below) by Teledyne Isotopes exhibit a consistent improvement in leak-rate performance and no failures have been recorded.

c. Receptacle procurement

Following the stainless steel material substitution for the receptacle elevated temperature leakage problem, receptacles were ordered for utilization on the Viking receptacle seal development program. Modified configuration receptacles were procured for the solder seal tests. However, this procurement of receptacles will not be subjected to thermal acceptance testing since all new work on the solder seal develop-

ment program was terminated in May, 1972. Thirty weld flange receptacles (Teledyne Isotopes drawing NSK-1186) for use in the diffusion bonded development work (see Figure II-6 for sketch of utilization) were procured. A joint procurement of 25 O-ring groove receptacles (DBA54H-16-26PN with 20CB-3 shell material) was placed for the Pioneer and Viking programs (10 receptacles for Viking and 15 for Pioneer). These 10 Viking receptacles are to be used in the Viton evaluation studies. (Pioneer G RTG's are being equipped with receptacles from this lot.)

Thirty weld flange receptacles (Lot 7224) and 22 O-ring groove receptacles (Lot 7221) have been received and have been submitted to incoming quality inspection. All 52 receptacles from the two lots were subjected to the Pioneer leak check acceptance procedure (Teledyne Isotopes drawing 452B5100310) and all receptacles passed the leak criteria of $< 10^{-7}$ scc Helium/sec atm at 400°F. The 40 Viking receptacles are scheduled for utilization in the receptacle seal development program during the next reporting period.

d. Backup electrical receptacle

An investigation effort was initiated during this period to select backup hermetic type weld-mounted electrical receptacles for the presently used electrical receptacle manufactured by Deutsch Electronics. This latter receptacle is rated per NAS 1599 specification and inclusive supplements thereof. It was the purpose of this effort to determine vendors:

- (1) with previous experience in high-temperature hermetic receptacle technology,
- (2) who are on the qualified vendor list (U. S. Air Force, U. S. Army, U. S. Navy) for specifications MIL-C-83723, MIL-C-26482, MIL-C-26500 and other applicable specifications,

- (3) who are tooled for manufacture of ultra-high reliability, 26-pin, 16 shell size, bayonet-lock type, weld-mount hermetic receptacles,
- (4) with previous experience of hermetic receptacle technology to provide a solid glass seal insert or individual pin glass beads,
- (5) with experience of high-temperature hermetic receptacles with thermocouple pins.

Preliminary discussions were held with six hermetic receptacle vendors. Detailed meetings with technical personnel from three vendors were held at Teledyne Isotopes facilities to discuss the generator receptacle application in all aspects. To complement these direct vendor contacts, the opinions of numerous users of high-temperature hermetic seals were sampled concerning the technical reputation and capabilities of their suppliers of hermetic terminations. As a result of these evaluations, a detailed specification (for an ultra-high reliability, 26-pin, 16 shell size, bayonet-lock, weld-mount, hermetic receptacles, rated for continuous 450°F temperature, 5 years life expectancy, and leak rate of less than 10^{-8} scc Helium/sec atm) was drafted and will be forwarded as RFQ to four interested vendors. These receptacles would be a direct replacement of the present unit with no interface cabling change implications.

C. TEST HARDWARE FABRICATION

This effort is concerned with the fabrication, assembly and quality inspection of test hardware necessary to perform the tests in Task 4. Test hardware fabricated during this period is listed below.

1. Thermal Cycle Test

The following hardware was fabricated for the thermal cycle testing of Pioneer ETG's S/N 41 and S/N 43:

- a. Water coolant assembly (2 assemblies) - This assembly consists of inlet and outlet water manifolds, fin tip cooling plates and interconnecting tubing, all made of copper with brazed connections. Details are specified in the Pioneer Generator Rework Procedure for Thermal Cycle Test (Teledyne Isotopes drawing 452A6000311). Figure II-1 shows this hardware mounted on ETG S/N 41.
- b. Fan cooling assembly (2 assemblies) - This assembly consists of a 9-inch diameter fan and an aluminum shroud. Figure II-2 shows the installation of these assemblies under each generator.
- c. Fin root heaters (12) - The heater assembly consists of a 0.37" diameter x 7" long 250-watt cartridge -type heater inserted into a pre-drilled 1.0" diameter copper bar. One assembly was installed at the root of each fin. Figure II-1 shows this hardware mounted to the fin root of ETG S/N 41.
- d. Miscellaneous - Thermal vacuum chamber feedthrough plates were fabricated and leak checked. These feedthrough plates permitted the passage of the water coolant and generator internal gas lines through

the chamber wall. Test cables previously fabricated for the Viking thermal vacuum chamber test in April-May 1971 were reworked to accommodate minor wiring changes. Strip heater rework was provided during the thermal mockup development tests.

2. Electrical Receptacle Seal Development Tests

The following hardware was fabricated for the electrical receptacle seal development and testing:

- a. Piece parts for 17 diffusion bonded electrical receptacle subassemblies, including 9 dummy receptacles (Teledyne Isotopes drawing NSK-1193).
- b. Piece parts for 45 test fixtures designed for qualification/reliability testing of the diffusion bonded seal, solder seal and electrical receptacle (Teledyne Isotopes drawing NSK-1207).
(Note: the solder seal test fixtures were fabricated prior to termination of new solder seal test effort.)
- c. Piece parts for one additional diffusion bonding furnace (Teledyne Isotopes drawing NSK-1156).
- d. Piece parts for diffusion bond shear and tensile test specimens (Teledyne Isotopes drawings NSK-1194 and NSK-1196).
- e. One test fixture for tensile testing of diffusion bond specimens (see Figure II-9).
- f. Miscellaneous hardware for weld development, e.g., chill blocks and fixtures.
- g. Two test fixtures for electrical receptacle thermal acceptance testing (Teledyne Isotopes drawings NSK-1203/452B5140038).

- h. Modified four O-ring test fixtures (Teledyne Isotopes drawing 452A4700012) transferred from Pioneer program for Viking-oriented O-ring testing.
- i. Assembled test station for qualification/reliability testing of diffusion bonded/welded receptacle assemblies.

D. LIFE TESTING PIONEER RTG S/N 47

Following the successful launch of Pioneer F, SNAP 19 Pioneer RTG S/N 47 was transferred to the SNAP 19 Viking program. Section I.B.4 discusses the chronology of tests conducted at Teledyne Isotopes between the time RTG S/N 47 was received from Cape Kennedy until shipment to Monsanto Research Corporation was accomplished. Daily sets of test data, utilizing Pioneer test procedures, were taken on regular working shifts throughout the stay of RTG S/N 47 at Teledyne Isotopes.

III. TASK 5 - HEAT SOURCE DEVELOPMENT AND TESTING

The SNAP 19 Viking heat source is the four-layer, Pioneer G-type refractory capsule which will be provided to Teledyne Isotopes specifications as Government Furnished Equipment. The plutonia-molybdenum-cermet (PMC) nominal fuel inventory will be 682 watts(t) per capsule. The PMC fuel will be encapsulated in a molybdenum-46% rhenium (Mo-46 Re) inner liner, followed by a tantalum-10% tungsten (Ta-10W) liner, a tantalum-8% tungsten-2.4% hafnium (T-111) refractory strength member, and a platinum-20% rhodium (Pt-20 Rh) outer clad. A small diameter Pt-20 Rh tube, approximately four inches in length, will be welded to the outer clad at one end of the capsule. The capsule length will be increased by 0.212 inch over that used in the Pioneer series to accommodate an increased nominal fuel loading of 40 watts(t).

A helium vent system will be developed for the SNAP 19 Viking heat source which will permit the helium gas produced by the radioactive decay of plutonium to vent either to a reservoir or directly to space through a controlled leak device. This system will provide positive isolation of the generator fill gas and the fuel capsule effluents, thus improving generator performance during the mission and also reducing capsule operating temperatures. The heat shield for the SNAP 19 Viking will be based on the SNAP 19 Pioneer design with appropriate modifications to accept the longer capsule with its associated vent piping system.

A. FUEL CAPSULE VENTING SYSTEM

The fuel capsule venting system is under development for the Viking RTG to maintain the generator fill gas at 75% Helium/25% Argon. This results in an additional power output of two watts(e) at EOM over a non-vented system, and maintains capsule operating temperatures consistent with Pioneer technology. Figure III-1 illustrates the general

FIGURE III-1
CAPSULE VENT SYSTEM

RESERVOIR (DOME) CONCEPT

C.L.D. CONCEPT

concept of the vent system. A small diameter Pt-20 Rh tube is EB welded to the capsule clad at one end. The other end of the tube penetrates the RTG housing. Hence, the helium produced (alpha particles) by isotopic decay is vented to space rather than allowing helium enrichment of the initial generator fill gas. For a nominal 682 watts(t) of radioisotopic fuel, the 100% helium release is about 3×10^{-5} sec/sec.

