SNAP 19

VIKING LANDER SYSTEM PROGRAM

MASTER

FINAL REPORT

JULY 1, 1970—JUNE 30, 1976

TES-3069-54

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DEVELOPMENT ADMINISTRATION UNDER CONTRACT E (49-15) 3069

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I. INTRODUCTION

The primary objective of the Viking Lander mission is to obtain scientific data on the characteristics of the Martian surface and surrounding atmosphere in order to significantly increase our knowledge of this planet. The Viking Lander provides the necessary scientific test instrumentation for obtaining data relevant to the search for life on Mars.

Two Titan III E/Centaur D-IT flight vehicles were launched from the Eastern Test Range, with the goal of placing two Viking spacecraft, each consisting of an Orbiter and Lander, on a nominal Mars interplanetary cruise trajectory. Because of unknown meteorological conditions on the Martian surface, the electrical power source for the Lander was required to exhibit minimum vulnerability to environmental extremes and very high reliability. Two Teledyne Energy Systems SNAP 19 radioisotope thermoelectric generators (RTG's) were selected to provide the continuous 70 watts(e) minimum electrical power required for the Viking Lander mission. These generators evolved from the Pioneer F and G RTG's which have successfully journeyed to and beyond the planet Jupiter.

The major components of the Viking spacecraft are shown in Figure I-1. Also depicted is the Orbiter configuration after Lander separation and the Lander in the Mars surface operational mode. Since the RTG waste heat from the thermoelectric conversion process is utilized for Lander thermal control, wind covers protect the RTG's from over-cooling by the Martian winds. Below is a summary listing of the investigations and instrumentation for accomplishing the Viking mission objectives:

FIGURE I-1. MAJOR COMPONENTS OF VIKING SPACECRAFT

INVESTIGATIONS

INSTRUMENTS

Orbiter

Imaging	2 TV Cameras
Water Vapor Mapper (Atmospheric)	Infrared Spectrometer
Thermal Mapper (surface temperature)	Infrared Radiometer

Entry

Atmospheric Composition	} One Science Topic }	Mass Spectrometer, Retarding Potential Analyzer, Pressure and Temperature Sensors, Accelerometers and Radar Altimeter
Atmospheric Structure		

Lander

Imaging	Fascimile Cameras, Color/Stereo Capability
Biology	3 Analyzers for Photosynthesis, Metabolism and Respiration
Molecular Analysis (organic)	Gas Chromatograph Mass Spectrometer (GCMS)
Mineral Analysis (inorganic)	X-Ray Fluorescence Spectrometer
Meteorology	Pressure, Temperature, Wind Velocity and Wind Direction Sensors
Seismology	3-Axis Seismometer
Magnetic Properties of Soil	Magnet Array on Soil Sampler; Cameras Used for Visual Study of Particles
Physical Properties of Soil	Analysis of Visual and Engineering Data from Applicable Instruments and Experiments <ul style="list-style-type: none">• Cameras - Visual Study of Soil Characteristics (e.g., clumping, grain size, cohesion, adhesion, etc.)• Soil Sampler - (with cameras) Engineering Force Measurements, Porosity Bearing Strength

Radio

Orbiter/Lander Location, Atmospheric and Planetary Data, Interplanetary Medium	Orbiter/Lander Radio and Radar Systems
--	--

II. RTG MISSION DEFINITION

The Viking mission utilized the August/September 1975 opportunity to launch two spacecraft to Mars for arrival in 1976 after about a one-year transit period. Upon achieving Mars orbit, each spacecraft, consisting of an Orbiter and Lander, will perform reconnaissance of proposed landing sites. When a suitable landing site has been selected, the Lander will separate from its Orbiter and descend to the Martian surface. The Orbiters will remain operational in orbit for data relaying and for further scientific investigations including surface mapping. The two Landers carry scientific instruments for visual examination of the selected landing site, characterization of the Martian atmosphere, temporal variations, wind velocity, organic compounds and ground movements.

A. ELECTRICAL PERFORMANCE/RELIABILITY REQUIREMENTS

Two SNAP 19/2N-TAGS thermoelectric generators serve as the basic power source for the scientific instrumentation on each Viking Lander. A total of five (5) flight RTG's (two RTG's for each Lander and one back-up RTG) were fabricated for the Viking mission under contract to the U. S. Energy Research and Development Administration (ERDA). Each Viking RTG is designed to produce a minimum of 35 watts of electrical power at the end of 90 days of Mars surface mission operations with a performance probability ≥ 0.99 (exclusive of meteoroid penetration). The end-of-mission (EOM) power performance goal is based on a load voltage of 4.4 volts DC and a fin root temperature of 330°F. In order to meet the EOM power requirement, the RTG's were delivered with a beginning-of-life (BOL) power in the range of 40.5 to 47 watts(e) while satisfying the weight limitation of 35 pounds (maximum).

B. RTG MISSION PROFILE

The specified 26 month (maximum) mission duration for the Viking RTG commences with the installation of the radioisotope fuel capsule into the generator and concludes with a successful 90 day (maximum) Mars surface operation. Table II-1 defines the maximum times and temperature conditions for significant activities of the mission profile.

TABLE II-1
MISSION PROFILE

<u>Mission Phase</u>	<u>RTG Status</u>	<u>Maximum Time</u>	<u>Maximum Average Fin Root Temperature</u>
Acceptance	Load	1 month	330° F
Preflight checkout*	Load	150 hours	330° F
Post-acceptance storage	Shorted	6 months	250° F
Sterilization	Shorted	150 hours	360° F
Preflight storage	Shorted	1.6 months	250° F
Interplanetary cruise and orbit	Shorted	14 months	360° F
Checkout and entry	Load	40 hours	360° F
Mars surface	Load	90 days	330° F

* The preflight power check will be accomplished after RTG delivery to ERDA, but for convenience it is considered as an extension of the initial Teledyne Energy Systems acceptance testing.

Detailed characterization of performance prior to delivery of the generators to NASA was accomplished in the acceptance test sequence consisting of:

- Parametric (voltage-current mapping)
- Hot Leak
- Vibration
- Series Functional
- Radiation Survey

A span time of about three months was required to complete the acceptance testing.

The five flight RTG's were then transported in their shipping containers to the Eastern Test Range (ETR) via ERDA supplied transportation. The flight RTG's arrived at ETR approximately six months prior to launch and were placed in a controlled storage area for safe keeping. After four months in storage, the RTG's were subjected to a preflight checkout program lasting nearly 150 hours. The RTG's were then integrated into the appropriate spacecraft with RTG's S/N 111 and S/N 112 being installed on Viking Lander Capsule (VLC) 1 and RTG's S/N 113 and S/N 114 being installed on Viking Lander Capsule (VLC) 2. After integration was completed, each Lander was encapsulated in a biobarrier and subjected to a sterilization process lasting approximately 150 hours. The RTG's, in the sealed biobarrier, were stored at the sterilization site prior to being mated to the Viking launch vehicle.

Both Viking spacecraft were successfully launched during the August/September 1975 time frame and have both achieved nominal Mars cruise trajectories. The RTG's will be subjected to 14 months (maximum) of interplanetary cruise and Mars orbit operating conditions. Once the landing site has been selected, the RTG's will be placed on load prior to starting the landing descent. After touchdown, the RTG's remain on load for a minimum of 90 days for conduction of the numerous scientific investigations performed by the Lander instrumentation. It is during this Mars surface operation that the RTG's must provide a minimum of 70 watts of electrical power to the Lander instrumentation.

III. RTG-TO-VLC INTERFACE REQUIREMENTS

A. MECHANICAL INTERFACE

The Viking RTG design is basically that of the previous Pioneer flight generators. Configuration changes for the Viking RTG are related to the Viking-peculiar mission requirements, in particular, the Lander mechanical and thermal integration considerations. Table III-1 presents a listing of the significant differences between the Viking and Pioneer designs. The heavier weight and larger overall size of the Viking RTG results principally from the increased radiator area necessary for waste heat rejection to the more severe Viking mission thermal environments. The thickened RTG housing is necessary to enhance waste heat conduction to the Lander for thermal control of the temperature-sensitive Lander equipment. The higher initial fuel inventory, initial RTG fill gas mixtures and gas management schemes were modified from those of Pioneer to provide maximum end-of-mission power while maintaining Pioneer-level heat source temperatures during the ground handling and prelaunch mission phases.

1. Weight and Center of Gravity

A total of seven RTG's were fabricated for the Viking program of which S/N 105 and S/N 106 are flight prototype units and S/N 111, S/N 112, S/N 113, S/N 114 and S/N 115 are flight level units. The average weight for the seven RTG's is 33.5 pounds (excluding any power output cables) which is well below the maximum interface requirement of 35.3 pounds. The center of gravity location was determined experimentally for the flight prototype RTG's (i. e., S/N 105 and S/N 106) only. The center of gravity coordinates for either RTG were found to lie 5.8 inches above the mounting plane (negative X direction) at the intercept of minus 0.02 inch Y and minus 0.02 inch Z. The slight displacement of the center of gravity in the negative Y direction is caused by the asymmetrically located power output receptacle, and the displacement in the negative Z direction results from the off-center installation of the pressure transducer in the lower cover. The experimentally determined RTG center of gravity location satisfies the interface requirement of 5.8 ± 0.25 inches in the negative X direction and 0 ± 0.25 inch in both the Y and Z directions.

2. Envelope Dimensions

The RTG mechanical interface drawing shown in Figure III-1 defines the external envelope configuration necessary to accommodate integration into the Viking Lander. The RTG

TABLE III-1

RTG COMPARATIVE DESIGN DESCRIPTION

	<u>SNAP 19 Pioneer</u>	<u>SNAP 19 Viking</u>
Overall Size (dia x lg) ¹ (in.)	20.0 x 11.2	23.0 x 11.3 (15.6)
Generator Weight (lbs)	30	34
BOL Power Output (watts(e))	40	42
BOL Fuel Inventory (watts(t))	645	682
BOL Pu-238 Inventory (curies)	19,500	20,600
Heat Shield Length (in.)	6.500	6.792
Capsule Length (in.)	4.797	5.009
Capsule Inner Liner Thickness (in.)	0.005	0.009
Capsule Weight (lbs)	7.6	8.0
T/E Converter Initial Gas Fill (%)	75 He/25 Ar	90 He/10 Ar
Dome Reservoir Initial Gas Fill (%)	Not Applicable	5 He/95 Ar
Capsule Cover Gas	Capsule exposed to T/E converter fill gas	
Heat Shield Getter Recess	No	Yes
End Cover Attachment	Bolted/Seal-Weld	Lock Ring/Seal-Weld
Electrical Receptacle Seal	Single Viton O-Ring	Dual Viton O-Rings
Dome Reservoir-to-T/E Converter Seal	Not Applicable	Single Viton O-Ring

¹ Diameter is across fin tips; length is mounting flange-to-mounting flange except value in parentheses for Viking is overall length including dome reservoir and pressure transducer boss on lower cover.

DIMENSION	ITEM	MAXIMUM INTERFACE DIMENSION	ACTUAL BASELINE DESIGN (MAXIMUM)
A	OVERALL DIAMETER	23.1	23.02
B	FLANGE-TO-FLANGE HEIGHT	12.0	11.352
C	OVERALL HEIGHT	15.925	15.622

FIGURE III-1. RTG INTERFACE DIMENSIONS

overall diameter is the maximum tip-to-tip distance across diametrically opposite radiator fins. The RTG flange-to-flange height is the maximum distance from the upper mounting flange to the lower mounting flange on the generator housing. The RTG overall height is the maximum distance from the top of the reservoir dome to the pressure transducer boss extension below the generator lower flange. The actual baseline design maximum values which include manufacturing tolerances are seen to satisfy the spacecraft requirements.

3. Mounting Provisions

The details of the RTG attachments to the Viking Lander are defined in Figure III-2. Prior to the installation of the Viking RTG's on the Lander, each RTG is fitted with an upper and lower end cap cooler assembly. The Martin Marietta Aerospace (MMA) supplied end cap coolers (ECC) are designed to remove waste heat from the RTG's prior to launch. The end cap coolers are bolted directly to the RTG upper and lower mounting flanges with the lower end cap cooler also attached to the Lander structure. Prior to launch, coolant flows through both end cap coolers thereby producing reduced RTG fin root temperature. After launch, the flow of heat from the RTG to the Lander is controlled by a thermal switch located between the lower end cap cooler and the Lander structure. This switch is used to maintain thermal control of the temperature-sensitive Lander equipment compartment during the interplanetary cruise portion of the mission.

4. Generator Fill Gas Leakage

The Viking RTG's employ a dual O-ring configuration to provide a gas seal between the power output receptacle and the generator housing. Since all other closures are welded, practically all gas leakage is controlled by the permeation rate of the gas (90% He/10% Ar) constituents through the O-ring seal configuration. The average helium leak rate for the five flight RTG's is 1.6×10^{-5} scc He/sec-atm for a fin root temperature of 360°F during interplanetary cruise operation. The maximum measured helium leak rate of 1.8×10^{-5} scc He/sec-atm (highest of the flight RTG's at 360°F) corresponds to a maximum argon leak rate of 8.2×10^{-7} scc Ar/sec-atm. This argon leakage rate is well below the specified maximum permissible value of 1×10^{-5} scc Ar/sec for an external pressure of 1×10^{-5} torr or less.

FIG. III-2. RTG/VLC MOUNTING CONFIGURATION

B. ELECTRICAL INTERFACE

The flight generators are connected in series in order to provide larger input voltage to the DC-DC converter of the Lander. The specified steady-state power output of the series generator pair, at delivery with an average fin root temperature of $330 \pm 5^{\circ}\text{F}$ and $8.8 \pm 0.2\text{ VDC}$, is in the range of 81 watts(e) minimum to 94 watts(e) maximum. The electrical interface between the generator and the Lander system is at the generator power output receptacle.

1. Operating Voltage

For all non-operating periods, the flight RTG's are maintained in a short-circuited condition with a load voltage $\leq 1\text{ VDC}$. During operating periods, the RTG's are operated with a load voltage no greater than 4.5 VDC with peak power occurring at 4.4 VDC.

2. Electrical Receptacle

The electrical receptacle used on Viking generators is a 26 pin hermetically sealed Deutsch bayonet lock receptacle (Deutsch Co. P/N 78033-16-26 PN). Twenty pins are used for power transmission and the remaining six pins are available for instrumentation signals. Figure III-3 shows the receptacle pin assignments. All receptacle pins are electrically isolated from the generator housing by a minimum of 5 megohms resistance as measured with 50 VDC potential at room temperature.

All electrically heated generators (ETG's) have, in addition to the power output receptacle, a similar receptacle which is used to provide power to an electrical heater block. The heater input power receptacle, located in the generator upper cover, is mated to a permanent heater input power cable which exits through the reservoir-simulating dome. Figure III-4 shows the heater receptacle pin assignments.

3. Hazard Monitor Receptacle

Each generator has an external fin root temperature sensor (thermistor) located on the housing body. The thermistor is located on the cylindrical portion of the housing just above the lower mounting flange approximately 120° circumferentially from the power output receptacle. The thermistor bead is cemented into a slot in the housing with its leads terminating in a two pin electrical receptacle. The MMA supplied receptacle (MMA P/N CSV81D127RB) is mounted on the radiator fin immediately adjacent to the generator power output receptacle.

View Looking at Mating Face of Pin Connector
Pin "A" Toward Mounting End of Generator

FIG. III-3. POWER OUTPUT RECEPTACLE PIN ASSIGNMENTS

View Looking at Mating Face of ETG Power Input Cable Receptacle
(Deutsch Co. Part No. U54-16-26N-059 or equivalent).

FIG. III-4. HEATER INPUT POWER RECEPTACLE PIN ASSIGNMENTS

4. Generator Instrumentation

All generator sensor (i. e. , hot junction RTD, fin root thermistor and the pressure transducer) signals, excepting the hazard monitor thermistor, are available at the power output receptacle. The Lander system conditions the signals from these sensors for subsequent telemetering.

C. THERMAL INTERFACE

When the flight RTG's are mated to the Lander structure, a thermal control subsystem adjusts the waste heat path to maintain Lander components within acceptable temperature limits during the Viking mission. In addition, the RTG's are enclosed in wind covers to reduce wind induced heat losses during Martian surface operation of the Lander.

1. Radioisotope Fuel Loading

To satisfy all aspects of the Viking mission environment, the Lander thermal control system is designed to accommodate RTG's with thermal inventory of $675 \begin{smallmatrix} + 10 \\ - 15 \end{smallmatrix}$ watts(t) per generator (at delivery). In accord with the thermal and electrical power requirements, each RTG is fueled with 682 ± 3 watts(t) of Plutonium-238 in the form of plutonium molybdenum cermet (PMC) discs.

2. Housing/Radiator Thermal Design Point

The Viking generator is designed to operate with a $330 \pm 10^\circ\text{F}$ fin root temperature when exposed to a 100°F totally absorbing radiation sink under full electrical load (4.4 ± 0.1 VDC).

3. Mission Temperature Profile

The RTG's will be subjected to the thermal environments outlined in Table III-1 during the Viking mission. The maximum allowable generator fin root temperature during steady-state load conditions is 340°F . The generators may be operated on load at a maximum fin root temperature of 360°F for an accumulated time not exceeding 50 hours. During all non-operating periods (load voltage ≤ 1 VDC) the fin root temperature shall be in the $340^\circ\text{F} - 365^\circ\text{F}$ range.

4. Emissive Coating Properties

The generator housing, fins and reservoir dome exterior surface are sprayed with an emissive coating to augment radiation heat transfer. The coating, which is zirconium oxide in a sodium silicate binder, is applied over the specially prepared surfaces to a thickness of $0.002 - 0.008$ inches. The coated surface has an emissivity of approximately 0.90 and a solar absorptivity of approximately 0.20.

TABLE III-1 - THERMAL ENVIRONMENTS

<u>MISSION PHASE</u>	<u>ENVIRONMENTS</u>	<u>CONDITION</u>	<u>COMMENT</u>
1. Presterilization	<p>* Radiation-Sink temperature of $75^{\circ}\text{F} \pm 20^{\circ}\text{F}$</p> <p>Conduction-End flanges cooled to $85^{\circ}\text{F} \pm 15^{\circ}\text{F}$. Transient temperatures are set by the fluid loop (see para. 3.4.4) Surface under RTG adiabatic.</p> <p>Convection-N₂ at 1 atm at $90^{\circ}\text{F} \pm 20^{\circ}\text{F}$. (natural convection)</p>	RTG short circuited or operating.	A minimum of 75 percent of the RTG thermal loading must be conducted out of the end flanges for the conditions specified. A maximum of 45 percent of the thermal loading shall be conducted from a single end flange.
2. Sterilization	<p>* Radiation-Sink temperature of $254 \pm 3^{\circ}\text{F}$</p> <p>Conduction-End flanges controlled to a maximum temperature of 325°F. Surface under RTG adiabatic.</p> <p>Convection-N₂ at 1 atm at 310°F (natural convection)</p>	RTG short circuited	
3. Post-sterilization	Same as 1	Same as 1	Same as 1
4. Launch to Trans Mars Insertion	Transient from environment 3, just after water flow shutdown (see para. 3.4.4), to environment 5 in a minimum of 0.5 hours. N ₂ pressure drops from 1 atm to hard vacuum in 5 min. End cap cooling is disconnected at launch.	RTG short circuited	RTG will experience transient temperature response resulting from environmental conditions specified.
5. Interplanetary Cruise and Mars Orbit	<p>* Radiation-Sink temperature 200°F maximum.</p> <p>Conduction - 20 watts maximum out of the lower flange.</p>	RTG short circuited.	

* RTG mounted on an adiabatic surface which extends at least two feet in diameter.

TABLE III-1 (Continued)

<u>MISSION PHASE</u>	<u>ENVIRONMENTS</u>	<u>CONDITION</u>	<u>COMMENT</u>
5a. GCMS Bakeout Sequence (8) (MOI -93 days) (MOI -87 days) (MOI -81 days) (MOI -75 days) (MOI -66 days) (MOI -60 days) (MOI -54 days) (MOI -48 days)	Radiation-Sink temperature 200° F maximum. Conduction -20 watts maximum out of lower flange.	RTG on load	8 each RTG load cycles of 7 hours duration each.
6. Maneuvers	Radiation-Sink temperature increased to 280° F for 3 hours. Conduction -20 watts maximum out of the lower flange.	RTG short circuited.	
7. Preseparation checkout to entry. Maximum time 30 hours	Same as 5	RTG under load	
8. Deorbit	* Radiation-Sink temperature - linear change from initial conditions prior to deorbit to 270° F $\pm$ 5° F at a rate of .5 $\pm$.1° F/sec. Maintain 270° F $\pm$ 5° F for 28 minutes. Conduction - 20 watts maximum out of the lower flange.	RTG under load	
9. Mars Surface	a) Hot Case - * Radiation-Sink temperature of 170° F $\pm$ 5° F. Conduction - 15 watts maximum out of the lower flange. Convection - 31 watts maximum to surrounding gas. b) Cold Case - * Radiation - minus 145° F $\pm$ 5° F. Conduction - 110 watts minimum to the lower flange. Convection 60 watts minimum to the surrounding gas.	RTG under load	

* RTG mounted on an adiabatic surface which extends at least two feet in diameter.

TABLE III-1 (Continued)

<u>MISSION PHASE</u>	<u>ENVIRONMENTS</u>	<u>CONDITION</u>	<u>COMMENT</u>
	c) Temperature Cycling - The RTG shall be capable of operating as specified herein with temperature cycling between environment (a) and (b) above a maximum of four times in a Mars day.		Mars day is 24.6 hours. Total time on Mars surface is 90 days.
	d) Thermal Switch Operation - A thermal switch is attached to the base of the RTG and is thermostatically controlled by lander interior temperature. The switch will take a maximum average of 100 watts from the base of the RTG. The switch has a maximum conductance of 1.5 watts/°F and is coupled to a minimum lander temperature of 50°F. The switch will cycle a maximum of 10 times per Mars day simultaneously with environments (a), (b) or (c) above.		

IV. GENERATOR DESCRIPTION

The generators fabricated for the SNAP 19 Viking program were designated Radioisotopic Thermoelectric Generators (RTG's) and Electrically heated Thermoelectric Generators (ETG's). A total of fifteen generators were fabricated of which seven are RTG's and the remaining eight are ETG's. The generators which were serialized S/N 105 and S/N 106 served as RTG prototype test generators, and those which were serialized S/N 111 through S/N 115 served as flight or flight backup generators. The ETG's which were serialized S/N 100 through S/N 104 and S/N 107 through S/N 110 served as engineering prototype generators.

A. PROTOTYPE AND FLIGHT RTG'S

Seven RTG's were built for the SNAP 19 Viking program; two were designated prototype generators; one is a flight backup generator; and four are flight generators aboard Viking Lander Capsules #1 and #2. A typical SNAP 19 Viking RTG is shown in Figure IV-1. The generator is composed of four major subsystems; the radioisotopic heat source, the thermoelectric converter, the housing/radiator assembly, and the instrumentation. Table IV-1 gives design characteristics of the four major subsystems.

1. Radioisotopic Heat Source

The radioisotopic heat source employs a four-layer, vented capsule enclosed in a right hexagonal prism graphite reentry body as shown in Figure IV-2. The heat source is designed for intact reentry through aerothermal heating, and fuel retention upon earth impact. The plutonium-238 oxide fuel is enclosed by an outer and inner liner fabricated from Ta-10%W and Mo-46% Re, respectively. A strength member of T-111 completely surrounds the outer liner providing structural integrity of the fuel capsule upon earth impact. An oxidation resistant Pt-20% Rh outer clad provides strength member protection during fuel capsule handling and RTG fueling activities. To prevent a pressure buildup in the capsule, a pressure release device allows the helium gas generated by fuel decay to be vented. The heat source initial thermal inventory is nominally 682 watts. A detailed description of the major heat source components is given below:

The fuel is plutonia-molybdenum cermet (PMC) hot pressed into discs. Based on a nominal thermal inventory of 682 watts at BOL, each capsule contains 20,600 curies of fuel. Prior to being

U.S. ATOMIC ENERGY COMMISSION SNAP 19 RTG VIKING A&B

FIGURE IV-1. SNAP 19 VIKING FLIGHT RTG CONFIGURATION

TABLE IV-1

VIKING RTG DESIGN CHARACTERISTICS

Housing/Radiator Assembly

Configuration	Finned cylinder with dome reservoir
Material	MgTh (HM21A)
Type gas seal	Seal-welds
Emissive coating	Zirconia with sodium silicate binder
Housing dimensions	
Minimum cylinder OD (in.)	6.44
Minimum cylinder wall thickness (in.)	0.093
Flange-to-flange length (in.)	11.3
Overall diameter, including fins (in.)	23.0
Overall length, including dome and lower cover boss (in.)	15.6
Number of fins	6
Fin dimensions	
Length, root-to-tip (in.)	8.25
Height (in.)	10.44
Root thickness (in.)	0.25
Tip thickness (in.)	0.03
Reservoir initial gas fill	5% He/95% A
Reservoir-to-thermoelectric converter seal	Single Viton O-ring and seal welds

Thermoelectric Converter Assembly

Conversion materials	TAGS-85/2N
Number of thermoelectric modules	6
Number of thermoelectric couples	90
N-element dimensions	
Diameter (in.)	0.377
Length (in.)	0.500
P-element dimensions	
Diameter (in.)	0.270
Length (in.)	0.100 SnTe + 0.400 TAGS
Thermal insulation	Johns-Manville Min-K Type 1301
Number of parallel-series strings	2
Cold-end hardware	
Material	Aluminum, SS springs
Number of heat sink assemblies	6
Power output receptacle gas seal	Dual Viton O-ring and seal welds
Thermoelectric converter initial fill gas	90% He/10% A
Hydrogen "getter" material	Zirconium
Heat shield	
Configuration	Right hexagonal prism with three concentric cylindrical sleeves
Materials	POCO AXF-Q1 graphite hexagonal prism; pyrolytic graphite cylindrical internal sleeves
Radioisotopic fuel	PuO ₂ (plutonia molybdenum cermet fuel form)

TABLE IV-1 (Continued)

Radioisotopic Heat Source Assembly

Fuel capsule	
Configuration	Four-layer, vented capsule
Inner liner	Mo-46% Re
Outer liner	Ta-10% W
Strength member	T-111
Outer clad	Pt-20% Rh

Instrumentation

Hot junction temperature sensor	Platinum resistance temperature detector (RTD) attached to thermoelectric couple hot shoe.
Fin root temperature sensor	Thermistor (glass encapsulated bead) mounted in a slot machined into inside cylindrical surface of the housing.
Converter pressure sensor	Potentiometric pressure transducer mounted in lower cover of generator.
Hazard Monitor sensor	Thermistor (glass encapsulated bead) mounted in a slot machined into the outside cylindrical surface of the housing.

FIGURE IV-2. VIKING HEAT SOURCE

loaded into the inner liner and liner, the stack of discs is established for the total thermal inventory requirement and must meet the requirements of a geometric envelope. Shims of pure molybdenum sheet are added to the fuel stack as required to satisfy the envelope requirement.

The molybdenum-46% rhenium inner liner consists of two hydroformed shells which slip fit and overlap each other. The inner liner, which completely encloses the fuel stack, is nominally 0.009 inch in thickness.

The tantalum-10% tungsten liner is fabricated from 0.020 inch thick stock. The liner is the primary fuel encapsulant and provides easy decontamination during fuel capsule assembly. The liner is fitted at one end with a pressure release device for the venting of gases generated by the fuel decay.

The T-111 strength member is fabricated from 0.090 inch thick stock. The strength member, which has two 0.004 inch diameter gas vent holes, is assembled over the liner and closed by a circumferential TIG weld. The strength member is designed to maintain fuel encapsulation in the event of adverse launch abort conditions.

The platinum-20% rhodium capsule clad is fabricated from 0.018 inch thick stock. The noble metal shell, which has a 0.020 inch diameter gas vent hole, is designed to act as an oxidation barrier to the other fuel capsule components during fuel capsule handling and RTG fueling activities.

Two zirconia load rings are used to provide a firm mount for the fuel capsule within the heat shield. The load rings bear against the hemispherical ends of the capsule and the shear rings of the heat shield end plugs.

