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POWER SUPPLIES FOR SPACE SYSTEMS QUALITY ASSURANCE BY SANDIA LABORATORIES

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ABSTRACT

This report summarizes the Sandia Laboratories participation in Quality Assurance programs for Radioisotopic Thermoelectric Generators which have been used in space systems over the past 10 years. Basic elements of this QA program are briefly described and recognition of assistance from other Sandia organizations is included. Descriptions of the various systems for which Sandia has had the QA responsibility are presented, including SNAP 19 (Nimbus, Pioneer, Viking), SNAP 27 (Apollo), Transit, Multi-Hundred Watt (LES 8/9 and MJS), and a new program, High-Performance Generator Mod 3. The outlook for Sandia participation in RTG programs for the next several years is noted.

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POWER SUPPLIES FOR SPACE SYSTEMS
QUALITY ASSURANCE BY SANDIA LABORATORIES

I. Introduction

The Sandia Quality Assurance organization has been involved in many programs in addition to those in Sandia's principal area of responsibility--engineering of nuclear weapons. One of the oldest such reimbursable efforts has been the QA responsibility for Radioisotopic Thermoelectric Generators (RTG's) for space systems, and more recently for terrestrial applications. June 1976 marked the completion of 10 years of Sandia QA responsibility in the RTG area. This anniversary, coupled with the completion of one RTG program and the launching of the Lincoln Laboratory Experimental Communications Satellites (LES 8/9) on March 14, 1976, have prompted the publication of this summary report concerning Sandia's QA role in RTG programs.

II. History

Overall responsibility for SNAP programs (Systems for Nuclear Auxiliary Power devices, more rightfully called RTG's since most often they are the sole source of satellite power) lies with the U. S. Energy Research and Development Administration (ERDA) Division of Nuclear Research and Applications (DNRA), formerly the Space Nuclear Systems Division (SNS). In mid-1966 SNS requested Sandia to assume technical direction of RTG programs, and transferred the QA responsibility from the Atomic Energy Commission's New York Operations Office to the AEC's Albuquerque Operations Office (AEC/ALO). This move consolidated RTG operations and implemented more of a weapons-type QA program for SNAP.

Quality Assurance Sandia Laboratories (QASL) became involved in the quality program for RTG systems in June 1966 when AEC/ALO formally requested assistance in areas of planning and development, scheduling, data collection, and analyses. Effective December 1, 1967, the AEC requested that QASL assume full responsibility for RTG QA programs with Sandia as Technical Director. On December 1, 1970, the Sandia role of Technical Director was terminated and transferred to the Division of Space Nuclear Systems (SNS) AEC Headquarters, except for safety analyses support, which was completed in 1971. At the same time, SNS requested that Sandia Laboratories continue to be responsible for RTG QA. It was mutually agreed that in July 1971, SNS and Sandia would review the desirability of continued QASL participation; both parties subsequently agreed to continue the arrangement.

Since mid-1966, QASL has been continuously involved in the RTG programs with resident Sandia Quality Assurance Representatives (SQAR's) at major contractors and some subcontractors, except for very short periods when the field activity was covered from Albuquerque. To date, programs on which QASL has performed the QA functions for ERDA/AEC, as well as acceptance of product, include: SNAP 19 (Nimbus, Pioneer, and Viking); SNAP 27 (Apollo); SNAP 29 (no mission, RTG program cancelled); Transit; Multi-Hundred Watt RTG (Lincoln Experimental Satellites 8 and 9 and Mariner-Jupiter/Saturn); and High-Performance Generator, Mod 3. In addition, launch site quality support has been provided by QASL on SNAP 27 and Lincoln Experimental Satellite 8/9 launches from Cape Kennedy and Cape Canaveral. Figure 1 shows a launch from Cape Canaveral on March 14, 1976.

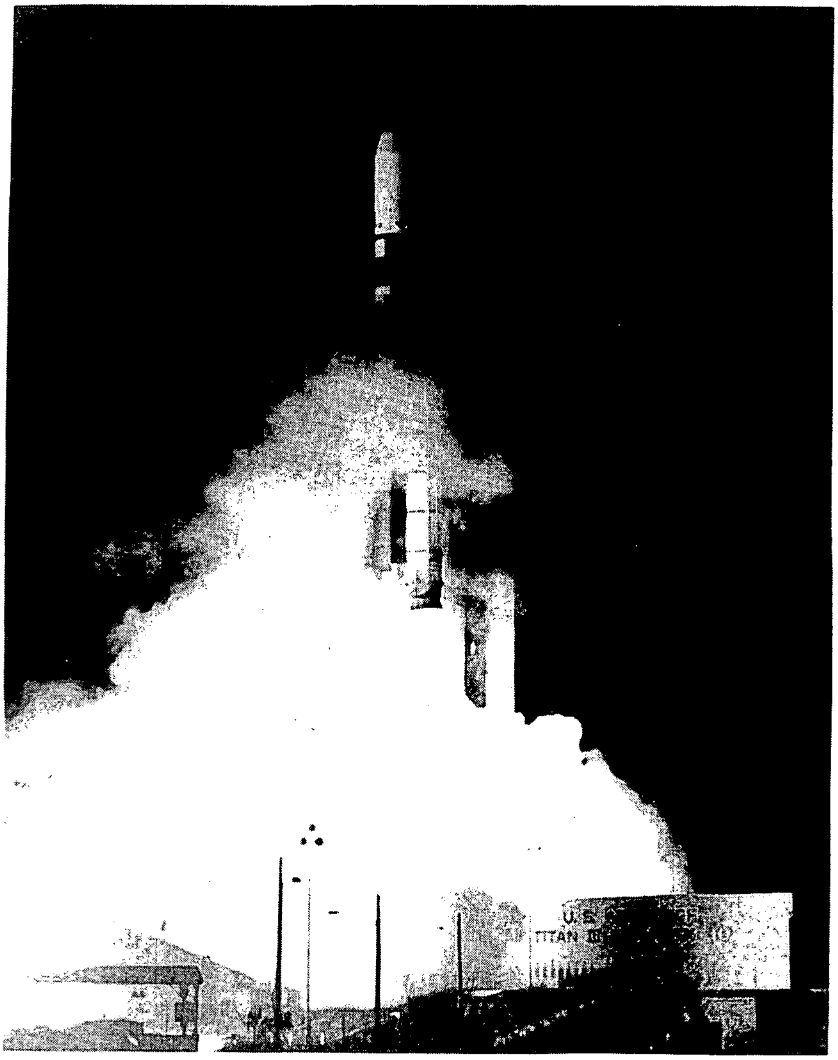


Figure 1. Launch of LES 8/9 Satellite from Cape Canaveral

III. Sandia Radioisotopic Thermoelectric Generator Quality Program

Early in each RTG program, QASL reviews contractor quality planning to verify compliance with approved system quality requirements, usually as prescribed in SNS-1, "Quality Assurance Program Requirements for Space Nuclear Systems." Later, surveys and audits are made to assure compliance with approved quality planning. Throughout all production and test phases, heavy emphasis is placed on monitoring of critical processes, assembly operations, and tests. Direction to the SQAR's and liaison with DNRA, contractor, and subcontractors is from the Albuquerque Quality Engineers.

QASL accepts all RTG program material on behalf of the government for subsequent delivery to the using agency. Inspections, monitoring of processes, assembly and testing and final acceptance of piece parts, sub-assemblies, and final assemblies are accomplished through Quality Assurance Verification Instructions issued by QASL Quality Engineers. Acceptance of hardware and/or testing is by means of Certificates of Inspection, modified from the similar weapons program document. Transfer of accountability is via the standard DD-250 form.

The division of responsibilities for QA activities on RTG programs can perhaps be most succinctly summarized as follows: Overall program directions and funding are from ERDA/DNRA (with input from QASL). Quality program planning and instructions for implementation are by QASL Quality Engineers. Monitoring of contractor quality operations is accomplished by resident SQAR's. Finally, acceptance of RTG deliverable hardware is completed by the SQAR's/QASL on behalf of the government.

Some measure of the extent of the QASL operations may be apparent from the level of effort provided on the recently completed LES 8/9. SQAR coverage at General Electric Company started at a one-man level and reached the five-man level during peak workload periods (when 24-hours-per-day and seven-days-per-week operations were in process). Also, one SQAR was assigned to RCA. During peak workload periods, Quality Engineers from Sandia and personnel from the Sandia Eastern Field Representative group have supported the field operations at GE and RCA. Approximately 125 Quality Assurance Inspection Notices and Quality Assurance Verification Instructions (QAIN and QAVI) were issued to cover hardware inspection and testing operations. In addition, revisions to QAVI's were necessitated by approved drawing and specifications changes. QAIN's are formal instructions to the contractor defining the product which is to be submitted to QASL. QAVI's are instructions to SQAR's on how to inspect and accept product, including monitoring of assembly and testing operations. Generally, two Quality Engineers were needed to support the field operations.

Approximately 1000 Certificates of Inspection (CI) were processed during the Lincoln Experimental Satellite program, representing mostly hardware lots accepted by QASL for the government, plus a small number of CI's on processes and testing operations. On this program, approximately 15 percent of the lots submitted to QASL for acceptance were rejected on the first submission. Additionally, about 6 percent of first lot submissions were "conditionally" accepted. Thus, about 21 percent of first lot submissions were of less than required quality.