In order to limit the capsule operating temperature, a leak device is incorporated in the system to maintain helium pressure within the capsule for heat transfer. The controlled leak device (CLD) consists of a small cylinder of pressed and sintered platinum powder within a nickel housing. (Other CLD's being considered include a capillary tube and Viton O-ring.) A backup approach being developed in parallel incorporates a reservoir of magnesium thorium (MgTh) at the housing cover (Fig. III-1). This latter approach allows the helium produced to remain in a closed (in dome) rather than venting to space. The reservoir volume is based upon the creep strain capability of the capsule clad to contain the gas with time (duration dependent on mission requirements).

The vent system development may be subdivided into a number of tasks and the status of each task is delineated in detail below for this reporting period.

1. Vent Tube

The Pt-20 Rh vent tubes were successfully fabricated and delivered by the vendor in support of this task. The tubes (Teledyne Isotopes drawing NSK-1145) have a small inside and outside diameter (0.050" O.D., 0.012 I.D.) at the capsule clad interface end with a tapered transition to the larger diameter (0.125" O.D., 0.063" I.D.) section at the RTG housing cover interface. The smaller section serves three purposes:

- a. Reduce operational heat losses - a study was completed where the results indicate a loss of approximately 1 watt(t).
- b. Minimize heat input to the capsule clad during heat source abort reentry environments.
- c. Facilitates welding to the thin (0.018" thick) capsule clad.

The larger diameter is conducive to minimizing any likelihood of helium flow stoppage from condensation of potential compounds emanating from the fuel capsule. The larger diameter also accommodates welding to the nickel fitting at the housing cover penetration.

A clad-vent tube weld program was conducted at Monsanto Research Corporation (MRC) and successfully completed. The tube was mated to the 0.050" diameter hole in the clad with an automatic EB weld interface. Metallography on sectioned weld specimens has indicated a complete fusion with a continuous uniform grain structure where no heat-affected zone (discontinuity) can be detected. Prior to performing the weld, the tubes had the following processing:

- a. Full anneal.
- b. Bending and trimming to length.
- c. Cleaning (internal and external).
- d. Radiography.
- e. Flow check.

Two development test capsules with fuel simulant were completed at MRC on June 23, 1972. One capsule with an all-up vent tube will be used for a system dynamic test utilizing a Pioneer housing (S/N 37) and generator internals (thermoelectric elements, insulation, etc.) as a test bed. This test generator will undergo room temperature launch vibration (sine and random) and shock (Mars entry pyrotechnic and Mars landing) environ-

ments to check out the vent tube system. The second capsule, with a short section of vent tube protruding through the heat shield, will receive end-on reentry heating simulation at NASA Ames via plasma arc. The intent of this test will be to evaluate thermal response of the vent tube and modified heat shield end plug. The instrumented heat source (Teledyne Isotopes drawing NSK-1256) is nearing completion. The design of the dynamic test model generator has been initiated.

2. Controlled Leak Device

These devices are presently being tested to determine their flow characteristics as a function of temperature, pressure differential and gas (helium, nitrogen, argon, etc.). Two test programs are planned, a flow characterization program (Teledyne Isotopes drawing 452A6020402) and a reliability test series.

A computer program has been completed for gas flow evaluations of the vent system. The digital program, based upon a forward finite difference solution of mass balance, will provide a flow analysis of the controlled leak device and/or capillary tube for any non-linear gas production. A number of runs have been completed for various helium production profiles with time. One of the outputs is the pressure history within the fuel capsule as a function time. These studies will continue for both ingress and egress of gases during the next reporting period.

3. Weld Development

With reference to Figure III-1, a number of welds is required in the system for both similar and dissimilar materials. The welding development program is continuing with the following milestones per this date:

Nickel - Nickel	Parameters complete.
Mg Th - Mg Th	Parameters complete for straight sections from 0.060" to 0.090" in thickness.

4. Reservoir System

The reservoir proposed is fabricated from the same MgTh alloy (HM21A) as the generator housing. The thickness is 0.090", providing a static internal pressure capability in excess of 600 psi. The preliminary sizing of an internal volume of ~70 cubic inches was based upon the pressure containment capability of the capsule clad for a duration of twenty-six months. The creep capability of the clad was based upon clad creep experiments conducted at Atomics International (AI) in support of the Pioneer program. The analytical portion of this task will continue when the final AI report is completed and distributed.

B. FUEL CAPSULE DESIGN

Advance drawings for both the Viking fueled capsule and the test capsule piece parts and assemblies were released to MRC on June 29, 1972 for their review and comments. The capsule includes a two-piece slip-fit inner liner of Mo-26 Re with a nominal thickness of 10 mils. Other than the vent tube and the new inner liner, the capsule piece parts (hydroformed at MRC) are identical to those required for Pioneer except in length. The Viking capsule is lengthened by 0.212" to accommodate an additional 40 watt(t) fuel disc.

In addition to the final release of drawings, a number of material and process specifications must be completed prior to production. The material specification for Mo-46 Re will be based upon the application of powder metallurgy processed ingots and will be dependent upon success of hydroforming development. The fuel capsule specification containing the capsule applicable documents and the functional performance

requirements has been initiated. The interface document for the fuel capsule between MRC and Teledyne Isotopes has been issued and concurred by both parties.

On June 20, the first Teledyne Isotopes/MRC monthly coordination meeting was held in Miamisburg, Ohio. The purpose of this series of meetings is to provide a more effective liaison between the two facilities for both the Viking and Pioneer programs.

C. HEAT SOURCE STUDIES

1. Vent Tube Heat Loss

Preliminary studies were made to determine the heat loss due to incorporating a vent tube in the SNAP 19 Viking RTG. The study assumed a Pt-20 Rh vent tube penetrated the end plug and end insulation disc. The portion of the tube at the capsule clad was 0.050" O.D. x 0.012" I.D.; the tube was enlarged (0.125" O.D. x 0.063" I.D.) near the cover. The study evaluated several tube configurations both quantitatively and qualitatively. It was shown that the heat loss due to the presence of the tube can be computed to a high degree of accuracy by accounting only for the flow of heat along the tube and neglecting the heat transfer between tube and insulation. The total heat loss due to the vent tube was determined to be less than 1 watt(t).

2. Heat Source Steady State Temperatures

Preliminary steady state temperatures of the heat source were computed for initial reentry conditions to be used in subsequent thermal studies. Two thermal models represented half of the heat source length. One model had the helium vent tube installed; the other had a solid end plug. The vent tube perturbed the temperatures less than a few degrees except in its immediate vicinity.

The following are computed heat source temperatures at the heat source midplane:

Fuel centerline	1635°F
Inner liner	1485°F
Outer liner	1460°F
Strength member	1420°F
Clad	1370°F
Heat shield	1020°F

Temperature and recession histories of the heat source were computed for an end-on reentry mode. Heat flux distributions and heat transfer across the sleeve restraint were treated as parameters. The influence of the vent tube was also evaluated.

The results of the study showed: (a) the vent tube has negligible influence on heat source temperatures, (b) a tantalum felt sleeve restraint is preferred to the current graphite felt sleeve restraint, and (c) heat flux distributions to the hexagonal flat surfaces have a strong influence on reentry temperatures.

Numerical results for the current heat source design are presented in Table III-1.

3. Aerophysics Analysis

An aerophysics analysis was performed on the Viking heat source in end-on attitude to define two reentry environments, orbital decay and superorbital, for use in the aerothermal analysis discussed above. The analysis reported in Reference III-1 for the Pioneer heat source were utilized for this study. Two reentry environments were investigated utilizing UB088. These trajectories are: orbital decay and superorbital ($V_i = 38 \text{ K fps}$ and $\gamma_i = -6^\circ$). The drag curve, convective and radiative heating factors and distributions, pressure distribution, and convective cooling curves which were used in the Pioneer study (see Reference III-1) were also used here for the end-on attitude.

The digital trajectory program, UB088, was used to define the aerodynamic and aerothermodynamic environment for the Viking heat source. This code solves the

TABLE III-1

HEAT SOURCE REENTRY TEMPERATURES

	Orbital Decay	Super Orbital $V_i = 38,000 \text{ fps}, \gamma_i = -6^\circ$
Peak Temperature ($^\circ\text{F}$)		
Heat shield	3804	5581
Clad	2757	3020
Strength member	2662	2767
Impact Temperature ($^\circ\text{F}$)		
Heat shield	686	--
Clad	2179	--
Strength member	2348	--
Stagnation Point		
Recession (in.)	0.143	

differential equations of motion by a Runge-Kutta method for a point-mass body trans-
versing three-dimensional paths about an oblate rotating planet.

IV. TASK 6 - SAFETY EVALUATION

The safety analysis activity during this reporting period was concerned with a preliminary assessment of the SNAP 19 RTG response characteristics to postulated malfunctions during the Viking mission. The tasks described below will provide part of the input to The Preliminary Safety Analysis Report (PSAR) to be submitted on September 30, 1972.