Three concentric pyrolytic graphite sleeves surround the fuel capsule within the heat shield. The sleeve assembly, which is 0.200 inch in thickness, is designed as a thermal barrier for the capsule clad during reentry aerothermal heating.

The heat shield is a container of hexagonal cross section with a central cylindrical cavity designed to house the fuel capsule and pyrolytic graphite sleeves. The heat shield is fabricated from AXF-Q1 fine grained isotropic Poco graphite. Each end of the heat shield contains internal stub Acme threads to accommodate the end plugs used to close the cylindrical cavity. The heat shield functions as a heat accumulator during normal generator operation and provides the ablation material necessary during heat source reentry.

The end plugs are cylindrical in shape with external stub Acme threads covering almost their entire length. The end plugs, which are fabricated from AXF-Q1 Poco graphite, are designed to restrict longitudinal movement of the fuel capsule within the heat shield and to provide reentry heating protection for the hemispherical ends of the fuel capsule. The end plugs contain an integrally machined shear ring which is designed to accommodate excessive thermal expansion of the fuel capsule.

The getter rings are constructed of zirconium metal housed in a palladium ring. The getter is designed to act as an absorber of hydrogen which may be released by generator materials.

A tantalum felt pad 0.125 inch thick is placed between the capsule load rings and the end plugs. The felt insulation pad serves as a thermal barrier between the load ring and the end plug during reentry aerothermal heating.

Two graphite felt restraint rings are used to protect the ends of the pyrolytic graphite sleeve assembly during launch vibration environment. A graphite washer is also placed between each restraint ring and end plug to prevent distortion of the felt during heat source assembly.

2. Thermoelectric Converter

The thermoelectric converter consists of six thermoelectric modules each bearing against one face of the hexagonal heat shield. Each of the modules (see Figure IV-3) consists of 15 thermoelectric couples, Min-K insulation, interconnecting electrical straps, and associated cold-end hardware. The cold-end hardware consisting of springs, pistons, alignment buttons and heat sink bar is located between the modules and the cylindrical generator housing and provides a compressive load on each thermoelectric element to maintain adequate electrical and thermal paths in the converter. Electrical insulation in the form of a 0.010 inch thick mica sheet is used to isolate the hot side of the modules from the graphite heat shield.

The thermoelectric couples are fabricated from Teledyne Energy Systems TAGS-85 material (with a thin SnTe segment at the hot side) for the P-leg and from 3M Company 3M-TEGS-2N(M) material for the N-leg. Figure IV-4 illustrates the makeup of a SNAP 19 thermoelectric couple assembly. Each of the six thermoelectric modules contains 15 couples yielding a total of 90 couples per generator. The intramodule electrical connections are supplied by copper straps soldered to the cold side of the thermoelectric elements forming a two couple parallel arrangement.

FIG. IV-3. THERMOELECTRIC MODULE AND COLD-END HARDWARE

FIG. IV-4. SNAP 19 TAGS-85/2N COUPLE CONFIGURATION

Each of the paralleled couple pairs are then connected in a series configuration. Figure IV-5 illustrates the electrical interconnections of two adjacent modules. The copper connector straps interface with the piston/button assembly of the cold-end hardware.

Each thermoelectric element is surrounded by Johns-Manville Type 1301 Min-K thermal insulation to minimize parasitic heat losses. This Min-K insulation is also used at both ends of the heat source to minimize longitudinal heat losses and to provide sufficient end preload for the heat source during launch dynamic environments. The Min-K module insulation is precast in one piece to fit closely around each thermoelectric element. In addition, microquartz is hand packed between the thermoelectric element and the Min-K to reduce material sublimation.

Each cold-end hardware assembly consists of 30 alignment buttons, 30 pistons, 30 helical compression springs and a heat sink bar. The piston/alignment button combination bears against the copper straps of the module at each individual element location. The loading supplied by the helical springs serves two basic purposes: (1) it minimizes the gap between interfacing surfaces resulting in low electrical and thermal resistances and (2) restricts vibration induced motion of the heat shield. The cold-end hardware, excepting the helical spring, is fabricated from aluminum alloys which have been subjected to an aluminum hardcoating process. The hardcoating process provides a tenacious oxide coating assuring electrical insulation of the thermoelectric circuit at the cold side. The alignment button has one flat surface which interfaces with the copper connector strap and one spherical surface which is lapped with its matched piston. The piston has a spherical surface which mates with the alignment button and a cylindrical recess at the other end to retain the helical compression spring. The helical spring is fabricated from type 302 stainless steel and possesses a spring rate of 32.3 lbs/inch. The heat sink bar has one flat surface and one curved cylindrical surface to match the inside diameter of the generator housing. The flat surface has 30 bored holes to accommodate the piston and spring combinations, and the cylindrical surface interfaces with the housing to complete the thermal path from the heat source to the housing/radiator assembly.

Electrical power generated in the thermoelectric circuit is routed through a 26-pin electrical receptacle installed in the side of the generator housing. Two redundant O-rings provide a gas seal between the housing and the electrical receptacle. The generator power circuit incorporates a magnetic compensation loop at the lower end of the generator to minimize the external magnetic field produced by the flow of electric current in the thermoelectric circuit.

FIG. IV-5. ELECTRICAL INTERCONNECTION OF ADJACENT MODULES

A ring-shaped "getter" assembly is installed near each of the heat source end plugs to absorb any hydrogen gas generated by moisture remaining within the generator components.

3. Housing/Radiator Assembly

The housing/radiator assembly consists of a six-finned cylindrical housing, two ribbed end covers, two U-channel seal-weld rings and a dome reservoir. All components are fabricated from the magnesium-thorium alloy, HM 214. The generator housing is hermetically sealed at each end during the welding of the seal ring to the housing cylinder and the end covers. Prior to the generator sealing operation, the generator is filled with a 90% He/10% Ar gas mixture. The dome reservoir is also seal welded to the housing cylinder to provide a gas reservoir at the generator upper end bounded by the end cover and the dome. Prior to sealing the reservoir, it is filled with a 5% He/95% Ar gas mixture. The thermoelectric converter and reservoir volume are separated by a Viton O-ring seal. The O-ring seal is designed to control gas interchange between the two volumes.

The housing is a thin-walled cylinder machined from a ring rolled billet of HM21A-T5 magnesium alloy. Six radial fin stubs, each equally spaced around the outside of the housing, are integrally machined into the housing to accommodate the heat rejection fins. Each end of the housing possesses a weld flange for attaching the end cover. In addition, the upper end of the housing possesses a weld flange for attaching the reservoir dome. Six mounting lugs located at the lower end of the housing (end opposite the reservoir dome) provide for the installation of the generator on the lower end cap cooler of the Viking Lander. A smaller flange on the housing upper end contains six holes for attaching to the generator the upper end cap cooler/radiator assembly of the Viking Lander. An electrical receptacle mounting boss is integrally machined into the side of the generator housing just above the lower flange. The mounting boss provides a weld flange for installation of a dual O-ring sealed electrical receptacle assembly.

Six tapered fins, one welded to each of the housing fin stubs, provide the majority of the heat rejection radiator surface. The fins, which are fabricated from HM21A-T8 magnesium alloy, taper from a thickness of 0.030 inch at the tip to a thickness of 0.210 inch at the point of attachment to the fin stub. One fin of each generator has a mounting hole to accommodate the MMA-supplied hazard monitor receptacle instrumentation.

Closure of the housing assembly is accomplished by the welding of ribbed covers fabricated from HM21A-T8 magnesium alloy to each end of the housing. The upper cover provides a mounting hole for a seal shell assembly (single Viton O-ring permeation device) used to control the interchange of gases between the thermoelectric converter and the reservoir dome. The lower cover provides a mounting recess to accommodate the installation of a pressure transducer. The lower cover also provides a fill tube for the final generator backfill of 90% He/10% Ar gas mixture.

The electrical power output receptacle is a Deutsch 26-pin type employing a dual O-ring seal configuration. A redundant seal between the receptacle and the generator housing is provided by two Viton 747-75 O-rings mounted in series. Figure IV-6 illustrates the dual O-ring seal configuration.

The housing, fin and reservoir dome (radiator) surfaces are coated with a zirconium oxide/sodium silicate emissive coating. The coating, which is applied to a thickness of 3-5 mils, consists of finely-milled zirconium oxide bonded to the radiator surfaces by a sodium silicate inorganic binder. The coated surfaces possess an emissivity of approximately 0.90 and a solar absorptivity of approximately 0.20.

4. Instrumentation

Viking generators contain two temperature sensors and one pressure sensor to monitor the operating conditions within the thermoelectric converter. A platinum resistance temperature detector (RTD), a metal oxide thermistor and a potentiometric (voltage divider) pressure transducer monitor the hot junction temperature, fin root temperature and internal gas pressure, respectively.

One thermoelectric couple assembly of each generator is instrumented with an RTG to sense the hot junction temperature. The RTD is spot welded to a tab which is attached to the hot shoe of the couple to be monitored. This is a precision type surface temperature probe which exhibits calibration stability at high temperature.

The thermistor is mounted in a slot machined into the inside cylindrical surface of the housing. The sensor consists of metal oxides sintered with a binder and glass encapsulated to form a hermetically sealed bead. The thermistor is calibrated to operate in the range of 80°F to 469°F.

FIGURE IV-6. DUAL O-RING ELECTRICAL RECEPTACLE

The lower cover of each generator provides a mounting recess for a potentiometric pressure transducer. The function of the pressure transducer is to monitor the absolute internal gas pressure of the hermetically sealed generator housing. The pressure sensing instrument transfers minute movements of a flexing pressure diaphragm to a wiping contact of a potentiometer. The potentiometer network consists of a wire-wound fixed resistive element with three electrical terminals. Two of the terminals establish the ends of the resistor and the third terminal is a moveable contact activated by the mechanical signal input from the diaphragm.

Each generator is also fitted with a MMA supplied hazard monitor thermistor and electrical receptacle. The hazard monitor thermistor is mounted in a slot machined into the exterior cylindrical surface of the housing. The leads of the thermistor are terminated in a fin mounted electrical receptacle adjacent to the thermistor mounting slot. The hazard monitor thermistor serves to monitor the generator fin root temperature during prelaunch operations when the generator internal instrumentation telemetry data is not readily available.

B. PROTOTYPE ETG'S

Eight ETG's were fabricated for the SNAP 19 Viking program. The generator design evolution can be traced starting with the first set ETG's (S/N 101 and S/N 102) and followed through the flight prototype generators (S/N 107, S/N 108 and S/N 109).

1. ETG's S/N 101 and S/N 102

The first two generators fabricated for the Viking program were serialized S/N 101 and S/N 102 and were designated ETG Set #1. ETG's S/N 101 and S/N 102 resembled the Pioneer generator design but with larger fuel capsule (heater block capable of 682 watts(e)), larger heat rejection fins and a housing designed to interface with the Viking Lander.

The generator housing differed from the Pioneer type in that it had a large mounting flange on each end with an increasing housing wall thickness from the center of the housing out to each flange. The housing was approximately 0.250 inch longer than Pioneer to allow for the additional fuel puck required to increase the fuel capsule thermal inventory to 682 watts. The increasing housing wall thickness was necessary to facilitate longitudinal heat conduction to the Viking Lander end cap coolers mounted on each end of the generator housing. The electrical

receptacle-to-housing seals were of the Viking solder seal type and were the same for both the power output receptacle (lower portion of housing) and the heater power input receptacle (upper cover) installations. The Pioneer end closure technology was employed with both covers being first bolted and then seal welded to the housing.

The thermoelectric converter was the same as Pioneer consisting of 90 couples connected in a series-parallel (ladder) network. The generator instrumentation consisted of a SNAP 19 Pioneer RTD and a chromel/alumel thermocouple for hot junction monitoring, a thermistor for internal case temperature measurement and 10 chromel/alumel thermocouples mounted on the exterior of the generator housing. In addition, there were DC output voltage taps internal and external to the electrical output receptacle, and two AC input voltage taps on electrical power input leads. The generator gas fill was 25% Ar and 45% He at 26 psia at operational temperatures. This gas mixture was selected to match EOM thermoelectric converter gas conditions for an RTG having a solder sealed receptacle and having the fuel capsule vented into the converter.

ETG's S/N 101 and S/N 102 were delivered to MMA-Denver in late May 1971 to be used in breadboard development tests. Generator performance testing at MMA consisted of (a) acceptance, (b) dynamic impedance, (c) series mode Phase I, and (d) cruise mode. These tests were conducted during the last part of 1971. Testing conducted in 1972 consisted of (a) converter, (b) series mode--Phase II and (c) end cap cooler (S/N 101 only).

During Phase II series mode testing, a significant decrease in power output for both ETG's was identified. The power loss since their delivery to MMA was approximately two watts more than normally expected for the 1000 hours of testing. The absence of an expected increase in both the hot junction temperature and the open circuit voltage appeared to be causing the unexpected power loss since the internal resistance was increasing as anticipated. The lack of increase in hot junction temperature was believed to be caused by hydrogen generated from water contained in the thermal insulation of the thermoelectric converter. Since the thermoelectric converter did not have a getter to react the hydrogen, a decrease in thermal insulation efficiency resulted. To confirm this postulation, ETG S/N 102 was delivered to Monsanto Research Corporation for a diagnostic evaluation of the generator fill gas. Spectrographic analysis of a gas sample from S/N 102 showed that the fill gas contained 28% hydrogen. Based

on this evidence, a gas fill change was performed on S/N 102 returning it to a 55% Ar/45% He mixture. Post-gas-change power checks on S/N 102 indicated a power recovery of approximately 1.5 watts(e) with a corresponding hot junction temperature increase of approximately 15°F. As a result of this finding, all subsequent Viking generators, beginning with the Engineering ETG (S/N 100)*, contained getter assemblies capable of reacting all potential hydrogen generated during a typical Viking mission.

ETG's S/N 101 and S/N 102 both suffered hot junction resistance temperature detector (RTD) failures. The RTD failures occurred during Phase II series mode testing of the generators at MMA-Denver. Despite the RTD failures, the testing continued, using the alarm thermocouples as the primary hot junction temperature sensors. Both RTD failures were characterized by a high resistance indicative of an open circuit condition. ETG S/N 101 had accumulated approximately 2860 hours of operating time, and ETG S/N 102 approximately 2790 hours at the time of RTD failure. Since both generators continued to operate after the RTD failures, no diagnostic efforts were made to identify the failure mode. However, the disassembly of an earlier Pioneer generator, which exhibited the same type RTG failure, pinpointed the failure mode associated with this particular RTD design. An improved RTD design was later developed through a joint effort of Teledyne Energy Systems and Rosemount Engineering Company (the RTD vendor) which was incorporated in all subsequent Viking generators.

ETG's S/N 101 and S/N 102 continued to serve for spacecraft integration testing at MMS-Denver. In order to bring the ETG's up to the current flight generator configuration, the following modifications were performed on the units while at Denver. Teledyne Energy Systems personnel installed hazard monitor thermistors on each generator, and reservoir domes were supplied to simulate the geometry of the flight RTG's. ETG's S/N 101 and S/N 102 were installed on Viking Flight Capsule #3 during the spacecraft build-up cycle during mid-1974.

2. ETG S/N 100

In March 1973, Engineering ETG S/N 100 was completed, thereby yielding the first major step in the design evolution of Viking generators. ETG S/N 100 included diffusion bond receptacle-to-housing seal, the improved hot junction RTD design, a pressure transducer for monitoring the generator internal gas pressure and a new generator housing closure technique.

* ETG S/N 100 was fabricated after ETG's S/N 101 and 102.

Development problems with the solder seal led to the diffusion bond receptacle seal technique being incorporated in ETG S/N 100. Both the power input receptacle (in the housing upper cover) and the power output receptacle (in the lower portion of the housing) were installed using the newly developed diffusion bond seal. Helium leak checks on the receptacles immediately after installation indicated that the seals were leak tight. However, because of recurring anomalies with the diffusion bond (e. g. , bond separation during receptacle welding and acceptance testing) during subsequent development efforts, ETG S/N 100 was the only Viking generator to use the pure diffusion bond technique.

The instrumentation used on ETG S/N 100 consisted of an improved hot junction RTD, a chromel/alumel hot junction thermocouple, a fin root thermistor, eleven external chromel/alumel thermocouples, two external DC output voltage taps in the connector saver cable, two internal AC input voltage taps in the power input leads, and an internal pressure transducer. Problems with the RTD's in S/N 101 and S/N 102 led to the development of an improved version of the RTD for use in S/N 100 (see Paragraph VII-A-6). ETG S/N 100 was the first Viking generator to have an internally mounted pressure transducer to monitor the generator gas fill pressure. Edcliff Instrument Company provided the transducer which was installed in the bottom cover during generator assembly (see Paragraph VII-A-5). However, irregular measurements were encountered with the pressure transducer initially installed thus leading to its replacement prior to shipment to MMA-Denver. The second pressure transducer also developed measurement failure after delivery of the generator to Denver. It appears that the pressure transducer did not operate at temperatures below 140°F although operation at elevated temperatures was satisfactory.

ETG S/N 100 was the first Viking generator to use the flight design housing end closure technique (see Paragraph VII-A-2). In this design , the upper and lower covers are secured in place by a lock ring which is threaded into the housing thus clamping the cover at its outer periphery. The lock ring is then captivated by a seal ring which is fusion welded to both the housing and the cover. The fusion weld is non-load bearing, however, it does serve as a hermetic seal between the housing and cover at both ends of the generator. The diffusion bond receptacle-to-housing seal coupled with the helium leak tight cover-to-housing welds yielded a generator with an overall leak rate in the range of 10^{-9} scc He/sec-atm.

The generator fill gas used in ETG S/N 100 was substantially different from that used in the first set ETG's (S/N 101 and S/N 102). While at operating temperature, S/N 100 was filled with one atmosphere of 75% He/25% Ar. The 75% He/25% Ar gas mixture used in S/N 100 was selected to match EOM converter gas conditions of a diffusion bond sealed RTG employing a fuel capsule which vented helium external to the thermoelectric converter. The leak tight generator housing (10^{-9} scc He/sec) enabled a constant gas mixture throughout the Viking mission, and the 75% He/25% Ar satisfied the power requirements at EOM.

ETG S/N 100 was the first Viking generator to be subjected to both acceptance and qualification level thermal cycling tests. The thermal cycle tests were conducted to evaluate the effects on performance of cruise mode and Mars orbit operating conditions, instantaneous shorting and power-up conditions and Mars surface ambient conditions. The total performance degradation measured on S/N 100 was 0.4 watt(e) which is approximately what would have been expected during normal steady-state operation at this period of the generator life.

ETG S/N 100 was delivered to MMA-Denver in July 1973. Upon its arrival at Denver, it was used primarily for breadboard and spacecraft integration testing. Later, it was teamed with ETG S/N 107 on Viking Flight Capsule #1 for the spacecraft build-up cycle at MMA-Denver.

3. ETG S/N 103

ETG S/N 103 was fabricated in June 1973 and was later joined with S/N 100 and designated ETG Set #2. The only major difference between S/N 100 and S/N 103 is that S/N 103 employs a composite receptacle-to-housing seal. In this design the power input receptacle (located in the upper cover) and the power output receptacle (located in the lower portion of the housing) both employ a seal consisting of a Viton V747-75 O-ring in series with a diffusion bond.

This modification was a result of continuing problems with the diffusion bond, and the demonstration of the Viton V747-75 O-rings to withstand simulated Mars surface thermal cycling after long-term exposure to elevated temperatures. The O-ring in series with the diffusion bond provides redundancy to prevent catastrophic gas leakage in the event of a diffusion bond failure. It is interesting to note that during the assembly of S/N 103, a diffusion bond separation was experienced as the receptacle was being installed in the housing. The decision to proceed with the separated diffusion bond was made after the redundant O-ring seal was found to be functioning.

The diffusion bond portion of the composite seal in the upper cover continued to perform satisfactorily without incident. ETG S/N 103 was the last Viking generator to use a diffusion bond receptacle seal.

The instrumentation used on S/N 103 was identical to that of S/N 100 except for the installation of a hazard monitor thermistor receptacle on fin number three, and mounting slots in fin number six for gas chromatograph mass spectrometer (GCMS) hardware. S/N 103 also contained an Edcliff pressure transducer with no operational problems.

The separation of the diffusion bond in the power output receptacle seal made it necessary to backfill S/N 103 with two atmospheres of 75% He/25% Ar gas mixture to compensate for increased gas leakage through the backup Viton O-ring seal during the extensive test program anticipated for this generator.

ETG S/N 103 was subjected to acceptance level thermal cycle testing prior to shipment to MMA-Denver. Power checks at the start and at the conclusion of testing were identical indicating no degradation of performance due to thermal cycling. Delivery was made to MMA-Denver in July 1973 and S/N 103 was teamed with ETG S/N 104 on the Viking Proof Test Capsule for heat compatibility tests.

4. ETG's S/N 104, S/N 107, S/N 108 and S/N 109

ETG's S/N 104, S/N 107, S/N 108 and S/N 109 were constructed to represent the flight version of the SNAP 19 Viking generators. The diffusion bond receptacle seal and the vented heat source concepts were deleted and in their place is a dual O-ring receptacle seal and an inert fill gas management system. ETG's S/N 104 and S/N 107 were designated ETG Set #3 and ETG's S/N 108 and S/N 109 were designated ETG Set #4.

The diffusion bond failures led to the elimination of both the diffusion bond receptacle seal concept and the vented heat source concept. The demonstration of a Viton O-ring seal to withstand the Viking mission environments led to the development of an all-Viton receptacle seal design. A dual O-ring receptacle seal design is employed for both the power input receptacle (upper cover) and the power output receptacle (housing) seals. Earlier tests proved that the benefits derived from the vented heat source concept were predicated wholly on the quality of the generator housing seal being in the 10^{-7} scc He/sec range or better. The decision to employ

an O-ring receptacle seal with a permeation rate in the 10^{-5} scc He/sec (@ 337°F) range rendered the vented heat source unnecessary. The vented heat source design was subsequently deleted from the generator design and replaced with a gas management system. All four generators were filled with two atmospheres of 75% He/25% Ar at operating conditions to insure sufficient fill gas after planned MMA testing.

ETG S/N 104, fabricated in September 1973, was the first Viking generator to employ the all-Viton dual O-ring receptacle seal. S/N 104 was the last ETG to be subjected to thermal cycle testing since no test related power degradation could be associated with the units tested. It has the same instrumentation as S/N 103 including an external hazard monitor thermistor receptacle on fin number three and mounting slots in fin number six for the gas chromatograph mass spectrometer (GCMS) hardware. S/N 104 contains an Edcliff pressure transducer which has exhibited intermittent operation following generator acceptance vibration testing. ETG S/N 104 was delivered to MMA-Denver in October 1973 after thermal cycle testing revealed no test related power degradation.

ETG S/N 107, fabricated in February 1974, was the last Viking generator to use an Edcliff pressure transducer for sensing the generator internal fill gas pressure. Curiously, the operation of this transducer has been quite accurate without any indication of the intermittent problems which have plagued other Edcliff units. The instrumentation on S/N 107 is the same as that on ETG's S/N 103 and S/N 104, except that the external chromel/alumel thermocouples were deleted and there were no mounting slots in fin number three for the GCMS hardware. ETG S/N 107 was delivered to MMA-Denver in March 1974.

ETG's S/N 108 and S/N 109, which were fabricated in March 1974, were the last two ETG's fabricated for the Viking program and the first Viking generators to employ Bourns Instruments pressure transducers. The Bourns pressure transducers have operated satisfactorily to date without exhibiting any of the irregularities associated with the Edcliff units. ETG's S/N 108 and S/N 109 were delivered to MMA-Denver in April 1974 and were mounted on Viking Flight Capsule #2 during the spacecraft buildup cycle at MMA-Denver.

V. FLIGHT RTG PERFORMANCE PREDICTIONS

A. POWER PERFORMANCE

The objective of the SNAP 19 Viking RTG performance analysis was to show that the end-of-mission (EOM) power requirement of 35 watts(e) was satisfied by each of the five Viking flight RTG's. To accomplish this objective, initial RTG performance was characterized and the expected RTG behavior during the mission was determined. The analysis technique used the flight profile and the performance approach as detailed in the Viking contract. The initial RTG characteristics were measured data except for the hot junction temperature which was obtained from test data on SNAP 19 Pioneer RTG's and modified for use on the Viking RTG's.

RTG behavior during the mission was calculated for each state of RTG operation (i. e. , normal operation, reservoir-to-converter seal failure, etc.) using the Teledyne Energy Systems digital code SNAPPER. Results from the SNAPPER analysis were then utilized as input to a Monte Carlo analysis to obtain the distribution of RTG EOM performance for each of the states of RTG operation. Total RTG EOM reliability-performance was then obtained by combining the individual power distribution outputs of the Monte Carlo analysis for each state of RTG operation with its respective probability of occurrence.

This section discusses the details of the SNAPPER program analysis, the Monte Carlo analysis and the total RTG EOM reliability-performance distribution.

1. SNAPPER Program Analysis

An analysis of the effect of the inert cover gas management on RTG behavior during the Viking mission was conducted using the Teledyne Energy Systems computer program SNAPPER. The procedure begins with initial RTG characteristics (supplied as input data) and through calculation of the thermoelectric converter gas pressure and composition, reservoir gas pressure and composition, hot junction temperature, and thermoelectric degradation, the RTG power output is determined as a function of mission time. Table V-1 summarizes a listing of SNAPPER input and output parameters.

Inputs to the SNAPPER program for normal operation of the RTG are discussed in section V. A. 1. a. For an analysis of RTG performance following each of the potential Category II

TABLE V-1
SUMMARY OF SNAPPER PROGRAM INPUT AND OUTPUT DATA

<u>Input Data</u>	<u>Parameters Printed Out Versus Time</u>	<u>Punched Card Output for EOM Generator Parameters</u>
Initial converter gas partial pressures	Converter partial and total pressures	Converter total pressure versus external and reservoir- to-converter initial seal leak rates
Initial reservoir gas partial pressures	Converter helium con- centration	
External environment profile	Reservoir partial and total pressures	Converter helium concentra- tion versus external and reservoir-to-converter initial seal leak rates
External seal leak rate profile	Reservoir helium con- centration	
Reservoir-to-converter seal leak rate profile	Converter gas leak rates	Hot junction temperature versus external and reservoir-to- converter initial seal leak rates
Fin root temperature profile	Hot junction temperature	
Seal temperatures relative to fin root temperature	Cumulative thermoelectric degradation	Thermoelectric degradation versus EOM hot junction tem- perature
Carnot effect	Nominal power	
Initial hot junction tem- perature		
Hot junction temperature and power change versus converter total pressure and helium concentration		
Load voltage profile		
Thermoelectric degradation versus hot junction temperature and time		
Initial fuel inventory		
Helium release rate		
Initial RTG power		
Voltage shift correction		

component failures identified in paragraph V. A. 2, the inputs to the SNA PPER analysis are modified to reflect the change in RTG behavior.

a. SNA PPER input data for normal operation

The inputs to the SNA PPER program analysis for normal RTG operation were as follows:

(1) Initial gas fills

The thermoelectric converter initial gas fill was 90% He/10% A. At the time the thermoelectric converter was sealed, the RTG was shorted, the fin root temperature and the fueling facility pressure were measured and recorded as tabulated in Table V-2. The converter gas temperature was assumed to be an average between the fin root temperature and the hot junction temperature.

The reservoir initial gas fill was 5% He/95% A. At the time the reservoir was sealed, the RTG was shorted, the fin root temperature and the fueling facility pressure were measured and recorded as tabulated in Table V-2. From SNAP 19 Viking ETG S/N 100 test data, the gas temperature in the reservoir was assumed to be 50°F less than the fin root temperature.