Dollar value of hardware accepted by Sandia for the Lincoln Experimental Satellite mission is quite high. Total costs of the contract, including development effort for five flight RTG's, were about $40 million (less radioistopic fuel). Actual hardware costs are not readily extracted from this number, but replacement of a single flight RTG would probably cost in excess of $1 million.

As a measure of effectiveness of the contractor quality program, QASL in mid-1975 started issuing a monthly Contractor Quality Assessment Report. In addition to the monthly quality rating (percentage of lots accepted on first submission), a Severity Index (gravity of reasons for rejected lots) and a Nonacceptable Incident Log Index (severity of operational type nonconformance as opposed to hardware nonconformance) are combined into a monthly plot of Performance Index (see Figure 2). Although this Performance Index is a new approach and is influenced by factors such as workload and type of operations underway, it does appear to be a viable technique to improve management visibility on status of the contractor's quality program.

IV. Sandia Resource Involvement

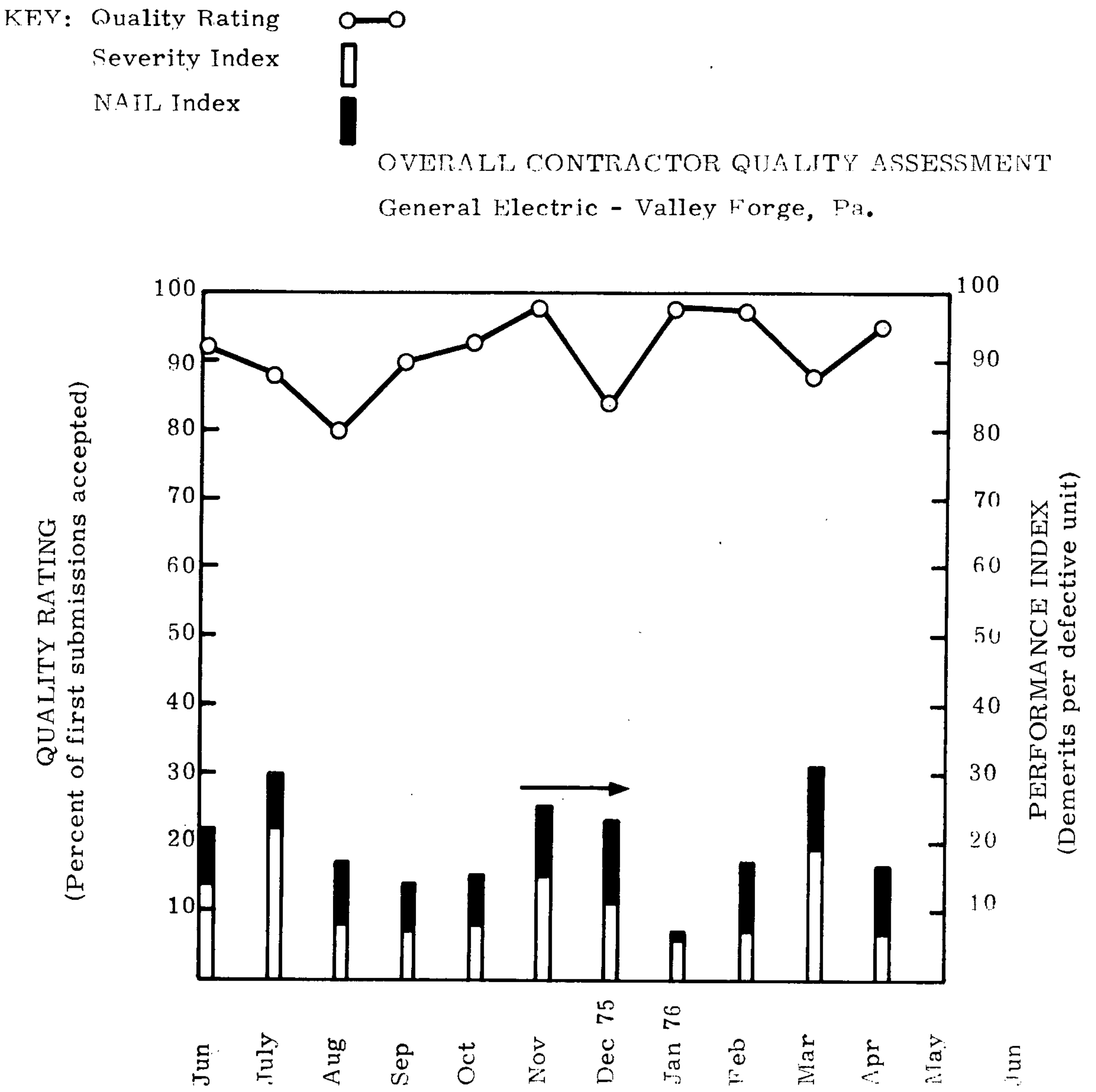
In the past decade the QASL SNAP QA effort has increased from an initial FY 67 budget of about $50K (somewhat less than two man-years of Quality Engineering and SQAR support) to a budget of $500K for FY 76 (or about 9 man-years of QA support).

Figure 3 shows the budget growth and man years for QA support. Expected budget for FY77 is $500K, with about 8 man-years support.

As part of the QASL SNAP QA program, other disciplines within Sandia have been utilized and funded from the QA reimbursable budget. Examples of other Sandia expertise applied to the RTG program include:

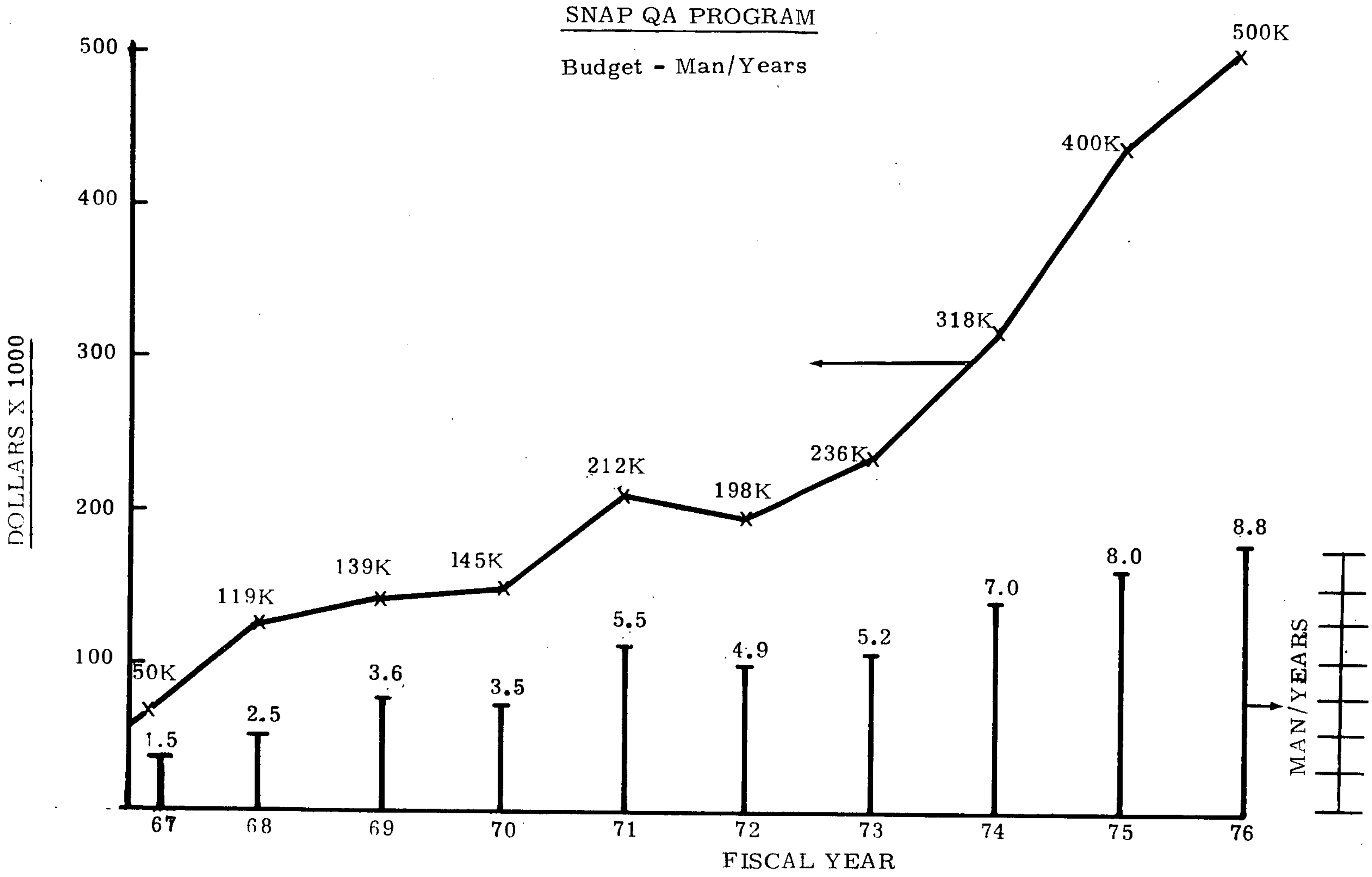
Reliability: Contractor reliability program review and evaluations; assistance in formulating reliability plans and tests; design review support.