A. ACCIDENT MODELS

The Viking mission, launch vehicle and spacecraft were evaluated to determine major variations in accident environments as compared with the Pioneer mission and vehicles. The launch abort accident environments were analyzed using data supplied by the NASA/Lewis Vehicle Group and the use of PYRO test data.

1. Mission Analysis

The Viking launch vehicle system consists of a two-stage Titan III booster, a two-burn Centaur D-1T Centaur vehicle, and the Viking spacecraft (orbiter and lander), Figure IV-1. An earth parking orbit of about seventeen minutes duration is achieved after the Centaur first burn. The Centaur second burn provides the required thrust for the transfer orbit injection to Mars. Major events in the launch sequence are presented in Table IV-1, and significant trajectory parameters are shown in Figure IV-2. These data were obtained from Reference IV-1 and Martin Marietta Corporation.

2. Centaur Second Burn Trajectory Simulation

To determine the final trajectory (direct entry, orbital capture, escape) resulting from postulated misorientation of the Centaur at various times during its second burn, a multipulse approximation was used to simulate the powered flight. This digital code is

Figure IV-1. Stage/Step Relationship for Titan III/Centaur D-1T.

TABLE IV-1

TITAN III/CENTAUR D-1T/VIKING PRELIMINARY SEQUENCE OF EVENTS

<u>EVENT</u>	<u>TIME, SECONDS</u>
Ignition	T - 0.21
Lift - off	T + 0
Begin Stage 0 Shutdown	T + 109.9
Jettison Heat Shield	T + 110.8
Jettison Stage 0	T + 122.1
Stage I Engine Shutdown	T + 257.2
Jettison Stage I	T + 258.0
Jettison Shroud	T + 268.0
Stage II Engine Shutdown	T + 466.9
Jettison Stage II	T + 474.7
First Centaur Main Engine Start	T + 485.2
Guidance Loop Closed	T + 496.2
First Centaur Main Engine Cutoff	T + 617.0
Begin Parking Orbit Coast	T + 617.5
Second Centaur Main Engine Start	T + 1614.3
Guidance Loop Closed	T + 1625.3
Second Centaur Main Engine Cutoff (MECO 2)	T + 1925.4
Solar Panels Deployed; Start Centaur Orientation Maneuver	MECO 2 + 14.
Centaur/Spacecraft Separation	MECO 2 + 203.
Spacecraft Sun Acquisition	MECO 2 + 1200.
Spacecraft Canopus Acquisition	MECO 2 + 3600.

FIGURE IV - 2 VIKING TRAJECTORY

TITAN III / CENTAUR D-1T / VIKING 75

GD/C Nov. 1971

4/29/72

described below in Section B.1.a. Since no misorientation trajectories were available from Convair, it was necessary to have a baseline reference against which to validate the multi-pulse trajectory results. The UB088 three-dimensional point mass trajectory code was used for this purpose.

Parameters from the Viking launch trajectory at the beginning of the Centaur second burn were input to the UB088 program. Tables of pitch and yaw angles-of-attack from Reference IV-1 were input so that the thrust-vector, assumed acting along the Centaur longitudinal axis, would have the proper orientation with respect to the velocity vector as stated in Reference IV-1. The following constants were used: flow rate = 66 lb/sec; thrust = 29,262 lbs; and specific impulse = 443 sec.

Table IV-2 presents a comparison of the results of this trajectory analysis during Centaur second burn. The times of comparison were made at 1729, 1829, and 1925.4 seconds after liftoff or 114.7, 214.7 and 311.1 seconds after Centaur second ignition. The last time represents Centaur Main Engine Cut Off. The following quantities were compared: longitude, geodetic latitude, altitude, inertial velocity, inertial flight path angle, inertial azimuth, and pitch and yaw angles-of-attack. The maximum absolute error in these quantities at the three times was always less than 0.5%.

3. Launch Pad Accident Environments

The significant launch pad accident modes and models to describe resulting environments are discussed in this section. Input data received from NASA/LeRC are first summarized. These vehicular data are then used to associate failure modes with effective explosive yields. Wherein data are lacking, use is made of related information developed under the Pioneer Safety Analysis program. The composite data are then integrated for selected reference accidents to estimate probability distributions for the significant environments.

TABLE IV - 2

COMPARISON OF RESULTS

	Reference	UB088	% Error	Reference	UB088	% Error	Reference	UB088	% Error
Time (secs)	1729	1729	--	1829	1829	--	1925.4	1925.4	--
Longitude (°E)	3.7911	3.7917	0.016	11.288	11.292	0.035	19.960	19.969	0.045
Geodetic Latitude (°S)	18.374	18.375	0.005	21.979	21.982	0.014	25.444	25.450	0.024
Altitude (ft)	601,935	601,855	-0.013	702,571	702,467	-0.015	1,029,656	1,029,981	0.032
V_I (fps)	29,152	29,160	0.027	33,161	33,180	0.057	38,422	38,455	0.086
γ_I (°)	0.60464	0.60168	-0.490	3.2773	3.2776	0.009	7.7555	7.7616	0.079
ψ_I (°)	117.10	117.10	0	114.33	114.33	0	110.63	110.63	0
α (°)	-0.86998	-0.86998	0	0.51780	0.51780	0	-0.29239	-0.29239	0
β (°)	1.7500	1.7500	0	1.4574	1.4574	0	1.0670	1.0670	0

1. Subscript I ~ inertial quantities

2. % Error = $\left[\frac{(\text{UB088} - \text{Reference})}{\text{Reference}} \right] \times 100\%$

a. Input data

Tables IV-3 and IV-4 summarize data received from LeRC, Reference IV-2, and from Martin Marietta regarding the launch vehicle and spacecraft. Table IV-3 lists propellants utilized for the various elements of the vehicle system and separation distances between RTG's and assumed centers for representative explosions. Note that "step" definition (as contrasted with "stage") is the same as that introduced by Convair and identified previously in this chapter.

Table IV-4 shows maximum abort environments for Steps 1 and 2 and the Centaur. The preliminary data contain no quantitative reference to explosive environments associated with solid propellants. Information has not yet been received pertinent to the spacecraft propellant explosion models.

The environments listed are described as maximum in that they are related to "maximum yields," terminology which we identify with 99 percentile specification, i.e. the conditional probability is 0.99 that the listed environments will not be exceeded. The yields are significantly smaller for hypergolic propellants (1 and 2) than for cryogenics, in keeping with the available test data.

Overpressure data shown in Table IV-4 assume ground reflection for step 1 and that step 2 and Centaur explosions would be air bursts. For this reason the latter overpressures shown are relatively small in spite of small separation distances. The above data are not derived from a failure mode analysis, however, and, as indicated subsequently, some failure modes for the Centaur are probably accompanied by blast wave reenforcement, resulting in greater overpressures with the same yield. The fragmentation environment, not treated in Table IV-4, was described as being less severe than for Pioneer, primarily owing to shielding effects of intervening structure between the Centaur and RTG's.

TABLE IV-3
LAUNCH VEHICLE PROPELLANT CHARACTERISTICS

<u>STAGE</u>	<u>PROPELLANT</u>	<u>PROP. WT. (LBS)</u>	<u>DISTANCE, EXPLOSION CENTER TO RTG's (FT)</u>
Lander	Hydrazine	331.5	3
Orbiter	Hydrazine	3097	5
Step III	Lox/LH ₂	30,200.	36
Step II	N ₂ O ₄ /N ₂ H ₄ - UDMH (50/50)	67,000.	57
Step I	N ₂ O ₄ /N ₂ H ₄ - UDMH (50/50)	258,000.	105
Step 0	Powdered Alum. Fuel, Ammonium	850,124.	105

TABLE IV-4
MAXIMUM ABORT ENVIRONMENTS

	<u>Step I</u>	<u>Step II</u>	<u>Centaur</u>
Percent Yield	5	5	20
TNT Equivalent (lbs.)	12,900	3,360	6,140
Overpressure (psi)	50	42	180
Impulse (psi-sec)	.65	.60	.96

In addition to the maximum abort parameters listed in Table IV-4, data were also received pertinent to the thermal and fragmentation environments. A fireball liftoff time was given in Reference IV-2 as 3.2 seconds. This was based on use of the TRW/Sandia Thermal Model and the total liquid fuel inventory of 355,000 pounds. The two solid propellant boosters contain about 350,000 pounds of composite solid propellant. Burning liquid propellant could ignite the solid propellants resulting in a flame temperature of 3000 to 5000°F for as long as ten minutes.

b. Failure modes

Failure mode analysis performed for the Pioneer launch vehicle was based on certain reference accident modes for a typical launch vehicle. These representative modes are also appropriate for the Viking launch vehicle and are shown in Table IV-5 for Step 2 and the Centaur vehicle. LeRC input data for Viking and Pioneer and Project Pyro experience (Reference IV-3) were used to develop maximum (99 percentile) conditions shown in this table.

