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Isotopic Power Supplies for Space and Terrestrial Systems: Quality Assurance by Sandia National Laboratories

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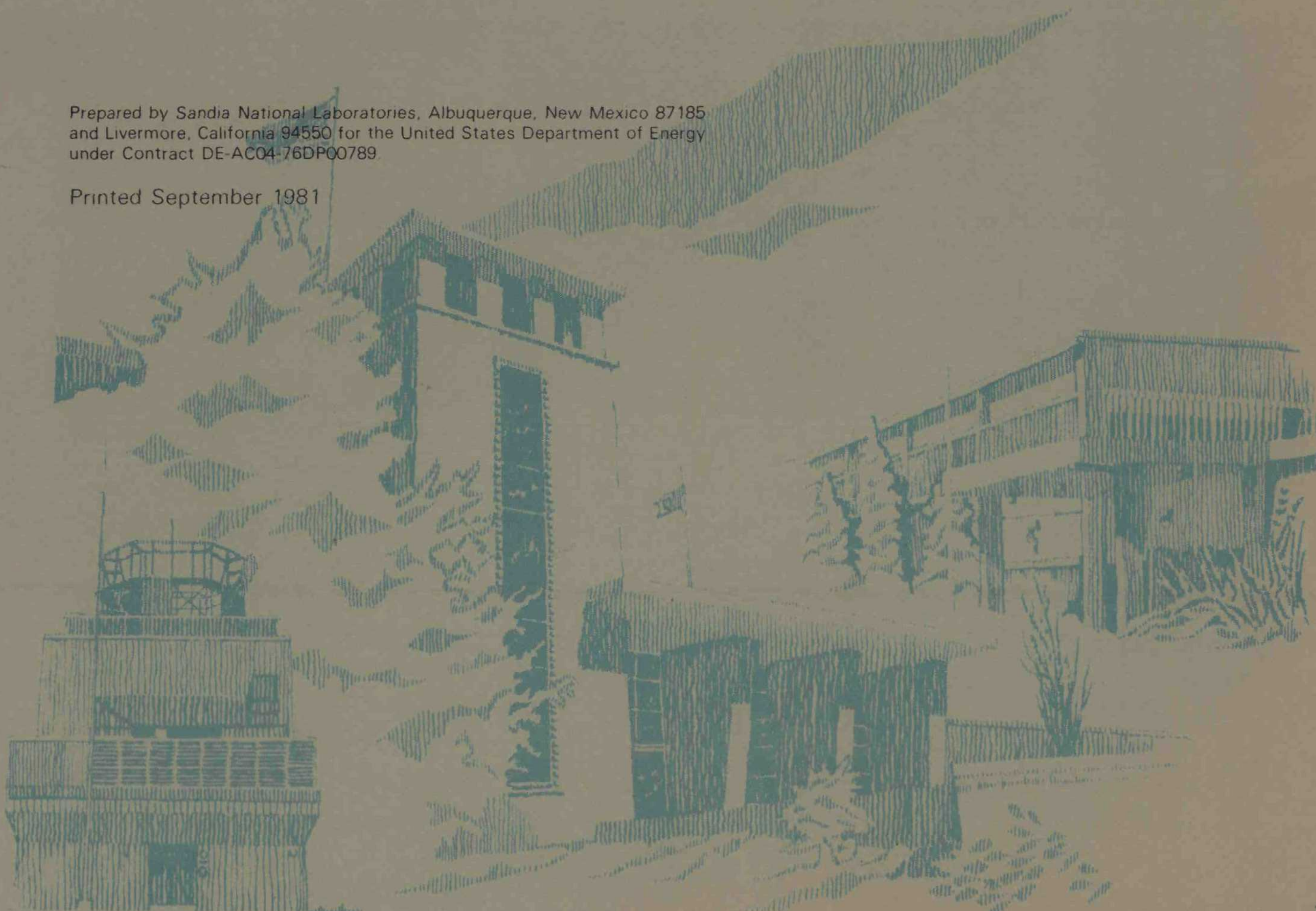

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Isotopic Power Supplies for Space and Terrestrial Systems: Quality Assurance by Sandia National Laboratories

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Abstract

This report summarizes the Sandia National Laboratories participation in Quality Assurance (QA) programs for Radioisotopic Thermoelectric Generators which have been used in space and terrestrial systems over the past 15 years. Basic elements of the 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 also presented. In addition, we note the outlook for Sandia participation in RTG programs for the next several years.