Operational Analyses: By QA, on MHW MJS program.



	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
CI LOTS:														Upper Curve
Submitted	46	68	30	39	63	47	50	31	38	48	40			
Rejected	5	8	6	4	5	1	8	1	1	6	2			
SI:	13.7	22	8	7	8	15	11.5	5.5	7	19	6.5			Lower Curve
Demerits	234	1513	116	223	217	61	493	11	21	112	26			
Defectives	17	71	15	33	29	4	43	2	3	6	4			
NAIL:	8.7	8	9	7	7	10	11	1.4	10	12	9.8			
Demerits	61	352	227	165	55	20	123	88	20	83	59			
Defectives	7	45	25	17	8	2	11	61	2	7	6			

Figure 2. Contractor Quality Assessment Report



NOTE: Reliability support included in FY 74 and later totals.

Figure 3. QASL RTG QA Program Budget/Manpower

Testing Technology:

a. Infra-red testing of Transit thermoelectric panel to detect open couples.

b. Investigation of possible methods of measuring silicon-nitride coating thickness of MHW unicouple elements and hot shoes. Techniques investigated included optical tests, holography, eddy current, ultrasonic and Beta backscatter (at LASL).

c. Demonstration of DXT technique to determine density gradients in aeroshell end caps for MHW heat sources. This may lead to separate reimbursable effort.

Solid State Sciences: Silicon-nitride coating thickness measurement using 1.83 MeV He + ion backscattering analysis; very successful, led to correlation and confidence in SEM technique.

Materials and Processes:

a. SNAP 19 contamination analyses to determine nature of foreign material on copper couple parts after a bonding operation.

b. Silicon-nitride coating thickness measurement on MHW Unicouples using Ellipsometer technique; unsuccessful because substrate was too rough.

c. Silicon-nitride coating thickness measurement on MHW Unicouples using scanning electron microscope; very successful, and RCA subsequently used SEM technique (destructive) to measure thickness on production samples and to calibrate a spectroscopy technique (nondestructive).

d. Contamination survey at RCA, including recommendations for improvement.

Aerodynamics: Consultation on problems with various graphitics, including discussions of physical properties and review of contractor specifications.

Measurement Standards: Sandia supplied standard helium leak and leak calibration service to Teledyne on SNAP 19 and HPG-3 programs.

General: QASL has provided pertinent documentation to contractors including Clean Practices Guide, Ultrasonic Cleaning Procedures, graphite specifications and data, etc.

In addition to the foregoing Sandia QA-budgeted support of RTG programs, Sandia has performed various testing activities with separate reimbursable funds. Testing of Isotopic Heat Sources for SNAP 19, SNAP 27, and MHW programs has been conducted, including sled-impact tests and fire and explosive tests. In addition, Sandia is currently negotiating on DXT tests on

MJS Aeroshell graphitics to determine density gradients. Funding for the above types of tests has been approximately $100K total for the past three years, and probably somewhat higher in previous years. Figure 4 shows a sled-impact test on the MHW Isotopic Heat Source in Sandia's Area III.

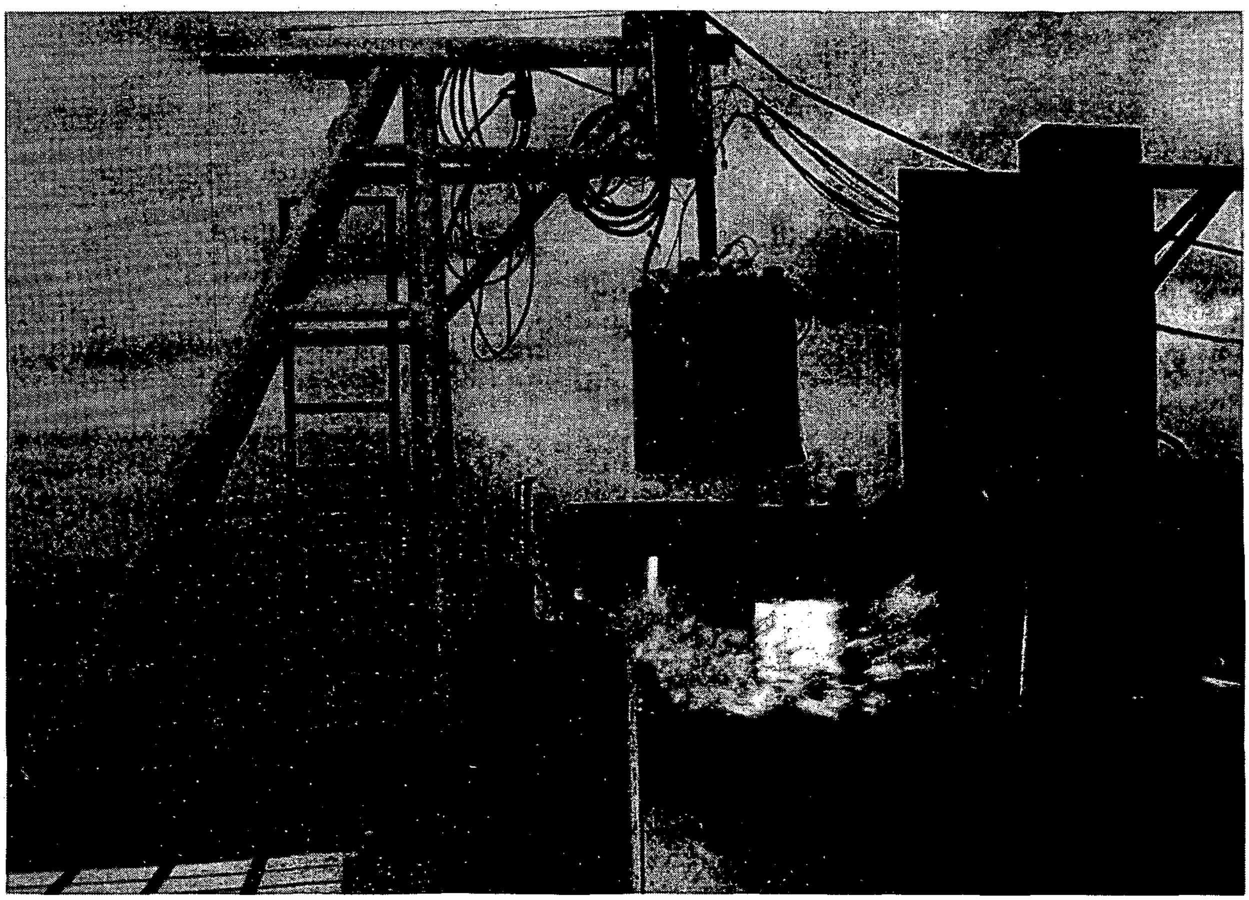


Figure 4. MHW Program Isotopic Heat Source Impact Test - Sandia Area III

V. Involvement with Other Organizations

One of the gratifying and interesting aspects of the SNAP job has been the large number of other organizations with which QASL interfaced in accomplishing the QASL QA assignment on RTG programs. This opportunity of spreading knowledge of Sandia expertise through a sizable segment of the Aerospace industry has stimulated and will hopefully continue to stimulate, more reimbursable work for Sandia.

Major contacts with prime contractor, major subcontractors, support and using agencies have included:

- Martin-Marietta Co.
  - 3M Company
  - NASA-AMES
- General Electric Company
  - 3M Company
  - Solar Division of IH Company
  - General Electric, Vallecitos
  - NASA, Johnson Space Center
  - NASA, Cape Kennedy
- TRW, Inc.
  - General Atomics
  - Applied Physics Laboratory
- General Electric Company
  - RCA, Harrison
  - Speedring, Inc.
  - Hitco
  - General Electric Company, Evendale
  - Lincoln Laboratory, MIT
  - Jet Propulsion Laboratory
  - Cape Canaveral
- Teledyne Energy Systems
  - 3M Company
  - General Electric Company
- Monsanto Research Corporation
- ERDA - Division of Nuclear Research and Applications
  - Dayton Area Office
  - Albuquerque Operations Office
  - San Francisco Operations Office

VI. Description of RTG Systems

Background

In the broad family of power generating devices, the RTG is relatively new. Actually, the principle of operation was demonstrated about 155 years ago by Thomas J. Seebeck when two dissimilar metals were joined (junctions at different temperatures) and an electric current was produced. This conversion of heat to electricity was quite inefficient and the principle essentially lay dormant for years.

In the late 40's publications on the discovery of transistor action by the Bell Telephone Laboratories provided a catalyst which led to the development of new materials which made the Seebeck principle attractive for the production of electrical power. RTG's to date have utilized a variety of semiconductor materials, including lead telluride, silicon germanium, and an alloy of tellurium, silver, germanium and antimony (TAGS 85). Still other materials are under development.

The development and expansion of space flight in the 50's, with the obvious requirement for high reliability, light weight, and long life, forced a marriage of this power conversion principal with radioisotopic fuel. The emerging converter is appropriately called the Radioisotopic Thermoelectric Generator (RTG). Design parameters of the various RTG's described in the following sections are summarized in Table I.