The most severe potential conditions from this analysis result from confined explosions of the Centaur and down range impact of the Centaur tanks. Note again, however, that spacecraft propellants have not yet been considered as explosion sources.

Fragment speeds shown in Table IV-5 were derived for the telemetry package identified in the Pioneer analyses as the most significant fragment produced in the Centaur explosion.

c. Environment distribution

A notion fundamental to accident analysis is that accident environments, for any given type of accident, have a probability structure. The assignment of a single, representative environment to an accident, therefore, may be misleading in that risks may be misjudged. Viking safety analyses (like the preceding Pioneer studies) will

TABLE IV - 5

MAXIMUM ABORT ENVIRONMENT CHARACTERISTICS

Vehicle Step	Failure Characteristics	% TNT Equiv. Yield	TNT Equiv. Wt. (lbs.)	Scaled Distance ft/lb ^{1/3}	Peak Over-Pressure (psi)	Impulse (psi-sec)	Fragmentation Speed (fps)
Step II	Bulkhead Rupture (CBM) or Fall-back (CBGS)	5.0	3,350	3.81	75	.84	
	Wall Ruptured (Unconfined) or Destruct (Unconfined)	3.0	2,010	4.52	42	.60	
Centaur	Bulkhead Rupture (CBM) or Fall-back (CBGS)	20.0	6,040	1.98	327	1.33	107
	Wall Rupture (Unconfined) or Destruct (Unconfined)	20.0	3,020	2.49	180	.96	75
	Down Range Impact (Reflection from ground)	100.0	30,200	1.15	1,350	2.36	253

consider the best available estimates of probability distributions for the environments as well as variance in durability of configurations containing the radioactive heat source. The method to be employed in these containment-failure risk estimates resembles the safety margin technique familiar in reliability analysis.

To exemplify the deduction of probability structure for environments we have listed in Table IV-6 the characteristic explosion modes from Table IV-5 and, for each environment, the 99, 90 and 50 percentile magnitudes. These results are preliminary and were based largely on results of the Pioneer failure mode analysis. Representative vehicle failure modes are also listed to show the interrelationship between vehicle failure modes and explosion modes.

The derivation of these probability distributions was based on 1) the specification of "maximum" (99 percentile levels) and 2) probability distribution data from Project Pyro (Reference IV-3). A "one-sided" normal distribution is assumed to describe yields for a specific explosion mode. The cumulative distributions for overpressure, impulse and fragment speed were then deduced based upon their functional dependance on yield.

TABLE IV - 6
ENVIRONMENT DISTRIBUTIONS

Vehicle Stage	Explosion Mode/Yield	Vehicle Failure Modes	Environment	Probability/Environment Level		
				0.99	0.9	0.5
Step II	Unconfined/ 3%	Pressure Loss Destruct	Propellant Wt. (lbs)	2,000	1,407	670
			Overpressure (psi)	42	40	13
			Impulse (psi-sec)	0.60	0.46	0.19
			Fragmentation Speed (fps)	--	--	--
			(Telemetry package)			
Step II	Confined/ 5%	Structural Failure	Propellant Wt. (lbs)	3,350	2,479	1,340
			Overpressure (psi)	75	60	36
			Impulse (psi-sec)	0.84	0.69	0.46
			Fragmentation Speed (fps)	--	--	--
			(Telemetry package)			
Centaur	Confined/ 20%	Fall back Tipover	Propellant Wt. (lbs)	6,040	3,866	1,208
			Overpressure (psi)	327	240	100
			Impulse (psi-sec)	1.33	1.09	0.56
			Fragmentation Speed (fps)	107	85	48
			(Telemetry package)			
Centaur	Confined/ 100%	Constant Pitch Mal- function, Pitch/yaw malf. Thrust Termination Engine hardover	Propellant Wt. (lbs)	30,725	24,580	16,592
			Overpressure (psi)	1,350	1,200	950
			Impulse (psi-sec)	2.36	2.24	1.79
			Fragmentation Speed (fps)	253	228	174
			(Telemetry package)			
Centaur	Unconfined/ 20%	On-pad aborts	Propellant Wt. (lbs)	3,020	1,782	302
			Overpressure (psi)	180	140	36
			Impulse (psi-sec)	0.96	0.70	0.24
			Fragmentation Speed (fps)	75	53	24
			(Telemetry package)			

B. IN-FLIGHT MALFUNCTIONS

The purpose of work reported in this section was to determine the range of initial reentry conditions appropriate for potential post-accident configurations. Attention was directed to two classes of failure modes: (1) misorientations during Centaur second burn giving rise to a continuum of speed and flight path angle combinations at 400,000 feet, and (2) a variety of failures causing orbital capture and, ultimately, orbital decay.

In the former case a trajectory simulation model was devised and checked out. Results of preliminary analyses are presented in terms of probability densities for speed and flight path combinations at 400,000 feet. A significant finding of this study, in addition to determining the aforementioned V, γ maps, was the strong likelihood of powered entry well below 400,000 feet.

Failure modes yielding orbital capture include non-ignition or early termination of Centaur second burn and thrust misorientation. These conditions were examined to determine, based on apogees and perigees from the nominal trajectory, ranges of orbital lifetimes. Orbital lifetime probabilistics influence the risk factors of fuel decay, capsule contamination, and initial temperature conditions within the RTG.

1. Misorientation Analysis

a. Models

The nominal injection phase of the Viking launch consists of Centaur second burn of 311 seconds starting from the parking orbit. Two malfunctions involving misorientation of the thrust vector (vehicle body axis) from its nominal trajectory were analyzed. The misorientation is assumed either fixed or variable:

- (i) Fixed misorientation - This misorientation may occur at any time during the burn. The direction of misorientation is described by polar and azimuthal angles (θ, ϕ) with respect to a space coordinate system in which the polar axis is the nominal flight direction. Misorientation having occurred, the body (thrust) axis remains in the direction of a fixed point in space. The nominal thrust continues throughout the remainder of the Centaur burn.
- (ii) Variable misorientation - This accident may start at any time during the burn. A failure of the guidance and control system occurs such that random changes are made in the misorientation direction throughout the remainder of the burn. The magnitude of the thrust is nominal.

The objective of the analysis is to determine the various prompt and delayed atmospheric reentry conditions and their associated conditional probabilities. Reentry conditions are described in terms of the inertial velocity and flight path angle (V, γ) at an altitude of 400,000 feet. To accomplish this, Monte Carlo analysis is used.

A Monte Carlo history consists of a "flight." Misorientation angles for this study were selected with equal probability over the unit sphere. Powered flight is simulated by a series of impulses delivered at the beginning of specified equal time intervals over the flight.

Following the impulse, free flight (non-powered) is described by the standard orbital equations (hyperbolic or elliptic). For fixed misorientations, appropriate rotations are performed to determine the current misorientation angles (θ', ϕ') with respect to the space axes. For variable misorientation, new θ, ϕ 's are picked at random just prior to each impulse.

At the end of powered flight, conditions are examined to determine if reentry occurs. For prompt reentry (conditions with perigee $\leq 400,000$ feet leading to direct descent) the V, γ conditions at reentry are determined and scored in the appropriate "bin." Should the vehicle be left in orbit (perigee $> 400,000$ feet) a routine establishes the orbital lifetime and determines whether or not loss of gas from the RTG occurs prior to reentry (seal failure or micrometeoroid penetration). If the vehicle reenters during powered flight, the history is terminated and V, γ conditions and remaining thrust time is recorded. Hover and skip escape boundaries are checked for each reentry to determine whether or not a multi-orbit or skip-escape condition has occurred.

Repetition of this process for a large number of histories with appropriate scoring allows computation of conditional probabilities for the various reentry conditions. A V, γ map is produced showing the scores for each bin of dimensions $\Delta\gamma = 1^\circ$, $\Delta V = 1000$ ft/sec.

A digital program, set up to perform the trajectory analysis within the Monte Carlo computation process, has been checked out by comparison of selected histories with computations performed using the more sophisticated program UB088. Results have proven quite satisfactory for the purposes of these analyses.

b. Results

Some preliminary results of the V, γ misorientation analysis are presented herein. Three cases were considered:

- (1) Fixed misorientation at the beginning of the Centaur second burn.
- (2) Fixed misorientation starting midway through the burn.
- (3) Variable misorientation throughout the entire burn.

V, γ plots are presented for these three cases in Figures IV-3 to IV-5. These plots represent numbers of Monte Carlo histories falling into 1000 fps and 1° subdivisions of V, γ space. Since the total number of histories for each case was 1000, the "bin" probability density functions (pdf's) may be obtained by dividing each indicated number of histories by 1000.