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Abbreviations

AEC	Atomic Energy Commission
ALO	Albuquerque Operations
ALSEP	Apollo Lunar Surface Experiment Package
Ar	Argon
Ast	Astroquartz
AU	Astronomical Unit
BCL	Battelle Columbus Laboratory
BIPS	Brayton Isotope Power System
BOM	Beginning of Mission
CI	Certificate of Inspection
DOE	Department of Energy
DXT	Density Times Thickness
EOM	End of Mission
ESA	European Space Agency
GLL	Galileo Mission
GPHS	General Purpose Heat Source
He	Helium
HPG	High Performance Generator
IH	International Harvester Co.
IHS	Isotope Heat Source
ISPM	International Solar Polar Mission
JPL	Jet Propulsion Laboratory
KIPS	Kilowatt Isotope Power System
LANL	Los Alamos National Laboratory
LES	Lincoln Experimental Satellite
MeV	Million Electron Volts
MHW	Multi-Hundred Watt
MJS	Mariner Jupiter Saturn
Mo	Molybdenum
MRC	Monsanto Research Corporation
mW	Milliwatt
NA	Not Applicable
NASA	National Aeronautics and Space Administration
OCSP	Office of Coordination and Special Projects
ORNL	Oak Ridge National Laboratory
PbSnMnTe	Lead-Tin-Manganese-Telluride
PbSnTe	Lead-Tin-Telluride
PbTe	Lead-Telluride
QA	Quality Assurance
QAIN	Quality Assurance Inspection Notification
QAVI	Quality Assurance Verification Instruction
RTG	Radioisotopic Thermoelectric Generator
SEM	Scanning Electron Microscope
SIG	Selinium Isotope Generator
SiGe	Silicon Germanium
SIPS	Stirling Isotope Power System
SNAP	System for Nuclear Auxiliary Power
SNS	Space Nuclear Systems Division of ERDA
SQAR	Sandia Quality Assurance Representative
TC	Thermocouple
TES	Teledyne Energy Systems
Vac	Vacuum

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Isotopic Power Supplies for Space and Terrestrial Systems — Quality Assurance by Sandia National Laboratories

I. Introduction

The Sandia Quality Assurance (QA) organization has been involved in many programs in addition to those in Sandia's principle area of responsibility--engineering of nuclear weapons. One of the oldest such reimbursable efforts has been the QA responsibility for Radioisotopic Thermoelectric Generators (RTGs) for space systems, and more recently for terrestrial applications. June 1981 marked the completion of 15 years of Sandia QA responsibility in the RTG area. This anniversary, coupled with the recent success of the RTG-powered Voyager missions, has prompted the publication of this updated summary report concerning Sandia's QA role in RTG programs.

II. History

The overall responsibility for RTG programs lies with the U.S. Department of Energy (DOE), Space Systems Office of Coordination and Special Projects (OCSP) formerly the Space Nuclear System 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.

Sandia 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 Sandia QA 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 National 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 participation; both parties subsequently agreed to continue the arrangement.

Since mid-1966, Sandia QA has been continually involved in the RTG programs with Sandia Quality Assurance Representatives (SQARs) resident at major contractors and some subcontractors, except for very short periods when the activity was covered from Albuquerque. To date, programs on which Sandia has performed the QA function for (successively) AEC, ERDA or DOE, 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 Voyager); High Performance Generator-Mod 3; 75 milliwatt RTG; Galileo/Solar Polar mission RTGs; Kilowatt Isotope Power System; Brayton Isotope Power System; Selenium Isotope Generator and Stirling Isotope Power System. In addition, launch site quality support has been provided on SNAP 27, Lincoln Experimental Satellites (LES) 8 and 9, and Voyager launches from Cape Kennedy and Cape Canaveral.

Figure 1 shows a Voyager launch vehicle on the pad at Cape Canaveral. Figure 2 is the LES 8/9 launch on March 14, 1976. Figure 3 is an artist's conception of the coming Galileo mission spacecraft. Note that this sketch shows three MHW RTGs on the spacecraft. A recent change will result in use of two GPHS/RTGs instead.