TABLE I

RTG Design Description and Nominal Performance Characteristics

	SNAP 27 Apollo	SNAP 27 AP 17	Transit	SNAP 19 Pioneer	SNAP 19 Viking	MHW LES 8/9	MHW MJS	HPG-3
Life (Years)	1	2	5	2	90 days	5	4	4
Pre Launch Pwr (Watts)	NA	NA	NA	NA	NA	120 typ	105	NA
BOM Pwr (Watts)	72 typ	75	35.6	40	41 to 47	150 typ	TBD	TBD
EOM Pwr Req (Watts)	63.5	63.5	30	30	35	125	128	150
Heat In (Watts)	1480	1520	850	645	675	2400	2390	~2400
Efficiency (%)	4.9	4.9	4.2	6.2	6.5	6.3	TBD	TBD
Load Voltage	16	16	5.7	4.2	4.4	26.5	30	13
Thermocouples	442	442	432	90	90	312	312	280
TC's in Parallel	2	2	4	2	2	2	2	2
P Element	PbSnTe	PbSnTe	PbSnMnTe	TAGS 85	TAGS 85	SiGe	SiGe	TAGS 85
N Element	PbTe	PbTe	PbTe	PbTe	PbTe	SiGe	SiGe	PbTe
Hot Junc Temp (°C)	593	593	400	516	580	1000	1000	TBD
Cold/Fin Root (°C)	274	274	137	166	166	270	270	TBD
Fill Gas (Oper)	Ar	Ar	Vac	Ar	3He/1Ar	Vac	Vac	He/Ar
Fill Gas (Gnd)	Ar	Ar	Na	Ar	3He/1Ar	Ar or Xe	Ar or Xe	He/Ar
Case Seal	Braze	Braze	Na	Weld	Weld	C-Seal Bolted	C-Seal Bolted	Weld
Dimensions (HtxDia)	18 x 16	18 x 16	18 x 25	11 x 19	18$\frac{1}{2}$ x 22	23 x 15.7	23 x 15.7	36 x 36
Weight (Lbs)	43$\frac{1}{2}$ typ	44	30	29.5	32.5	84 typ	TBD	150 Max
Insulation	Powder Min K	Powder Min K	A1/A1 Op	Solid Min K	Solid Min K	Mo/Ast	Mo/Ast	Solid Min K

Nimbus III -- In early 1968, two SNAP 19 RTG's (Martin-Marietta Company) were launched to supplement solar power on the Nimbus III weather satellite. Due to a guidance malfunction, the entire missile was destroyed. The fuel capsule was later recovered from the ocean floor off Santa Barbara, California, and found to be in excellent condition.

In April 1969, two more SNAP 19 RTG's were launched aboard a second Nimbus III satellite. Initial power from these RTG's was approximately 28 watts each. These RTG's utilized 90 lead telluride (3M Company) thermocouples wired in a series parallel network and MIN-K (Johns Manville) thermal insulation. Hot junction temperatures were approximately 538° C and an argon cover gas was used to suppress the expected high rate of hot junction erosion (sublimation). The fuel capsule contained a thermal inventory of approximately 630 watts derived from the decay of plutonium dioxide microspheres contained in a super alloy case. The RTG outer case was sealed (Vitron seal) via a bolted flange. Combined power from the two RTG's was approximately 47 watts at the end of one year and decayed to approximately 30 watts at the end of two. This unusually high rate of degradation (although design requirements were met) is generally attributed to oxidation attack of the thermoelectric metallurgical bonds and hot junction sublimation due to gas leakage.

Pioneer 10 and 11 -- Hostile environments such as are encountered by deep space probes and the day-night temperature excursions found on the lunar surface are the forte of the RTG's. The Pioneer 10 mission to Jupiter was launched in March 1972 with four SNAP 19 RTG's providing the sole source of power. Successful Jupiter encounter occured in December 1973 and the space probe is now programmed to leave the solar system--the first (and of course, the first RTG) to do so. Figure 5 shows performance of RTG's on Pioneer 10 and 11.

The SNAP 19 Pioneer RTG was produced by Teledyne Energy Systems (TES). The 90 thermoelectric elements are the 3M Company's lead telluride (N leg) and the TES TAGS 85 alloy. This is a change from the Nimbus version of this RTG and partially accounts for the power-out increase. Hot junction design operating temperatures are approximately 516° C. The design incorporates a degaussing loop for magnetic suppression and the series parallel network has been modified to two couples in parallel vice 3 for the Nimbus version. The heat source contains a nominal 645 thermal watts and is a spin-off from the Transit Heat Source design. The thermopile case was sealed by welding. The Pioneer 11 shot to Jupiter was launched in April 1973 with Jupiter encounter (within 27, 000 miles--three times closer than Pioneer 10) occurring in December 1974. The Atlas Centaur launch vehicle was used for both missions. Four SNAP 19 RTG's again provided the sole source of electric power. Following Jupiter encounter, this space probe was reprogrammed for a Saturn flyby which is expected to occur in mid 1979. Both spacecraft continue to transmit data relative to space conditions beyond Jupiter.

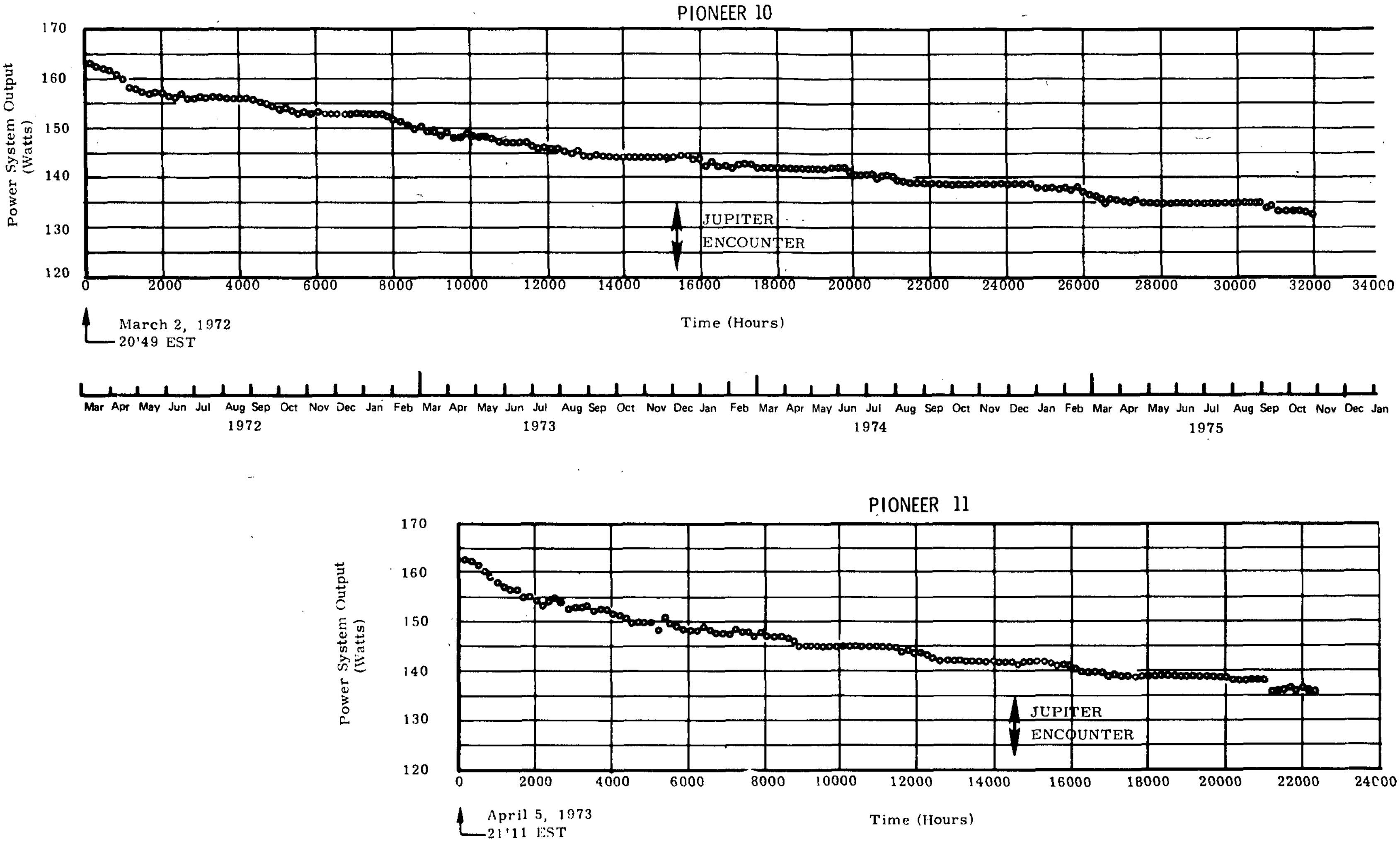


Figure 5. RTG Flight System Performance, Pioneer 10 and 11

These RTG's were designed to provide a minimum of 30 watts each during the nearly two-year journey to Jupiter. All have exceeded that goal and continue to do so. Figure 6, the Viking RTG, is representative of the Pioneer RTG, except for the end dome which is unique to Viking.