(2) Initial hot junction temperature

The Viking RTG initial hot junction temperature was based on the SNAP 19 Pioneer RTG beginning-of-life (BOL) experimental data. The Pioneer BOL hot junction temperature was measured on RTG's S/N 43 through 53. It was determined (Table V-3) to be 949°F (with a -20°F biased RTD reading) for the following conditions:

Fin root temperature = 330°F (biased thermistor reading)

Fuel loading = 645 watts(t)

Gas fill = 75% He/25% A at one atmosphere absolute pressure

Load voltage = 4.2 volts

Non-optimized getter installed

To obtain an initial Viking RTG hot junction temperature, corrections to the Pioneer data were required to account for changed fuel inventory, load voltage, getter optimization, and converter gas fill. The experimentally determined generator sensitivity to a parameter change was as follows:

TABLE V-2

SNAP 19 VIKING RTG INITIAL ANALYSIS DATA

	RTG S/N				
	<u>111</u>	<u>112</u>	<u>113</u>	<u>114</u>	<u>115</u>
Power (watts(e))*					
Measured	41.9	42.6	43.0	43.2	42.6
BOL**	41.4	42.1	42.5	42.7	42.1
Thermal inventory (watts(t))	683	683	682	682	682
Leak rates (scc He/sec-atm @ 337°F)					
External (post-vibration)	1.5×10^{-5}	1.3×10^{-5}	1.3×10^{-5}	1.4×10^{-5}	1.2×10^{-5}
Reservoir-to-converter	1.9×10^{-5}	1.9×10^{-5}	1.7×10^{-5}	1.8×10^{-5}	1.9×10^{-5}
Conditions at time of reservoir seal plug weld					
Fin root temperature (°F)	277	285	286	291	312
Fueling facility pressure (psia)	14.6	14.2	14.7	14.5	14.5
Conditions at time of converter seal plug weld					
Fin root temperature (°F)	237	230	234	235	242
Fueling facility pressure (psia)	14.6	14.6	14.6	14.4	14.5

* Power at 4.4 volts and a fin root temperature of 330°F.

** BOL - Beginning-of-life.

TABLE V-3

SNAP 19 PIONEER RTG RTD TEMPERATURE AT FUELING PARAMETRIC

$$E_L = 4.2 \text{ volts}$$

$$T_{FR} = 330^\circ\text{F}$$

Gas Fill 75% He/25% Ar at ~ One Atmosphere

<u>Pioneer RTG Serial No.</u>	<u>RTD Temperature (° F)</u>	<u>Fuel Inventory (watts)</u>	<u>Adjusted RTD Temperature for 645 Watts Fuel Inventory (° F)</u>
43	958	648	955
44	963	649	959
45	954	646	953
46	953	647	951
47	937	647	935
48	963	649	959
49	932	649	928
50	944	643	946
51	953	650	948
52	957	649	953
53	958	649	954
Average			949

ΔT_{HJ} due to fin root temperature change (ΔT_{FR}) = $1.0^{\circ}\text{F}/^{\circ}\text{F}$

ΔT_{HJ} due to thermal inventory change (ΔQ) = $1^{\circ}\text{F}/\text{W (t)}$

ΔT_{HJ} due to load voltage change (ΔE_L) = $30^{\circ}\text{F}/\text{V}$

ΔT_{HJ} due to gas composition or pressure change in Figure V-1

Using the above correction factors, the Viking RTG initial hot junction temperature was calculated to be 1047°F as shown in Table V-4. This temperature was adjusted up or down 1°F for each watt(t) that the actual fuel loading differed from the nominal 682 watts(t).

(3) Fuel inventory

The fuel inventory for the Viking RTG's was determined by MRC during fabrication and was furnished for each fuel capsule in the MRC capsule data package. The measured fuel quantity was adjusted by radioactive decay to give the fuel inventory on the day of RTG fueling. The fuel inventory on the day of fueling was used as the initial fuel inventory in all SNAPPER calculations, and the values are tabulated in Table V-2.

(4) Helium release rate

The helium release rate was assumed to be 100% of the theoretical helium generated by the fuel decay.

(5) Thermoelectric degradation

Generator data on thermoelectric degradation was derived from 17 ETG's and RTG's. The generator data gave degradation values at hot junction temperatures up to 1135°F and operating times up to 30,000 hours. The thermoelectric degradation model derived from the data is shown in Figure V-2.

While operating on the surface of Mars, the generator will experience thermal cycling due to diurnal temperature variations and surface winds. A temperature cycling test, which was performed on ETG's S/N 41 and S/N 43 in 1972, showed no significant thermoelectric degradation for normal steady state operation at the maximum average diurnal temperature (i.e., fin root temperature = 330°F). Thus, thermoelectric degradation associated with steady state operation at a fin root temperature of 330°F was used in this analysis to account for Mars surface operation.

Based on Generator S/N 41 Data

FIG. V-1. TEMPERATURE CHANGE WITH GAS COMPOSITION AND PRESSURE

TABLE V-4
 EXPECTED VIKING MIDPLANE HOT JUNCTION
 TEMPERATURE AT FINAL ASSEMBLY

Baseline

Average Pioneer biased RTD temperature	949 °F
--	--------

Normalization Factors

Remove negative bias applied by Pioneer calibration tables	+ 20 °F
ΔT_H due to fin root temperature definition	+ 18 °F
ΔT_H due to increased fuel loading	+ 37 °F
ΔT_H due to getter optimization	+ 13 °F
ΔT_H for midplane temperature compared to RTD temperature	+ 15 °F
ΔT_H for load voltage change	+ 6 °F
ΔT_H for 90% He/10% Ar gas mixture instead of 75% He/10% Ar	- 11 °F

Viking Result

Viking RTG midplane hot junction temperature at final assembly	1047 °F
--	---------

FIG. V-2. TAGS/2N THERMOELECTRIC DEGRADATION

(6) Voltage shift correction

The voltage-current (EI) characteristics of the SNAP 19 Viking flight RTG's were measured during acceptance testing at Teledyne Energy Systems. From the series functional test data of these generators the peak power load voltage was determined to be 4.0 to 4.1 volts. From a previous study, the peak power load voltage for an ETG operating at constant power input and gas conditions was seen to decrease with time (after first reaching a peak value). Combining the actual RTG acceptance test data and the previous study, the EOM power prediction was reduced by 0.35 watt(e) to account for RTG operation at a constant 4.4 volts rather than the predicted EOM peak power load voltage of 3.6 to 3.8 volts.

(7) Carnot effect

The Carnot effect is the change in generator power as a result of fin root temperature change for constant power input and constant voltage operation. The relationship was determined from SNAP 19 Viking ETG and RTG tests. It is shown in Figure V-3 for a reference temperature of 330°F.

(8) Initial power

The initial power for each RTG was determined during acceptance testing at Teledyne Energy Systems. The measured power for RTG's S/N 111, S/N 112, S/N 113 and S/N 114 was obtained from the series functional test E-I curves for the individual generators. The power for RTG S/N 115 was obtained from the final load voltage parametric test data.

The measured power for each RTG was obtained at less than 500 heated hours at a hot junction temperature greater than 900°F. The measured power was reduced by 0.5 watt(e) to obtain the initial power which was used as input for the SNAPPER digital program. These values are tabulated in Table V-2.

(9) Performance-gas relationships

Changes in the converter gas pressure and composition affect the parasitic heat losses, thus resulting in a change of the heat flow to the thermoelectrics. The resultant output power and hot junction temperature changes were determined experimentally with ETG S/N 41. The variation of power output and hot junction temperature with the helium-argon mixture and pressure is shown in Figures V-4 and V-1. Note that the reference point on the graphs is 75% He/25% A at one atmosphere absolute pressure.

Converter Pressure = ~1 Atmosphere
 Thermal Inventory = Viking Equivalent
 Load Voltage = 4.4 Volts

Average Fin Root Temperature Defined as the Average
 of Five Thermocouples Located Along Fin #3

FIG. V-3. TYPICAL GENERATOR STEADY STATE POWER OUTPUT VARIATION AT
 FIN ROOT TEMPERATURES ABOVE AND BELOW THE NOMINAL DESIGN
 VALUE OF 330°F

FIG. V-4. POWER CHANGE WITH GAS COMPOSITION AND PRESSURE

(10) Mission profile

The external environment history delineates the gas partial pressures on the RTG exterior which affect the gas leakage through the power output receptacle dual O-ring seal. For the input to the SNAPPER analysis, air was considered the external environment through launch, and vacuum was considered the external environment after launch.

The load voltage history affects the hot junction temperature history. For example, the hot junction temperature is increased by 90°F as the RTG electrical load is shifted from short to 4.4 volts.

The fin root temperature history impacts the leak rate of the external and reservoir-to-converter seals. The external seal temperature, the reservoir-to-converter seal temperature, and the reservoir gas temperature are all related to the fin root temperature. The maximum fin root temperature profile, which was used primarily in this report, is plotted in Figure V-5 as a function of mission time. A reduced fin root temperature profile is also included in Figure V-5. This was used in order to determine its effect on the RTG EOM performance. The data for the reduced fin root temperature profile was estimated from test data on Viking simulated models which were tested at the Martin Marietta Aerospace (MMA) facility at Denver. Results of the reduced fin root temperature profile analysis are discussed later.

The fin root temperature during Mars surface operation will cycle about a diurnal average fin root temperature due to environmental fluctuations on the Mars surface. Test data on ETG's S/N 41 and S/N 43 indicated that the nominal generator performance during a Martian day can be conservatively based on the maximum expected diurnal average fin root temperature. The maximum expected diurnal average fin root temperature of 330°F is presented in Figure V-5 for the fin root temperature during the Mars surface portion of the Viking mission.

The fin root temperature on the Viking program is defined as: "The integrated average over the entire fin root." On Viking ETG's and RTG's and on refurbished Pioneer ETG's tested on the Viking program, this definition was approximated by averaging the readings of five thermocouples attached along the fin root of fin number 3. For the refurbished Pioneer ETG's, this average fin root temperature (average of five thermocouples) was 20°F below an equivalent Pioneer thermistor measured fin root temperature. Therefore, the Pioneer data which were

FIG. V-5. SNAP 19 VIKING RTG FIN ROOT TEMPERATURE PROFILES

utilized for determining the initial RTG hot junction temperature and power were applicable at a fin root temperature of 310°F when corrected for Viking conditions instead of the reported 330°F. The thermistor-measured temperature of the Viking generators (Viking housing is thicker than the Pioneer housing) agreed closely with the average fin root temperature.

(11) Seal leak profiles

The leak rates of the receptacle dual O-rings and the reservoir-to-converter O-ring were measured during the RTG assembly and acceptance testing (Table V-2). The reservoir-to-converter O-ring leak rate was measured after the upper cover seal weld was completed and the reservoir welded to the housing. The receptacle O-ring seal leak was measured at the time of the generator final assembly and again after the RTG vibration tests were completed. The leak rate measurement following vibration testing was the initial O-ring leak used in the performance calculations. A range of leak rates above and below these values was used as input to the SNAPPER program.

In Table V-5 is shown the minimum and maximum leak rates which were specified as acceptable for the Viking RTG's. These leak rates were used in the SNAPPER program in some of the studies.

TABLE V-5
VIKING RTG INITIAL SEAL LEAK SUMMARY

	<u>Initial Seal Leak (scc He/sec-atm at 337°F)</u>	
	<u>External Seal</u>	<u>Reservoir-to-Converter Seal</u>
Minimum acceptable	0.5×10^{-5}	0.6×10^{-5}
Maximum acceptable	4.0×10^{-5}	5.0×10^{-5}

The leak rate of the Viton O-ring material has been observed to increase with time. The leak rate increase data used in all computations was presented initially at the Fifth Viking Reliability Program Review on April 11, 1974. The leak rate model is presented in Figure V-6.

From thermocouple temperature measurements on Viking generators S/N 100 and 103 to 106, it was established that the electrical receptacle-to-housing seal operates at about the

FIG. V-6. VITON (V747-45) LEAK GROWTH WITH TIME

same temperature as the average fin root temperature. From S/N 100 data, the reservoir-to-converter seal was shown to operate about 15°F lower than the average fin root temperature. For the SNAPPER computer calculations, these fin root temperature-to-seal temperature differences were assumed to be valid for all RTG conditions.

b. RTG characteristics during normal operation

SNAPPER calculations were performed for each flight RTG based on the Viking mission profile and several leak rates around the reservoir-to-converter and converter external seal leak rates identified in Table V-2. RTG characteristics were determined as a function of time during the Viking mission. Punched card output for EOM RTG converter gas pressure, converter helium concentration and hot junction temperature was obtained parametric in the two seal leak rates. The thermoelectric degradation experienced over the mission was also obtained as a function of EOM RTG hot junction temperature. These punched card output data were provided as input to the Monte Carlo analysis to be discussed later.

Figures V-7 through V-11 show typical results of the RTG characteristics versus time for each of the flight RTG's. The effect of the reservoir on the converter gas is seen by the stabilization of the converter total pressure during cruise and the Mars orbit (Figure V-7) where the argon inflow to the converter counterbalances the helium outflow. This effect is also observed in the converter helium concentration (Figure V-8) where the incoming argon continues to dilute the helium concentration. The helium concentration of the reservoir (Figure V-10) is seen to continue increasing throughout the Viking mission.

The hot junction temperature history of Figure V-11 reflects the temperature at the module midplane, while the module end temperatures (RTD-measured temperatures) are 15 F° lower than the values shown. The hot junction temperature profile includes an experimentally observed 25 F° increase during the first seven months of generator operation. Also included in the profile is the result of fuel decay.

c. RTG characteristics with reduced fin root temperature profile

A study of the effects on the Viking RTG EOM performance for a fin root temperature profile other than the maximum profile specified in the contract was conducted for the temperature profile introduced earlier in Figure V-5.

100% Helium Release Rate to Converter Initial Gas Fill:

Converter - 90% Helium/10% Argon
Reservoir - 5% Helium/95% Argon

Seal Leak Has Nominal Growth

FIG. V-7. SNAP 19 VIKING FLIGHT RTG'S CONVERTER TOTAL PRESSURE

100% Helium Release Rate to Converter Initial Gas Fill:

Converter - 90% Helium/10% Argon

Reservoir - 5% Helium/95% Argon

Seal Leak Has Nominal Growth

FIG. V-8. SNAP 19 VIKING FLIGHT RTG'S CONVERTER HELIUM CONCENTRATION

100% Helium Release Rate to Converter Initial Gas Fill:

Converter - 90% Helium/10% Argon

Reservoir - 5% Helium/95% Argon

Seal Leak Has Nominal Growth

FIG. V-9. SNAP 19 VIKING FLIGHT RTG'S RESERVOIR TOTAL PRESSURE

100% Helium Release Rate to Converter Initial Gas Fill:

Converter - 90% Helium/10% Argon
Reservoir - 5% Helium/95% Argon

Seal Leak Has Nominal Growth

FIG. V-10. SNAP 19 VIKING FLIGHT RTG'S RESERVOIR HELIUM CONCENTRATION

100% Helium Release Rate to Converter Initial Gas Fill:

Converter - 90% Helium/10% Argon

Reservoir - 5% Helium/95% Argon

Seal Leak Has Nominal Growth

FIG. V-11. SNAP 19 VIKING FLIGHT RTG'S MIDPLANE HOT JUNCTION TEMPERATURE

(1) SNAPPER input data

Input parameters to the SNAPPER program were the same as for a typical Viking RTG except for the minimum fin root temperature and the reservoir-to-converter and converter external leak rate values. Four combinations of the minimum acceptable and maximum acceptable leak rate values for each of the seals were considered.

(2) Calculated results

Results of the SNAPPER program analysis for the reduced fin root temperature profile showed a small sensitivity of RTG EOM performance to fin root temperature. The effect of the reduced fin root temperature is to reduce the leak rate of the Viton O-ring seals and thereby yield slightly higher EOM converter total pressures and helium concentrations. As the reduced temperatures, the thermoelectric degradation is reduced, but the higher converter gas pressure and helium content causes increased parasitic heat loss. The total effect on the RTG's shown in Table V-6 ranges from a decrease of 0.1 watt(e) to an increase of 0.3 watt(e) for the extreme values of leak rates listed. The actual Viking RTG leak rates are located near the center of this extreme range and hence negligible effect on EOM power is predicted.

TABLE V-6
EOM POWER CHANGES AS AFFECTED BY THE
REDUCED FIN ROOT TEMPERATURE PROFILE

	<u>Reservoir-to-converter Leak Rate*</u>	
	<u>0.6×10^{-5}</u>	<u>5×10^{-5}</u>
External leak rate*		
0.5×10^{-5}	-0.1 watt(e)	+0.1 watt(e)
4×10^{-5}	+0.2 watt(e)	+0.3 watt(e)

* scc He/sec-atm @ 337°F maximum range

2. Analysis Category II Component Failure

There are several component seal failures which do not result in the total loss of the RTG converter gas. They are: (a) the failure of the outer receptacle seal weld, (b) the failure of the reservoir external seal, and (c) the failure of the gas seal between the reservoir and converter. The RTG EOM performance for any of these failures will be affected by the time in the mission at which the failure occurs. To facilitate performance computations, the failures were assumed to occur at three discrete times: (a) acceptance plus one day, (b) launch, and (c) Mars landing.

a. SNAPPER input data

Input parameters to the SNAPPER program were those characteristic of Viking RTG S/N 112, which is a typical flight RTG. For times prior to the component failure, the seals were considered to be operating normally. At the time of component failure, the leakage of the appropriate seal was assumed to change to reflect the new state of RTG operation. The failure of the outer receptacle seal weld was assumed to double the converter external seal leak rate. The failure of the reservoir external seal was assumed to cause an increase in the external seal leak rate since the reservoir-to-converter O-ring seal would be exposed to the ambient environment. A failure of the reservoir-to-converter seal was assumed to allow instantaneous and complete intermixing of the converter and reservoir gases.

SNAPPER analyses were performed for 25 combinations of reservoir-to-converter and converter external initial leak rates for each of the three types of component failure assuming that the failures occurred at the three discrete mission times. As with the normal RTG operation discussed in Section V.A.1, punched card output for EOM RTG performance parameters was obtained. This punched card output was provided as input to the Monte Carlo analysis.

b. SNAPPER results for failure of reservoir and converter external seals

Results of the SNAPPER program analysis for the first two component failures indicates a decrease in the thermoelectric converter EOM pressure with an accompanying increase in the EOM hot junction temperature (up to 15° F increase). The decrease in thermoelectric converter pressure was very small if the failure occurred during Mars landing. If failure occurred prior to or at launch there were cases where thermoelectric converter pressures as low as eight psia were calculated. These pressures are presumed to be satisfactory for continued RTG operation.

c. SNAPPER results for failure of reservoir-to-converter seal

SNAPPER results for the reservoir-to-converter seal failure indicated little influence on RTG EOM performance, however, an increase in the strength member temperature was observed. The strength member temperature increases because of argon enrichment of the gas in the thermoelectric converter and heat source. The hot junction temperature increases 20 to 40°F; the strength member temperature increases about 100 C°. During acceptance testing when the RTG is on load and at a fin root temperature of 330°F, the strength member temperature would increase to a maximum of 935°C.

It should be noted that this component failure will be readily apparent in generator performance characteristics. There will be a power increase of approximately 2 watts(e) and a 20 to 40°F increase in the hot junction temperature. When these events occur, immediate remedial action can be taken. The RTG can be placed on short circuit and the fin thermal insulation removed. These actions will reduce the strength member temperature to 850°C or below within a period of approximately four hours. After the RTG is encapsulated in the bioshield with the end cap cooler operational, a failure of the reservoir-to-converter seal will not result in pre-launch strength member temperatures greater than 850°C.

3. Monte Carlo Analysis

The RTG EOM performance was analyzed using a Monte Carlo technique to obtain a mean power and the probability of achieving power levels other than the mean. The Monte Carlo analysis permits combination of non-linear by related variables (e.g., initial power, thermoelectric degradation, pressure) to provide an RTG EOM output power distribution. The variables are selected randomly from input probability density functions. The variable relationships are derived from previous test data, program requirements and from previous analyses of RTG behavior.

A typical calculation of one power output point (called history) is shown in Figure V-12. The notation "pick" refers to the random selection of a parameter value from the prescribed distribution. The notation "determine" calls for interpolation of input tables which relate a dependent variable to its parameters. This process is repeated a large number of times to obtain a distribution function for the EOM power output. A reliability requirement of approximately

See next page for nomenclature

FIG. V-12. CALCULATION OF A HISTORY

FIGURE V-12 (Continued)

CALCULATION OF A POWER HISTORY

Symbols

C	Gas concentration
H	Helium release rate into the converter from the fuel
L	Converter external leak rate
P	Output power
p	Total pressure
R	Reservoir-to-converter leak rate
q	RTG fuel inventory
T	Midplane temperature of thermoelectric converter hot junction
η	Symbolic notation for a modified normal distribution with a mean value and standard deviation indicated in parentheses
γ	Ratio of power at time t to BOL power (T/E degradation factor)
σ	Standard deviation

Subscripts

c	Converter
EI	Power penalty for peak power load voltage shift
EOM	End-of-mission
H	Helium release rate into converter from the fuel
He	Helium
L	Converter external leak rate
o	Mean value at BOL
P_1	Initial power
R	Reservoir-to-converter leak rate
r	Reservoir
1, 2, 3, 4	Interim values used during calculations

0.99 dictates that about 10,000 histories be calculated to yield statistically significant results. In addition to final power, the distribution of several intermediate quantities (e.g., P_2 , P_3 , q) may also be obtained.

a. Input data for Monte Carlo analysis

Inputs to the Monte Carlo analysis were as follows:

(1) Initial power

Definition of the mean value of initial power was discussed in section V.A.1. The measurement is assumed normally distributed with error defined in the Viking contract as being $3\sigma = 0.2$ watt(e).

(2) Fuel inventory

The initial value of the fuel inventory was defined in section V.A.1. A normal distribution with measurement error of $3\sigma = 0.18\%$ of nominal fuel loading was used. The fuel decay will be about 12 watts(t) during the Viking mission.

(3) Initial converter external leak rate

The mean value of the converter external leak is defined as the measured generator total leak following vibration. The measurement error is defined in the Viking contract as a normal distribution with $3\sigma = 15\%$ of the measured value.

(4) Initial reservoir-to-converter leak rate

The mean value is measured during fueling operations as described in section V.A.1. The measurement is assumed normally distributed with $3\sigma = 15\%$ of the measured value.

(5) RTG EOM converter parameters (p , C_{He} , T)

The RTG EOM thermoelectric converter pressure, helium concentration and hot junction temperature are obtained from the punched card output of the SNAPPER program analysis for the different states of RTG operation.

(6) Mission thermoelectric degradation ($\gamma(T)$)

The EOM thermoelectric degradation is obtained from the punched card output of the SNAPPER program and is based on the degradation model presented in an earlier section of this chapter. The deviation is assumed to be zero.

(7) Power-gas relationship $\left(\frac{\Delta P}{P_2}\right)$

The change in the RTG power output as a function of converter pressure and helium concentration was obtained from data shown in Figures V-7 to V-11.

(8) Voltage shift correction $\left(\Delta P_{EI}\right)$

Since the EOM optimum load voltage is less than the 4.4 volt operating point, the predicted power is decreased by a constant 0.35 watt(e) in the last step of the flow chart of Figure V-12. The basis for this correction was given previously in the discussion of inputs to the SNAPPER program.

b. Results of Monte Carlo analysis

RTG EOM power distributions were calculated for each of the flight RTG's for normal RTG operation and for a typical RTG, S/N 112, with Category II failure modes at each of the three assumed failure times. For each type of Category II failure, a composite power distribution was obtained by combining the three distributions associated with the three times of component failure. In addition to the above, a total reliability-power distribution at EOM was obtained by combining the three composite potential Category II failure mode power distributions with the normal operation power distribution and the probability of a Category I failure. Figure V-13 shows a schematic diagram of the method used in combining the results of the Monte Carlo analyses to obtain the RTG total reliability-power distribution at EOM.

Extensive SNAP 19 Viking EOM performance analysis efforts indicated that a good approximation of the SNAP 19 RTG EOM total reliability-performance distribution is yielded by the following expression:

$$CDF_T(P_x) \approx CDF_1(P_x) \cdot P_{CAT I} + CDF_5(P_x) \cdot (1 - P_{CAT I}).$$

(The nomenclature is presented in Figure V-13.)

Calculations performed with this approximation and the more rigorous formulation shown in Figure V-13 showed agreement within less than 0.1 watt(e) for both the nominal power and the 0.99 probability power. Therefore, the approximation was utilized for the contract compliance calculations of the SNAP 19 Viking flight RTG's.

* MCA-Cumulative distribution function (CDF) obtained from Monte Carlo

See following page for math model and nomenclature

FIG. V-13. TOTAL RELIABILITY-POWER PREDICTION MODEL

TOTAL RELIABILITY-POWER PREDICTION MODEL

Model for Combining Probability Distributions

1. Sample model for combined power distributions for various times of failure.

$$CDF_4(P_x) = CDF_{4A}(P_x) \cdot P_{4A} + CDF_{4B}(P_x) \cdot P_{4B} + CDF_{4C}(P_x) \cdot P_{4C}$$

where: $CDF_4(P_x)$ = Probability of RTG EOM power equaling or exceeding the power P_x assuming that the reservoir fails.

$CDF_{4A}(P_x)$ = Probability of RTG EOM power equaling or exceeding the power P_x assuming that the reservoir fails at "acceptance plus one day."

P_{4A} = Conditional probability that the reservoir failure occurs at "acceptance plus one day" given that the reservoir fails.

$CDF_{4B}(P_x)$ = Probability of RTG EOM power equaling or exceeding the power P_x assuming that the reservoir fails at launch.

P_{4B} = Conditional probability that the reservoir failure occurs at launch given that the reservoir fails.

$CDF_{4C}(P_x)$ = Probability of RTG EOM power equaling or exceeding the power P_x assuming that the reservoir fails at Mars landing.

P_{4C} = Conditional probability that the reservoir failure occurs at Mars landing given that the reservoir fails.

2. Model for obtaining RTG EOM total reliability-power distribution.

$$CDF_T(P_x) = CDF_1(P_x) \cdot P_{CAT I} + CDF_2(P_x) \cdot P_W + CDF_3(P_x) \cdot P_C + CDF_4(P_x) \cdot P_R + CDF_5(P_x) \cdot P_{NO}$$

where: $CDF_T(P_x)$ = Total probability of RTG EOM power equaling or exceeding the power P_x .

$CDF_1(P_x)$ = Probability of RTG EOM power equaling or exceeding the power P_x assuming a Category I failure has occurred.
= 0 for all powers greater than zero

$P_{CAT I}$ = Category I failure probability.

$CDF_2(P_x)$ = Probability of RTG EOM power equaling or exceeding the power P_x assuming that the seal weld of the power output receptacle fails open during the mission.

P_W = Probability that the seal weld of the power output receptacle will fail during the mission.

$CDF_3(P_x)$ = Probability of RTG EOM power equaling or exceeding the power P_x assuming that the reservoir-to-converter seal fails open during the mission.

FIGURE V-13 (Continued)

TOTAL RELIABILITY-POWER PREDICTION MODEL

- P_C = Probability that the reservoir-to-converter seal will fail during the mission.
- $CDF_4(P_x)$ = Probability of RTG EOM power equaling or exceeding the power P_x assuming that the reservoir fails during the mission.
- P_R = Probability that the reservoir will fail during the mission.
- $CDF_5(P_x)$ = Probability of RTG EOM power equaling or exceeding the power P_x assuming that the RTG operates normally throughout the mission.
- P_{NO} = Probability that the RTG will operate normally through the mission.

c. Results of contract compliance calculations

The EOM 0.99 probability power was determined for each of the flight RTG's using the techniques described above. The EOM power for each of the RTG's exceeded the required 35 watts(e) by at least 1.5 watts(e). The results are tabulated in Table V-7.

TABLE V-7

VIKING FLIGHT RTG EOM 0.99 PROBABILITY POWER

<u>RTG S/N</u>	<u>EOM 0.99 Probability Power (watts(e))</u>
111	36.5
112	37.0
113	37.4
114	37.6
115	37.0

B. HEAT SOURCE STEADY STATE OPERATION

1. Operational Temperature Guidelines

The guideline was established that, the temperature of the Viking fuel capsule strength member was not to exceed that of the Pioneer fuel capsule strength member temperature (825°C at acceptance), though the Viking RTG's contain about 35 watts(t) more fuel than the Pioneer RTG's. To this end, an evaluation was made of the effect on the fuel capsule temperatures of changing the RTG gas fill from 75% He/25% A (which is the Pioneer RTG gas fill) to 100% He. From this evaluation, the gas fills for both the converter and the reservoir were selected to satisfy the fuel capsule temperature limitations and the RTG power requirements.