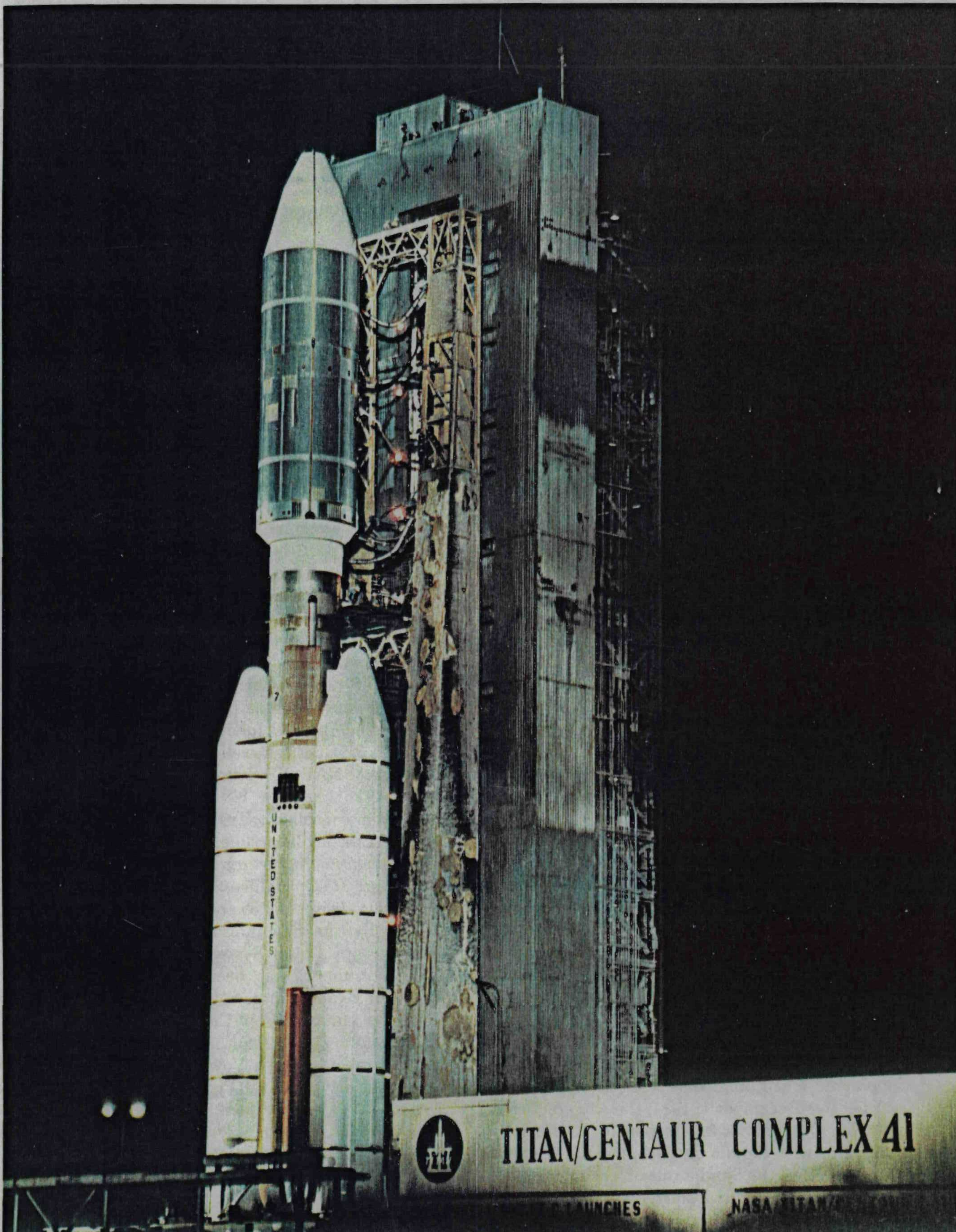

Figure 1. Voyager Launch Vehicle on Pad at Cape Canaveral

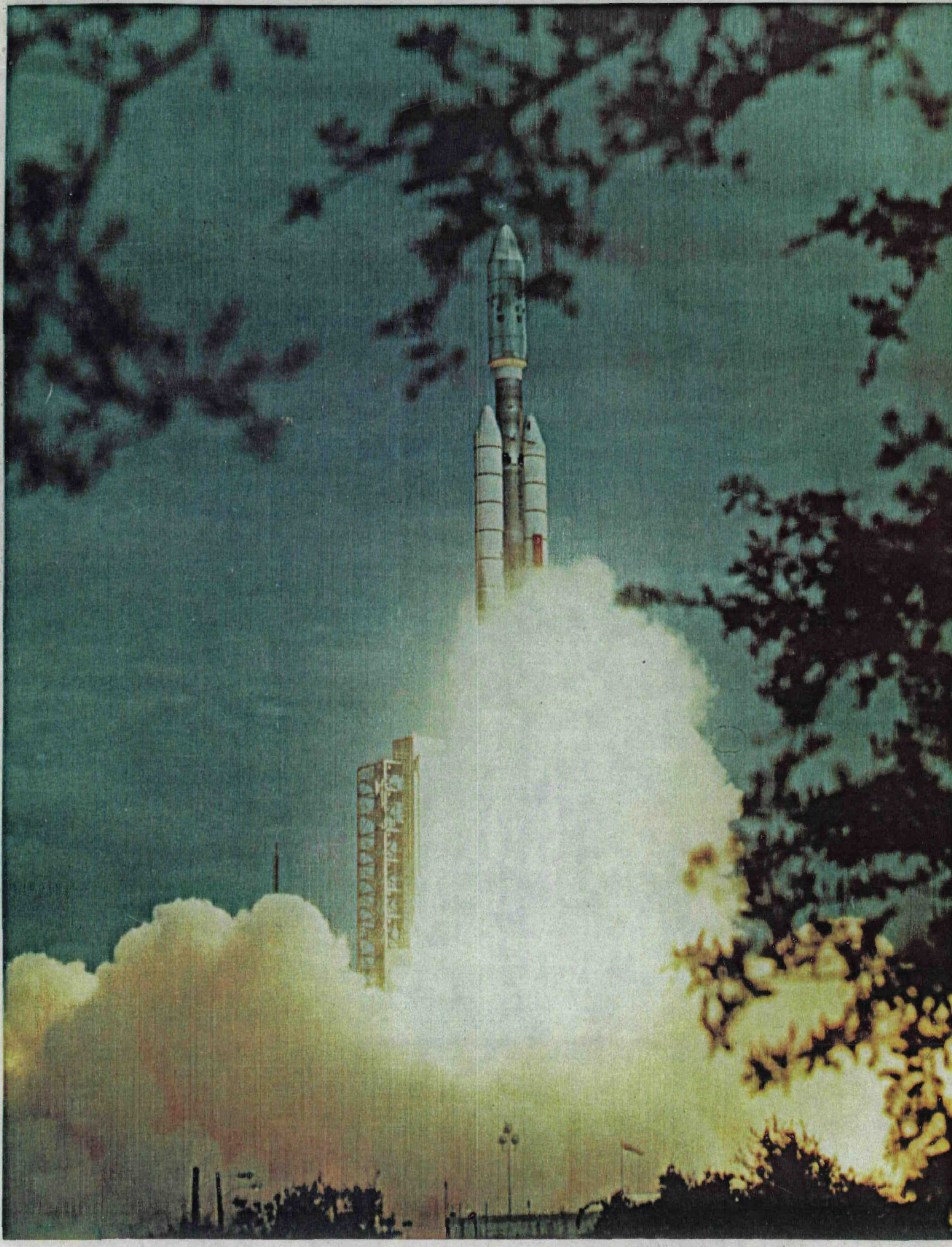

Figure 2. Launch of LES 8/9 Satellite From Cape Canaveral

Figure 3. Galileo Mission Spacecraft

III. Sandia Radioisotopic Thermoelectric Generator Quality Program

Early in each RTG program, Sandia QA reviews the contractor's quality planning to verify compliance with approved system quality requirements, usually as prescribed in NRA-1, "Quality Assurance Program Requirements." 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 SQARs and liaison with DOE/OCSP, contractor, and subcontractors is from the Albuquerque Quality Engineers.