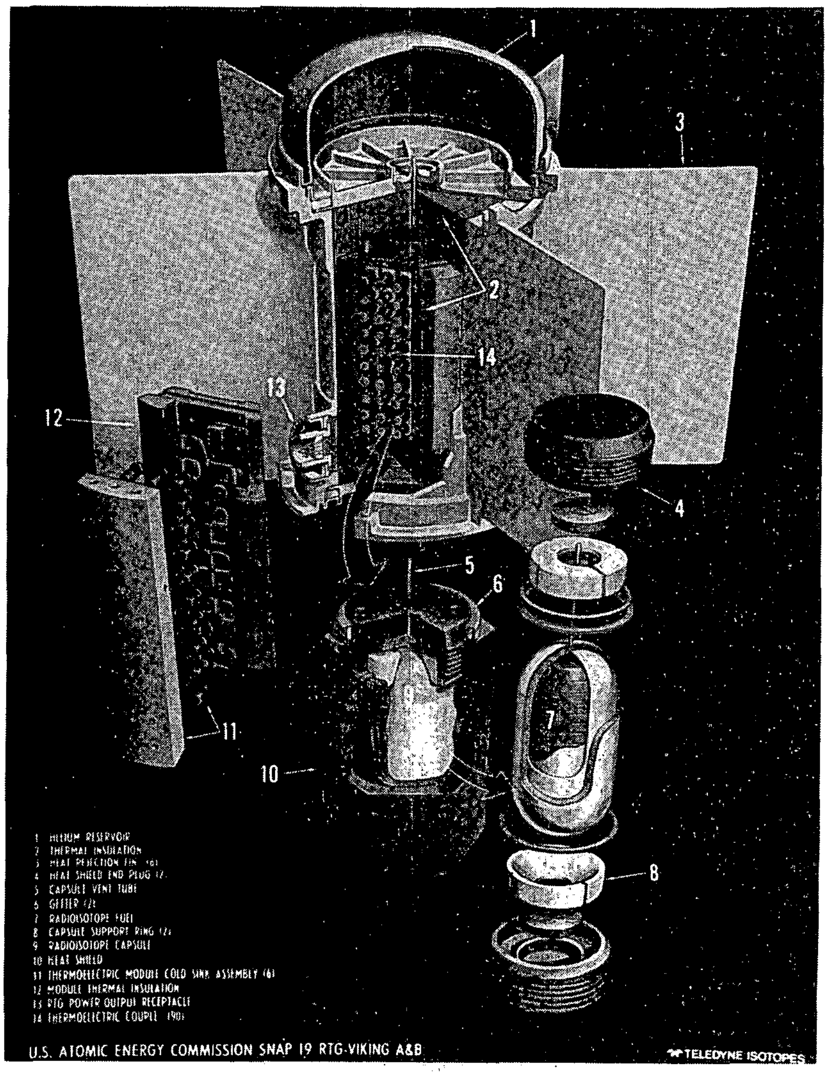


Figure 6. Viking (SNAP 19) RTG

Viking -- Two Viking Spacecraft, each containing two SNAP 19 RTG's, were launched in mid-1975. These craft are now programmed to arrive at the planet Mars on or near July 4, 1976. Each spacecraft contains an "orbiter" and a "lander" (Figure 7) which contains the RTG's. Design requirements for each RTG provide for a life (on Mars) of 90 days, with a minimum power output of 35 watts. Primary mission goals are to obtain data relative to the existence of life on Mars. Additionally, data on the atmospheric composition, wind velocity, ground movements, etc. will be returned.

The Viking SNAP 19 RTG's (Figure 6) are modifications of those used for the Pioneer 10 and 11 missions. The Heat Source fuel loading has been increased to a nominal 675 watts (thermal), the operating temperature of the hot junction has been increased to 579°C and a unique dome reservoir has been added for increased gas management control. To extend life, the RTG's are short-circuited (except for brief periods of enroute monitoring) during the 11-month voyage to Mars. (In the short-circuited condition, the electric current approximately doubles. This current cools (Peltier cooling) the thermocouple hot junction and is used as a means to reduce hot junction sublimation. All flight RTG's are normally stored in the short-circuited condition.)

SNAP 27 -- The SNAP 27 RTG (Figure 8) was designed to provide the sole source of electric power for the NASA Apollo Lunar Surface Experiments Packages (ALSEP). Apollo 11 (July '69) was solar powered; however, Apollo 12 (November '69), 14 (January '71), 15 (July '71), 16 (April '72), and 17 (December '72) were RTG powered. Apollo 13 (April '70), which contained a SNAP 27 RTG, was aborted due to an explosion in the Service Module. The crew used the Lunar Module as a "lifeboat" until just before earth atmosphere reentry.

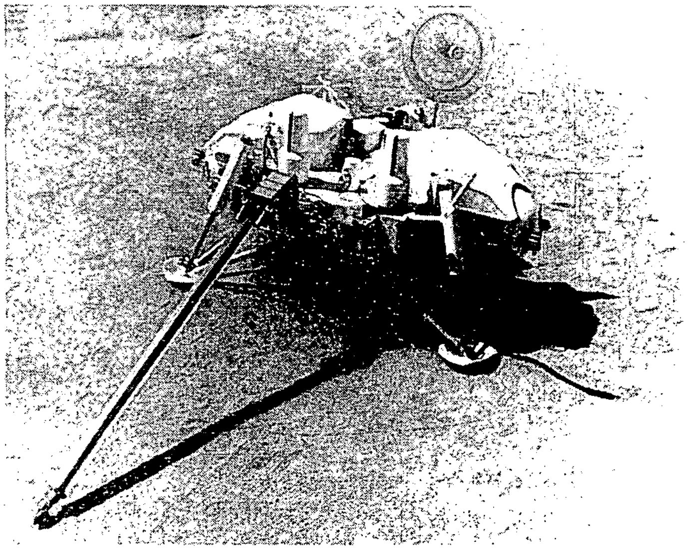


Figure 7. Viking Mars Lander

Figure 8. SNAP 27 RTG on Lunar Surface

The prime contract for the SNAP 27 RTG was held by the General Electric Company, Valley Forge, Pennsylvania, and a major subcontract by the 3M Company (Converter). The SNAP 27 thermoelectric elements, lead telluride, initially operated at a hot junction temperature of 593°C. The thermal insulation was powdered MIN-K and the thermopile was encased in a beryllium outer case. A fill gas (argon) to suppress sublimation was sealed in the converter. The fuel capsule contained a thermal inventory of approximately 1480 watts (1520 for Apollo 17) derived from plutonium dioxide microspheres encased in a super alloy shell. Reentry protection for this capsule was provided by a graphite (Hitco) cask attached to the Lunar Module.

The original design requirements provided for a one-year life at a minimum power output level of 63.5 watts electrical. The SNAP 27 RTG's have far exceeded this design goal. Currently, all five RTG's are still producing power (Figure 9).

Transit -- The purpose of the Transit program was to provide accurate navigational location data. The first Transit satellite utilized the Doppler frequency shift principle, and was launched in April 1960, while the fourth (June '61) used the first RTG (SNAP 3) as a secondary power source. The Transit RTG which had no SNAP designation (Figure 10) was launched aboard the Triad OI-1 spacecraft via the Scout launch vehicle in September 1972.