2. Steady State Temperature Analysis

Thermal analysis of the Viking RTG heat source under steady state conditions was performed on the flight RTG heat source design described in Chapter IV. Three gas fill conditions were studied: (1) 95% He/10% A at one atmosphere pressure, (2) 65% He/35% A at one atmosphere pressure, and (3) 100% A at one atmosphere pressure. The gas mixture was assumed to be uniform throughout the thermoelectric converter heat source.

For each gas fill, the internal heat source temperatures were calculated as a function of heat shield temperature. Individual component temperatures were obtained by determining the heat shield temperature and gas composition for the RTG condition of interest.

a. Analytical model

A two-dimensional thermal model of the Viking heat source was constructed for use in the Teledyne Energy Systems TAP-3C digital computer program. The nodal arrangement of this model is shown in Figure V-14. This model represents the half of the heat source that contains the inner liner cap where the largest gap exists between the inner liner and the liner, thereby yielding the highest predicted temperatures of the fuel, inner liner, and liner.

Heat transfer between the internal nodes of the model was specified to occur by both radiation and conduction. Material properties (thermal conductivity and emissivity) for the heat source materials are presented in Figures V-15 and V-16. Heat transfer between the heat shield surface (nodes 124 to 128) and the sink temperature (node 151) was assumed to occur with a uniform conductance to provide the average heat shield surface temperature.

b. Steady state temperature at selected conditions

Analyses were conducted for several average heat shield surface temperatures for the three gas fill compositions. A typical nodal temperature distribution is shown in Figure V-17 for a heat shield surface temperature of 950°F and a 65% He/35% A gas mixture.

The maximum temperature of each heat source component was graphed as a function of average heat shield temperature. Figures V-18 to V-20 show the results for the 90% He/10% A, 65% He/35% A and 100% A gas fills, respectively. A graph of strength member temperature for various gas fills is shown in Figure V-21.

3. Fuel Capsule Strength Member Temperature Histories

RTG temperatures and helium concentrations at several mission times between fueling and completion of the Viking mission are shown in Table V-8. The heat shield surface temperatures were obtained by adding 40°F to the midplane hot junction temperature.

From this data and Figure V-21, the strength member temperature was obtained. A nominal-operation prelaunch strength member temperature history is shown in Figure V-22. It is seen that the strength member temperature will be about 825°C during Teledyne Energy Systems acceptance testing and 835°C during post-delivery checkout testing.

1-13	Fuel	41-62, 97-99	Three Piece Sleeve
14-18	Fuel Surface	63-93	Load Ring
19-23	Inner Liner	94-96	Insulation
24-28	Liner	100-113, 129-135	End Plug
29-33	Strength Member	114-128, 136	Heat Shield Body
34-40	Clad	137-150	Getter Assembly
		151	Boundary

Note: For clarity, all nodes are not shown

FIG. V-14. HEAT SOURCE THERMAL MODEL

FIG. V-15. THERMAL CONDUCTIVITY SNAP 19 HEAT SOURCE MATERIALS

FIG. V-16. SURFACE EMISSIVITY SNAP 19 HEAT SOURCE MATERIALS

Not to Scale

FIG. V-17. SNAP 19 VIKING CALCULATED HEAT SOURCE TEMPERATURES AVERAGE
HEAT SHIELD SURFACE TEMPERATURE = 950°F FUEL INVENTORY = 685W
GAS FILL = 65% HE/35% A

Fuel Inventory = 685 Watts
Gas Fill = 90% He/10% A at 1 Atm

FIG. V-18. MAXIMUM COMPONENT TEMPERATURE SNAP 19 VIKING HEAT SOURCE

Fuel Inventory = 685 Watts
Gas Fill = 65% He/35% A at 1 Atm

FIG. V-19. MAXIMUM COMPONENT TEMPERATURE SNAP 19 VIKING HEAT SOURCE

FIG. V-20. MAXIMUM COMPONENT TEMPERATURE SNAP 19 VIKING HEAT SOURCE

FIG. V-21. VIKING RTG MAXIMUM FUEL CAPSULE STRENGTH MEMBER TEMPERATURE

Initial Fuel Inventory = 685 Watts(t)
 100% Helium Release Rate to Converter
 Initial Gas Fill (RTG Shorted; Converter, $T_{FR} = 230^{\circ}\text{F}$;
 Reservoir, $T_{FR} = 270^{\circ}\text{F}$; 1 Atmosphere)
 Converter: 90% Helium/10% Argon
 Reservoir: 5% Helium/95% Argon
 Leak Rate (scc He/sec atm) at 337°F
 External: 2.2×10^{-5}
 Reservoir-to-converter: 2.77×10^{-5}
 Seal Leak has Nominal Growth

FIG. V-22. MAXIMUM STRENGTH MEMBER TEMPERATURE DURING PRELAUNCH ACTIVITIES

TABLE V-8

SNAP 19 VIKING RTG TEMPERATURES FOR NORMAL OPERATION

<u>Time</u>	<u>RTG Status</u>	<u>Temperature (°F)</u>			
		<u>Fin Root</u>	<u>Midplane Hot Junction</u>	<u>Heat Shield Surface</u>	<u>Gas Fill (% He/% A)</u>
BOL	Load	330	1047	1087	90/10
Storage (beginning)	Short circuit	250	890	930	89/11
Storage (end)	Short circuit	250	900	945	89/11
Post-delivery checkout	Load	330	1070	1105	89/11
Sterilization	Short circuit	360	1010	1050	89/11
Prelaunch	Short circuit	250	900	940	88/12
Post-launch (start of cruise)	Short circuit	360	1010	1050	88/12

A temperature evaluation was made also for an RTG which experiences a reservoir-to-converter seal failure at acceptance, a condition which yields the maximum time/temperature prelaunch history. The RTG temperatures and helium concentrations at several mission times were extracted from Viking RTG S/N 112 analysis data for a reservoir-to-converter seal failure (Table V-9). It was found that the strength member temperatures during acceptance and checkout testing are about 100 C° higher than for normal operation. The high temperature results from argon in the reservoir entering the converter through the failed seal, thereby raising the argon content of the converter and heat source cover gas. The hot junction temperature also rises by 20 to 40°F when the seal failure occurs prior to launch. As discussed in section V.A.1, this failure can be detected and corrective action can be taken. Within four hours after detection the strength member temperature can be reduced to about 850°C or less.

TABLE V-9

SNAP 19 VIKING RTG TEMPERATURES WITH RESERVOIR-TO-CONVERTER
SEAL FAILURE AT ACCEPTANCE

<u>Time</u>	<u>RTG Status</u>	<u>Temperature (°F)</u>				<u>Gas Fill (% He/% A)</u>
		<u>Fin Root</u>	<u>Midplane Hot Junction</u>	<u>Heat Shield Surface</u>		
BOL	Load	330	1080	1120		48/52
Storage (beginning)	Short circuit	250	915	955		50/50
Storage (end)	Short circuit	250	925	965		55/45
Post-delivery checkout	Load	330	1095	1135		55/45
Sterilization	Short circuit	360	1030	1075		56/44
Prelaunch	Short circuit	250	925	965		57/43
Post-launch (start of cruise)	Short circuit	360	1030	1070		57/43

VI. GENERATOR TESTING

A. QUALIFICATION AND ACCEPTANCE

Seven fueled generators were tested in the Viking program. These were the prototype generators S/N 105 and S/N 106, and the flight generators S/N 111 through S/N 115. All were subjected to acceptance level performance tests, leakage tests, vibration, vacuum exposure and radiation survey. Qualification level tests conducted on the prototype generators consisted of vibration, pyrotechnic and landing shock and thermal cycle tests. Mass properties, series functional performance and insulation resistances were measured on selected units.

1. Parametric Tests in Load Voltage

The relationship between output power and load voltage was measured for all Viking generators prior to delivery. An initial measurement was usually performed within four days following completion of manufacture and/or fueling, and a second was conducted at the conclusion of acceptance testing, either as a part of the series functional test, or, as in the case of S/N 115, separately. The last performance test was used for determination of the characteristic power of each generator. Results of these parametric tests in load voltage are presented in Figures VI-1 through VI-15. It is apparent that hot junction temperature, internal resistance and open circuit voltage initially increase with time. As a consequence, the peak power output occurs at higher load voltage with increasing time. A summary of this optimum voltage/time behavior is given in Figure VI-16. It is seen (from the logarithmic presentation) that the rate of rise in peak power load voltage diminishes with time, and by delivery a degree of stability is achieved which allows satisfactory characterization of each generator. All data are presented at actual fuel inventory for RTG's and for heater powers equivalent to a 675 watt fuel inventory for ETG's. In addition, test data were normalized to a constant fin root temperature of 330°F. The test procedure used is identified in Ref. 4.

2. Leak Test at Operational Conditions

Leak checks were performed of the closures made during manufacturing and fueling operations. Upon determination of satisfactory indications, the generators were released for performance tests (parametric in load voltage) and for a total leakage evaluation test at

FIG. VI-1. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 100

FIG. VI-2. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 101

FIG. VI-3. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 102

FIG. VI-4. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 103

FIG. VI-5. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 104

FIG. VI-6. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 105

Fig. VI-7. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 106

Fin Root Temperature: 330°F
 690 Watts (Heater Power)
 Fill Gas: 75% Helium/25% Argon

FIG. VI-8. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 107

FIG. VI-9. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 108

FIG. VI-10. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 109

FIG. VI-11. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 111

FIG. VI-12. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 112

Fin Root Temperature: 330°F
 682 Watts (Capsule Inventory)
 Fill Gas: 90% Helium/10% Argon

FIG. VI-13. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 113

Fin Root Temperature: 330°F
 683 Watts (Capsule Inventory)
 Fill Gas: 90% Helium/10% Argon

FIG. VI-14. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 114

Fin Root Temperature: 330°F
 682 Watts (Capsule Inventory)
 Fill Gas: 90% Helium/10% Argon

FIG. VI-15. PARAMETRIC TEST RESULTS, SNAP 19 VIKING GENERATOR S/N 115

FIGURE VI-16. VARIATION OF PEAK POWER LOAD VOLTAGE WITH TIME

operational conditions (hot leak test). The hot leak test was repeated at least one more time prior to delivery, following dynamic tests where performed. Results of post-fueling and pre-delivery hot leak tests are presented in Table VI-1 for both electrically heated and fueled Viking generators. In order to permit a direct comparison between converters as to leak tightness, all data were normalized to a constant partial pressure of helium (one atmosphere) and seal area temperatures of 337°F. The current seal configuration and the sequence of leakage tests evolved during the generator development period is discussed below.

a. ETG tests

Electrically heated generators S/N 101 and S/N 102, the first SNAP 19 Viking generators built, were delivered as hermetically sealed units. As in all other Viking units, the housing end covers were of welded closure design. The interfaces between the two electrical connectors and the generator housing were soldered on S/N 101 and S/N 102, diffusion bonded on S/N 100, and secured by a composite seal consisting of an O-ring-backed diffusion bond seal on S/N 103. All remaining Viking generators featured the Viking double O-ring connector seals. The measured total leakage rates shown in Table VI-1 reflect the differences in configuration. S/N 103, which was intended to be hermetically sealed, suffered release of one of the connector-to-housing diffusion bonds during assembly stages and its leak rate is characteristic of the permeation rate through the O-ring elastomer backup seal.

b. RTG tests

In addition to total generator leakage rate evaluation, the gas management design (refer to Section VII-A-1) necessitated evaluation of constituent component leakages such as end cover leakage, dome-to-converter seal leakage and dome-leakage. Results of these tests which were conducted during post-fueling assembly and, where applicable, after vibration, are summarized in Table VI-2. It is apparent that the magnitude of normally encountered connector seal leakages could readily mask a slightly faulty reservoir or lower cover weld in total leakage tests.

3. Dynamic Testing

Generator response to dynamic loads expected during the launch vehicle ascent phase, separation, and spacecraft landing was evaluated by exposure to vibration and shock test environments. Other dynamic loads, such as those created by handling and transportation were deemed

TABLE VI-1

TOTAL LEAK RATES OF SNAP 19 VIKING GENERATORS

<u>Generator S/N</u>	<u>Rate of Helium Permeation in scc/sec*</u>	
	<u>Post-Fueling</u>	<u>Pre-delivery</u>
<u>ETG's</u>		
100	6.1×10^{-8}	3.3×10^{-7}
101	$5.0 \times 10^{-7} **$	9.5×10^{-9}
102	$4.4 \times 10^{-7} **$	—
103	3.5×10^{-5}	3.7×10^{-5}
104	4.5×10^{-5}	4.8×10^{-5}
107	2.5×10^{-5}	2.3×10^{-5}
108	2.5×10^{-5}	2.5×10^{-5}
109	2.8×10^{-5}	2.6×10^{-5}
<u>RTG's</u>		
105	2.3×10^{-5}	3.0×10^{-5}
106	2.6×10^{-5}	2.9×10^{-5}
111	1.3×10^{-5}	1.6×10^{-5}
112	1.5×10^{-5}	1.5×10^{-5}
113	1.0×10^{-5}	1.3×10^{-5}
114	1.2×10^{-5}	1.4×10^{-5}
115	1.3×10^{-5}	1.2×10^{-5}

* At a seal temperature of 337° F and a helium pressure differential of one atmosphere across the seal.

** Includes leak check valve assembly.

TABLE VI-2

SUMMARY OF PARTIAL LEAKAGE RATES OF SNAP 19 VIKING RTG'S

(Rate of Helium Permeation in scc/sec x 10⁵)

	<u>S/N 105</u>	<u>S/N 106</u>	<u>S/N 111</u>	<u>S/N 112</u>	<u>S/N 113</u>	<u>S/N 114</u>	<u>S/N 115</u>
Generator top cover leak (post-fueling)	NA	NA	2.0	2.0	2.1	1.8	2.1
Converter-to-reservoir leak (post-fueling)	NA	NA	1.8	1.9	1.7	1.8	1.9
Reservoir leak (post-fueling)	0.003	0.003	0.003	0.005	0.004	0.005	0.004
Reservoir leak (post-vibration)	NA	NA	0.0003	0.004	0.0007	0.00005	0.0001
Lower cover leak (post-vibration)	NA	NA	0.00004	0.0003	0.002	0.0001	0.0001

 NA = Not Available

negligible in comparison. A record of the dynamic tests performed on generators S/N 100 through S/N 115 presented in Table VI-3.

All dynamic testing of the generators was accomplished at the Space and Electronics System Division of Fairchild Industries in Germantown, Maryland. The first generator to be tested under the Viking program was electrically heated generator (ETG) S/N 101. This generator was tested during April 1971. The last generator, RTG S/N 115, was dynamically tested during March 1975.

a. Vibration tests

Vibration testing was accomplished on a Ling Model A300B shaker with input applied in each of three mutually perpendicular axes as shown in Figure VI-17. Figure VI-18 shows a typical generator mounted on the shaker to be vibrated in the X-axis (shaker vertical) and in the Y-axis (shaker horizontal). As shown, the upper end cooler was attached to the generators prior to vibration testing. Vibration testing was performed with the generator load voltage at 4.4 volts and the fins uninsulated.

An accelerometer was located on the shaker table adjacent to the generator mounting flange. Vibration level and power input were recorded on an oscillograph. A Sanborn chart recorder was utilized to monitor and record pressure transducer output, and generator output voltage and current. In addition, hot junction temperature (RTD) and fin root (thermistor) temperature were recorded manually during vibration. A parallel digital readout was utilized also for output voltage and current measurements to provide increased accuracy and correlation with recorded data.

The vibration input levels and durations are shown in Table VI-4. Sinusoidal and random vibration were applied in each of three mutually orthogonal axes. Sinusoidal vibration preceded random vibration for each axis and testing was conducted in the axis sequence of X, Y, Z. References 2 through 11 give X-Y plots of the applied vibration versus frequency for the generators as well as detailed descriptions of the individual tests. Reference 1 is the test procedure utilized for the vibration tests.

The performance parameters of all generators exhibited satisfactory behavior during tests. The only anomaly occurred on generator S/N 100 when the pressure transducer wiper

TABLE VI-3

RECORD OF DYNAMIC TESTS FOR VIKING PROGRAM GENERATORS

<u>Generator S/N</u>	<u>Vibration</u>		<u>Shock</u>
	<u>Acceptance</u>	<u>Qualification</u>	
100 (ETG)	x	x	x
101 (ETG)	x		
103 (ETG)	x		
104 (ETG)	x		
105 (RTG)	x	x	x
106 (RTG)	x		
107 (ETG)	x		
108 (ETG)	x		
109 (ETG)	x		
111 (RTG)	x		
112 (RTG)	x		
113 (RTG)	x		
114 (RTG)	x		
115 (RTG)	x

FIG. VI-17. VIKING GENERATOR AXES DESIGNATION

RTG S/N 105 in X Axis

RTG S/N 105 in Y Axis

FIG. VI-18. VIBRATION TEST AXES ORIENTATION

TABLE VI-4

ACCEPTANCE VIBRATION

Sinusoidal

Frequency range:	5 to 250 to 5 Hz
Acceleration amplitude:	5-19 Hz @ 0.25 in. D. A. 19-250 Hz @ 5.0 g peak
Logarithmic sweep rate:	6 octaves/minute*
Number of sweeps	1

Random

Flat 250 Hz to 1000 Hz at $0.027 \text{ g}^2/\text{Hz}$
 Roll off below 250 Hz at 3 dB/octave
 Roll off above 1000 Hz at 6 dB/octave
 Overall level: 6.0 g's RMS
 Test duration: 60 seconds

* Generator S/N 100, S/N 101, and S/N 103 sweep rate: 4 octaves/minute

QUALIFICATION VIBRATION

Sinusoidal

Frequency range:	5 to 250 to 5 Hz
Acceleration amplitude:	5-19 Hz @ 0.4 in. D. A. 19-250 Hz @ 7.5 g peak
Logarithmic sweep rate:	1 octave/minute (S/N 100) 2 octaves/minute (S/N 105)
Number of sweeps	1

Random

20 to 250 Hz	+3 dB/octave
250 to 1000 Hz	$0.075 \text{ g}^2/\text{Hz}$ (S/N 100) $0.054 \text{ g}^2/\text{Hz}$ (S/N 105)
1000 to 2000 Hz	-6 dB/octave
Overall level: 10 g's RMS (S/N 100)	
8.5 g's RMS (S/N 105)	
Test duration: 300 seconds	

became intermittently open circuited during qualification vibration testing. A comparison of stable generator performance data obtained before and after environmental testing is presented for each generator in Table VI-5.

b. Shock tests

Viking generators ETG S/N 100 and RTG S/N 105 were subjected to pyrotechnic and landing shock as part of their environmental qualification tests. ETG S/N 100 was shock tested during March 1973 and RTG S/N 105 was shock tested during July 1973.

Pyrotechnic shock testing was performed on the Ling Model A300B shaker used for vibration testing with the addition of a Ling Model ESD 13 Synthesizer Equalizer and a Spectral Dynamics analyzer. One shock was applied in each direction of three orthogonal axes for a total of six shocks. Spectrum shaping was accomplished prior to each shock with the use of a mass model. Because the mass model was not identical to the RTG, six additional shocks to S/N 105 were required for spectrum trimming. Pyrotechnic shock testing was conducted in the axis sequence of X, Y and Z with the positive direction tested first in each axis. The pyrotechnic shock spectrum criteria are shown in Figure VI-19 and a typical shock spectrum is shown in Figure VI-20. Both generators performed nominally during and after shock testing except the pressure transducer failed by open circuit.

Landing shock performed on the Ling shaker was produced by a Hewlett Packard pulse generator and shaped by a Khron-Hite filter. The landing shock criteria are shown in Figure VI-21. Three shocks were applied in each direction of three orthogonal axes for a total of 18 shocks at 30 g's--22 ms. nominal. Pulse shaping was accomplished with the mass model. Landing shock testing was conducted in the axis sequence of X, Y and Z with the positive direction tested first in each axis. An oscillograph photograph of a typical shock pulse is shown in Figure VI-22. Generator operation was nominal after the landing shock tests.

Shock testing of ETG S/N 100 is described in Ref. 2 and the procedure is given in Ref. 12. RTG S/N 105 shock testing is described in Ref. 5.

4. Mass Properties Tests

Measurements to evaluate mass properties of the Viking generators were conducted during 1973 on four units, electrically heated generators S/N 103 and S/N 104, and fueled generators

TABLE VI-5

GENERATOR PERFORMANCE DATA

(Normalized to a fin root temperature of 330°F and load voltage of 4.4 v.)

Generator S/N	Prior to Environmental Testing				After Environmental Testing			
	Power (watts)	RTD (°F)	E _{OC} (volts)	Internal Pressure (psia)	Power (watts)	RTD (°F)	E _{OC} (volts)	Internal Pressure (psia)
100	44.65	1029	7.17	15.8	44.40	1032	7.24	—*
101	42.75	1037	7.23	26.3	42.54	1037	7.21	26.2
103	43.70	964	7.00	25.4	43.59	966	7.03	25.4
104	43.38	980	6.97	25.0	42.83	980	6.96	25.1
105	41.85	1007	6.95	16.2	42.16	1003	6.98	16.5
106	42.07	1017	6.99	14.7	42.23	1019	7.00	14.6
107	42.90	987	6.98	25.5	42.46	989	6.96	25.5
108	42.25	968	6.91	26.1	42.33	969	6.94	26.0
109	43.12	993	7.00	25.5	42.94	991	7.02	25.6
111	42.46	1020	7.15	16.6	42.13	1025	7.10	16.5
112	43.11	1002	7.00	16.5	43.05	1003	7.07	16.7
113	42.43	1012	6.95	16.1	42.47	1017	6.96	15.8
114	42.62	1010	6.95	16.2	42.46	1014	6.95	15.8
115	42.49	1008	6.90	16.5	42.29	1009	6.89	16.5

* Pressure transducer open circuited during pyrotechnic shock testing.

FIG. VI-19. VIKING PYROTECHNIC SHOCK CRITERIA

TES-3069-54
VI-29

FIG. VI-20. PYROTECHNIC SHOCK IN +X AXIS, RTG S/N 105

+ Shocks

10 g's/div.

5 ms./div.

- Shocks

10 g's/div.

5 ms./div.

FIG. VI-22. RTG S/N 105 LANDING SHOCK IN + AND - Y AXIS

S/N 105 and S/N 106. All measurements were performed at facilities of Fairchild Industries in Germantown, Maryland, following successful completion of dynamic testing of the subject generators.

Mass properties were measured with a Miller Dynamic Balancing (Airdyne) Machine, Model 299. With this facility, the center of gravity is determined by measuring the static force on a load sensitive device at the periphery of a table supported by an air bearing. Moment of inertia determination is obtained by measuring the period of oscillation of a torsional pendulum which supports the specimen and mounting fixture. Figure VI-23 shows a typical test set-up for the determination of center of gravity.

Precise weight measurements of the four generators were performed on a HOMS beam balance scale model 105 TWX, using NBS master weights.

Results of the mass properties tests are summarized in Table VI-6. Data are referenced to the coordinate system shown in Figure VI-17. Detailed procedures and test data are contained in Ref. 13 through Ref. 15.

5. Thermal Design Point Verification Test

Fueled SNAP 19 Viking generators were designed to operate with average fin root temperatures near 330°F at conditions as follows:

Electrical load condition of 4.4 volts.

Exposed to 100°F totally absorbing sink.

No heat loss from lower flange and lower end cover.

Thermal inventory of 675 watts.

Tests were conducted to verify the thermal radiation design point for each RTG in vacuum and the results are presented in Table VI-7. In addition, tests conducted on electrically heated generators indicated fin root temperatures in the same range.

6. Thermal Cycle Test

Thermal cycle tests were conducted on three ETG's and two fueled RTG's to characterize generator response to operational load switching and to evaluate performance at and between diverse fin root temperatures. The acceptance level test sequence performed on generators S/N 100, and S/N 103 through S/N 106 commenced with a power check at 330°F. The generators

VIKING GENERATOR MASS PROPERTY EVALUATION

ELECTRICALLY HEATED
GENERATOR (S/N 104)
MOUNTED IN X-AXIS

Y-AXIS MOUNTING OF
S/N 104 IN MASS PROPERTIES
TEST FIXTURE

FIG. VI-23. DETERMINATION OF CENTER OF GRAVITY

TABLE VI-6

MASS PROPERTIES DATA SUMMARY

RTG S/N	Center of Gravity			Moments of Inertia about CG			Weight (lbs)
	$\bar{X}$ (in.)	$\bar{Y}$ (in.)	$\bar{Z}$ (in.)	I_{XX} (lb-in. ²)	I_{YY} (lb-in. ²)	I_{ZZ} (lb-in. ²)	
105	-5.782	-0.019	-0.004	351	451	383	33.56
106	-5.813	-0.028	-0.039	374	468	475	33.60
103	-5.736	-0.192	-0.063	549	503	510	34.08
104	-5.815	-0.229	-0.089	500	502	566	33.91

TABLE VI-7

VIKING RTG THERMAL RADIATION DESIGN POINT TEST RESULTS

<u>RTG S/N</u>	<u>Average Fin Root Temperature at Test Operating Conditions (°F)</u>
105	329
106	329
111	327
112	328
113	326
114	327
115	325

were then shorted, held at this condition for 12 hours, and then switched back to load (4.4 VDC). Subsequently, three thermal cycles from 325°F average fin temperature to 175°F, and back to 325°F, were performed with the generators allowed to stabilize at each thermal level. Following these tests, a second power check was conducted at the pretest reference conditions 330°F on fin root and 4.40 load volts. Figures 24 and 25 show the current, voltage and temperature response of S/N 106 to the load switching. Figure 26 depicts the thermal cycle test. No adverse effects of acceptance level load switching or thermal cycling on performance were noted.

Qualification level thermal cycle tests were conducted on ETG S/N 100 and on RTG S/N 105. For these tests the generators were on short circuit for 36 hours at a fin root temperature of 360°F ± 10°F and then cycled ten times with the nominal fin root temperature cycle being 335°F to 150°F to 335°F. Figure 27 contains the qualification level testing of S/N 105. The overall generator power decreases measured were nominal in all instances so that no degradation of performance was attributed to the thermal cycling.

The procedure for these tests is identified in Ref. 16 and test reports are listed in Ref. 17 through 21.

7. Series Functional Tests

The operation of series-connected generators was checked for several generator pairs, including flight RTG's S/N 111 through 114. These tests, prescribed by procedure (Ref. 22), consist of performance of an insulated fin parametric test in combined generator load voltage. Since the generator electrical characteristics are not identical, the voltage for each generator will be slightly different for this common current (series) arrangement. Thus, the total power exhibited will be different from that obtained by summing the power of individual generators (at either the reference or peak power voltage). However, when pairing generators of similar age and operating characteristics, the differences between combined generator power and the power of two individual generators are of ± 0.2 watt or less. These findings were concluded from tests of the following generator pairs:

ETG S/N 100 with ETG S/N 103
RTG S/N 105 with RTG S/N 106
ETG S/N 108 with ETG S/N 109
ETG S/N 111 with RTG S/N 112
RTG S/N 113 with RTG S/N 114

Power output versus current for single and combined Viking flight generators is illustrated in Figures VI-28 and VI 29.

FIG. VI-24. GENERATOR RESPONSE TO INSTANTANEOUS LOAD SWITCHING SNAP 19 VIKING
GENERATOR S/N 106 GENERATOR THERMAL CYCLE TEST, ACCEPTANCE LEVEL

FIG. VI-25. GENERATOR RESPONSE TO INSTANTANEOUS LOAD SWITCHING SNAP 19 VIKING
GENERATOR S/N 106 GENERATOR THERMAL CYCLE TEST ACCEPTANCE LEVEL

FIG. VI-26. TYPICAL MARS SURFACE THERMAL CYCLE SNAP 19 VIKING GENERATOR
S/N 106 ACCEPTANCE LEVEL TEST

FIG. VI-27. TYPICAL MARS SURFACE THERMAL CYCLE SNAP 19 VIKING GENERATOR S/N 105
QUALIFICATION LEVEL TEST

Data Normalized to: 330°F Average Fin Root Temperature

— Represents least squares straight line fit of normalized voltage versus current data (excluding short circuit data)

FIG. VI-28. SERIES FUNCTIONAL TEST RESULTS SNAP 19 VIKING RTG'S S/N 111 AND S/N 112

Data Normalized to: 330°F Fin Root Temperature

FIG. VI-29. SERIES FUNCTIONAL TEST RESULTS SNAP 19 VIKING RTG'S S/N 113 AND S/N 114

8. Radiation Survey

The levels of radiation emitted from individual fuel capsules were measured in generator survey tests at Teledyne Energy Systems and on individual fuel capsules at MRC. Results of these tests for each generator are presented in Figures VI-30 through VI-36 which show total dose rates at distances up to about ten feet from generator side and bottom surfaces. Procedures for generator level radiation measurements are identified in Ref. 22.