The effect of time of onset of the misorientation condition is demonstrated by Figures IV-3 and IV-4. The V, γ map for Case 1, Figure IV-3, shows concentrations of the pdf in regions having relatively small speeds and a discernible separation between pitch-up (steep) and pitch-down (shallow) misorientations. In contrast, Figure IV-4 (Case 2) exhibits a trend toward higher speeds with a smaller difference in flight path angle between pitch-up and pitch-down cases.

For the case of variable misorientations, Figure IV-5, it is seen that the probability density is much more localized than for the fixed misorientation cases. Inertial speeds at 400,000 feet tend to be small, centered in the 25,000 to 26,000 fps range. Both of these results are to be expected in contrast to those for fixed errors.

The principle results of these analyses are summarized in Table IV-7. Conditional probabilities are presented for the three cases for various conditions of interest at 400,000 feet.

Powered entry into the atmosphere is seen to be quite likely if a misorientation of either type occurred early in the Centaur second burn. Prompt, non-powered, entry appears to have about the same likelihood as for Pioneer. Orbital capture modes are emphasized while escape is deemphasized compared with Pioneer, again as one would expect, owing to the lower maximum speed for the Viking launch vehicle and spacecraft.

Figure IV-3. V, δ Statistics for Viking Misorientations - Fixed Misorientation
at Beginning of Centaur Second Burn.

		VELOCITY (KFT/SEC)																																					
		10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39								
GAMMA (DEG)		11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40								
39-40		0	0	0	0	0	0	0	0	0	0	0	0	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	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	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	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	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	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	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	0	0	0	0	0	0	0	0	0	0	0	0						
31-32		0	0	0	0	0	0	0	0	0	1	1	3	3	2	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	1	1	0	3	2	2	3	3	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	1	0	3	0	0	2	0	1	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	2	0	1	0	2	0	1	1	0	3	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
27-28		0	0	0	0	0	0	0	1	2	0	1	1	3	1	1	0	0	3	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	1	1	0	1	1	1	2	1	2	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
25-26		0	0	0	0	0	2	0	2	0	2	1	1	0	1	4	1	2	0	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0					
24-25		0	0	0	0	0	1	1	0	1	1	0	0	0	1	3	1	1	1	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0					
23-24		0	0	0	0	1	0	2	1	0	0	0	2	1	1	1	1	3	7	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0					
22-23		0	0	0	0	2	0	1	1	1	2	1	0	0	0	0	0	0	1	2	2	1	2	0	0	0	0	0	0	0	0	0	0	0					
21-22		0	0	0	0	2	0	1	1	1	1	0	1	0	1	1	0	0	0	1	1	2	0	6	2	0	0	0	0	0	0	0	0	0					
20-21		0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	3	1	0	2	1	1	2	0	0	0	0	0	0	0	0	0					
19-20		0	0	0	0	1	0	0	1	0	0	1	0	0	1	1	0	2	0	1	0	0	0	2	1	2	0	0	0	0	0	0	0	0					
18-19		0	0	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	1	3	3	0	0	0	0	0	0	0					
17-18		0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	1	0	1	0	0	0	1	0	4	3	0	0	0	0	0	0	0	0					
16-17		0	0	0	0	1	0	1	0	0	3	1	0	0	0	0	2	0	0	0	1	2	1	3	0	2	4	0	0	0	0	0	0	0					
15-16		0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	2	1	4	0	1	0	4	0	0	0	0	0	0	0	0					
14-15		0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	2	1	0	0	1	0	1	3	0	2	0	0	0	0	0	0	0					
13-14		0	0	0	0	0	0	0	1	0	0	2	1	1	0	0	0	2	0	1	0	1	1	0	0	3	2	1	0	0	0	0	0	0					
12-13		0	0	0	0	0	0	0	2	0	0	0	1	0	0	1	0	0	3	0	1	0	0	0	0	0	2	2	0	0	0	0	0	0					
11-12		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0					
10-11		0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0					
9-10		0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	2	0	1	2	0	1	3	0	0	0	0	0	0					
8-9		0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0	0	0	0	0	3	0	2	0	0	0	0	0	0	0					
7-8		0	0	0	0	0	0	0	0	1	10	11	11	12	14	17	3	0	0	1	1	0	1	1	1	1	1	0	2	0	0	0	0	0					
6-7		0	0	0	0	0	0	0	0	0	0	4	10	11	10	25	38	23	2	0	1	1	1	1	0	2	0	2	0	0	0	0	0	0					
5-6		0	0	0	0	0	0	0	0	0	0	0	3	11	9	6	6	21	25	7	2	0	1	1	1	0	1	0	0	0	0	0	0	0					
4-5		0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	3	7	12	17	11	0	0	0	0	0	0	0	0	0	0	0	0	0					
3-4		0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	2	5	8	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
2-3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
1-2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0-1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					

Beginning Midway Through Centaur Second Burn.

[illegible]

Figure IV-5. V, γ Statistics for Viking Misorientations - Variable Misorientation

Throughout Centaur Second Burn.

IV-20

= GAMMA (DEG)	VELOCITY (KFT/SEC)																																					
	10 11	11 12	12 13	13 14	14 15	15 16	16 17	17 18	18 19	19 20	20 21	21 22	22 23	23 24	24 25	25 26	26 27	27 28	28 29	29 30	30 31	31 32	32 33	33 34	34 35	35 36	36 37	37 38	38 39	39 40								
30-40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
20-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
19-20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
18-19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
17-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
16-17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
15-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
14-15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
13-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
12-13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
11-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
10-11	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	4	4	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
9-10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	6	6	7	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
8-9	0	0	0	0	0	0	0	0	0	0	0	0	0	3	6	5	9	1	1	5	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
7-8	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	4	8	14	9	6	4	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0		
6-7	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	8	11	19	15	11	4	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0		
5-6	0	0	0	0	0	0	0	0	0	1	1	0	13	25	40	33	24	17	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
4-5	0	0	0	0	0	0	0	0	0	0	1	2	8	16	30	32	19	11	9	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
3-4	0	0	0	0	0	0	0	0	0	0	1	2	3	6	25	28	21	25	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
2-3	0	0	0	0	0	0	0	0	0	0	0	0	4	8	10	21	23	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
1-2	0	0	0	0	0	0	0	0	0	1	0	0	0	2	7	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

TABLE IV-7

CONDITIONAL PROBABILITIES FOR PRINCIPAL EVENTS

Result	<u>Probability</u>		
	<u>Case 1</u> Fixed, at $t = 0$	<u>Case 2</u> Fixed, at $t = \frac{t_{\text{burn}}}{2}$	<u>Case 3</u> Variable throughout
1. Prompt powered reentry	.36	.07	.28
2. Earth orbit	.09	.18	.19
3. Multi-orbit reentry*	.06	.06	.04
4. Prompt non-powered reentry	.38	.49	.49
5. Escape	.11	.20	0

*Reentry involving two or more passes in and out of the atmosphere.

The V, γ probability maps shown in Figures IV-3 to IV-5 do not distinguish between powered and quiescent reentry histories. Figure IV-6 was constructed to demonstrate the relationship between speed, flight path angle, and residual thrust. The shaded regions on the V, γ map show residual thrust intervals of 0-100, 100-150, and 150-200 seconds. Also presented are the cumulative probabilities for each amount of residual thrust.

The so-called hover boundary indicated in Figure IV-6 is the line of demarcation for non-thrusting reentry bodies ($W/C_D A = 55$ psf) between prompt and multi-orbit (grazing) entry. The effect of residual thrust in either region in V, γ space has not yet been evaluated.

2. Orbital Capture Modes

Several postulated accidents during the post launch interval can result in the vehicle being left in earth orbit. These accidents include:

- a. Non-ignition of the Centaur second burn - Orbital conditions are those of the nominal parking orbit prior to Centaur second burn ignition.
- b. Loss of thrust during Centaur second burn (nominal flight conditions) - A wide range of orbital conditions may result varying from the nominal parking orbit to orbits with long lifetimes.
- c. Misorientation during Centaur second burn (fixed or random misorientation) - A wide range of orbital lifetimes result depending upon misorientation mode and time of misorientation (relative to start of burn).

For these accidents, the orbiting configuration assumed is the Viking spacecraft (paddles deployed). Barring an explosion, it is assumed that normal separation of the Centaur will occur.

Fig. IV-6. POWERED REENTRY ANALYSIS - FIXED MISORIENTATION AT BEGINNING OF CENTAUR SECOND BURN

3. Orbital Lifetimes

a. Centaur second burn malfunctions

The second burn of the Centaur engine during the Viking launch trajectory takes the Viking spacecraft from an earth parking orbit of approximately 600,000 foot altitude to an interplanetary trajectory to Mars. The trajectory parameters at the beginning and end of the Centaur second burn are:

	<u>Main Engine Start (MES 2)</u>	<u>Main Engine Cutoff (MECO 2)</u>
Time from lift-off, sec.	1614.27	1925.38
Altitude, ft.	595,214	1,029,656
Velocity, inertial, fps	25,599	38,422
Flight path angle, inertial, deg.	-.05	7.76

Since an orbiting RTG is subject to penetration of the outer skin by meteoroids, and seal failure, the resulting failure probabilities are a function of time in orbit. The orbital lifetimes are therefore used to first compute an orbital lifetime probability density function.