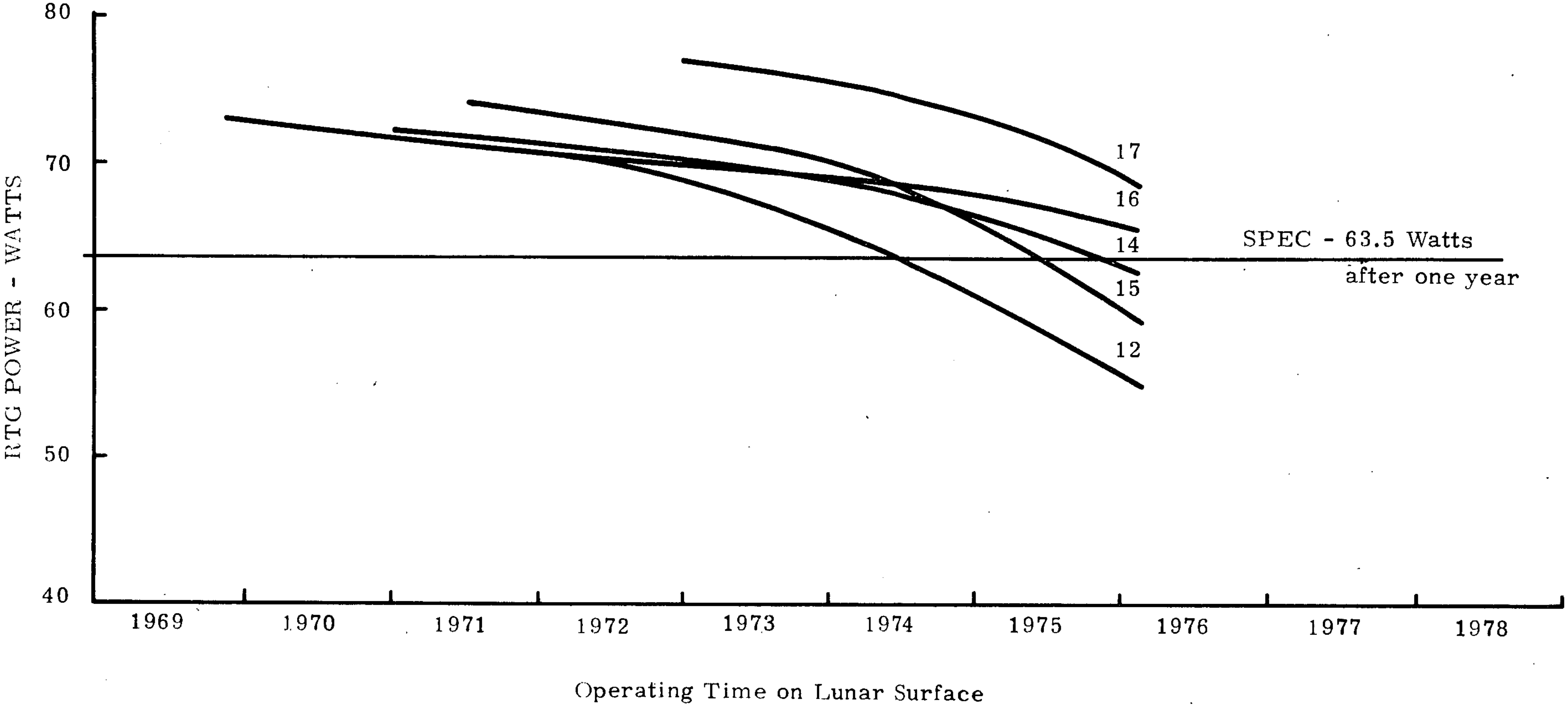


Figure 9. SNAP 27 Lunar Power Performance

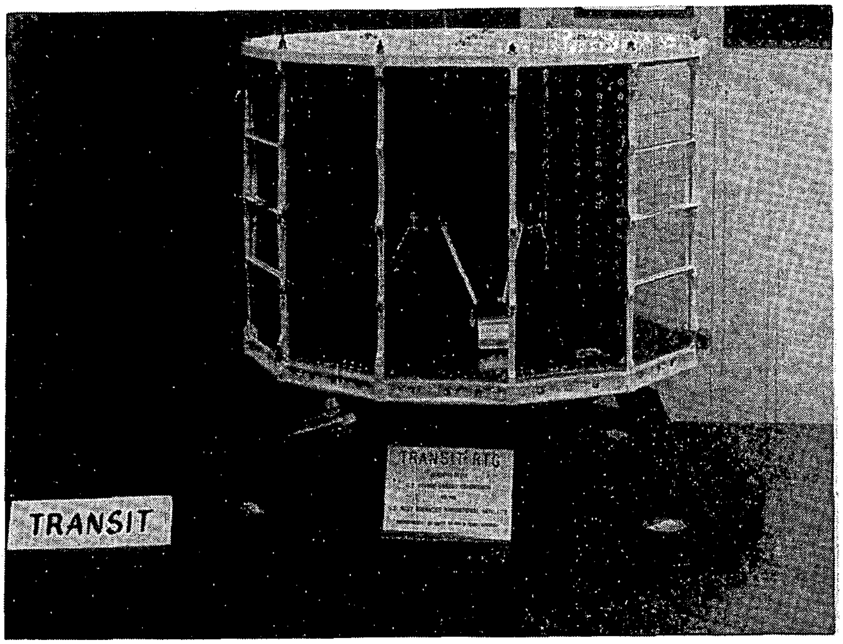


Figure 10. Model of Transit RTG for Navigational Satellite

The Transit RTG (TRW prime contractor/General Atomics major subcontractor) relies on modular construction which is an outgrowth of the Gulf General Atomics Isotec technology. A basic module (or panel) consists of 36 lead telluride (3M Company) couples arranged in a series parallel network and contained in a multi-layer aluminum-aluminum opacified paper (Linde) thermal blanket. Each module is approximately 6 by 14 inches and is structurally reinforced by phenolic honeycomb. Each element is surrounded by moly-opacified paper washers to suppress sublimation and to fill the voids between the elements and the foil insulation system. Thermal emittance and solar absorbency are controlled by the use of 6-mil thick silicon-dioxide mirrors which are attached to the outer surface of each panel. Twelve such panels are used. These are structurally interattached to Mg-Th corner posts and a honeycomb reinforced base. A heat source and removable honeycomb top cover complete the assembly. The Transit heat source utilizes plutonium moly cermet fuel. A molybdenum rhenium liner isolates the fuel and the T111 strength member. Between these two members is a Ta10W liner, while outside is a platinum-rhodium clad. Partially surrounding this clad is a pyrolytic-graphite sleeve to inhibit the influx of heat during reentry. A POCO graphite outer shield serves as the ablator during reentry. Surrounding this assembly is the super alloy (Inconel) metallic case. Attached to this case is a length of capillary tubing which manages the internal atmosphere.

The Transit satellite is no longer operational. Despite loss of spacecraft telemetry after approximately one month in orbit, the program yielded significant RTG performance data before the loss prevented continued performance evaluation. The initial one-month data showed that the RTG was delivering more than 35-watts of power at the expected voltage and current levels and also was reliably satisfying the spacecraft power needs.

Lincoln Experimental Satellites 8 and 9 -- These satellites, designed to provide increased survivability, are experimental communication systems developed by Massachustetts Institute of Technology's Lincoln Laboratory (Figure 11). They have been placed in synchronous earth orbit and are intended to provide communications between each other as well as earth stations. RTG's, rather than solar cells, were chosen because of their spacecraft integration simplicity and because of their ability to survive hostile enironments.

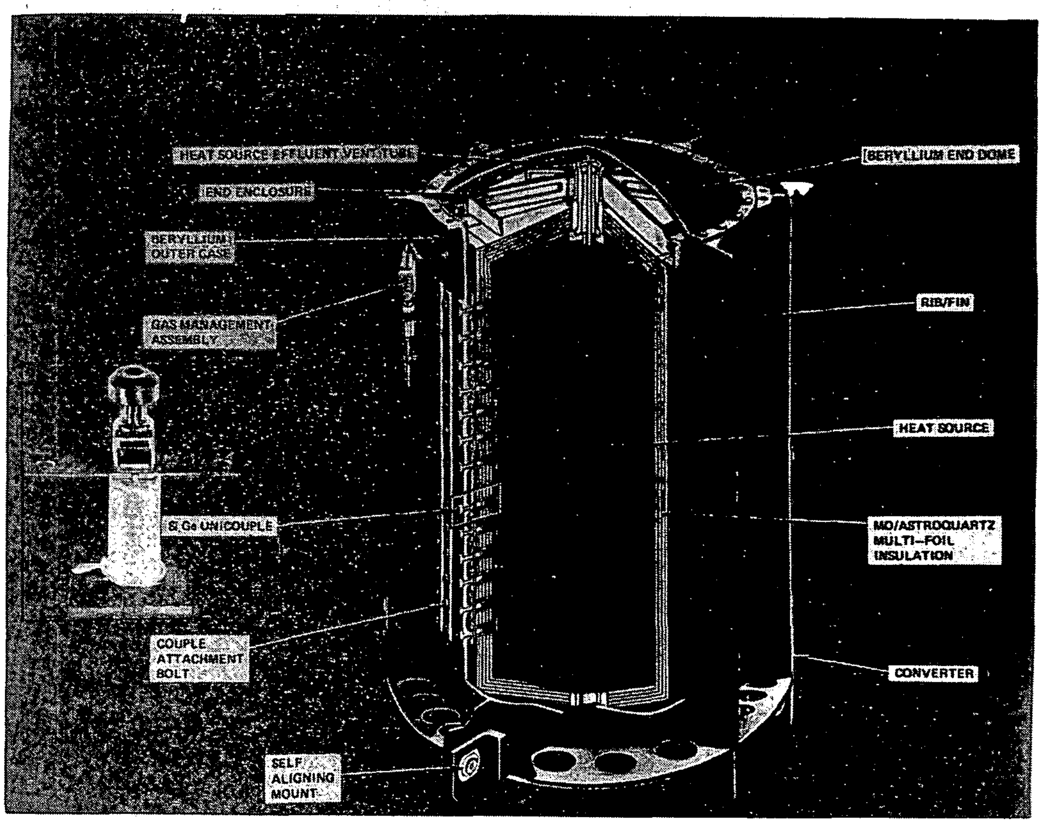


Figure 11. MHW RTG for LES 8/9 Mission

The Multi-Hundred Watt (MHW) RTG (Figure 12) developed by the General Electric Company, utilizes the silicon germanium technology from RCA. The heat source contains 24 spheres of plutonium-dioxide fuel, each with a nominal inventory of 100 watts (thermal). Each sphere is encapsulated in an iridium post impact containment shell which, in turn, is encased in a graphite (Hitco Pyrocarb) impact shell. These spheres are arranged in six planes and are contained in a structural (POCO) graphite cylindrical aeroshell for reentry protection. This assembly is encased in an iridium container which provides for internal heat source gas management as well as protection of the heat source during certain skip types of reentry. An outer graphite (Hitco) ablation cylinder completes the assembly and additionally provides for increased rupture strength, reentry capability, and emissivity. This assembly is unique in that only three basic materials (plutonium-dioxide, iridium, and graphite) are used.