9. Insulation Resistance

The insulation resistance at 50 VDC was measured in Viking flight generators at various stages between completion of assembly and generator installation on the Viking lander at KSC. Measurements were obtained between the generator housing, the thermoelectric circuit, and the instrumentation circuit. The minimum allowable resistance values as specified in the generator performance acceptance criteria document, Ref. 23, are shown in Table VI-8 together with the set of measurements taken at Teledyne Energy Systems prior to delivery. The generators were short circuited during these tests.

TABLE VI-8
PRE-DELIVERY RTG INSULATION RESISTANCE

	<u>Instrumentation to RTG Housing (megohms)</u>	<u>Circuits to T/E Power Circuit (megohms)</u>	<u>T/E Power Circuit to RTG Housing (megohms)</u>
Specification, Ref. 23	1.0 minimum	1.0 minimum	0.02 minimum
RTG S/N 111	600	480	43
RTG S/N 112	780	530	200
RTG S/N 113	580	670	78
RTG S/N 114	280	260	60
RTG S/N 115	170	70	150

FIG. VI-30. GENERATOR S/N 105 DOSE RATES CAPSULE VF-1

FIG. VI-31. GENERATOR S/N 106 DOSE RATES CAPSULE VF-2

FIG. VI-32. GENERATOR S/N 111 DOSE RATES CAPSULE VF-4

FIG. VI-34. GENERATOR S/N 113 DOSE RATES CAPSULE VF-6

FIG. VI-35. GENERATOR S/N 114 DOSE RATES CAPSULE VF-7

FIG. VI-36. GENERATOR S/N 115 DOSE RATES CAPSULE VF-8

VI. REFERENCES

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3. Acceptance Vibration Test Report for Viking ETG S/N 101, INSD-2960-7, July 1971.
4. Acceptance Vibration Test Report for ETG S/N 103 and S/N 104, ESD-2960-120.
5. Dynamic Qualification Test Report for RTG S/N 105, ESD-2960-116.
6. Acceptance Vibration Test Report for RTG S/N 106, ESD-2960-123, October 1973.
7. Acceptance Vibration Test Report for ETG S/N 107, ESD-3069-4, March 1974.
8. Acceptance Vibration Test Report for ETG S/N 108 and S/N 109, ESD-3069-11, May 1974.
9. Acceptance Vibration Test Report for RTG S/N 111 and S/N 112, ESD-3069-29, January 1975.
10. Acceptance Vibration Test Report for RTG S/N 113 and S/N 114, ESD-3069-31, February 1975.
11. Acceptance Vibration Test Report for RTG S/N 115, ESD-3069-32, March 1975.
12. Pyrotechnic and Landing Shock Generator Qualification Test Procedure Drawing 452A6000410.
13. Generator Mass Properties Test Procedure Drawing 452A6000411.
14. Mass Properties Test Report RTG's S/N 105 and S/N 106, ESD-3069-14, June 1974.
15. Mass Properties Test Report, ETG S/N 103 and S/N 104, ESD-3069-16, August 1974.
16. Generator Thermal Cycle Test Procedure Drawing 452A6000412.
17. Thermal Cycle Test Report, S/N 100, ESD-2960-99, July 1973.
18. Thermal Cycle Test Report, S/N 103, ESD-2960-115, August 1973.
19. Thermal Cycle Test Report, S/N 104, ESD-2960-144, November 1973.
20. Thermal Cycle Test Report, S/N 105, ESD-2960-125, September 1973.
21. Thermal Cycle Test Report, S/N 106, ESD-2960-126, September 1973.
22. Generator Radiation Survey Test Procedure Drawing 452A6100400.
23. Generator Performance Acceptance Criteria Drawing 452A6000501.

VII. GENERATOR TECHNOLOGY EFFORTS

A. GENERATOR DESIGN

1. Inert Cover Gas Management

The Viking RTG configuration is shown schematically in Figure VII-1. The thermoelectric converter is sealed at the electrical receptacle/generator housing interface and at the upper cover/reservoir dome interface by Viton O-rings. During generator assembly, both the converter and reservoir volumes are individually filled with helium/argon gas mixtures. The thermoelectric converter is initially filled with a 90% He/10% Ar gas mixture to maintain satisfactory fuel capsule temperatures during prelaunch operations. However, since fuel generated helium is exhausted directly into the thermoelectric converter the concentration of helium in the thermoelectric converter would increase with time causing increased parasitic heat loss and reduced cover output. By initially filling the reservoir with a highly enriched argon gas mixture (5% He/95% Ar), argon gas can enter the thermoelectric converter by permeation through the Viton O-ring seal. The transfer of the lower thermal conductivity gas (i.e., argon) into the thermoelectric converter negates the helium buildup and allows the hot junction temperature to increase with time. This inert cover gas management system enables reduced hot junction and heat source temperatures during prelaunch activities while providing for an increase in hot junction temperature with time. The highest hot junction temperatures and the associated enhanced power performance occur late in the mission when the fuel thermal inventory is less and the Lander electrical power requirement is high. The 5% He content in the reservoir gas is necessary for leak checking the reservoir welds during generator assembly operations.

Selection of the initial composition of the helium/argon fill gas mixtures in both the reservoir and the thermoelectric converter was based on the following ground rules:

- (1) Maintain heat source strength member temperatures during acceptance testing at levels consistent with SNAP 19 Pioneer experience.
- (2) Maintain EOM power above specification requirements with a margin as high as practical while satisfying other selection criteria.
- (3) Provide sufficient helium gas in the reservoir to facilitate determining the seal integrity of the reservoir welds.

FIG. VII-1. VIKING RTG O-RING SEAL LOCATIONS

- (4) Select gas mixtures such that a failure of the O-ring seal between the converter and reservoir can be readily detected by changes in generator characteristics, thereby allowing corrective action to be instituted.

Parametric studies conducted in item (1) indicated that a gas composition with a helium concentration greater than 88% in the converter would maintain prelaunch heat source strength member temperatures below the Pioneer data of 825°C. Figure VII-2 shows the calculated SNAP 19 Viking RTG heat source strength member temperatures during acceptance testing as a function of initial converter gas composition.

A study was conducted to determine the strength member temperatures for the event of a seal failure allowing complete intermixing of the converter and reservoir gases. This study indicated that strength member temperatures would exceed 850°C unless 100% helium were placed in the converter and the reservoir were filled with greater than 50% helium gas mixture. However, insufficient EOM electrical power would be obtained with a 100% helium converter gas and a greater than 50% helium mixture in the reservoir. Thus, a reservoir gas mixture of 5% He/95% Ar was selected to maximize EOM performance while providing adequate helium to facilitate leak checking of the reservoir welds. A converter gas mixture of 90% He/10% Ar was selected to satisfy the heat source temperature criteria and to maintain the EOM power margin as high as practical. Although the selected gas mixtures could result in heat source temperatures near 950°C in the event of a reservoir-to-converter seal failure, changes in the generator hot junction temperature and power would indicate such a seal failure. Corrective action consisting of placing the generator on short circuit would then reduce the strength member temperature below 850°C.

The transfer of gases between the thermoelectric converter and the reservoir is accomplished by a controlled leak device mounted in the RTG upper cover. The controlled leak device consists of a simulated electrical receptacle (Deutsch P/N DBA54H-16-26PN) with an O-ring groove designed to accommodate the Pioneer-size Viton O-ring (1.188 x 0.076 - V747-75). The body of the controlled leak device, referred to as a seal shell, is fabricated from type 304 stainless steel. The seal between the upper cover and the seal shell is accomplished by the Viton O-ring. A hardcoated aluminum jam nut, which is torqued to 100-110 in-lbs, is used to compress the O-ring into the groove of the seal shell. Once the O-ring seal is made, gas transfer

He/Ar Gas Fills at 1 Atmosphere
Initial Fuel Inventory: 682 ± 3 Watts (t)
Fin Root Temperature: 330°F
Load Voltage: 4.4 Volts

FIG. VII-2. VIKING FUEL CAPSULE STRENGTH MEMBER TEMPERATURE AT ACCEPTANCE

between the converter and reservoir is controlled by permeation through the Viton. All seven RTG's fabricated on the Viking program utilize the seal shell controlled leak device for the gas management system. Helium leak checks of the controlled leak devices have yielded consistent leak rate values in good agreement with the Pioneer leak rate data. Table VII-1 lists the helium leak rate measurements made on each of the seven Viking RTG's. Figure VII-3 shows a typical installation of a controlled leak device in an RTG upper cover.

2. Generator End Closure

End closure of the generator housing is accomplished by clamping each end cover to the housing by means of a threaded lock ring and then seal welding a seal ring to the cover and housing. Figure VII-4 illustrates a typical RTG end closure configuration. The closure technique is the same for both ends of the generator housing.

During assembly, the end cover is initially placed atop the appropriate end of the generator housing, resting on the Min-K thermal insulation which protrudes slightly out of the converter. A bearing load is applied to the cover until it bottoms on the cover mounting surface of the generator housing. This cover seating operation yields a preload of the heat source through compression of the Min-K thermal insulation. The cover is then clamped in place at its outer periphery by a threaded lock ring. The lock ring is fabricated from 6061-T651 aluminum alloy which has been hardcoated to facilitate the threading of the lock ring into the housing. The lock ring has external stub Acme threads to mate with those of the generator housing. The lock ring is threaded into the housing via a spanner-type lock ring wrench and torqued to a value of 225 in-lbs. A seal ring, with a U-channel cross section, is then placed atop the installed lock ring fitting between the cover weld flange and the housing weld flange. The seal ring is fabricated from HM21A-T5 magnesium alloy, the same material as the housing and covers. Once in place, the seal ring is fusion welded to the cover on the inner edge and to the housing on its outer edge. This welding operation provides a non-loadbearing hermetic seal of the thermoelectric converter.

3. Electrical Receptacle-to-Housing Seal

a. Solder seal

Feasibility studies were initiated in 1970 to evaluate sealing techniques for continuous operation at temperatures up to 400°F. The candidates consisted of Viton 77-545 O-rings, metal

TABLE VII-1
COMPARISON OF THE LEAK RATE MEASUREMENTS FOR THE
CONTROLLED LEAK DEVICES IN VIKING RTG'S

Viking RTG S/N	Helium Leak Rate Normalized to One Atmosphere and 337° F (<i>sec</i> He/ <i>sec</i> -atm)
	During Generator Fueling Operations
105	2.0×10^{-5}
106	1.0×10^{-5}
111	1.9×10^{-5}
112	1.9×10^{-5}
113	1.7×10^{-5}
114	1.8×10^{-5}
115	1.8×10^{-5}

O-rings, metal V-seals and soldering. In late 1970, soldering was selected as the sealing technique for use on the Viking program.

After an extensive effort, a receptacle seal design and bonding procedure was developed to permit soldering of electrical receptacles into the generator housing and cover. In early 1971 the soldering technique was employed for the installation of electrical receptacles in ETG's S/N 101 and S/N 102. Figure VII-5 shows the receptacle seal configuration utilized. The electrical receptacle was a copper-plated Deutsch (DBA 54H-16-26PM) 26 pin, jam nut-type with an O-ring groove and a type 321 stainless steel body. The seal ring was fabricated from HM21A-T8 magnesium alloy, copper-plated and then seal-welded into the generator housing. Solder washers of 100% tin were used in combination with Nokorode flux to produce the solder joint. Copper screens and brass thermal compensators were machined into washers, tinned with 100% tin, and added to the solder joint for additional strength. The solder seals incorporated in generators S/N 101 and S/N 102 are still operating satisfactorily in current NASA Lander testing employing these generators.

Typical RTG
Upper Cover
Installation

FIG. VII-3. RESERVOIR-TO-CONVERTER CONTROLLED LEAK DEVICE

FIG. VII-4. RTG END CLOSURE CONFIGURATION

FIG. VII-5. VIKING ETG S/N 101 AND S/N 102 SOLDER RECEPTACLE SEAL CONFIGURATION

Subsequent attempts to fabricate long-term test specimens met with only limited success due to variations in the quality of the copper platings on components received from candidate plating vendors and the "wetting" characteristics of the plated components. In addition, the long-lead times associated with component plating and high rejection rates for received parts resulted in serious schedule delays. Finally, on May 26, 1972, the increasing difficulties with the solder seal forced the termination of the solder seal development effort.

b. Diffusion bond

In late 1971, diffusion bonding and Viton V747-75 compound O-rings were evaluated as potential backup approaches to the solder seal. In May 1972, the termination of solder seal development resulted in the elevation of the diffusion bond as the primary seal approach with the Viton O-ring as the backup. The diffusion bond technique was selected because of the Viking mission design criteria of maintaining a constant inert cover gas within the generator housing to reduce power change during the mission.

The diffusion bonding technique supplied a means of joining an electrical receptacle (shell material being 20CB-3 stainless steel) to the SNAP 19 Viking generator housing (housing material being magnesium alloy HM21A-T5). First the electrical receptacle was fusion welded to the nickel-201 detail of a Ni/MgTh diffusion bonded subassembly. The magnesium thorium portion of the diffusion bond subassembly was then fusion welded into the generator housing. Figure VII-6 shows the arrangement of the details forming the diffusion bond electrical receptacle assembly. By October 1972, a total of 22 diffusion bonded test samples were on test, 6 employing "dummy" (simulated) receptacles and 16 of the all-up configuration. The success of the test samples prompted the use of the diffusion bond sealing approach for the SNAP 19 Viking Proof Design Review conducted in December 1972.

The application of diffusion bonding as a joining technique was considered for the electrical receptacle seal because of the metallurgical incompatibility of stainless steel and the magnesium thorium alloy posed by common welding or brazing processes. 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 determine the most likely candidate to achieve the Viking mission requirements. The metal couple systems selected for evaluation were made primarily

FIG. VII-6. DIFFUSION BOND ELECTRICAL RECEPTACLE ASSEMBLY

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. Results of the theoretical and experimental evaluation of the candidate metal couple systems established Ni-201/MgTh (HM21A-T8) system as the best choice. Bonding studies on the Ni/MgTh bimetal couple system yielded consistently good joints with bonded joint strengths of 3020 psi (ultimate tensile) and 2430 psi (shear) at room temperature.

In January 1973, while performing thermal acceptance testing on diffusion bonded receptacle assemblies for use in the Viking Engineering ETG (S/N 100), diffusion bond separations were experienced. In subsequent attempts to determine the cause of the separation, a total of five separations were experienced with the assemblies mounted in the thermal acceptance test fixtures. Based on the installation success of the diffusion bonded receptacle assembly test samples, the decision was made to forego the thermal acceptance test and to weld the diffusion bond assembly directly into the housing for generator S/N 100. This operation was performed and found to be successful in that both diffusion bonded receptacle assemblies (one for power input; one for power output) were leak-tight after installation and remained intact throughout qualification level testing.

c. Composite seal

Continuing anomalies with the diffusion bond (e. g. , bond separations during receptacle welding), and the demonstration of the Viton V747-75 O-rings to endure simulated Mars thermal cycling after long-term exposure, led to the composite seal design. The composite seal design (see Figure VII-7) consists of a Viton V747-75 O-ring placed in series with the diffusion bond assembly to provide a redundant system in the event of a diffusion bond failure. Four test fixtures were assembled with the composite seal to verify the design approach. Two additional composite seals were installed in the pressure and thermal test generator housing mockup (half-housing assembly). One diffusion bond separation was experienced in the test fixtures during testing, while the seals installed in the half-housing assembly successfully completed simulated end cap cooler operational thermal transient testing.

During the assembly of Viking ETG S/N 103, the diffusion bond assembly portion of the composite seal separated during installation of the receptacle seal into the generator housing.

FIG. VII-7.
COMPOSITE RECEPTACLE SEAL DESIGN

The decision was made to proceed with the separated diffusion bond in the housing since the redundant O-ring seal was still functioning acceptably. Because of the recurring bond separations, a move was initiated to eliminate the diffusion bond seal from further generator designs.

d. Dual O-ring seal

During the period of March 1973 through May 1973, extensive analytical studies were performed to evaluate the effect on electrical performance of the receptacle seal options then under consideration. The studies showed that for the Viking mission there was no electrical performance penalty associated with the use of an all-Viton receptacle seal design. The selected design (see Figure VII-8) provided redundancy and minimum perturbation from the composite seal design, thus permitting use of established installation techniques and available hardware. Five test fixtures employing the dual O-ring receptacle seal configuration were assembled and leak tested. In June 1973, the dual O-ring receptacle seal design was used in the assembly of the prototype RTG's S/N 105 and S/N 106. These generators successfully completed the Viking qualification testing and have continued to perform acceptably during life testing at MMA-Denver. The success of the dual O-ring configuration in the prototype generators qualified its usage in all five of the flight RTG's, S/N 111 through S/N 115.

The fabrication of the dual O-ring electrical receptacle seal is performed in a methodical step-by-step assembly procedure. The Deutsch electrical receptacle is first leak checked to verify a leak-tight glass-to-metal seal between the receptacle shell and the solder pins. The receptacle is then fusion welded to a stainless steel seal ring by an automatic welding process. The weld is then leak checked. The two Viton 2-031-V747-75 O-rings are then fitted into the O-ring grooves of the seal ring and the entire assembly is installed into the mounting boss of the housing. A magnesium thorium compression ring is placed atop the assembly and the O-rings are compressed with a 200 lb load applied by a hydraulic press. With the O-rings compressed, the compression ring is tack welded at four locations to the housing weld flange. The generator housing is then moved to an automatic welding machine for the completion of the compression ring to housing seal weld. Upon the completion of the final welding operation, the installed dual O-ring seal configuration is helium leak checked at room temperature to verify acceptability of the seal.

FIG. VII-8.
DUAL O-RING RECEPTACLE SEAL

Helium leak checks of the dual O-ring receptacle seals installed in Viking RTG's have yielded consistent leak rate values. Table VII-2 lists the leak rates measured for the seven RTG's fabricated. The generator leak rate values also agree favorably with the test data recorded for the five dual O-ring test fixtures. Further, taking into account the size difference, the leak rate of a dual O-ring configuration (series leakage path) is in agreement with the Pioneer type single O-ring data.

4. Getter Optimization

Design evaluation and analytical studies were conducted with the intent of improving the Viking ETG/RTG getter configuration over that of the Pioneer design. The studies were aimed at reducing the parasitic heat losses associated with the Pioneer design through changes in the getter configuration and physical location within the thermoelectric converter. Experience with Pioneer generators and HPG S/N 1 indicated that heat loss through the getter assemblies (two per generator) decreased generator electrical output by approximately 1.6 watts(e).

The following ground rules were established for the getter optimization studies:

- (1) The thermoelectric modules, including the RTD location, would not be altered.
- (2) The getter would operate in contact with the heat shield unless the studies dictated otherwise.
- (3) 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.
- (4) The Pioneer getter materials would be retained (70 to 80% dense zirconium in palladium housing).

Results of thermal analyses (using nominal 1050°F heat shield and the 300°F housing boundary temperatures) 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. The proposed getter design promised a decrease in thermal losses of 13 watts with an attendant increase in initial generator output power of 1.3 watts(e) and 1.2 watts(e) at EOM. Figure VII-9 shows the optimized getter configuration.

The optimized getter configuration contains 65% of the amount of zirconium used in the Pioneer configuration. Based on conservative assumptions for the quantity of water remaining

TABLE VII-2
COMPARISON OF DUAL O-RING RECEPTACLE SEAL
LEAK RATES FOR VIKING RTG'S
(sec He/sec-atm)

Viking RTG S/N	<u>Helium Leak Rate Normalized to One Atmosphere and 337° F</u>		
	After Generator Assembly	After Vibration Testing	After Thermal Cycle Testing
105*	1.1×10^{-5}	1.2×10^{-5}	1.4×10^{-5}
106*	1.2×10^{-5}	1.4×10^{-5}	1.4×10^{-5}
111	1.2×10^{-5}	1.5×10^{-5}	—
112	1.4×10^{-5}	1.3×10^{-5}	—
113	1.0×10^{-5}	1.3×10^{-5}	—
114	1.2×10^{-5}	1.5×10^{-5}	—
115	1.3×10^{-5}	1.2×10^{-5}	—

* Leak rates adjusted to compensate for uncertainty in calibrated leak standard.

in the generator after outgassing, 65% of the Pioneer quantity of zirconium is more than sufficient to getter all O₂ and H₂. The thermal studies also indicated that the Pioneer getter location adjacent to the heat shield should be retained. This location enables a getter temperature that is within 5°F of the adjacent heat shield temperature, thereby assuring the required minimum getter temperature of 450°C (842°F) for complete getter effectiveness.

Because the revised getter location necessitated a shortening of the heat shield by approximately 0.40 inch at each end, the heat shield end plug engagement was reduced from 13 to 9 threads. Structural analysis showed that the load rating for a stub Acme thread in shear is approximately 1000 pounds. Since the shear ring load relief mechanism is designed for a load of 4600 pounds, the 9000 pounds provided by the 9 threads is sufficient to retain the fuel capsule

Heat Loss Compared to Pioneer Getter:	-13.2 Watts Thermal
Average Heat Shield Temperature:	1070°F
Average Fin Root Temperature:	330°F
Getter Operating Temperature:	1066°F

FIG. VII-9.

VIKING OPTIMIZED GETTER CONFIGURATION

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

within the heat shield. The recess in the heat source is designed to permit the getter assembly to separate from the heat shield during generator reentry breakup. The increase in ballistic coefficient for the recessed heat shield is approximately 2% which causes negligible effect on reentry heating.

5. Internal Pressure Transducer

Design efforts were conducted to investigate commercially available pressure transducers for monitoring the absolute internal pressure of SNAP 19 Viking generators. Preliminary discussions were held with twenty four pressure transducer vendors whose instruments had been used on spacecraft, nuclear reactor, or in other high temperature applications. Eleven meetings were held at Teledyne Energy Systems with technical personnel from interested vendors. In addition, customers of some of the interested vendors were contacted to gather technical opinions on the performance of their pressure transducers. A detailed RFQ was transmitted to twenty vendors and an RFQ evaluation board was appointed to evaluate the vendor responses.

The pressure transducer, was to be installed inside the generator housing to monitor the absolute internal pressure of the hermetically sealed generator housing. Important characteristics required of the pressure transducer were the following:

- (1) Calibration stability and long-term reliability (three years storage, five years operational life) at an operating temperature of 450° F.
- (2) Minimum dimensional envelope of 1-1/4" x 1-1/4" x 1-3/4" long for the transducer configuration.
- (3) Maximum transducer weight of six ounces.
- (4) Minimum weight, size and power demand for the associated flight hardware signal conditioning unit (if required).
- (5) Capable of withstanding the effects of low-level nuclear radiation.
- (6) Capable of withstanding the dynamic environments associated with launch and 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.

Ten pressure transducer design proposals were received in response to the twenty RFQ's transmitted. The proposal designs received included strain gage, potentiometric, eddy-current and variable reluctance type pressure transducers. In the course of the proposal evaluation stage, Teledyne Energy Systems received direction from ERDA to limit the pressure transducer selection to only a resistive type pressure measurement system. The resistive type system was to have only two (or maximum of three) signal lead wires and not need a signal conditioning unit external to the generator. The only candidates satisfying these requirements were the potentiometric type transducer vendors, Edcliff Instruments and Bourns Instrumentation Division. Edcliff Instruments Company was selected as the primary supplier with Bourns Instruments as backup primarily on the basis of design experience with high temperature, potentiometric pressure transducers (850°F) and the more compact transducer envelope. A detailed specification drawing was drafted to serve as a baseline for the Teledyne Energy Systems Controlled Commercial Item. Also, a detailed vendor acceptance test program was developed for the qualification of pressure transducers prior to shipment to Teledyne Energy Systems.

A total of ten pressure transducers were ordered from Edcliff Instrument Company for use in Viking generators. Edcliff pressure transducers were subsequently installed in ETG's S/N 100, S/N 103, S/N 104 and S/N 107 in addition to RTG's S/N 105 and S/N 106. Of the ten pressure transducers received, seven units failed to satisfy the design performance requirements. Problems with pressure transducers installed in generators S/N 100, S/N 104 and S/N 105 were discovered after delivery of the generators to MMA-Denver. Table VII-3 lists the pressure transducers installed in Viking generators. In addition, problems developed at the vendor's facility with regard to obtaining satisfactory units due to mishandling and failure to satisfy pre-shipment acceptance testing requirements. An inability to meet delivery requirements, combined with the above problems, led to the replacement of Edcliff Instruments Company as the primary source.

Bourns Instruments, initially the backup vendor, was asked to fabricate ten pressure transducer units for use in the remainder of the Viking generators. Bourns delivered two transducer units to Teledyne Energy Systems for evaluation testing. These units were tested along with three units from Edcliff for comparison purposes. Both Bourns units satisfied all

TABLE VII-3

PRESSURE TRANSDUCERS USED IN VIKING GENERATORS

Viking Generator S/N	Vendor	Pressure Transducer S/N	Comments
100	Edcliff	6588	Transducer does not operate between room temperature and ~ 140° F
103	Edcliff	6587	Performs normally
104	Edcliff	6541	Transducer operates erratic over temperature range of generator
105	Edcliff	6543	Transducer has high wiper circuit resistance
106	Edcliff	6586	Performs normally
107	Edcliff	6591	Performs normally
108	Bourns	0874-001	Performs normally
109	Bourns	0874-003	Performs normally
111	Bourns	3974-109	Performs normally
112	Bourns	3974-108	Performs normally
113	Bourns	3974-111	Performs normally
114	Bourns	4374-204	Performs normally
115	Bourns	3974-110	Performs normally

test requirements while only one of the three Edcliff units functioned properly after testing. Results of the evaluation tests established the Bourns units superior to the problem-laden Edcliff transducers. Bourns pressure transducers were subsequently installed in Viking ETG's S/N 108 and S/N 109, and in all the Viking flight RTG's S/N 111 through S/N 115 (see Table VII-3). All of the Bourns units installed in generators continued to perform in an acceptable manner.

6. Improved Hot Junction Temperature Sensor

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 approximately 2800 hours of RTD operation. The failure mode in both cases was characterized by an open circuit condition in the RTD circuit inside the generator. Since both generators were still operational in long-term field tests, no diagnostic efforts were undertaken to determine the exact cause of the RTD failure. Similar RTD failures were experienced in Pioneer generators with the same RTD model after over 5000 hours of continuous operation. In all of these cases, the same symptoms appeared in the RTD performance characteristics indicating imminent breakdown just prior to the actual failure. The failed RTD from Pioneer RTG S/N 37 was removed from the generator and analyzed. The failure mode was traced to multiple breaks in the 0.0006 inch diameter platinum wire sensing coil. In view of this experience, design efforts were conducted to achieve an improved RTD for the Viking generators.

The Viking generator hot junction temperature sensor is a platinum wire-wound RTD designed to measure temperature over the range of 0°F to 1300°F. Each generator contains one RTD welded directly to a tab on the hot shoe of a thermoelectric couple in the thermoelectric converter circuit. The principal goals of the design evaluation were:

- (1) Improve the configuration design of the sensing coil element assembly by providing better protection to the coil against chemical attack during long-term operation of the generator.
- (2) Improve the hermetic seal integrity of the entire RTD configuration.
- (3) Improve the test and quality assurance program for the RTD during its manufacturing process.