Perigee and apogee altitudes for thrust termination at various times during the Centaur second burn were obtained from Reference IV-1, and are shown in Table IV-8. It will be noted from Table IV-8 that the variation in perigee altitude is relatively small, approximately 50,000 feet, before a hyperbolic orbit is achieved. Perigee and apogee altitudes were also determined for random and fixed misorientations of the Centaur during the second burn.

Orbital lifetimes were obtained using the MSFC/LMSC Orbital Analysis Program, References IV-4 and IV-5, on a UNIVAC 1108 digital computer. The following data remained constant for all runs:

TABLE IV-8

ORBITAL PARAMETERS DURING VIKING '75
CENTAUR SECOND BURN

Time from Lift-Off (sec)	Weight (lb)	Perigee Altitude		Apogee Altitude		Comments
		(ft)	(km)	(ft)	(km)	
1579.27	34,024	586,300	178.70	659,142	200.91	Centaur MES 2 Pre-start
1614.27	33,898	586,249	178.69	669,336	204.01	Centaur MES 2
1649.00	31,678	588,729	179.44	4,238,902	1292.02	
1699.00	28,377	588,601	179.41	11,970,755	3648.69	
1749.00	25,076	591,341	180.24	25,368,907	7732.44	
1799.00	21,775	598,608	182.46	54,301,421	16,551.07	
1849.00	18,475	613,309	186.94	163,907,890	49,959.12	
1879.00	16,494	627,688	191.32	1,147,828,900	349,858.25	
1889.00	15,834	633,710	193.15	--		Hyperbolic Orbit
1899.00	15,147	640,506	195.23	--		
1925.38	13,342	662,793	202.02	--		Centaur MECO 2
1925.88	13,413	662,895	202.05	--		Orbit Injection

Launch date	August 17, 1975
Inclination	32.25 deg.
Earth radius (equatorial)	6378.165 km
Atmosphere	1697 Jacchia
10.7 cm solar flux	Nominal table dated March 15, 1972
Solar and lunar gravity	Not included
Ballistic parameters	Normalized (= 1.0)

Parametric lifetime data are presented in Figure IV-7. The data are normalized for a ballistic coefficient, $M/C_D A = 1$ (M = mass of vehicle in kg, C_D = drag coefficient, and A = area in m^2). For any given configuration, the actual orbital lifetime is obtained by multiplying the lifetime shown in Figure IV-7 by the $M/C_D A$ value of the configuration.

The date of launch has a significant effect on the orbital lifetime. For the given orbital conditions, perigee = 163 km and apogee = 80,000 km, and all other input parameters the same; the resulting lifetimes were:

<u>Date</u>	<u>Lifetime ($M/C_D A = 1$), days</u>
3/1/72 (Pioneer launch)	61.5
8/17/75 (Viking launch)	81.8

The launch time dependence of the orbital lifetimes is a function of solar and geomagnetic activity which effect the density of the upper atmosphere (120-700 km altitude). A running yearly mean of the solar flux is presented in Figure IV-8. It can be seen from Figure IV-8 that the Viking '75 launch date occurs when the solar flux is at its minimum value.

FIGURE IV-8. MSFC PREDICTED SOLAR ACTIVITY (3-15-72)

JH
5-11-72

b. Solar and lunar gravity effects

An orbital lifetime study for the Pioneer F launch conducted by NASA/MSFC, Reference IV-6, indicated that solar and lunar gravity effects caused significant variations in the orbital lifetimes from day to day, as well as compared with estimated orbital lifetimes excluding solar and lunar gravity effects.

The solar and lunar gravity subroutines were incorporated in the Orbital Analysis Program described in the previous section. However, trial runs did not check the results presented in Reference IV-6. The Teledyne Isotopes results are plotted on Figure 3 of Reference IV-6 and shown in Figure IV-9. These anomalous results have been discussed with cognizant personnel at NASA/MSFC. When the digital code yields consistent data, the solar and lunar gravity effects on orbital lifetimes will be evaluated for the Viking launch.

C. RESPONSE ANALYSIS

Various aerophysics studies were performed to evaluate environments resulting from potential Viking launch vehicle malfunctions and postulated reentry configurations into the earth's atmosphere.

Temperature and recession histories of the heat source were computed for an end-on reentry. This work is reported in Task 5 in connection with studies incorporating a vent tube in the SNAP 19 Viking RTG. For continuity, the results are repeated below.

Estimates of extremal, initial temperature conditions (resulting from an evacuated RTG in orbit) for the heat source, when released during reentry, are presented based upon Pioneer analyses. Predictive models are described according

FIGURE IV-9

Perigee = 163 Km; Apogee = 140,208 Km
Nominal Density Including Solar and Lunar Gravity

FIGURE 3. EFFECTS OF SOLAR AND LUNAR GRAVITY ON LIFETIME

to which conditional probabilities for occurrence of these events, given an abort, can be calculated.

1. Aerophysics Studies

a. Direct, multi-orbit and escape boundaries

The effect of ballistic coefficient ($W/C_D A$) on the boundaries between direct and multi-orbit reentries, and multi-orbit reentry and escape were determined. Since the Viking system is composed of various subsystem configurations (therefore, various $W/C_D A$'s) configuration and altitude have an effect on the above described boundaries.

For constant ballistic coefficient trajectories (invariant to altitude and Mach number) the UB088 digital code was used to determine whether or not the reentry configuration stayed in the atmosphere (direct reentry) or skipped out of the atmosphere (multi-orbit reentry or escape). UB088 is a three-dimensional, point mass trajectory code which solves the differential equations of motion during atmospheric flight by the Runge-Kutta numerical method. Reentry configurations represented by ballistic coefficients of 5, 50 and 100 were investigated.

For those configurations that skipped out of the atmosphere, the DEORBIT digital code was used to calculate the eccentricity (e) of the resulting conic. If $e < 1$, the conic is elliptic and the trajectory is a multi-orbit reentry. When $e \geq 1$, the conic is parabolic for $e = 1$ and hyperbolic for $e > 1$ and the resulting trajectory is classified as escape. In the DEORBIT code, the two-body vacuum planar equations are solved for an inverse-square, central-force gravitational field. Reentry was assumed to occur at an altitude of 400,000 feet.

Figure IV-10 shows the individual V, γ combinations and the resulting trajectories (direct, multi-orbit or escape) for the constant values of $W/C_D A$ investigated. The solid curves represent an estimate of the width of the boundaries. Figure IV-11 presents the estimated boundaries between direct and multi-orbit reentries, and multi-orbit reentry and escape trajectories at constant $W/C_D A$. Figure IV-11 indicates that the boundary width (uncertainty) for a given $W/C_D A$ varied between $1/4^\circ$ - and $1/2^\circ$ - degree over the range of velocities and angles studied. The maximum angle span for a constant velocity over the complete $W/C_D A$ range (5 to 100 psf) is approximately one degree.

b. Post-misorientation trajectory analysis

A preliminary abort analysis was performed on two reentry configurations: a powered Centaur (during second burn) plus the Viking spacecraft, the the Viking spacecraft by itself in the base cover leading altitude. Various initial values of velocity and flight path angle at an altitude of 400,000 feet were assumed. The resulting velocities and flight path angles for subsequent arbitrary release altitudes of the RTG are shown in Table IV-9. An aerothermal analysis will be performed to determine the breakup altitude of the RTG for the release conditions shown, which in turn will define the initial conditions for the release of the heat source.

2. End-on Reentry Temperatures

A study to investigate the influence of the vent tube on heat source temperatures during the end-on reentry mode as well as the influence of sleeve restraint materials and heating distributions is reported in Task 5. Pertinent results for the heat source in an end-on altitude and for orbital decay and superorbital trajectories are repeated below:

FIGURE IV-10 BOUNDARIES BETWEEN DIRECT AND MULTI-ORBIT REENTRIES,
AND MULTI-ORBIT REENTRY AND ESCAPE TRAJECTORIES
FOR CONSTANT BALLISTIC COEFFICIENTS.

UBOBB & DEORBIT CODE RESULTS

(a) $W/GA = 5 \text{ PSF}$

FIGURE IV-10 (CONTINUED)

(b) $W/GA = 50 \text{ PSF}$

FIGURE II-10 (CONCLUDED)

(C) $W/C_D A = 100 \text{ PSF}$

FIGURE II-11. SUMMARY OF BOUNDARIES BETWEEN DIRECT AND
MULTI-ORBIT REENTRIES, AND MULT-ORBIT REENTRY
AND ESCAPE TRAJECTORIES FOR CONSTANT BALLISTIC
COEFFICIENTS.