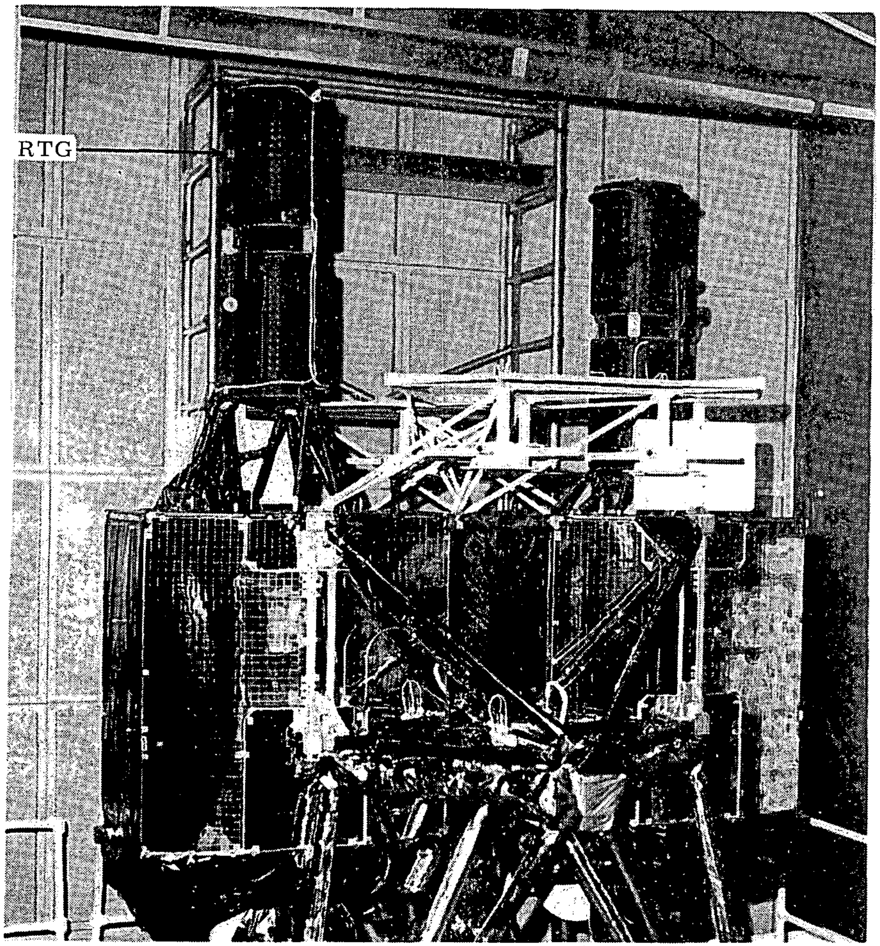


Figure 12. MHW RTG's on LES 8/9 Spacecraft

The basic converter (RCA) consists of 312 silicon-germanium thermocouples (unicouples) with a design hot-junction temperature of 1000° C. These are arranged in a series parallel network for increased reliability and are contained in a multi-layer molybdenum-astroquartz thermal insulation blanket which surrounds the heat source. The electrical network includes a degaussing loop to suppress the internally generated magnetic field. RTG structural integrity, gas management, and heat rejection control is provided by a beryllium outer case.

Maximum power from the RTG is developed with an internal vacuum (space), while earth storage requirements dictate an inert gas atmosphere. Gas management is effected through a valve for maintenance purposes and via an automatic atmospherically-activated puncture device for flight. Design requirements include 145-watt power level after launch, five-year life, and a power level of 125 watts at the end of the five-year period. Four RTG's (two on each satellite) were launched in early March 1976 (Figure 1). Reports show that the available maximum power for each satellite is in excess of 300 watts (electrical). The five-year power level prediction is approximately 130 watts per RTG.

Early prelaunch power requirements for the Lincoln Experimental Satellites were set at 80-watts minimum. In mid-1975 the need for increased power was evident and a request was made by Lincoln Laboratory to change the internal gas atmosphere from Argon to Xenon (low-thermal conductivity) in order to achieve increased power levels. Both the converter argon gas and the heat source helium gas atmospheres were exchanged at Cape Canaveral. Figure 13 shows the resulting power levels. The power increase on February 24-26 is attributed to the installation of air conditioning which lowered the RTG case temperature to a range of 40° to 60°C and thereby slightly increased the thermocouple delta temperature. Power degradation can probably be attributed to the heat source helium generation (high-thermal conductivity) which leaked into the RTG cavity.

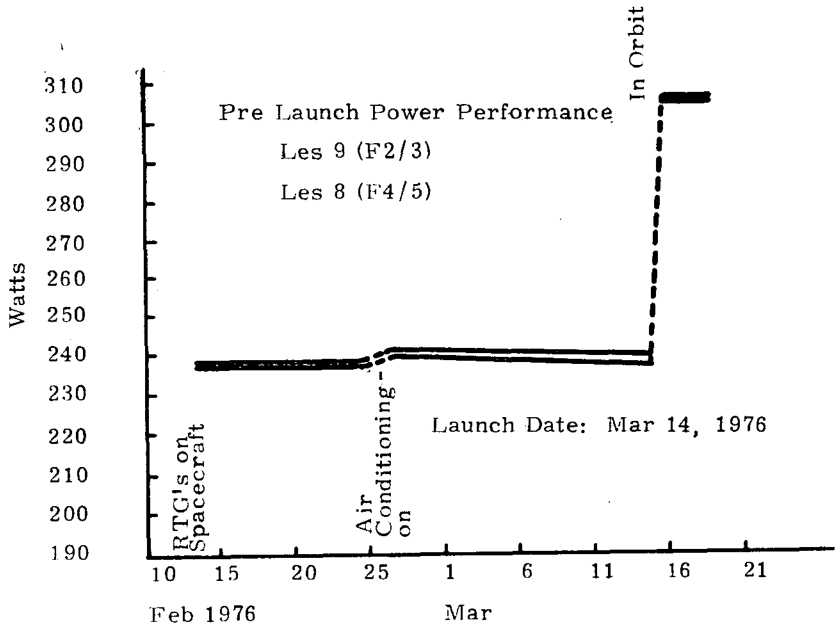


Figure 13. MHW LES 8/9 RTG Power Output

Mariner-Jupiter/Saturn -- This Jet Propulsion Laboratory mission involves two identical spacecraft to be launched in 1977. These craft (Figure 14) will be more sophisticated than Pioneer 10 and 11 and are destined to encounter Jupiter approximately 1-1/2 years after launch, and Saturn some 3-1/2 years after launch. Data are to be returned concerning atmosphere, surface features, physical properties, etc. At this time there is some speculation that the second shot may be delayed for approximately one year and be reprogrammed for a Uranus flyby.

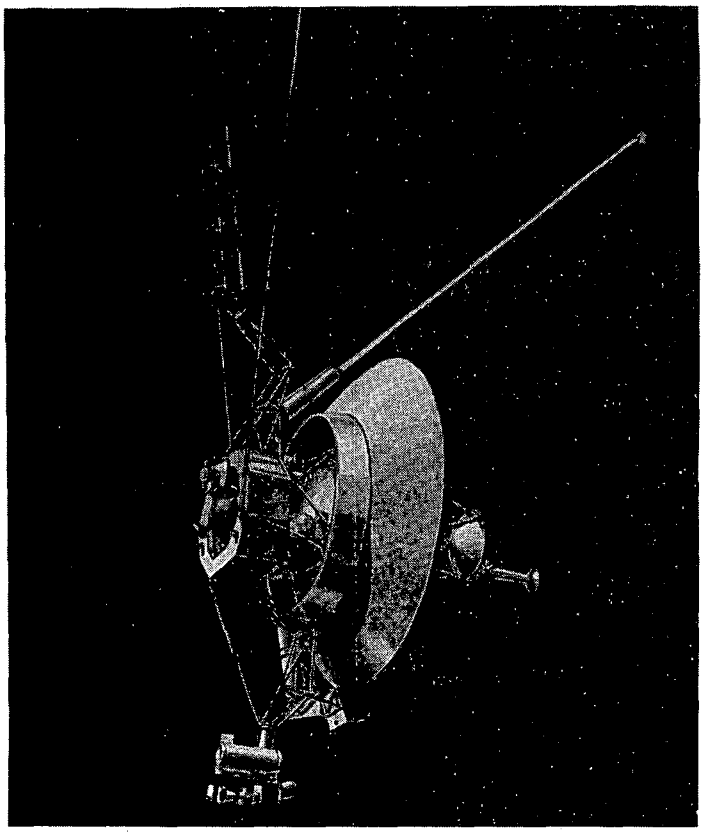


Figure 14. Mariner-Jupiter/Saturn Satellite

The Mariner- Jupiter/Saturn RTG is now in the production and test phase. Changes from the RTG's used on the Lincoln Experimental Satellite include deletion of the Heat Source iridium container and its related gas-management system. Other changes include a stronger Beryllium case, changed gas release puncture device, and a revised case temperature monitoring arrangement.

Design requirements include a four-year life with an initial power of 146 watts (after launch), end of mission power of 128 watts, and 105 watts per RTG for launch pad power.