The purpose of the improved RTD design effort was to formulate a better RTD design assuring long-term reliability based on the experiences gained from the disassembly of Pioneer RTG S/N 37. The efforts of Teledyne Energy Systems and Rosemount Engineering Company, the RTD vendor, yielded the following design improvements:

- (1) The sensing coil wire diameter was increased from 0.0006 inch to 0.001 inch. The larger diameter sensing coil wire affords better structural integrity of the coil in addition to allowing a greater current to flow through the RTD without self-heating.
- (2) A single coil, encapsulated with high purity alumina by a flame-spray technique, enclosed in a platinum cylinder. This cylinder serves as a barrier against chemical attack of the coil by gas constituents developed inside the generator during long-term operation. The entire coil assembly is encapsulated again inside a hermetically sealed housing fabricated from inconel 600. The old consisted of two coils (wired in series) mounted inside a hermetically sealed 304 stainless steel housing.
- (3) A single coil which is bifilar-wound on a high purity alumina mandrel anchored inside the platinum cylinder that serves as a chemical barrier. No cement is used on the sensing coil. The old design consisted of two sensing coils freestanding (no support mandrel) with the loops of the coil cemented to a 304 stainless steel base plate.
- (4) Barrel assembly replaced with a 1000°F rated commercially available electrical feedthrough header. The old design consisted of a fused glass composition hermetic barrel seal which was capable of 700°F.
- (5) In addition, the improved design added numerous intermediate inspection steps to enhance RTD quality assurance:
 - 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 with 100 VDC.

The improved RTD design exhibited operational sensitivities essentially identical to those of the old RTD design. Figure VII-10 shows the vendor drawing of the improved RTD configuration used in Viking generators S/N 100 through S/N 115 (S/N 101 and 102 excluded as mentioned previously).

7. Vented Heat Source Studies

A helium vent system was under development for the SNAP 19 Viking heat source to 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 vent system was to provide positive isolation of the generator fill gas from the fuel effluents, thus improving generator performance in addition to lowering fuel capsule temperatures. By maintaining the generator gas fill at 75% He/25% Ar, an additional two watts(e) at EOM could be achieved by a vented system.

A proposed vent system consisted of a small diameter Pt-20Rh tube EB welded to the capsule clad at one end with the other end of the tube penetrating the generator housing at the upper cover. Figure VII-11 describes the capsule vent system concept. In order to limit the capsule operating temperature, helium pressure was to be maintained within the capsule by a controlled leak device consisting of a small cylinder of pressed and sintered platinum powder within a nickel housing. A backup approach was also developed which incorporated the use of a reservoir to accumulate the decay gases instead of venting to space. The reservoir, fabricated from magnesium thorium, would be attached directly to the generator housing above the upper cover.

The Pt-20Rh vent tube had a small inside and outside diameter (0.050 O.D., 0.012 inch I.D.) at the capsule clad interface with a tapered transition to the larger diameter (0.125 inch O.D., 0.063 inch I.D.) section at the RTG housing cover interface. The small diameter section of the tube minimized heat losses and facilitated welding of the tube to the thin (0.018 inch thick) capsule clad. The larger diameter section reduced the likelihood of helium flow stoppage by condensation of fuel capsule effluents, and facilitated welding to the nickel fitting at the cover penetration. The small diameter section of the tube was successfully mated to the 0.050 inch diameter hole in the capsule clad as a result of a weld development program at Monsanto Research Corporation.

FIG. VII-10. IMPROVED RTD CONFIGURATION

FIG. VII-11. FUEL CAPSULE VENT SYSTEM - VENT TO RESERVOIR

The controlled leak device was subjected to a series of tests at Teledyne Energy Systems to characterize the operation of the orifice. Tests to determine the flow characteristics as a function of temperature, pressure differential and type of gas were conducted. A digital computer program was written to allow gas flow evaluations of the vent system. Flow analyses were conducted on the controlled leak device and/or capillary tube for several non-linear gas production conditions.

Preliminary thermal studies were performed to determine the heat loss associated with the vent tube in the Viking RTG. The study assumed that the Pt-20Rh tapered vent tube penetrated the heat shield end plug and end Min-K insulation disc. The total heat loss was less than one watt(t) and accounted for by conduction heat transfer along the tube. Steady-state thermal analysis on the heat source, for initial reentry conditions, indicated that the end plug penetration caused less than a few degrees increase over the solid end plug case.

Elimination of the receptacle diffusion bond obviated use of the capsule vents, and in March 1973, further development of the capsule vent system was halted in favor of a more basic inert gas management system. However, the substituted gas management system carried over some of the capsule vent system technology, in that it included a gas reservoir and a device to control the transfer of gases between the reservoir and the thermoelectric converter.

B. GENERATOR DEMONSTRATION TESTS

Tests were conducted to evaluate RTG response to severe environments of certain Viking mission operations. The following operations identified as potentially deleterious to RTG performance were simulated.

1. Thermal cycling on the surface of Mars.
2. On-load interplanetary cruise.
3. Cruise phase power switches for GCMS bake out.
4. Operation on open circuit.
5. Aged RTG vibration.

1. Simulated Mars Surface Thermal Cycling Test

The Martian surface environment may cause the RTG fin root temperature to vary from as low as 175°F to as high as 340°F. To determine the effect of the thermal cycling on the performance of the generators, two electrically heated SNAP 19 Pioneer program test generators were subjected to 370 consecutive thermal cycles. The two generators used, S/N 41 and S/N 43, were defueled Pioneer generators which had been refurbished for this test. They were tested at the Viking operating conditions of 690 ± 3 watts electrical power input and a load voltage of 4.4 ± 0.1 volts. The test was performed in accordance with the procedures given in Ref. 1.

The test was conducted in four phases: (1) initial performance evaluation, (2) thermal cycling, (3) post-cycling performance evaluation, and (4) Mars orbit power-up simulation. The initial performance evaluation established the characteristics of each generator prior to the thermal cycling. Subsequently, 370 thermal cycles were imposed, each consisting of a fin root temperature swing of 350°F - 150°F - 350°F over a six-hour time span. During the thermal cycling phase, periodic performance checks were made by allowing the generators to reach thermal stability for brief periods. At the conclusion of the thermal cycles, another performance evaluation was made to determine the effect, if any, the test conditions had on generator performances. The fourth test exposed the generators to high fin root temperatures to simulate the Mars orbit thermal conditions. Power checks were made at the conclusion of these high temperature tests to measure the effects on performance.

Steady state performance data collected during the thermal cycle testing program is presented in Tables VII-4 and VII-5 for refurbished Pioneer ETG's S/N 41 and S/N 43, respectively. This data includes: (a) the power check at the nominal (330°F) fin root temperature during characterization, (b) the 4.4 volts load voltage point from the load voltage parametric prior to automatic thermal cycling, (c) seven steady state power checks conducted periodically during automatic thermal cycling, (d) the 4.4 volts load voltage point from the load voltage parametric at the conclusion of automatic thermal cycling, (e) fin root temperature during the fin root sweep, and (f) the power check just prior to generator cooldown. Generator steady state operating conditions for all these power checks consisted of (a) a thermal inventory of 690 watts(t), (b) a load voltage of 4.4 volts, and (c) a fin root temperature of 330°F. The fin root temperature is defined as the average of three thermocouple measurements located along fin #3.

TABLE VII-1
VIKING MARS SURFACE THERMAL CYCLE TEST
COMPARISON OF STEADY STATE PERFORMANCE DATA - SNAP 19 ETG S/N 41

	STEADY STATE PERFORMANCE DATA *												
	Power Check During Cycle Characterization	Load Voltage Parametric Prior to Cycling	Power Checks During Cycling								Load Voltage Parametric Following Cycling	Power Check During Fin Root Sweep	Power Check Prior to Cooldown
			6/30/72	7/5/72	7/21/72	8/7/72	8/21/72	9/5/72	9/15/72	10/2/72			
Date	6/30/72	7/5/72	7/21/72	8/7/72	8/21/72	9/5/72	9/15/72	10/2/72	10/9/72	10/11/72	10/17/72	10/22/72	
Time	16:55	10:25	13:16	13:30	12:45	13:30	13:50	14:05	15:00	13:15	9:25	12:30	
Number of thermal cycles completed	6	6	72	127	182	241	292	347	374	374	374	374	
Hot junction temperature (°F)	1072	1077	1073	1075	1075	1083	1079	1082	1084	1088	1086	1097	
Fin root temperature (°F)	330	330	330	330	330	330	330	330	330	330	330	330	
Load Voltage (volts)	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	
Current (amps)	8.80	8.80	8.79	8.76	8.75	8.72	8.65	8.70	8.70	8.72	8.64	8.69	
Power output (watts)	38.7	38.7	38.7	38.5	38.5	38.4	38.0	38.3	38.3	38.4	38.0	38.2	
Open circuit voltage (volts)	7.179	7.204	-	7.229	7.226	7.233	7.220	7.238	7.246	7.216	7.169	7.062	
Internal resistance (ohms)	0.316	0.319	-	0.323	0.323	0.325	0.326	0.326	0.327	0.323	0.320	0.306	
Thermal inventory (watts)	690	690	690	690	690	690	690	690	690	690	690	690	
Heater Block Temperature (°F)	1394	1394	1396	1393	1393	1395	1392	1394	1394	1394	1393	1394	

*Data normalized to:

1. 4.4 volt load voltage
2. 330°F fin root temperature (defined as the average of 3 thermocouples along fin #3 adjacent to module bar).
3. 690 watts(t) thermal inventory

TABLE VII-5
VIKING MARS SURFACE THERMAL CYCLE TEST
COMPARISON OF STEADY STATE PERFORMANCE DATA - SNAP 19 ETG S/N 43

	STEADY STATE PERFORMANCE DATA *												
	Power Check During Cycle Characterization	Load Voltage Parametric Prior to Cycling	Power Checks During Cycling								Load Voltage Parametric Following Cycling	Power Check During Fin Root Sweep	Power Check Prior to Cooldown
Date	6/30/72	7/5/72	7/24/72	8/7/72	8/21/72	9/5/72	9/18/72	10/2/72	10/9/72	10/11/72	10/17/72	10/22/72	
Time	16:30	9:35	13:05	13:40	13:00	13:45	14:00	14:00	13:30	13:20	9:35	12:10	
Number of thermal cycles completed	4	4	70	125	180	239	290	345	372	372	372	372	
Hot junction temperature (°F)	1055	1059	1060	1061	1064	1062	1064	1059	1065	1063	1052	1062	
Fin root temperature (°F)	330	330	330	330	330	330	330	330	330	330	330	330	
Load Voltage (volts)	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	
Current (amps)	9.27	9.30	9.30	9.18	9.19	9.08	9.05	8.99	9.08	9.09	9.08	8.98	
Power output (watts)	40.8	40.9	40.9	40.4	40.4	40.0	39.8	39.6	39.9	40.0	40.0	39.5	
Open circuit voltage (volts)	7.189	7.220	-	7.270	7.297	7.266	7.264	7.227	7.260	7.252	7.238	7.095	
Internal resistance (ohms)	0.301	0.303	-	0.313	0.315	0.315	0.317	0.315	0.315	0.314	0.313	0.300	
Thermal inventory (watts)	690	690	690	690	690	690	690	690	690	690	690	690	
Heater Block Temperature (°F)	1371	1371	1372	1371	1372	1373	1371	1367	1371	1369	1372	1367	

*Data normalized to:

1. 4.4 volt load voltage
2. 330°F fin root temperature (defined as the average of 3 thermocouples along fin #3 adjacent to module bar).
3. 690 watts(t) thermal inventory

Generator electrical power output as a function of time is presented in Figures VII-12 and VII-13. An explanation of the indicated decrease in degradation rate experienced by both test generators during the simulated Mars surface thermal cycle operation (as compared to earlier period steady state data) is a lowered time averaged hot junction temperature. Figure VII-14 presents data from a typical transient thermal cycle. The minimum and maximum average fin root temperatures were 163°F and 349°F, respectively. The minimum and maximum hot junction temperatures were 920°F and 1073°F. The average hot junction temperature during the transient thermal cycle is 991°F, approximately 85°F below that for steady state operation with a 330°F fin root temperature at a 4.4 volts load voltage. Since power degradation is dependent on the hot junction temperature (degradation increases with increasing hot junction temperature), the degradation experienced while a generator is operated under Mars thermal cycle conditions will be less than if the generator was operated under steady state conditions at 330°F fin root temperature and 4.4 volts load voltage. For S/N 43, a secondary reason for the decrease in degradation rate during the simulated Mars surface thermal cycle operation is attributed to the relatively low amount of "on-load" operating time previously accumulated by this generator. SNAP 19 testing programs have established that generators experience a burn-in period of approximately 1000 to 2000 hours where electrical power output increases noticeably for about the first 500 hours and then decreases (by an amount equal to the increase) in the next 500 to 1500 hours. Based on the accumulated "on-load" time (≈ 1032 hours), S/N 43 was possibly still experiencing the steep decrease in power output associated with the conclusion of the generator burn-in period. Therefore, a portion of the decrease in degradation rate evidenced between the transient thermal cycle operation and the earlier Viking steady state operation (Figure VII-13) could be the result of normal generator beginning-of-life operating characteristics.

During the cycle presented in Figure VII-14, the power output ranged from a minimum of 34.0 watts(e) to a maximum of 47.0 watts(e), with a time averaged value of approximately 39.4 watts(e). This average power output is approximately 1.0 watt(e) higher than the power output under steady state operating conditions (330°F fin root temperature and 4.4 volts load voltage), and is a result of reduced fin root temperature. The average fin root temperature for the simulated Martian thermal cycle is 254°F, approximately 75°F lower than the nominal 330°F reference value.

- NOTES:
1. 2906 hours of testing as an ETG and as an RTG on the SNAP 19 Pioneer program.
 2. Steady state performance data normalized to: (a) 330°F fin root temperature, (b) 690 watts thermal inventory, and (c) 4.4 volts load voltage.
 3. Fin root temperature defined as the average of five thermocouple measurements located along the fin root of fin number 3.
 4. Fin root temperature defined as the average of three thermocouple measurements located along the fin root of fin number 3 adjacent to the module bar.
 5. Generator gas fill: 75% helium/25% argon.
 6. * Indicates load voltage parametric testing.
 7. Δ Indicates partial thermal cycle due to loss of input power.
 8. Data points presented are 4.4 volt measurements from load voltage parametric tests--straight line fit of data has been assumed to show performance trend.

FIG. VII-12. SNAP 19 ETG S/N 41 DEGRADATION DATA THERMAL CYCLE TEST PERFORMANCE COMPARED TO PREVIOUS PERFORMANCE

- NOTES:
1. 2611 hours of testing as an RTG on the SNAP 19 Pioneer program (1032 hours on load and 1579 hours stored in short circuit mode).
 2. Steady state performance data normalized to: (a) 330°F fin root temperature, (b) 690 watts thermal inventory, and (c) 4.4 volts load voltage.
 3. Fin root temperature defined as the average of five thermocouple measurements located along the fin root of fin number 3.
 4. Fin root temperature defined as the average of three thermocouple measurements located along the fin root of fin number 3 adjacent to the module bar.
 5. Generator gas fill: 75% helium/25% argon.
 6. * Indicates load voltage parametric testing.
 7. Δ Indicates partial thermal cycle due to loss of input power.
 8. Data points presented are 4.4 volt measurements from load voltage parametric tests--straight line fit of data has been assumed to show performance trend.

FIG. VII-13. SNAP 19 ETG S/N 43 DEGRADATION DATA THERMAL CYCLE TEST PERFORMANCE COMPARED TO PREVIOUS PERFORMANCE

FIG. VII-14. TYPICAL GENERATOR TRANSIENT RESPONSE DUE TO TRANSIENT FIN ROOT THERMAL CONDITIONS

Generator power output and hot junction temperature as a function of fin root temperature is presented graphically in Figures VII-15 and VII-16, respectively. It is seen that the steady state hot junction temperature change is nearly equal to the fin root temperature change.

Leak checks performed after thermal cycling showed that the gas seal of each generator was not adversely affected by the simulated Mars surface thermal cycle test. Detailed results are contained in Ref. 2.

2. On-load Interplanetary Cruise

The operational mode of a Viking generator during the cruise phase of the flight to Mars will be principally with the load short circuited. An extended on-load operating condition caused by a malfunction of the power transfer switch would create higher hot junction temperatures than is presently considered in performance predictions. To evaluate the effect of such a condition, a four-month endurance test was performed. A steady state fin root temperature (average of five thermocouples) of 355°F was assumed ("worst case" fin root temperature for the cruise mode) resulting in hot junction temperatures (at RTD locations of S/N 41 and S/N 43) of approximately 1100°F. A comparison of measured temperatures for the simulated short circuit and on-load conditions for the test generators is shown in Table VII-6.

Normalized steady state performance data collected during the four-month on-load endurance test program are presented in Tables VII-7 and VII-8 for ETG's S/N 41 and S/N 43, respectively. This data includes: (a) the 4.4 load voltage point from the load voltage parametric following conclusion of the load cycling tests, (b) 18 steady state power checks conducted periodically, and (c) the 4.4 load voltage point from the load voltage parametric test following completion of the endurance test. Power check data, taken near 355°F, are presented normalized to 355°F and parametric data which were obtained with fin root temperatures near 330°F are presented normalized to 330°F. The power input for all data points was 690 watts (electrical) and the external resistance was adjusted to obtain 4.40 volts at the ETG power output connector location. Periodic power check data are shown graphically in Figure VII-17.

Both generators lost power at an accelerated rate and experienced a lowering of the peak power load voltage point by approximately 0.1 volt. The conclusion is that "on-load" RTG operation during cruise mode for periods in excess of the contract-specified mission profile

FIG. VII-15. TYPICAL GENERATOR STEADY STATE POWER OUTPUT VARIATION AT FIN ROOT TEMPERATURES ABOVE AND BELOW THE NOMINAL DESIGN VALUE OF 330°F

FIG. VII-16. TYPICAL GENERATOR STEADY STATE HOT JUNCTION TEMPERATURE VARIATION AT FIN ROOT TEMPERATURES ABOVE AND BELOW THE NOMINAL DESIGN VALUE OF 330°F

TABLE VII-6

ETG TEMPERATURES INSTRUMENTATION DATA

	<u>S/N 41</u>	<u>S/N 43</u>
<u>1. Operation On Short Circuit</u>		
Fin root thermistor temperature (°F)	385	385
Fin root temperature (average of five T/C's) (°F)	365	365
Nominal hot junction (RTD) temperature (°F)	1044	1005
Nominal heater block (T/C) temperature (°F)	1332	1298
 <u>2. Operation On Load</u>		
Fin root thermistor temperature (°F)	373	373
Fin root temperature (average of five T/C's) (°F)	355	355
Nominal hot junction (RTD) temperature (°F)	1122	1094
Nominal heater block (T/C) temperature (°F)	1412	1387

TABLE VII-7

VIKING ON-LOAD CRUISE ENDURANCE TEST
COMPARISON OF STEADY STATE PERFORMANCE DATA
ETG S/N 43

Power Check Identification	Test Date	Test Time (hrs)	Power Output (watts)	Fin Root Temperature (° F)	Hot Junction Temperature (° F)	Heater Block Temperature (° F)	Current (amps)	Open Circuit Voltage (volts)	Internal Resistance (ohms)
Post-cycling Parametric	6/24/74		39.9	330	1064	1368	9.08	7.26	0.32
Power check	6/27/74	0	39.1	355	1089	1389	8.89	7.27	0.32
^	7/2/74	119	39.2	↑	1092	1387	8.91	7.27	0.32
	7/10/74	313	39.2		1096	1384	8.90	7.25	0.32
	7/17/74	487	39.0		1095	1386	8.87	7.26	0.32
	7/24/74	647	39.0		1097	1385	8.86	7.25	0.32
	8/1/74	839	38.4		1094	1377	8.72	7.20	0.32
	8/7/74	983	38.6		1090	1393	8.78	7.21	0.32
	8/14/74	1151	38.6		1099	1379	8.77	7.23	0.32
	8/21/74	1319	38.5		1102	1377	8.75	7.22	0.32
	8/28/74	1487	38.3		1103	1378	8.71	7.22	0.32
	9/4/74	1656	38.3		1104	1376	8.70	7.22	0.32
	9/11/74	1823	38.1		1105	1373	8.66	7.21	0.32
	9/18/74	1991	37.9		1102	1376	8.62	7.22	0.33
	9/25/74	2162	37.7		1103	1378	8.57	7.21	0.33
	10/2/74	2327	37.6		1106	1377	8.54	7.23	0.33
	10/9/74	2495	37.5		1106	1374	8.51	7.21	0.33
	10/16/74	2663	37.4	↓	1106	1378	8.49	7.20	0.33
Power Check	10/23/74	2831	37.1	355	1107	1377	8.43	7.18	0.33
Post-endurance Parametric	10/23/74	2841	38.0	330	1075	1365	8.63	7.16	0.32

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TABLE VII-8

VIKING ON-LOAD CRUISE ENDURANCE TEST
COMPARISON OF STEADY STATE PERFORMANCE DATA

ETG S/N 41

Power Check Identification	Test Date	Test Time (hrs)	Power Output (watts)	Fin Root Temperature (° F)	Hot Junction Temperature (° F)	Heater Block Temperature (° F)	Current (amps)	Open Circuit Voltage (volts)	Internal Resistance (ohms)
Post-cycling Parametric	6/24/74		38.9	330	~ 1098	1388	8.84	7.24	0.32
Power check	6/27/74	0	38.2	355		1406	8.67	7.24	0.33
	7/2/74	119	38.2			1406	8.67	7.21	0.33
	7/10/74	313	38.1			1404	8.66	7.20	0.32
	7/17/74	487	38.0			1405	8.65	7.20	0.32
	7/24/74	647	37.8			1403	8.59	7.20	0.33
	8/1/74	839	37.9			1403	8.61	7.20	0.33
	8/7/74	983	37.9			1402	8.61	7.20	0.33
	8/14/74	1151	37.6			1403	8.55	7.19	0.33
	8/21/74	1319	37.6			1402	8.54	7.20	0.33
	8/28/74	1487	37.5			1401	8.52	7.20	0.33
	9/4/74	1656	37.5			1401	8.53	7.19	0.33
	9/11/74	1823	37.3			1399	8.49	7.18	0.33
	9/18/74	1991	37.2			1402	8.45	7.20	0.33
	9/25/74	2162	37.1			1402	8.42	7.18	0.33
	10/2/74	2327	36.9			1403	8.38	7.20	0.33
	10/9/74	2495	37.0			1403	8.40	7.19	0.33
	10/16/74	2663	36.8			1403	8.36	7.20	0.34
Power Check	10/23/74	2831	36.8	355		1404	8.37	7.20	0.33
Post-endurance Parametric	10/23/74	2841	37.5	330	~ 1100	1390	8.52	7.17	0.33

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RTG has failed - assumed to be
~ 1122° F

FIG. VII-17. SNAP 19 VIKING INTERPLANETARY CRUISE TEST GENERATOR PERFORMANCE HISTORY

will result in reduced generator power at end-of-mission (EOM), the degree of reduction depending on the accumulated on-load time. Based on this test, a four-month period of cruise mode operation on-load will decrease EOM nominal RTG power output by 1.5 to 2.0 watts.

The test procedure is listed in Ref. 3, and a report describing these tests is shown in Ref. 4.

3. Simulated GCMS Bakeout Power Switches

Occasional operation of a heater for bakeout of the gas chromatograph mass spectrometer (GCMS) on the Viking spacecraft during initial phases of the interplanetary cruise would require RTG power. Normally, the RTG's will be on short circuit during the cruise, a condition which allows hot junction temperatures to run approximately 90°F cooler than for a generator on-load. The effect of this switching was investigated in simulated eight-cycle power switch tests performed in June 1974 on Pioneer electrically-heated generators (ETG) S/N 41 and S/N 43.

These tests were conducted in the Teledyne Energy Systems thermal vacuum chamber with the chamber backfilled with a 75% He/25% Ar cover gas. The cover gas was used to preclude air entry into the generators during the tests (these generators used an early Viton O-ring seal compound that had less reliability than the presently used compound). Generator fin root temperature control was obtained through a combination of fin insulating pads and individual heaters attached to the fins. The thermal vacuum chamber liquid nitrogen thermal control system provided the capability of lowering the fin root temperature for reference parametric testing of the generators.

Prior to the power switch tests, a load voltage parametric test at a fin root temperature of 330°F was performed on each generator to characterize its initial performance. After the parametric tests, the fin root temperature was raised to 390°F (thermistor) for the start of the power switch tests.

The power-up was performed by switching the stable shorted generators to a transistor load bank which maintained each generator at a constant load voltage of 4.4 ± 0.1 volts for seven hours. At the end of seven hours, stable data was recorded before the generator output was short circuited for the power-down test. The short circuit was maintained until thermal stability was obtained and then the generator was switched back on load for the power-up cycle. A total of eight power-up/power-down cycles were performed in the above manner.

At the conclusion of eight cycles, a second load voltage parametric test at a fin root temperature of 330°F was performed to ascertain the effect of the cycling on the performance of each generator.

It was determined from the power switch tests that generator thermal equilibrium is disturbed for approximately three hours when going from either short circuit to load or load to short circuit conditions. A representation of the power output, hot junction temperature, fin root temperature and heater block temperature during one of the cycles is shown in Figure VII-18. Consecutive cycles were similar in shape and level at which stability was achieved and these data are summarized in Table VII-9.

The pre- and post-power-up test parametric plots are shown in Figures VII-19 and VII-20.

During October 1974, Viking RTG S/N 106 was subjected to a power switch test similar to that performed on ETG S/N 41 and S/N 43. This test was conducted at Monsanto Research Corporation, Miamisburg, Ohio. To determine detrimental effects to this generator, power checks were performed before and after the switching test. The results of the power checks are shown in Table VII-10.

As a result of the switching tests, it was determined that load switching as defined in the Viking contract mission profile will not impact significantly nominal generator performance.

4. Stable Open Circuit Test

During October 1974, Viking generator RTG S/N 105 was subjected to an open circuit test while mounted alone on a shipping container in an uninsulated condition. This test was performed at Monsanto Research Corporation. The procedure consisted of open circuiting the generator from a shorted condition and monitoring generator performance for a 24-hour period. After six hours, the generator was approaching stability when it was decided to insulate the generator fins to increase the fin root temperature from 207°F to 229°F. Prior to and after the open circuit test, power checks were performed to determine changes in performance. Table VII-11 is a summary of data showing that the generator survived a short term hot junction temperature up to 1070°F without significant effect on power.

FIG. VII-18. VIKING GENERATOR VOLTAGE SWITCHING

TABLE VII-9

VIKING GENERATOR VOLTAGE SWITCHING RECORD
OF STEADY STATE PERFORMANCE DATA

	S/N 41		S/N43	
	<u>Power-Up**</u>	<u>Power-Down</u>	<u>Power-Up**</u>	<u>Power-Down</u>
ETG Power Output* (watts)				
Prior to 1st Cycle	—	6.67	—	7.33
Following 1st Cycle	38.13	6.58	39.18	7.24
Following 2nd Cycle	38.24	6.54	39.26	7.31
Following 3rd Cycle	38.12	6.57	39.16	7.24
Following 4th Cycle	38.19	6.56	39.22	7.39
Following 5th Cycle	38.28	6.69	39.21	7.34
Following 6th Cycle	38.26	6.70	39.24	7.57
Following 7th Cycle	38.24	6.79	39.31	7.51
Following 8th Cycle	38.24	6.59	39.17	7.44
ETG RTD Temperature* (°F)				
Prior to 1st Cycle	—	1041	—	1007
Following 1st Cycle	1126	1038	1097	1007
Following 2nd Cycle	1129	1042	1098	1006
Following 3rd Cycle	1134	1044	1097	1007
Following 4th Cycle	1134	1041	1098	1004
Following 5th Cycle	1139	1044	1096	1006
Following 6th Cycle	1145	1042	1097	1003
Following 7th Cycle	1148	1044	1095	1006
Following 8th Cycle	1153	1046	1098	1006

* Presented for fin root temperatures (average of five thermocouples) of 355°F on-load, 365°F on short circuit and 690 watts input power.