$W/GA(\text{PSF})$

FIGURE II-11 (CONCLUDED)

(b) MULTI-ORBIT REENTRY & ESCAPE BOUNDARIES

TABLE IV-9
INITIAL CONDITIONS OF THE ABORT TRAJECTORIES

Initial Configuration	<u>Initial Conditions</u>				<u>RTG Release Conditions</u>			
	h K ft.	V _I (K fps)	γ_I (°)	ψ_I (°)	h (K ft.)	V _I (K fps)	γ_I (°)	ψ_I (°)
1. Centaur (powered plus Viking S/C	400	30	-8	120	244	31	-8.9	120
					195	32	-9.1	120
					145	32	-9.3	121
2. Centaur (powered) plus Viking S/C	400	32	-5	120	249	34	-5.6	120
					200	34	-5.7	120
					149	35	-5.8	120
3. Viking S/C	400	26	-0.1	120	349	26	-0.2	98
					263	25	-0.6	111
					188	21	-2.3	114
4. Viking S/C	400	32	-5	120	249	32	-2.9	118
					200	29	-1.8	117
					149	16	-3.0	114
5. Viking S/C	400	35	-16		239	35	-15.0	120
					185	34	-15.0	120
					135	30	-15.0	120

	Orbital Decay	Super Orbital ($V_i = 38,000$ fps, $\gamma = -6^\circ$)
<hr/>		
Peak Temperature °F		
Heat shield	3804	5581
Clad	2757	3020
Strength Member	2662	2767
<hr/>		
Impact Temperature °F		
Heat Shield	686	-
Clad	2179	-
Strength Member	2348	-
<hr/>		
Stagnation Point Recession (in.)	.143	-

The vent tube had a negligible influence on heat source temperatures.

3. Initial Temperature Conditions

The preceding thermal response analysis was performed using nominal initial temperatures throughout the heat source. These temperatures apply approximately in the event that the RTG retains its cover gas until the point at which the heat source is released during reentry. A failure mode analysis performed for the Pioneer mission indicated that this was the most likely initial condition for the heat source temperature distribution.

On the other hand, should the cover gas be lost, during the interval of orbital capture, for example, temperatures internal to the RTG housing would increase significantly. Table IV-10 shows the change in temperature between operating and evacuated conditions of the RTG as calculated for the Pioneer heat source. The results are approximately valid for the Viking configuration as well.

TABLE IV-10
EQUILIBRIUM TEMPERATURE DISTRIBUTIONS IN THE HEAT SOURCE

<u>Component</u>	<u>Temperature °F</u>	
	<u>Operational</u>	<u>Evacuated RTG</u>
Fuel (centerline)	1660	3280
Liner (midplane)	1510	2980
Strength Member (midplane)	1460	2710
Clad (midplane)	1370	2280
Heat Shield (midplane)	1060	1280

These increased temperatures are expected to have a significant effect on maximum reentry temperatures for the heat source; accordingly, the probability of RTG gas loss for orbital capture events will be a useful quantity in estimating the risk of fuel release.

Two mechanisms giving rise to gas loss were considered: seal failure and micrometeoroid puncture of the RTG housing. These mechanisms and associated predictive models are discussed below.

a. Seal failure

The catastrophic seal failure probability density has been assumed to have Poisson structure. Thus the cumulative failure probability is

$$P_{SF} = 1 - e^{-\lambda_{SF} t}$$

The failure rate constant has been based on a catastrophic reliability allocation of 1500 ppm (Reference I-4) for the mission duration of 26 months.

$$\text{Hence, } \lambda_{SF} = \frac{1.5 \times 10^{-3}}{2.17 \text{ years}} = 6.92 \times 10^{-4} / \text{year}$$

The seal failure model will be updated as applicable reliability test data become available for simulated environmental conditions.

b. Micrometeoroid penetration

A probabilistic model, developed for Pioneer analysis, was revised to consider slant path incidence of the particles on the RTG housing and shielding factors (earth and spacecraft structure). The elements of this model include:

- A cumulative mass spectrum model for the micrometeoroid flux and a representation of its variance.
- A relationship between the penetrated thickness and meteoroid size, density, and impact speed, and an estimate of the variance in the penetration parameters.
- A method of estimating the target statistics, given a penetrating meteoroid flux.

These are discussed in the following:

(i) Cumulative mass spectrum

The mass spectrum for micrometeoroids in the near earth region is fitted in the form of

$$\phi_o = 2.43 \times 10^{-10} m^{-0.931}$$

where ϕ_o = flux of particles exceeding mass, m , ($\text{ft}^{-2} \text{ day}^{-1}$), and m = particle mass (gm).

For any specific flux value, the uncertainty in this value was described by a log normal density function of the form:

$$p(\phi) d(\ln \phi) = \frac{1}{\sqrt{2\pi} \ln \sigma} \exp \left[- \frac{(\ln \phi / \phi_o)^2}{2 (\ln \sigma)^2} \right] d(\ln \phi)$$

where $\ln \sigma = 1.96$

ϕ_o = nominal flux

ϕ = actual flux

(ii) The penetration law used was:

$$t = 0.65 \frac{d_m^{19/18}}{\epsilon_T^{1/18}} \left(\frac{\rho_m}{\rho_T} \right)^{1/2} V^{7/8}$$

where t = thickness of target material, (cm)
 d_m = meteoroid diameter, (cm)
 V = relative impact speed, (25 km/sec $\pm$ 10%)
 ρ_m = meteoroid density, (3.5 gm/cm³)
 ϵ_T = elongation of target material, (10%)
 ρ_T = target material density, (1.8 gm/cm³)

The penetration law and the impact speed were both assumed uncertain by 10% (normal distribution with a 10% standard deviation).

(iii) Target statistics

A Poisson distribution was assumed to determine the probability of impacting (and penetrating) the housing. Thus, if the exposed portion of the RTG has an Area, A , the expected number of hits is ϕAT and the probability of not penetrating the housing is $\exp(-\phi AT)$ where T is the time in orbit.

Monte Carlo analysis is employed to determine the penetration probability as a function of T , the orbital lifetime. A Monte Carlo history consists of the following steps:

- (i) Select v from a normal density.
- (ii) Select $\cos \theta$, where θ is the angle of incidence. (θ is a polar angle and its density is uniform with respect to the cosine θ in the range 0° to 88° .)
- (iii) Given v , compute the nominal mass m_{oi} which just penetrates each thickness, $\frac{t_i}{\cos \theta}$, experienced over the RTG housing. (The subscript i refers to the thickness, an area A_i is associated with each t_i .)

- (iv) Select m_1 from a normal distribution. m_1 is the actual penetration mass for the first material thickness. Form the fraction $\frac{m_1}{m_{o1}}$. Compute the remaining m_i as

$$m_i = m_{o_i} \cdot \frac{m_1}{m_{o1}} \quad i = 2, 3, \dots; I$$

- (v) For each m_i , compute ϕ_{o_i} .

- (vi) Select ϕ_1 from a log normal distribution. Compute the fraction $\frac{\phi_1}{\phi_{o1}}$.

Compute the remaining ϕ_i as

$$\phi_i = \phi_{o_i} \cdot \frac{\phi_1}{\phi_{o1}}$$

- (vii) Form the summation

$$\lambda = \sum_{i=1}^I \phi_i A_i$$

- (viii) Compute $S_F \lambda T_j$ for each specified time ($j=1, 2, \dots, J$)

where S_F is the shielding factor (that fraction of the RTG not shielded by the earth or structure from meteoroids).

- (ix) Select X from an exponential distribution.

- (x) Compare X to each $S_F \lambda T_j$ ($j=1, 2 \dots J$)

if $S_F \lambda T_j \leq X$, score a success for that time T_j

if $S_F \lambda T_j > X$, score a failure for that time T_j

Repetition of this process for a large number of histories, produces the failure distribution.

Typical results of this analysis are shown on Figure IV-12. It is seen here that the density function retains the characteristics of a log normal distribution. Over the range of interest (times less than 10^4 years) the distribution of $\log_{10}(\text{lifetime})$ is approximately normal with the following parameters:

	<u>Mean</u>	<u>Standard Deviation</u>
A. No shielding	3.75	1.23
B. Half shielded	4.03	1.23

The half shielded case is appropriate for Viking earth orbit analysis.

D. FUEL RESPONSE AND BIOLOGICAL IMPLICATIONS

GFE data on the PMC fuel form and capsule, which have accumulated since the Pioneer SAR, were reviewed critically for preparing an up-to-date analysis of fuel form response. The new data, principally from LASL, include both basic fuel properties and SSCS correlations of capsule response to various abort environments. The principal areas of new information since the Pioneer SAR are:

1. effect of vibration on respirable fines fraction;
2. capsule impact on soil;
3. Long-term aging of PMC fuel.

The significant environments identified for Viking, including consideration of the above new information, are summarized in Tables IV-11 through IV-13.

Additional explanation of the fuel response analysis for each environment is contained in a preliminary draft of Viking PSAR Volume III, the Safety Analysis Document.