High-Performance Generator - Mod 3 -- The High-Performance Generator - Mod 3 (HPG-3) program's contractor is Teledyne Energy Systems, Timonium, Maryland. This program provides for one electrically-heated generator and four RTG's to be delivered by the end of 1977. This system, designed for a terrestrial application, uses the Multi-Hundred Watt Isotopic Heat Source. The design envisions 10 thermoelectric modules, each with 28 thermocouples, for a total of 280 couples in a series parallel arrangement, to produce 150 watts after four years with a 13-volt load, nominal, and a 150-pound maximum weight. The design is to parallel closely that of the previous HPG engineering unit, except that the outer case will be aluminum rather than magthorium which was previously used. General Electric is responsible for the Isotopic Heat Source which Monsanto Research Corporation will assemble and ship as GFE to Teledyne.

VII. Outlook

As of mid 1976 two RTG programs were active:

1. Multi-Hundred Watt Mariner-Jupiter/Saturn (MHW)
2. High-Performance Generator Mod 3 (HPG-3)

MHW Status

The hardware processing workload peaked, and RTG assembly, processing, and testing efforts were dominant at mid-year. Flight RTG's are scheduled to be accepted from GE in April, July, August, September, October, and December 1976 (total of seven RTG's). Sandia's field workload will taper off starting in the fall of 1976.

HPG-3 Status

Manufacturing operations are commencing. One fulltime SQAR, starting in May 1976, is expected to handle the field workload. One electrically-heated generator is scheduled for delivery in September 1976, with flight RTG's scheduled for delivery in October 1976 and March, August, and December 1977 (total of four RTG's).

DNRA expects to seek Sandia QA support for several new programs. After MJS and HPG-3 field activities phase out, it appears that QASL's major emphasis for several years will be on quality engineering because the new programs are several years away from the production phase. Expected activities on these new programs include participation in preliminary and final design reviews, reviews and audits of contractor QA and Reliability plans, and eventually the field SQAR monitoring and acceptance functions. It is expected that in the future QASL will concentrate more on quality engineering and assurance functions and less on quality control activities.

New programs include:

Brayton Isotope Power System (BIPS) -- AiResearch is the prime contractor to build a demonstration 0.5 to 2.0 kilowatt nuclear power space system based on the Brayton cycle for missions in the 1980's. (Figure 15).

Kilowatt Isotope Power System (KIPS) -- Sundstrand is the prime contractor to build a demonstration 0.5 to 2.0 kilowatts system using the organic Rankine cycle. In April 1978, either BIPS or KIPS will be selected for flight systems development. (See Figure 16).

Static Outerplanetary RTG system, based on new 3M Company Selenide technology, is to be designed, qualified, and delivered by early 1981 to support a NASA outerplanetary launch scheduled for late 1981.

Unmanned Free-Swimming Submersible (UFFS) -- GE is the prime contractor and Phillips is the converter subcontractor to GE. Details are not yet available.

Navy 1/2-watt RTG -- Possible QASL involvement in the production phase of this program. To date, Sandia has reviewed QA and Reliability plans, and Sandia's Reliability organization has worked with Navy and JPL on test programs. Four contractors have delivered demonstration RTG's which the Navy has on test. Status of next (evaluation) phase of program is unclear.

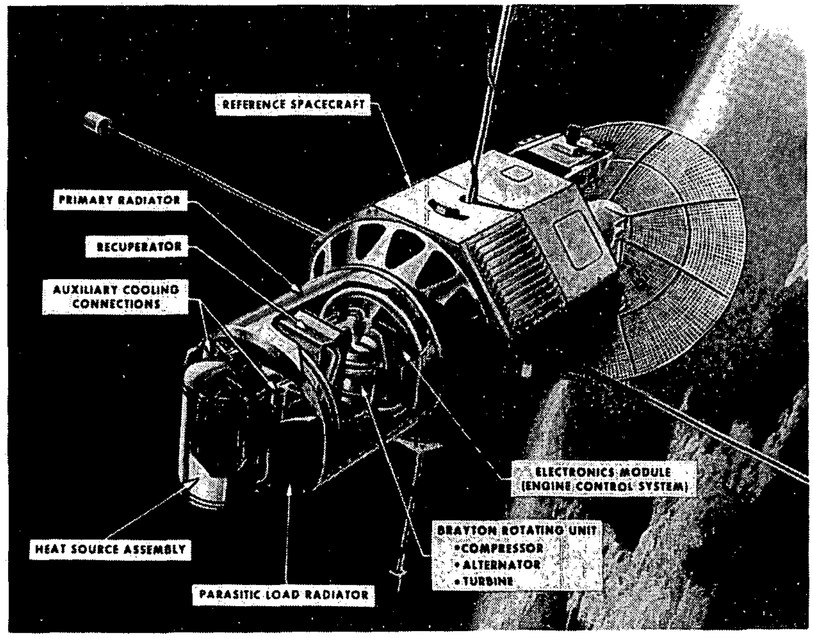


Figure 15. Brayton Isotope Power System

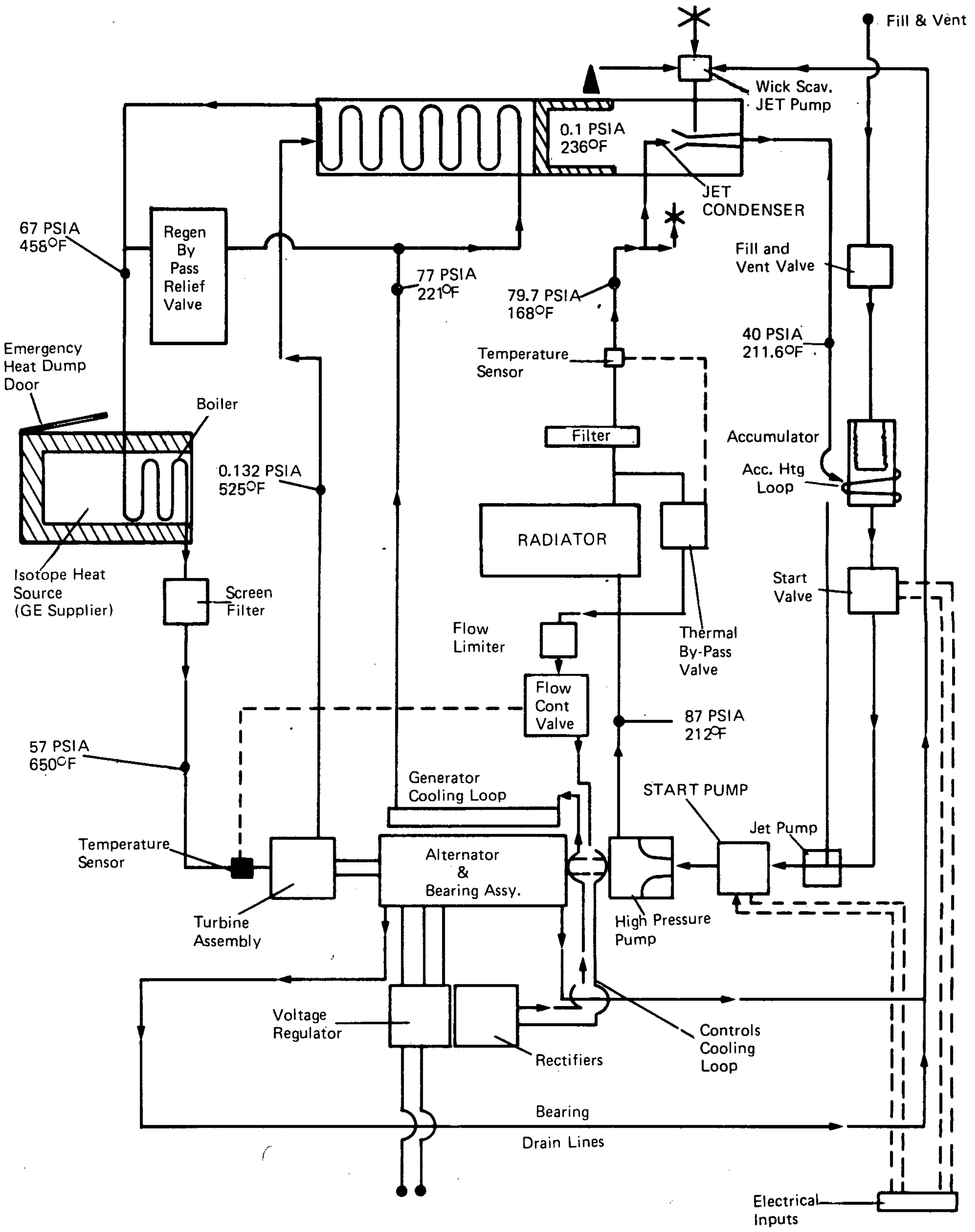


Figure 16. Kilowatt Isotope Power System

VIII. Summation

In reviewing Sandia's 10-year involvement in the RTG QA programs, it is possible to highlight numerous positive accomplishments. As mentioned earlier, Sandia has had the opportunity of working with many different organizations and surely has influenced some of them to do a better quality job. The QASL-SNAP-1 Quality Control Policy for Isotopic Power Systems, dated May 1, 1969, was the first Quality Control Specification issued by Sandia Laboratories. Sandia has enjoyed an excellent interface relationship with the U. S. Energy Research and Development Administration. The Laboratories has provided the U. S. Government with a quality program which has helped assure 100 percent success with RTG's launched thus far. The RTG QA program reimbursable budget has increased 10-fold over this 10-year period. The fascinating nature of these space power programs has been a good growth experience, particularly for SQAR's who often worked long and unusual hours during test operations.

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