** Power and temperature at a load voltage of 4.4 volts.

FIG. VII-19. VIKING PARAMETRIC TEST RESULTS, SNAP 19 ETG S/N 41

FIG. VII-20. VIKING PARAMETRIC TEST RESULTS, SNAP 19 ETG S/N 43

TABLE VII-10
 VIKING GENERATOR RTG S/N 106 POWER
 SWITCH TEST POWER CHECK DATA

	<u>Before Cycles</u>	<u>After Cycles</u>
RTD reading (°F)	1039	1028
Thermistor reading (°F)	333	333
Load voltage (volts)	4.36	4.40
Load current (amperes)	8.89	8.79
Power output (watts)	38.76	38.68
Open circuit voltage (volts)	7.29	7.18
Generator pressure (psia)	18.3	18.0
T/C 10-17 average (°F)	334.8	335.8

TABLE VII-11

VIKING GENERATOR RTG S/N 105 PERFORMANCE DATA
STABLE OPEN CURCUIT TEST

	<u>Pre-test Power Check</u>	<u>6 Hours Open Circuit (Fins Uninsulated)</u>	<u>24 Hours Open Circuit (Fins Insulated)</u>	<u>Post-test Power Check</u>
RTD reading (° F)	1027	1045	1070	1026
Thermistor reading (° F)	328	207	227	331
Load voltage (volts)	4.39	—	—	4.38
Load current (amperes)	8.75	—	—	8.70
Power output (watts)	38.41	—	—	38.10
Open circuit voltage (volts)	7.45	8.82	8.81	7.33
Generator pressure (psia)	22.1	20.5	21.0	22.2
Fin root (5) T/C average (° F)	334.3	222.5	245.5	337

5. Vibration Testing of Aged RTG

RTG S/N 106 was subjected to acceptance level random vibration of six g's for a period of one minute in each of three orthogonal axes at Monsanto Research Corporation during November 1974. The purpose of this test was to determine the response to vibration exposure of a flight RTG aged approximately one year prior to launch. RTG S/N 106 was previously vibration tested in July 1973.

Power output was stable before, during, and after each axis of vibration. The pre- and post-vibration power check data is shown in Table VII-12. The post-vibration power check was performed at a fin root temperature 15°F cooler than normal because of a facility temperature control problem. RTG power output, normalized to a constant fin root temperature of 330°F, is also presented in Table VII-12. These data show the RTG performance did not degrade as a result of the vibration test.

TABLE VII-12

VIKING GENERATOR RTG S/N 106 PERFORMANCE DATA
ACCEPTANCE LEVEL RANDOM VIBRATION TEST

(11,600 Hours After RTG Fueling)

	<u>Pre-vibration Power Check</u>	<u>Post-vibration Power Check</u>
RTD reading (°F)	1034	1016
Thermistor reading (°F)	328	308
Load voltage (volts)	4.39	4.42
Load current (amperes)	8.77	8.79
Power output (watts) (raw data)	38.50	38.85
Power output (watts) (normalized data*)	38.43	38.43
Open circuit voltage (volts)	7.23	7.21
Generator pressure (psia)	18.4	17.6
T/C 10-15 average (°F)	334.7	315.8

* Normalized to fin root temperature of 330°F.

REFERENCES, SECTION VII

1. Mars Surface Thermal Cycle Test, Drawing 452A6000406.
2. Mars Surface Thermal Cycle Test Report, ESD-2960-78, September 1973.
3. Power-up and Endurance Test Procedure, Drawing 452A6040400.
4. SNAP 19 Viking Cruise Mode Power-up and Endurance Test Report, ESD-3069-28, December 1974.

VIII. AEROSPACE NUCLEAR SAFETY SYNOPSIS

The safety evaluation for the Viking Mission was an extension of the Pioneer safety effort. The Viking SNAP 19 RTG is substantially the same as the Pioneer SNAP 19 RTG, however, the launch and abort reentry environments were different for Viking and Pioneer as a result of the different launch vehicles and mission requirements. Generally, the safety analyses indicated the Viking environments to be less severe than for Pioneer. The Viking safety evaluation was initiated in September 1972 (some Viking-related safety testing had been accomplished previously) and terminated with the Viking launches in August and September 1975.

Significant innovations were introduced during the Pioneer safety analysis program* which resulted in more quantitative estimates of the risk of releasing radioactive fuel to the environment. These innovations were also applied to the Viking analysis. In addition, the following new analytical concepts were developed and applied:

1. Development and utilization of a Monte Carlo analysis of launch pad accidents and the resulting statistical distribution of respirable and non-respirable source terms.
2. Estimates of the statistical distribution of source terms resulting from various environments were developed and used in (1) above.
3. Extension of the reentry analysis technique to include the distribution of altitudes as well as appropriate speed and flight path angle as initial conditions when the heat source begins reentry as a free body.
4. Development of ad hoc Monte Carlo programs to integrate over the significant vehicle failure modes to estimate the risk of fuel release or heat source damage during the reentry process.

Most of the safety test data obtained during the Pioneer program (IESD-2873-172) were utilized in the safety analysis for the Viking. Additional safety tests conducted for the Viking program are summarized in the Viking Safety Analysis Report, Volume I (ESD-3069-15-1) and

* SNAP 19 Pioneer F & G Final Report, Teledyne Isotopes Report IESD-2873-172, June 1973.

presented in more detail in the reports identified in the following bibliography. Most of the test results were documented in, and used in the analyses described in the Safety Analysis Report, Volume II (ESD-3069-15-2). Significant results are summarized below:

1. Early test demonstrated that interaction of molten clad with graphite was not catastrophic (vent tube reentry simulation in the NASA-Ames Planetary Gas Facility).
2. Impact tests at LASL demonstrated:
 - (a) Impact failure velocity of Viking-type capsule on pointed steel target was somewhat in excess of 150 ft/sec.
 - (b) Melting of clad and subsequent wetting of the T-111 strength member, which could result if a free capsule were exposed to a fireball during a launch pad abort, resulted in no discernible deterioration of the capsule impact capability. This conclusion was drawn after a test sequence in which the clad was melted in a thermal profile simulating the flame temperature-time dependence of a fireball and subsequent impact at 150 ft/sec on a flat steel target.
 - (c) Reentry heating distribution tests, similar to those for the Pioneer heat shield, were performed to evaluate the effect of the Viking heat shield modifications.

The safety evaluation effort culminated with the completion of the Safety Analysis Report in August 1974. Subsequently, the results were presented at Interagency Safety Review Panel (INSRP) sub-group meetings at Kirtland Air Force Base, New Mexico, Timonium, Maryland and Cape Canaveral, Florida, December 3-5, 1974. Responses to questions raised at some of these reviews were incorporated into Safety Analysis Report Supplements noted in the bibliography.

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ESD-3069-15-2, Volume II,
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ESD-3069-15-3, Volume III,
Safety Analysis Document
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ESD-3069-15S-1, Heat Source
Multi-Orbit Reentry,
October 21, 1974

ESD-3069-15S-2, Atmospheric
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Significant Contents

Describes Viking mission objectives and profile, launch site and launch vehicle. The nuclear system comprising the RTG and Heat Source is described in greater detail. Safety methodology is summarized and heat source safety test objectives and parameters are presented.

Describes procedures for evaluating the effects of accidents on the nuclear system and presents results of analyses. Vehicle failure modes, accident environments, response of the nuclear system and conditional fuel release probabilities for launch pad, in-flight and post-impact are described.

Describes the best data and analytical models used for radiobiological safety assessment. Models for estimating the internal source terms consider the applicable statistical fluctuations likely to occur, meteorology and population distribution for each representative environment during normal mission and accident events.

Describes the combinatorial procedures which relate the response of the nuclear system to the various accident environments, evaluates the probabilities of fuel release and assesses the consequences.

BIBLIOGRAPHY (Continued)

<u>Reference</u>	<u>Significant Contents</u>
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ESD-2960-100, Plasma Arc Reentry Simulation Test Report - SNAP 19 Viking Heat Source Safety Program, May 1973	
GDCA-BKM73-022 Viking AEC Safety Study ' Phase I (General Dynamics/Convair), June 1, 1973	A detailed description of the launch vehicle hardware, launch complex and launch trajec- tory simulation data.
CASD/LVP73-026 Viking AEC Safety Study Phase II (General Dynamics/Convair), December 18, 1973	Contains range safety hardware description and procedures, assessment of potential launch pad failures, probabilities and environments, ascent failure probabilities, impact probability data and reentry environment. Also contains Martin Marietta Appendix on the Viking space- craft/RTG reentry breakup, fragmentation and overpressure response study.

IX. GROUND SUPPORT EQUIPMENT (GSE)

A. ELECTRICAL GSE

The electrical GSE comprises equipment designed for functional checkout, calibration and performance monitoring of both ETG's and RTG's.

Electrical GSE units are designed to operate on conventional 115 VAC, 60 Hz, 1 phase facility power. Self-contained internal battery power supplies are provided in GSE units for critical generator monitoring during generator transportation or during facility power interruptions.

Critical generator/GSE equipment control circuits are provided with electrical interlocks to safeguard against errors by the operator.

All electrical GSE units are designed to operate fail-safe with respect to connected generators in case of a facility power interruption.

1. Portable Monitor Package (PMP)

The functional purpose of the portable monitor package (PMP) is to provide a compact suitcase type instrumentation unit for functional checkout, calibration and performance monitoring of either two ETG's or two RTG's or one ETG and one RTG. The PMP units are employed during generator operations, storage, RTG shipments and with generators mounted on the mobile carriage.

Figure IX-1 shows a PMP unit assembled for transportation. Figure IX-2 presents the PMP front panel with readout instrumentation, PMP and generator controls and all interface connectors. Figure IX-3 depicts the PMP front panel assembly removed from its carrying case and ready for mounting into a standard GSE console. Figure IX-4 illustrates PMP employment with two RTG's mounted in the RTG shipping container and all equipment mounted on the mobile carriage.

The complete PMP system consists of a carrying case with two removable hinged covers, a removable front panel assembly, one 15-foot long facility power interface cable, two 60-foot long generator interface cables and a detailed operations manual.

FIG. IX-1. PMP UNIT ASSEMBLED FOR TRANSPORTATION

FIG. IX-2. PMP UNIT PANEL METER READOUTS

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IX-4

FIG. IX-3. VIEW OF PMP UNIT, FRONT CASE COVER REMOVED FROM SEPARABLE HINGES

TES-3069-54
IX-5

RTG Shipping Container 452B6130000

FIG. IX-4. RTG SHIPPING CONTAINER, MOBILE CARRIAGE AND PMP

a. PMP front panel assembly

The PMP front panel assembly is removable from its carrying case for servicing and for mounting into standard 19-inch GSE consoles. The front panel is provided with controls for two separate and independently variable generator power load banks from generator short circuits to full power load; individual switches for each generator for short circuit and open circuit voltage measurements; switches for arresting fast changing voltage readouts during open circuit measurements; one generator mode switch to place generators electrically in series or into individual generator hook-up; a multiple channel thermocouple selector switch and a three-position AC/DC operation power switch. All these functions can be accomplished with the PMP front panel as a control center for the SNAP 19 Viking power system without changing any PMP/generator interface cabling.

A PMP unit is capable of providing the following data from two generators:

(1) DC output voltages (digital readouts)

Range: 0 to 19.99 VDC

Resolution: ± 10 millivolts ± 1 digit

(2) DC output current (digital readouts)

Range: 0 to 30.00 amperes DC

Resolution: ± 10 milliamperes ± 1 digit

Power output can be obtained from (1) and (2)

(3) RTD hot junction temperatures

Range: 70°F to 1220°F

Resolution: $\pm 2^\circ\text{F}$

(4) Thermistor fin root temperatures

Range: 70°F to 400°F

Resolution: $\pm 2^\circ\text{F}$

(5) Generator internal pressures

Range: 0 to 60 psia

Resolution: ± 0.2 psia

- (6) Thermocouple temperatures (digital readout) with 48 channel capacity

Range: 0°F to 1999°F

Resolution: $\pm 1^\circ\text{F} \pm 1$ digit

Generator voltage and current data from two generators are displayed simultaneously. RTD hot junction temperatures, thermistor fin root temperatures, generator internal pressures and thermocouple temperatures are displayed from respective generators via selector switches.

- b. PMP connections for external readout

Terminals are provided on the PMP front panel to facilitate connections of recorders or computer input terminals if continuous, automatic and/or high speed data gathering is required during generator operational activities. All data of both generators can be monitored simultaneously. Terminals for periodically checking the status of the internal battery power supply are available on the PMP front panel.

- c. PMP weight, size and power demand

The completely cased PMP unit weighs 55 pounds and the closed instrument case is 19 in. high, 26 in. wide and 10-1/2 in. deep. The removed front panel assembly (without case) weighs 33 lbs and the assembly is 18 in. high, 19 in. wide and 6 in. deep. The three PMP interface cables weigh 85 lbs.

The PMP power demand is 45 watts for AC operation and 0.08 watts for DC operation (240 hours running time). The voltage current, and thermocouple temperature meters require AC power for operation. The RTD hot junction temperatures, the thermistor fin root temperatures and the generator internal pressures measurement sections of the PMP are operational in PMP DC mode as well as the AC mode.

- d. PMP modules and quantity

Five PMP units were delivered. PMP S/N 001 was part and model number 452A6030004 with only analog type readout instrumentation. PMP S/N 002 through S/N 005 were part and model number 452A6030040 with digital type readout instrumentation.

- e. PMP calibration adaptor unit

The functional purpose of the PMP calibration adaptor unit is to provide a convenient test tool for checkout and calibration of all PMP measurement sections. The unit is provided

with terminals for connections of laboratory test equipment and instrumentation for simulation of RTD, thermistor, pressure transducer, thermocouple signals and generator voltage and current outputs.

The PMP calibration adaptor unit was a non-deliverable GSE item.

2. ETG Power Supply Console (EPSC)

The ETG power supply console (EPSC) provides a fail-safe and automatic method of supplying programmed and highly regulated DC power to the electric cartridge heaters of two ETG's. Figure IX-5 presents the front view of an EPSC and Figure IX-6 illustrates details of the console control panel.

The complete EPSC system comprises the console with seven panel assemblies, two 60-foot long ETG interface cables, a console load test unit for calibration and checkout and a detailed operations manual.

a. EPSC main control panel and controls

The main control front panel of the console has two separate control systems for managing programmable DC heater input power to each ETG. Two separate and electrically isolated AC/DC power supply units, each with independent voltage regulation, are located in the lower part of the console and provide separate power inputs directly to the heater circuits of the ETG's. The heater input power is electrically isolated from output power and instrumentation. Remote voltage band switching of the AC/DC power supply units by command control from the main control panel is achieved via two separate relay networks and diode logics guard each ETG against thermal shock in case the console operator should execute a wrong heater power input function.

Each AC/DC power supply system is a solid-state type regulated system consisting of a master/slave combination. Each of these master/slave units has positive features to prevent any detrimental effects to the ETG electrical heaters and/or the generators in case of a malfunction in one of the individual power supply units. If for example, there would be a thermal overload in any one of the four units, a thermostat/circuit breaker monitor in each unit would switch the unit off automatically. In this case, the remaining master unit or slave unit would then prevent a thermal shock for the respective ETG by still providing sufficient heater input power.

FIG. IX-5. ETG Power Supply Console Instrumentation Layout

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FIG. IX-6. Front Panel Controls of A-7 Panel

b. ETG overtemperature alarm protection

The EPSC main control panel is also provided with controls and readout instrumentation for two separate ETG over-temperature alarm systems which are individually (or both) activated if the thermocouple hot junction temperature in either of the two ETG's (or both) should reach a critical level (1080°F).

This event then automatically activates the following control functions for the respective ETG console section:

- (1) A programmed reduction in heater input power to the respective ETG, however, without causing a thermal shock.
- (2) Light-up of a bright red warning light identifying the respective ETG to alert the console operator.
- (3) Turn-on of two loud sirens (each 94 db acoustic level).

After the automatic alarm function is executed, the visual and audible alarms will continue until the alarm indication is acknowledged by the console operator by pressing a red-illuminated alarm indicator switch (Figure IX-6). This first pushbutton action will change the red to a blue light of the same alarm indicator switch which remains on until the ETG hot junction temperature has fallen below the preset alarm temperature point. When the temperature has fallen below the alarm point, pushbutton action by the console operator will turn the blue light off and restore the heater input power for the ETG to the original programmed level.

c. EPSC readout instrumentation

The EPSC is capable of reading out, simultaneously, the following measurement data for two ETS's:

- (1) DC heater input powers (digital readouts)
Range: 0 to 1000 watts DC
Resolution: ± 1 watt ± 1 digit
- (2) Thermocouple hot junction temperatures (digital readouts) and alarm temperatures
Range: 0°F to 1999°F
Resolution: ± 1 °F ± 1 digit
- (3) DC heater input voltages (terminals)
- (4) DC heater input currents (terminals)

d. EPSC connections for external readout

Terminals are provided on the EPSC main control panel to facilitate connections of recorders or computer input terminals if continuous, automatic and/or high speed data gathering is required during generator operations.

e. EPSC configuration, weight, size and power demand

The EPSC weighs 680 pounds (Figure IX-5) and the console is 58 in. high, 24 in. wide and 27 in. deep. The four console interface cables weigh 75 lbs.

The console power demand per ETG section at 690 watts DC output is 21 amperes at 115 VAC, 60 Hz, 1 phase. The maximum deliverable DC power output capacity of a console is in excess of 1000 watts per ETG section. For versatility of facility power distribution and to afford complete electrical power source isolation between two ETG heater systems, the console is provided with two separate AC power facility cables for connection to outlets from separate facility feeder lines.

The top of the caster-mounted console is provided with four heavy duty eyebolts to facilitate lifting. The console is equipped with a self-contained cooling system. The rear of the console is provided with a locked door to deny inadvertent access by unauthorized personnel.

f. EPSC modules and quantity

Four EPSC units were delivered. All units were part and model number 452A6030010. EPSC S/N 001 was provided with only analog type readout instrumentation, EPSC S/N 002 through S/N 004 were provided with digital type readout instrumentation.

3. ETG Power Supply Load Test Unit

The purpose of the ETG power supply load test unit is to provide a convenient and accurate method for functional checkout and calibration of the EPSC console. In addition to simulating the electrical heater loads of two ETG's connected to the ETG power supply console for realistic ETG heat-up, full load and cool-down tests, the load test unit is used for checkout and calibration of the two console temperature alarm circuits. The following systems tests may be conducted with this unit:

- (1) Simulated ETG heater load power calibration and power stability tests.
- (2) Voltage calibration tests for the two thermocouple measurement systems of the console.

- (3) Overtemperature alarm trigger set-point tests.
- (4) Overtemperature alarm cancellation set-point tests.
- (5) Thermocouple circuit loop break tests.
- (6) Reversed thermocouple circuit connection tests.
- (7) Alarm condition power reduction tests.
- (8) Tests for circuit insulation and level of noise coupling between ETG 1 and ETG 2 system of the console.

Figure IX-7 shows a load test unit with its adapter cable assemblies for mating with the two console/ETG interface cables. The load test unit contains four power load resistors (two for each console ETG system) which have the same resistance/power dissipation characteristic as the electrical cartridge heaters in an ETG. The power load resistors are housed in a perforated metal case. Convenient access to the two console temperature alarm circuits is obtained by special thermocouple receptacles on the side of the unit (Figure IX-7).

The load test unit weighs 30 lbs and is 10 in. high, 13 in. wide and 17 in. deep.

Four load test units were delivered. All units are part and model number 452A6030015.

4. Connector Saver Cables

The purpose of the connector saver cable is to preserve the functional integrity of the hermetically sealed generator power output receptacle. This receptacle is of the bayonet-lock type with 26 #20 gauge pins. The connector saver cable is mated once, after generator assembly completion, with the generator receptacle and remains mated throughout all generator operations until the final mission application of each generator. The connector saver cable is then disengaged from the generator receptacle to be replaced with the mating connector of the final generator mission interface. Thus, the hermetic seal and functional integrity of the generator receptacle is enhanced by minimizing the number of direct engagements. Use of this cable reduces the possibility of inadvertent bending of receptacle pins, exerting excessive mechanical stresses on the hermetic seal material of the receptacle and arcing between pins of RTG's when generator interface cables are changed.

The connector saver cable by virtue of its design also affords an easy means to short circuit a generator or connect a generator load and simultaneously have access for measurements right at the generator output pins.

Unit has a dual system. Each system has a 1KW D. C. power dissipation rating.

FIG. IX-7. LOAD TEST UNIT WITH ADAPTOR CABLES

Figure IX-8 shows a connector saver cable assembly with attached generator short circuit plug. Connector saver cables are made of non-outgassing materials and can be employed in a hard vacuum environment.

a. Connector saver cable description

The connector saver cable configuration has the shape of the letter "Y". A high temperature plug, mating with the generator receptacle, is provided on one cable termination (bottom of "Y", Figure IX-8). The other two cable terminations are equipped with in-line connectors similar to the generator output receptacle. Permanently attached to the shorter leg of the cable is a generator power output shorting plug to be used whenever a generator short circuit condition is required. The connector of the longer leg can be mated with the connector of the generator load or generator readout instrumentation. When the generator load is connected to the connector of the longer leg, readout instrumentation can be connected to the connector of the shorter leg.

A special safety feature of the connector saver cable are two built-in resistors in the generator voltage tap lines in each leg of the cable. The purpose of these protective resistors is to prevent an excessive current flow through pins of the hermetically sealed generator output receptacle in case the operator should inadvertently short circuit leads of generator voltage measurement equipment. Thermal shock due to excessive current flow in a generator receptacle pin could possibly damage the hermetic seal material.

b. Connector saver cable model and quantity

Each generator, both ETG and RTG, was supplied with a connector saver cable assembly. Two part and model number 452A6030017 and 14 model and part number 452A6030028 connector saver cables were delivered. The difference between the two types is that the first one is provided with a mating generator connector with a non-conductive shell, the latter one with a conductive shell.

5. Interconnecting Cables

GSE interconnecting cables are highly flexible assemblies covered with protective sleeving. All connector terminations are provided with cable pull relief clamps.

Internal instrumentation signal lines are twisted and shielded wires, double-ended grounded. Power lines carrying large currents are tightly twisted against EMI (radiation and susceptibility).

FIG. IX-8. CONNECTOR SAVER CABLE ASSEMBLY

Power, instrumentation and shielding grounds are carried through from cable termination to cable termination. Where no special pins for ground are available, ground is carried through conductive connector shells on each cable termination.

Multiple layers of heat-shrinkable tubing are applied over internal cable splices and connector pin terminations. Heat-shrinkable tubing is also provided along the entire length of extremely long cable assemblies containing wire runs from very small to very large wire gauges to afford additional protection and flexibility.

AC power facility cables are heavy-duty oil-resistant neoprene power cords with separate large gauge conductor to carry facility ground as safety ground to structures and circuits of GSE equipment units. The facility power plug is of the twist-lock type to prevent accidental disconnection from facility power during generator operational activities.

a. PMP interface cables

Each PMP unit was furnished with one set of interface cables consisting of three cable assemblies. One cable is used for 115 VAC facility power connection. The other two PMP cables, each with polarized PMP connector, are used for generator No. 1 and generator No. 2 interface.

One set of PMP cables with generator interface cables 35-feet long and four sets of PMP cables with generator cables 60-feet long were furnished. All sets included one AC power cord, 15-feet long.

b. ETG power supply console interface cables

Each ETG power supply console (EPSC) was furnished with one set of external interface cables consisting of four cable assemblies and one set of internal interface cables consisting of 13 cable assemblies.

Two external cables are used for 115 VAC facility power connections so that the heavy power demand of the EPSC can be distributed to two different fused facility power lines. Each AC facility power cord supplies a separate ETG system of the console. The AC facility power interface cables are 25-feet long. The other two external cables, each with polarized console connector, are used for ETG No. 1 and ETG No. 2 interface. One set of EPSC external interface cables with ETG interface cables, 35-feet long, and four sets of ETG interface cables, 60-feet long, were furnished.

Four sets of EPSC internal interface cables were furnished. All internal console cables are provided with polarized connectors on each termination to assure correct mating with either ETG No. 1 or ETG No. 2 system subpanels of the console assembly.

Four sets of interface cables for the load test unit were furnished (Figure IX-7). Each set consists of two cable assemblies. The load test unit cable assembly is 4-foot long.

One set of PMP interface cables consisting of two cable assemblies were furnished with the mobile carriage unit. The cables, each with polarized PMP connector, are used for generator No. 1 and generator No. 2 interface. Each cable assembly is 6-foot long.

6. Systems Checkout Test

Complete systems checkout tests of the SNAP 19 Viking power system were conducted with three different PMP units and three different sets of RTG pairs. All measurement data were compared with data obtained concurrently from standard laboratory test equipment.

One of the RTG's/PMP system tests was conducted with RTG's emplaced in their RTG shipping container and the container and PMP mounted on the mobile carriage (Figure IX-4). The purpose of this test setup was to verify proper PMP operation with mobile carriage interface cabling and the PMP unit exposed to the thermal environment caused by the proximity of two operating generators.

Figure IX-9 presents a systems test setup for an ETG power supply console in combination with two ETG's or a load test unit. Figure IX-10 shows the test setup for 2 RTG's connected to a PMP.

B. MECHANICAL GSE

1. Generator Handling Tool

The generator handling tool is used to facilitate the vertical lifting of a thermally hot generator. The handling tool attaches to three mounting lugs (which are a part of the top flange protector plate described below) by means of quick release pins. A central lifting eye provides for lifting using handling equipment supplied by the spacecraft integrator.

2. Flange Protector Plates

A lower flange protector plate is provided to avoid damage to the generator housing lower flange prior to installation of the generator on the lower end cap cooler.

FIG. IX-9. SNAP 19 VIKING ETG CABLE INTERCONNECTION

FIG. IX-10. SNAP 19 VIKING RTG CABLE INTERCONNECTION

A top flange protector plate is provided to avoid damage to the housing top flange prior to installation of the upper end cap cooler. Three integral lugs in the top flange protector plate provide an attachment interface for the generator handling tool described above.

3. ETG Shipping Container

The ETG shipping container holds a single generator. It is approximately 33 inches square by 25 inches high, and is constructed of plywood. Heavy wooden cleats are attached to the bottom to permit handling by a forklift truck.

The inside bottom of the shipping container serves as a base for four elastomeric shear mounts which support a 0.375 inch thick aluminum plate to which the generator is mounted. These shear mounts reduce the dynamic load inputs to the generator during transportation and handling.

When in transit, the upper and lower flange protector plates remain attached to the generator. The generator handling tool is also attached to the upper flange protector plate and the fin insulation pads are in place on each of the generator fins. The generator is inside of a polyethylene bag which has been backfilled with argon gas and heat sealed.

4. RTG Shipping Container

The RTG shipping container supports and protects two generators mounted vertically end-to-end. It is approximately 30 inches square by 43 inches high, and is constructed of aluminum structural framing covered with heavy gauge expanded metal screening. The screening provides an open but rugged protective cage around the RTG's. Air may circulate freely around the generator fins allowing adequate cooling by natural convection. Lifting and anchoring points are provided by four lugs, located on each corner at the top of the shipping container cage. In addition, one lug, located in the center at the top of the container cage is capable of supporting the entire load. Large runners on the bottom of the shipping container skid provide adequate clearance for forklift handling. The basic generator support stand is supported by eight elastomeric shear mounts in order to reduce dynamic load inputs to the generators.

An access door in the container cage permits plug-in of the GSE interface cabling. Thus, the generators can readily be connected to the Portable Monitor Package, thereby permitting performance evaluation prior to, during and after transporting the generators without removal from the container.

5. Generator Fin Insulating Pads

When generators are operated in air, convective and radiative cooling yields low fin root temperatures. To simulate space operating fin temperatures, insulating pads are placed over the fin. These pads, constructed of Fiberfrax ceramic blanket filler covered with silicon rubber coated fiberglass cloth and sewed with fiberglass thread are supplied in sets of six. Metal snap fasteners join adjacent pads. By adjusting the pads inward or outward on the fins, the heat loss can be controlled, and a high operating temperature can be maintained.

6. RTG Mobile Carriage

A mobile carriage is provided for the transporting of generators between working areas. It is a three wheeled cart capable of being towed or pulled manually while accommodating the RTG shipping container is attached to the cart floor. The carriage has provisions for supporting a Portable Monitor Package (PMP) including cables, to facilitate monitoring generator performance parameters during movement or storage.