IV-46
Log₁₀ T

TABLE IV-11

SIGNIFICANT LAUNCH PAD ENVIRONMENTS

Pre-launch and launch vibration
Sequential blast and fragmentation
10m solid propellant fire
100 ft/sec granite impact end-on
500 ft/sec soil impact end-on

TABLE IV-12

SIGNIFICANT ENVIRONMENTS FOR HIGH ALTITUDE EXPOSURE

Reentry Conditions: 137K ft, 27.2K ft/sec, -15.4°

Nominal
Exposure Mode

Graphite Stress Failure
(super-orbital decay)

Reentry Conditions: 104K ft, 4.0K ft/sec, -10.5°

Nominal
Exposure Mode

Graphite Recession
(Multi-orbit decay)

TABLE IV-13
SIGNIFICANT POST-REENTRY ENVIRONMENTS

Pre-launch and launch vibration

135 ft/sec granite impact
(bare disks)

135 ft/sec soil impact
(bare disks)

325 ft/sec granite impact side-on

325 ft/sec soil impact side-on

Partial burial and oxidation at 1450°F

GFE documentation on methods of estimating atmospheric transport and biological exposure was also received since the Pioneer SAR and was critically reviewed for Viking application:

1. M. A. Parsont et al, "Environmental and Demographic Data Summary for the Cape Kennedy Florida Vicinity," NUS-793, June 1971.
2. M. A. Parsont and J. R. Coleman, "Worldwide Environmental Summary, Part I: Demographic, Soils and Meteorological Data," SNS-NUS-932 (Draft), 30 June 1972.
3. J. R. Coleman and P. M. Altomare, "Atmospheric Dispersion and Inhalation Analysis for Plutonium-Fueled Space Nuclear Systems," SNS-NUS-827, September 1971.

The information in these three NUS documents will be the primary data base for completing remaining PSAR analysis.

E. UNCERTAINTY IMPLICATIONS

Effort has been initiated on evaluating the effect of errors in the various aerodynamic parameters on the temperature response of the Viking heat source. Two parameters considered to date are the hypersonic drag coefficient and atmospheric density. Both of these quantities were varied ± 25 percent from their nominal values. Since the exterior geometry of the Viking heat source is the same as that for the Pioneer heat source, the hypersonic drag coefficient was obtained from Reference III-1. The nominal drag curve together with curves representing variations of ± 25 percent is shown in Figure IV-13.

With the UB088 digital trajectory program, it is inexpedient to vary the atmospheric density directly. Rather, the effect of varying density was accomplished by using the appropriate drag curve and varying the heating factor by either $(1.25)^{1/2}$, 1.0 or $(0.75)^{1/2}$. The stagnation convective heating rate varies as the square root of the atmospheric density. Calculated stagnation pressure values were multiplied directly by the error factor to reflect the change in density.

Trajectories incorporating the above variations are about to be run. The results and the effect on the temperature response of the heat source will be described in the next report.

VIKING ERROR ANALYSIS

FIGURE IV-13 HYPERSONIC DRAG COEFFICIENT VS ALTITUDE FOR THE VIKING HEAT SOURCE IN SIDE-ON, FLAT-LEADING ATTITUDE.

$$A_{REF} = l \cdot b = 0.163 \text{ FT}^2$$

$$l (\text{LENGTH}) = 6.712 \text{ IN.}$$

$$b (\text{DISTANCE ACROSS HEXAGONAL FLATS}) = 35 \text{ IN.}$$

V. TASK 8 - QUALITY ENGINEERING

Three meetings were held at Teledyne Isotopes including participating representatives from AEC Project Management, AEC Quality Branch of the Safety and Reliability Group, and Sandia Corporation in order to review the format and contents of the Quality Program Plan. As a result of these meetings, the format of the Plan was entirely restructured and many of the criticisms and suggestions of the reviewers were incorporated into the Plan. The Quality Program Plan (ESD-2960-38B) was subsequently approved by the AEC as Part B of the Product Definition Plan. The Plan includes ten Quality Procedures that define broad quality policy, and fifteen Quality Directives that contain detailed instructions to Quality Operations personnel defining their duties and responsibilities. Thirteen of these Quality Directives were reviewed internally and updated to reflect current practice. To increase the extent of conformance with the applicable AEC quality document (SNS-1, dated October 1971), two Quality Directives (Q.D. 5.5, Quality Planning Documentation and Q.C. 3.7, Corrective Action Board System) were created to document and detail existing activities.

A. DOCUMENT REVIEW

As a result of instituting Quality Directive 2.2 "Review of Technical Documents" on the Viking program, all new and revised drawings are now reviewed and approved by Quality Engineering prior to release.

Procurement documents continue to be reviewed, approved and coded for proper certifications and test requirements. Current Procurement Department procedures that interface with Quality Operations activities were edited to bring them up to date with current practices. The procedures were subsequently reviewed with Procurement to settle on properly descriptive wording. A formal revision of the

procedures by Procurement is planned after the start of the next contractual phase.

B. NON-CONFORMANCE REPORTING AND MATERIAL REVIEW BOARD

A Corrective Action Board (CAB) is in effect at Energy Systems Division whose activities include the functions of a Material Review Board. All discrepancies not receiving a scrap or rework disposition by Quality Engineering are forwarded to the CAB for final disposition and appropriate corrective action to diminish or eliminate the possibility of recurrence. A detailed description of the system used to process non-conforming articles and materials may be found in the Quality Directives contained in the Product Definition Plan.

A Corrective Action Status Report to Teledyne Isotopes, Energy Systems Division management was instituted in response to the requirements of Quality Directive 3.7. This report summarizes open corrective action items which result from non-conformance listed on Isotopes Reporting System tags and assigns responsibility for their completion. A single report is used for both the Viking and Pioneer programs.

C. CERTIFICATION AND CALIBRATION

Detailed activities in effect to control the certification of employees having special skills and certification of equipment are described by Quality Directives 9.1 and 7.1, respectively.

A list of Energy Systems Division measurement and test equipment which requires calibration under the provisions of Quality Directive 7.1 was prepared for use by the Standards and Calibration section of Quality Control.

Auditing of Energy Systems Division activities as required by Quality Directive 5.3 was initiated during this contractual period. The initial audit covered the employee skill certification as defined in Quality Directive 9.1.

VI. REFERENCES

<u>Reference</u>	<u>Title</u>
I-1	"Viking 75 Project Radioisotope Thermoelectric Generator Specification," M75-135-0, January 7, 1972 (draft copy).
I-2	"SNAP 19 Viking Lander System Program - Program Plan," ESD-2960-39, April 15, 1972.
I-3	"SNAP 19 Viking Lander System Program - Product Definition Plan," ESD-2960-38, May, 1972.
I-4	"SNAP 19 Viking Parametric Performance Study," INSD-2960-28, December 17, 1971.
I-5	"Operational Data for Viking Generators S/N 101 and S/N 102 as Received from the Martin Marietta Corporation," S19V-WS-154, March 28, 1972.
I-6	"SNAP 19 Viking Parametric Performance Study, Addendum A," INSD-2960-28, July 24, 1972.
I-7	"Viking RTG Thermal Analysis," Martin Marietta Corporation Report TN3370156, January 28, 1972.
I-8	"RTD Failure Diagnostic and Report of Findings," SN19-SR-470, July 19, 1971.
II-1	Brouns, Robert C., letter to Vincent G. Redmond, "Temperature Time Histories for RTG Electrical Connector," 159/PL-4013-RCB, February 16, 1972.
III-1	"SNAP 19 Pioneer F Safety Analysis Report, Vol. II, Accident Model Document," INSD-2873-42-2, June, 1971.

VI. REFERENCES (Cont'd)

<u>Reference</u>	<u>Title</u>
IV-1	"Viking Project, Launch Vehicle Mission Design," General Dynamics Report No. GDC-BKM70-035-3, November, 1971.
IV-2	Stofan, A. J., "Preliminary Launch Vehicle Data to Support Viking Safety Analysis Report (SAR)," Lewis Research Center Letter 9321 (GJS), February 25, 1972.
IV-3	Willoughby A. B., Wilton, C. and Mansfield J., "Liquid Propellant Explosive Hazards - Vol. 3," AFRPL-TR-68-92, December, 1968.
IV-4	McNair, Ann R. and Boykin, Edward P., "Earth Orbital Lifetime Prediction Model and Program," NASA TM X53385, February 1, 1966.
IV-5	Brakensiek, R. R., "User's Manual for the UNIVAC 1108 MSFC/LMSC Orbital Analysis Program," Lockheed Report LMSC/HREC D162647 (TM-54/30-238), March, 1971.
IV-6	NASA/MSFC Letter S & E-AERO-MM-78-71 (P. Dreher to M. I. Haar) Subject: Lifetimes for Highly Elliptic Orbits, dated December 3, 1971.