X. CONFIGURATION CONTROL

Configuration control was implemented subsequent to the design freeze of January 15, 1973. Before that date, changes to technical documents were reviewed and signed-off by the responsible individuals and subsequently released into the system for final action. After the design freeze, changes in configuration or work effort fell into two categories; Class I type, a change in scope or within program scope causing a change of total program cost and Class II type, changes within program scope and within total program cost estimate. Class I and Class II changes required ERDA Program Manager and/or Contracting Officer approval. Some Class II changes were further defined as minor changes when less than \$200 was involved, and therefore did not require ERDA Program Manager and/or Contracting Officer approval. Change requests at any level were subject to written documentation (EDCS). Class I change numbers were preceded by the letter A, Class II change numbers were preceded by the letter B and Class II minor change numbers were preceded by the letter M.

A change control board (CCB) was established to determine the Class of the proposed change and to evaluate and coordinate the proposed change with all affected departments. After completing the change evaluation the CCB forwarded the EDCS (Class I and Class II but not Class II minor changes) to the ERDA Program Manager and/or the Contracting Officer for formal direction. After receiving direction, the change was implemented through the cognizant group. The CCB also maintained records of all EDCS actions.

Not all of the engineering drawings were subject to configuration control. Only drawings of generator components and generator testing together with process and material specifications were subjected to configuration control standards. Ground Support Equipment (GSE), tooling drawings and component test procedures were not subject to configuration control. Revisions to non-configuration controlled drawings were made according to the standard system.

Generator S/N 100 was not subject to configuration control requirements but for record purposes, the "as-built" configuration was documented and is a part of the drawing listing. Generator S/N 101 and S/N 102 were earlier engineering models which were modified to simulate the external configuration of the current Viking generators. A complete listing of drawings, procedures and specifications applicable to these two generators is not listed within this report.

However, the generator configuration and the associated GSE can be found on drawings 452A6000010 and 452A6000000 respectively.

a. Listing of drawings and procedures

The complete drawing and "as-built" configuration listing for each generator is divided into seven sections. They are:

- A. Generator Component Drawings, Assemblies, and Test Procedures,
- B. Ground Support Equipment,
- C. Tools and Test Fixtures
- D. Process Specifications,
- E. Material Specifications,
- F. Procurement Specifications
- G. Fuel Capsule Specifications/Procedures (MRC)

Sections A and D are each divided into two sections. The first section is the "as-built" configuration listing for each generator; the second section is a listing of drawings, procedures and specifications which were generated by the Program but were not subject to configuration control.

1. Drawing Listing and "AS-Built" Configuration Listing *
Section A. Generator Component Drawings, Assemblies and Test Procedures

DRAWING NUMBER	TITLE	ETG			RTG		ETG			RTG				
		100	103	104	105	106	107	108	109	111	112	113	114	115
452A6000000	Viking System Cable Connections		C	D	D	D	D	D	D	G	G	G	G	G
452A6000003	Fin	A	C	C	C	C	C	C	C	C	C	C	C	C
452A6000011	Generator Assembly	A	A	D			E	F	G					
452A6000012	Receptacle Assembly	B	D	E	E	E	E	E	E	F	F	F	F	F
452A6000020	Seal Plug	A	B	B	B	B	B	B	B	B	B	B	B	B
452A6000022	Piston and Button	B	B	C	C	C	D	D	D	D	D	D	D	D
452A6000023	Module Bar	C	C	D	D	D	D	D	D	D	D	D	D	D
452A6000025	Housing Assembly	A	E	J	H	H	J	K	K	M	M	M	M	M
452A6000026	Housing Body	B	E	F	F	F	G	H	H	H	H	H	H	H
452A6000027	Getter Assembly	A	NEW	A	A	A	A	A	A	A	A	A	A	A
452A6000028	Getter	A	A	A	A	A	A	A	A	A	A	A	A	A
452A6000029	Getter Housing	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW
452A6000030	Lower Cover Assembly	C	D	D										
452A6000031	Lock Ring	A	A	B	B	B	B	B	B	B	B	B	B	B
452A6000032	Seal Ring	NEW	NEW	A	A	A	A	A	A	A	A	A	A	A
452A6000033	Upper Cover Assembly	C	E	F			G	G	G					
452A6000034	Receptacle Seal Ring	A	A											
452A6000035	Receptacle Seal Ring	NEW	NEW											
452A6000036	Seal Ring Assembly	B	D											
452A6000037	Pressure Transducer	A	NEW	B	A	B	C							
452A6000038	Inner Insulation Ring	A	A	B	B	B	B	B	B	B	B	B	B	B
452A6000039	Middle Insulation Ring	B	B	C	C	C	C	C	C	C	C	C	C	C
452A6000040	Outer Insulation Ring	NEW	NEW	B	A	B	B	B	B	B	B	B	B	B
452A6000041	End Insulation Disc	A	A	B	B	B	B	B	B	B	B	B	B	B
452A6000042	End Insulation Ring	A	A	A			A	A	A					
452A6000043	End Insulation Disc	A	A	A			A	A	A					
452A6000044	Electrical Receptacle	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW
452A6000045	Reservoir Assembly	NEW	A	A	A	A	A	A	A	B	C	C	C	C
452A6000046	Reservoir	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW
452A6000047	Weld Ring	A	B	B	B	B	B	B	B	B	B	B	B	B
452A6000048	Reservoir Tube				NEW	NEW				A	A	A	A	A
452A6000049	Clamp	NEW	NEW	NEW			A	A	A					
452A6000050	Receptacle Seal Ring			NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW
452A6000051	Compression Ring			A	A	A	A	A	A	A	A	A	A	A
452A6000052	Pressure Transducer							NEW	NEW	NEW	NEW	NEW	NEW	NEW
452A6000053	Lower End Cover						NEW	NEW	NEW					
452A6000309	Generator Gas Sample Test Procedure	A	A	A	A	A	A	A	A	A	A	A	A	A
452A6000312	Electrical Receptacle Acceptance Test Procedure			NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW

* NOTE: Column without an entry indicates that drawing is not applicable to that generator

[illegible]

DRAWING NUMBER	TITLE	ETG			RTG		ETG			RTG				
		100	103	104	105	106	107	108	109	111	112	113	114	115
452A6010500	Acceptance Specification	A	A	A	A	A	B	B	B	B	B	B	B	B
452A6010501	Acceptance Specification	A	B	B	B	B	B	B	B	C	C	C	C	C
452A6010502	Acceptance Specification	NEW	A	A	A	A	A	A	A	A	A	A	A	A
452A6020006	Insulator Strip	A	A	B	B	B	B	B	B	B	B	B	B	B
452A6020009	Insulator	B	B	B			B	B	B					
452A6020010	Heat Shield	NEW	A	A			A	A	A					
452A6020012	Heater Block	B	B	B			C	C	C					
452A6020016	Load Ring	C	C	C	C	C	C	C	C	C	C	C	C	C
452A6020018	Retainer Plug	B	B	B			B	B	B					
452A6020028	Heater Block Cap	NEW	NEW	NEW			A	A	A					
452A6020029	Heater Block Assembly	A	A	B			C	C	C					
452A6020030	End Plug Assembly	NEW	NEW	NEW			NEW	NEW	NEW					
452A6020031	End Plug	A	B	B			B	B	B					
452A6080004	Nameplate	B	B	B			B	B	B					
452B6100000	Generator Assembly				B	B				F	F	G	G	G
452B6100001	Lower Cover				B	B								
452B6100002	End Insulation Ring				NEW	NEW				NEW	NEW	NEW	NEW	NEW
452B6100003	Upper Cover				E	C				E	E	E	E	E
452B6100007	Nameplate				A	A				A	A	A	A	A
452B6100008	Seal Shell				NEW	NEW				A	A	A	A	A
452B6100009	Nut				A	A				B	B	B	B	B
452B6100010	Lower End Cover									NEW	NEW	NEW	NEW	NEW
452B6100300	RTG Assembly Procedure				B	B				D	E	E	E	E
452B6100301	Generator Core Assembly Procedure				B	C				D	D	D	D	D
452B6100302	RTG Fueling Procedure				NEW	A				C	D	D	D	D
452B6100303	Disassembly and Assembly Procedure Pressure Transducer Replacement									NEW				
452B6100304	RTD Replacement Procedure										NEW			
452B6100305	Disassembly and Assembly Procedure RTG Lower Cover											NEW		
452B6100400	Radiation Survey				NEW	NEW				NEW	NEW	NEW	NEW	NEW
452B6120000	Capsule Assembly				B	B				B	B	B	B	B
452B6120001	Body, Capsule Clad				B	B				C	C	C	C	C
452B6120003	Cap, Capsule Clad				A	A				A	A	A	A	A
452B6120005	Liner, Strength Member Assembly				A	A				A	A	A	A	A
452B6120006	Body, Strength Member				NEW	NEW				NEW	NEW	NEW	NEW	NEW
452B6120007	Cap, Strength Member				A	A				A	A	A	A	A

DRAWING NUMBER	TITLE	ETG			RIG		ETG			RIG				
		100	103	104	105	106	107	108	109	111	112	113	114	115
452B6120008	Liner Assembly				B	B				B	B	B	B	B
452B6120009	Body, Liner				NEW	NEW				NEW	NEW	NEW	NEW	NEW
452B6120010	Cap Assembly, Liner				NEW	NEW				NEW	NEW	NEW	NEW	NEW
452B6120011	Cap				A	A				A	A	A	A	A
452B6120012	Pressure Relief Device				NEW	NEW				NEW	NEW	NEW	NEW	NEW
452B6120013	Body, Inner Liner				A	A				A	A	A	A	A
452B6120016	Cap, Inner Liner				A	A				A	A	A	A	A
452B6120017	Simulant Fuel Stack				NEW	NEW				NEW	NEW	NEW	NEW	NEW
452B6120018	Fuel Stack- PMC				A	A				A	A	A	A	A
452B6120020	Heat Shield				NEW	A				A	A	A	A	A
452B6120021	Sleeve Assembly				NEW					NEW	NEW	NEW	NEW	NEW
452B6120022	End Plug Assembly				A	A				A	A	A	A	A
452B6120023	End Plug				A	A				A	A	A	A	A
452B6120025	Sleeve Restraint and Washer				NEW	A				A	A	A	A	A
452B6120500	RTG Fueled Capsule Specification				A	A				A	A	A	A	A
452A6000324	Viton O-Ring Receptacle Seal Test Procedure	452A6020408	PMC Simulant- Viking Development Test Capsule Specification											
452A6000327	O-Ring Compression Set Test Procedure	452A6020410	SNAP 19 Viking Heat Source Hypersonic Convective Heating Distribution Test Procedure											
452A6000315	Electrical Receptacle/Diffusion Bond Seal Test Procedure	452A6020411	Solid Propellant Fire Test Plan- SNAP 19 Viking RTG Test Specimen											
452A6000401	Void Volume Test	452A6040302	V.A.C. Submarine Operating Procedure											
452A6000406	MARS Surface Thermal Cycle Test	452A6040400	Interplanetary Power-Up and Life Test											
452A6000801	SNAP 19 Viking Systems Operations Reference Manual	452A6050400	SNAP 19 Temperature Sensor and Generator Connector Check Procedure											
452A6020020	Development Test- Fuel Capsule Assembly	452A6050401	RTD Nominal Calibration Curve											
452A6020021	Simulant Fuel Stack- PMCS	452A6050402	Thermistor Nominal Calibration Curve											
452A6020023	Cap Assembly- Capsule Clad	452B6100700	Installation and Removal Procedure- RTG Into Shipping Container											
452A6020024	Tube, Vent- Generator Vibration Test	452B6100701	Loading, Transporting and Unloading Procedure of SNAP 19 Viking Generators and Associated Ground Equipment											
452A6020025	Tube, Vent- Plasma Arc Test	452B6180400	SNAP 19 In-House Hazard Review and Emergency Plan											
452A6020300	Vent System Vibration and Shock Development Test													
452A6020402	Controlled Leak Device Flow Characteristic Test Procedure													
452A6020406	Plasma Arc Test Procedure													
452A6020407	Test Plan- SNAP 19 Viking Capsule Impact Test													

Section B. Ground Support Equipment (G.S.E.)

DRAWING NUMBER	TITLE	DRAWING NUMBER	TITLE
452A6030000	Shipping Container Assembly	452B6130000	Generator Shipping Container
452A6030001	Shipping Container	452B6130001	Tie Down Assembly- Generator Shipping Container
452A6030002	Mounting Plate- Pallet	452B6130002	Skid Assembly- Generator Shipping Container
452A6030003	Heater Power Supply Control Panel	452B6130003	Nameplate
452A6030005	Miscellaneous Details- P.M.P.	452B6130004	Nameplate
452A6030010	ETG Power Supply	452B6130006	Welded Base Assembly- Mobile Carriage
452A6030011	Nameplate	452B6130007	Mobile Carriage- Generator Shipping Crate and P.M.P.
452A6030014	Adapter Cable- Load Test Unit		
452A6030015	Load Test Unit- ETG Power Supply		
452A6030018	Cable Assemblies- P.M.P.		
452A6030020	Panel		
452A6030021	Terminal Board		
452A6030022	Bracket- Component Board Mounting		
452A6030023	Nameplate		
452A6030024	Silkscreen		
452A6030025	Shipping Container Assembly- P.M.P.		
452A6030026	Generator Handling Tool and Top Flange Protection Ring		
452A6030027	Silkscreen		
452A6030028	Connector Saver Cable Assembly		
452A6030029	Power Input Cable Assembly		
452A6030030	Insulating Sleeve		
452A6030031	Lower Flange Protector Plate		
452A6030032	Adapter Unit- P.M.P. Calibration		
452A6030033	Facility Outlet Conversion Cable		
452A6030034	Insulation Resistance Test Fixture		
452A6030035	Shipping Container Assembly- Power Supply Rack		
452A6030036	Wiring Schematic- Heater Power Supply Control Panel		
452A6030037	Internal Cable Assembly- ETG Power Supply		
452A6030038	External Cable Assembly- ETG Power Supply		
452A6030039	48 Measurement T/C Switching Unit		
452A6030040	Portable Monitor Package (P.M.P.)		
452A6030041	Silkscreen		
452A6030042	Wiring Schematic- P.M.P.		
452A6030804	P.M.P. Operations Manual		
452A6030805	ETG Power Supply Operations Manual		

Section C. Tools and Test Fixtures

Drawing Number	TITLE	Drawing Number	TITLE
452A6040001	Plug Adapter	452B6140000	Generator Outgassing Tool
452A6040010	Installation Tool	452B6140001	Seal Plate, Lower End
452A6040011	Module Strap Bonding Tool	452B6140002	Heater Block Cap
452A6040012	Vacuum Furnace and Clamping Fixture- Diffusion Bonding	452B6140003	Filler Block
452A6040013	Cover Adapter- Assembly and Installation	452B6140004	Heater Block
452A6040014	Compression Tool- End Covers	452B6140005	Leak Check Tool Installation
452A6040015	Split T/E Element Mold		
452A6040016	Electrical Receptacle Test Fixture		
452A6040017	Wrench		
452A6040018	Leak Check Valve Assembly		
452A6040019	Seal Plate- End Cover		
452A6040020	Adiabatic Surface Tool		
452A6040021	Generator Test Sling		
452A6040022	Mandrel		
452A6040025	Crimping Tool		
452A6040026	Mass Properties Test Fixture		
452A6040027	Thermal Cycle Test Stand		
452A6040028	Assembly and Leak Check Fixture		
452A6040030	Dual O-Ring Leak Check Fixture Assembly		
452A6040031	Outgassing Cover		
452A6040032	Pressure Transducer Vibration Test Fixture		
452A6040033	Pressure Transducer Acceptance Test Fixture		
452A6040034	Receptacle/Seal Ring Test Fixture		
452A6040035	Compression Set Test Fixture		

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Section D. Process Specifications

Process NUMBER	TITLE	ETG			RTG		ETG			RTG				
		100	101	102	103	104	07	108	109	111	112	113	114	115
PS0100001	Module Assembly and Bonding	J	J	J	J	J	M	M	M	M	M	M	M	M
PS0100003	Assembly of TACS 85-F/2N Type Thermoelectric couples	F	F	F	F	F	F	G	G	G	G	G	G	G
PS0100004	Soldering Electrical Connections	A	A	A	A	A	A	A	A	A	A	A	A	A
PS0100006	Qualification Procedure for the Certification of Fusion Welders and Welding Operators	A	A	A	A	A	A	A	A	A	A	A	A	A
PS0100011	Installation of Resistance Temperature Detector (RTD)	C	C	C	C	C	C	C	C	C	C	C	C	C
PS0100012	Thermoelectric Couple Hot Shoe Brazing	B	C	C	C	C	C	C	C	C	C	C	C	C
PS0100019	Tinning, Thermoelectric Couple Cold Shoe	A	A	A	A	A	A	A	A	A	A	A	A	A
PS0100020	Welding, Resistance, Tabs and Extensions to Thermoelectric Couple Hot Shoe	A	B	B	B	B	B	B	B	B	B	B	B	B
PS0100021	Welding Magnesium and Magnesium Alloys	NEW	A	A	A	A	A	B	B	C	D	D	D	D
PS0100022	Welding Nickel to Stainless Steel	NEW	NEW											
PS0100023	Welding of Stainless Steels		NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW
PS0200001	Bake-Out and Outgassing of Thermal and Electrical Insulation	E	E	E	E	E	F	F	F	F	F	F	F	F
PS0200002	Electrical Heat Source Heat Treatment	F	F	F			F	G	G					
PS0200004	Rolling and Annealing High Purity Iron	A	B	B	B	B	B	B	B	B	B	B	B	B
PS0200008	Outgassing of High Temperature Generator Details	G	G	G	G	G	I	I	I	I	I	I	I	I
PS0300001	Nickel Plating of High Purity Iron Sheet	A	B	B	B	B	B	B	B	C	C	C	C	C
PS0300002	Grit Blasting of Magnesium-Thorium Alloy Details and Assemblies	C	D	E	E	E	E	E	E	E	E	E	E	E
PS0300004	Hardcoating of Aluminum Alloys	C	C	C	C	C	C	D	D	D	D	D	D	D
PS0300008	Alkaline Cleaning, Non-Etch	NEW	A	A	A	A	A							
PS0300009	Vapor Degreasing of Metal and Metal Parts	C	C	C	C	C	C	C	C	C	C	C	C	C
PS0300014	Deoxidation of Aluminum Alloys	NEW	A	A	A	A	A							
PS0300016	Zirconium Oxide Coating Application	B	B	B			B	B	B					
PS0300020	Chemical and Abrasive Cleaning of TZM (Alloy)	NEW	NEW	NEW										
PS0300025	Hydrogen Cleaning	A	A	A	A	A	A	A	A	A	A	A	A	A
PS0300026	Emissivity Coating Application	B	C	C	C	C	C	C	C	C	C	C	C	C
PS0300030	Ultrasonic Cleaning	A	A	A	A	A	C	C	C	C	C	C	C	C
PS0300031	Solvent Cleaning of Couple Details	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW
PS0300032	Cleaning of Copper	NEW	A	A	A	A	A	A	A	A	A	A	A	A
PS0300033	Protection and Cleaning of Magnesium and Magnesium Alloys	B	C	C	C	C	C	C	C	C	C	C	C	C

PROCESS NUMBER	TITLE	ETG			RTG		ETG			RTG				
		100	103	104	105	106	107	108	109	111	112	113	114	115
PS0500001	Clean-Up and Final Finishing of Thermoelectric Couples	E	E	E	E	E	E							
PS0500002	High Temperature Manganese Nickel Braze Disc Fabrication	A	B	B	B	B	B	C	C	C	C	C	C	C
PS0500004	Fabrication of TAGS 85 P Type Thermoelectric Elements	D	E	E	E	E	E	E	E	E	E	E	E	E
PS0500006	Fabrication of Tin-Tellurium Wafers	B	C	C	C	C	C	C	C	C	C	C	C	C
PS0500007	Fabrication of Tin-Tellurium Bonded Wafers	C	C	C	C	C	C	C	C	C	C	C	C	C
PS0600001	Crimping of Terminals, Splices and Shield Ferrules	E	E	E	E	E	F	F	F	F	F	F	F	F
PS0600003	Instrumentation Thermocouple Installation	D	D	D	D	D	D	D	D	D	D	D	D	D
PS0600004	Installation of Micro-Quartz Insulation in T/E Conversion Assemblies	B	B	B	B	B	C	C	C	C	C	C	C	C
PS0700001	Handling of Dangerous and Toxic Materials	NEW	NEW	NEW	NEW	NEW	A	A	A	B	B	B	B	B
PS0700002	Handling Procedures for RTG'S				B	B				B	B	B	B	B
PS0700003	Protection and Handling of Emissive Coated Components	B	B	B	B	B	C	C	C	C	C	C	C	C
PS0700005	Dry Box Operating Procedure	A												
PS0700006	Generator Assembly Room Process Control	B	B	B	B	B	B	B	B	B	B	B	B	B
PS0700009	Glove Box Line Operating Procedure	B	B	B	B	B	B	C	C	C	C	C	C	C
PS1100001	Resistivity Determination of T/E Elements at Ambient Temperature	B	B	B	B	B	B	C	C	C	C	C	C	C
PS1100002	Seebeck Voltage Determination of T/E Elements	B	C	C	C	C	C	C	C	C	C	C	C	C
PS1100005	Resistance Determination of T/E Couples at Ambient Temperature	A	A	A	A	A	A	B	B	B	B	B	B	B
PS1100006	Determination of T/E Couple Power Output	C	D	D	D	D	E	E	E	E	E	E	E	E
PS1100007	Resistivity Determination of T/E Element Sticks	A	B	B	B	B	B	B	B	B	B	B	B	B
PS1100009	Measurement of Electrical Resistance Keithley Milliohmometer Technique	B	B	B	B	B	B	B	B	B	B	B	B	B
PS1200001	Storing of Couple Details	C	C	C	C	C	C	C	C	C	C	C	C	C
PS1200002	Packaging and Storing of T/E Couples	C	C	C	C	C	C	C	C	C	C	C	C	C

PROCESS NUMBER	TITLE		
PS0100002	Fusion Welding Aluminum and Magnesium Alloys		
PS0600006	Assembly of Soldered Electrical Components		
PS0600008	Installation of Heat Shrinkable Tubing and Molded Parts		
PS0600014	Installation of Terminal Lugs, Solder Type		

Section E. Material Specifications

Specification Number	Title	ETG			RTG		ETG			RTG				
		100	103	104	105	106	107	108	109	111	112	113	114	115
MS115-201	Iron, High Purity	NEW	A	A	A	A	A	A	A	A	A	A	A	A
MS130-201	Nickel, High Purity	NEW	A	A	A	A	A	A	A	A	A	A	A	A
MS140-101	Tin, High Purity	NEW	A	A	A	A	A	A	A	A	A	A	A	A
MS140-102	Germanium, High Purity Semiconductor Grade	A	B	B	B	B	B	C	C	C	C	C	C	C
MS140-103	Antimony, High Purity	NEW	A	A	A	A	A	A	A	A	A	A	A	A
MS140-601	Tin Powder, High Purity	A	B	B	B	B	B	B	B	B	B	B	B	B
MS140-701	Manganese, High Purity	A	B	B	B	B	B	B	B	B	B	B	B	B
MS 140-901	Tellurium, High Purity	NEW	A	A	A	A	A	A	A	A	A	A	A	A
MS140-902	Silver, High Purity	NEW	A	A	A	A	A	A	A	A	A	A	A	A
MS140-903	Magnesium Alloy Rolled Ring Forgings 2.0 Th-0.78 Mn (HM21A-T5)	NEW	NEW	NEW	NEW	NEW	A	A	A	B	B	B	B	B
MS150-001	Specification for Pyrolytic Graphite				C	C				E	E	E	E	E
MS150-701	Specification for Fine Grained Isotropic Poco Graphite- AXF-Q1	B	B	B	B	B	B	B	B	B	B	B	B	B
MS160-901	Specification for Tantalum Web				NEW	NEW				NEW	NEW	NEW	NEW	NEW
MS180-001	Specification for High Purity Hydrogen	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW

Section F. Procurement Specifications

65N1	Spring	6	6	6	6	6	6	6	6	6	6	6	6	6
74N7	Resistance Temperature Detector	11	13	13	13	13	13	13	13	13	13	13	13	13
74N8	Heater Cartridge	6	6	6			6	6	6					
92N4	Thermistor	6	6	6	6	6	7	7	7	7	7	7	7	7

Section G. Fuel Capsule Specifications/Procedures (MRC)

NUMBER	TITLE				RTG					RTG				
					105	106				111	112	113	114	115
MDI-13457	Pt-20Rh, Material				10	10				10	10	10	10	10
MDI-13458	T-111, Material				4	4				4	4	4	4	4
MDI-13459	Ta-10W, Material				4	4				4	4	4	4	4
MDI-14428	Plasma Coating				4	4								
MDI-14531	PuO ₂ - Moly Cermet Discs				10	10				L	L	L	L	L
MDI-14532	PuO ₂ - Moly Cermet Discs				10	10				L	L	L	L	L
MDI-14679	Component Hydroforming				2	2				2	2	2	2	2
MDI-14680	Heat Treat- Tantalum Alloys				2	2				D	D	D	D	D
MDI-14681	Heat Treat- Pt-20Rh				2	2				D	D	D	D	D
MDI-14682	Cleaning- Tantalum Alloys				2	2				D	D	D	D	D
MDI-14683	Cleaning- Pt-20Rh				2	2				D	D	D	D	D
MDI-14684	Marking of Parts and Assemblies				NEW	NEW				NEW	NEW	B	B	B
MDI-14721	Molybdenum, Material				NEW	NEW				NEW	NEW	NEW	NEW	NEW
MDI-14722	Cleaning- Molybdenum				NEW	NEW				B	B	B	B	B
MDI-14723	Waster Sheet Removal Procedure				NEW	NEW				B	B	B	B	B
MDI-14734	Procedure Manual- USC				1	1								
MDI-14812	Mo-46Re, Material				1	1				1	1	1	1	1
MDI-14861	Cleaning- Mo-46Re				NEW	NEW								
MDI-14867	Cleaning- Mo-46Re Alloy				NEW	NEW				B	B	B	B	B
MDI-14868	Fuel Capsule Acceptance				1	1				C	C	D	D	D
MDI-14882	Fabrication and Installation of Ta Wire Into Liner				NEW	NEW				B	B	B	B	B
MDI-14883	General Vacuum Outgassing Procedure				1	1				C	C	C	C	C
MDI-14884	Procedure Manual Universal Shipping Container				NEW	NEW				A	A	A	A	A

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b. RTG drawing tree

The RTG drawing tree is a component/assembly breakdown of a typical SNAP 19 Viking flight generator. Drawings and procedures which are applicable only to a particular generator will not be found within the drawing tree. All specifications (engineering, process or material) which are required during the fabrication process for each component are listed within the identification box of each component. An explanation of a typical component listing is as follows:

GENERATOR ASSEMBLY - FUELED
 452B6100000-009
 452AG0000319 452AG0000413 452B6100700
 452AG0000326 452AG0000414 452B6100701
 452AG0000407 452AG0000501 PS0100021
 452AG0000408 452AG0040302 PS0300026
 452AG0000409 452B6100302 PS0700003

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GENERATOR ASSEMBLY

GENERATOR ASSEMBLY - ELECTRICALLY HEATED
 452BG100000-019
 452AG0000309 452AG0000501 452BG1000001 PS07000006
 452AG0000317 452AG0100015 PS01000021 PS07000009
 452AG0000318 452AG040302 PS02000001TYIII
 452AG0000319 452AG050400 PS06000001
 452AG0000408 452BG1000300 PS07000003

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HOUSING ASSEMBLY
452AG000025-019
452AG0000322
PS0100021
PS0300026

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MODULE ASSEMBLY
452AG010000-009
PS0100001TY III
PS0600004
PS1100009

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T/E MODULE ASSEMBLY

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MODULE ASSEMBLY
452AG010000-029
PS0100001 TY III
PS0600004
PS1100009

T/E MODULE ASSEMBLY

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MODULE ASSEMBLY
452AG010000-039
PS0100001TYIII
PS0100011
PS0600004
PS1100009

T/E MODULE ASSEMBLY

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T/E COUPLE ASSEMBLY

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T/E COUPLE ASSEMBLY

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◇ DENOTES TRW CONTROLLED DRAWING

CAPSULE - CLAD