Sandia QA accepts all RTG program material, with the exception of isotopic heat sources, on behalf of the government for subsequent delivery to the final assembly or 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 Sandia Quality Engineers. Acceptance of hardware and/or testing is evidenced by means of Certificates of Inspection (CI), modified from the similar weapons program document. Transfer of accountability is via the standard DD-250 form.

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

Some measure of the extent of the Sandia QA operations may be apparent from the level of effort provided on the LES 8/9 program. SQAR coverage at the General Electric Company, Valley Forge, PA (the prime RTG contractor) 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, the principle subcontractor responsible for the thermopile. During peak workload periods, Quality Engineers from Sandia and personnel from the Sandia Eastern Field Representative group supported the field operations at GE and RCA. Approximately 125 Quality Assurance Inspection Notices and Quality Assurance Verficiation Instructions (QAIN and QAVI) were issued to cover hardware inspection and testing operations. In addition, revisions to QAVIs were necessitated by approved drawing and specification changes. QAINs are formal instructions to the contractor defining the product which is to be submitted. QAVIs are instructions to SQARs on how to inspect and accept the product, including monitoring of assembly and testing operations. Generally, two Quality Engineers were needed to support the field operations.

Approximately 1000 Certificates of Inspection were processed during the Lincoln Experimental Satellite program, representing mostly hardware lots accepted for the government, plus a small number of CIs on processes and testing operations. On this program, approximately 15 percent of the lots submitted 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.

The dollar value of hardware accepted by Sandia for the Lincoln Experimental Satellite mission was quite high. Excluding radioisotopic fuel, the total cost of the contract, including development effort for five flight RTGs, was about $40 million. 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. A comparable level of effort was applied to the Voyager program RTGs and is planned for the current Galileo/Solar Polar activity.

IV. Sandia Resource Involvement

In the past 15 years, Sandia RTG QA effort has increased from an initial FY 67 budget of about $50K to a maximum of just over $600K in FY 78. QA manpower has increased from less than two men per year in FY 67 to a maximum of 8.8 in FY 76. The level of Sandia QA effort on the RTG program has stabilized at about $525K and 4.5 men per year annually.

As part of the Sandia QA program, other disciplines within Sandia have been used and funded from the QA reimbursable budget. Sandia's expertise was applied to the RTG program as follows:

Reliability

a. Review and evaluation
b. Formulation of plans and tests
c. Design review

Operational Analysis

Analysis of the MHW Voyager, Galileo and Solar Polar programs

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 included optical tests, holograph, eddy current, ultrasonic and Beta backscatter (at LANL).

c. Demonstration of DXT technique to determine density gradients in aeroshell end caps for MHW heat sources (Figure 4).

d. Eddy current testing for internal cracks in heat source capsule welds.

e. Development of a phased array ultrasonic technique for determining location and size of internal flaws in the material.

f. Funded an outside contract for developing a non-destructive technique for evaluating welds in stainless steel bellows using a scanning laser acoustic microscope.

Solid State Sciences

Silicon-nitride coating thickness measurement using 1.83 MeV He + ion backscattering analysis. This was very successful and led to correlation and confidence in the SEM technique.

Materials and Processes

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

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

c. Silicon-nitride coating thickness measurement on MHW Unicouples using scanning electron microscope. This measurement was very successful, and RCA subsequently used the SEM technique (destructive) to measure thickness on production samples and to calibrate a nondestructive spectroscopy technique (Figure 5).

d. Contamination surveys at RCA, GE, AiResearch and Sundstrand. Recommendations were made 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

Pertinent documentation provided to contractors including Clean Practices Guide, Ultrasonic Cleaning Procedures, graphite specifications and data, etc.

In additional 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. Figure 6 shows a sled-impact test on the MHW Isotopic Heat Sources conducted in Area III at Sandia National Laboratories.

V. Involvement With Other Organizations

One of the most gratifying and interesting aspects of the RTG QA assignment has been the large number of organizations with which Sandia interfaces in accomplishing the QA function. 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. Table 1 identifies the major interfacing contractors, subcontractors, support and using agencies.

Figure 4. Density Gradient Measurement in Graphite

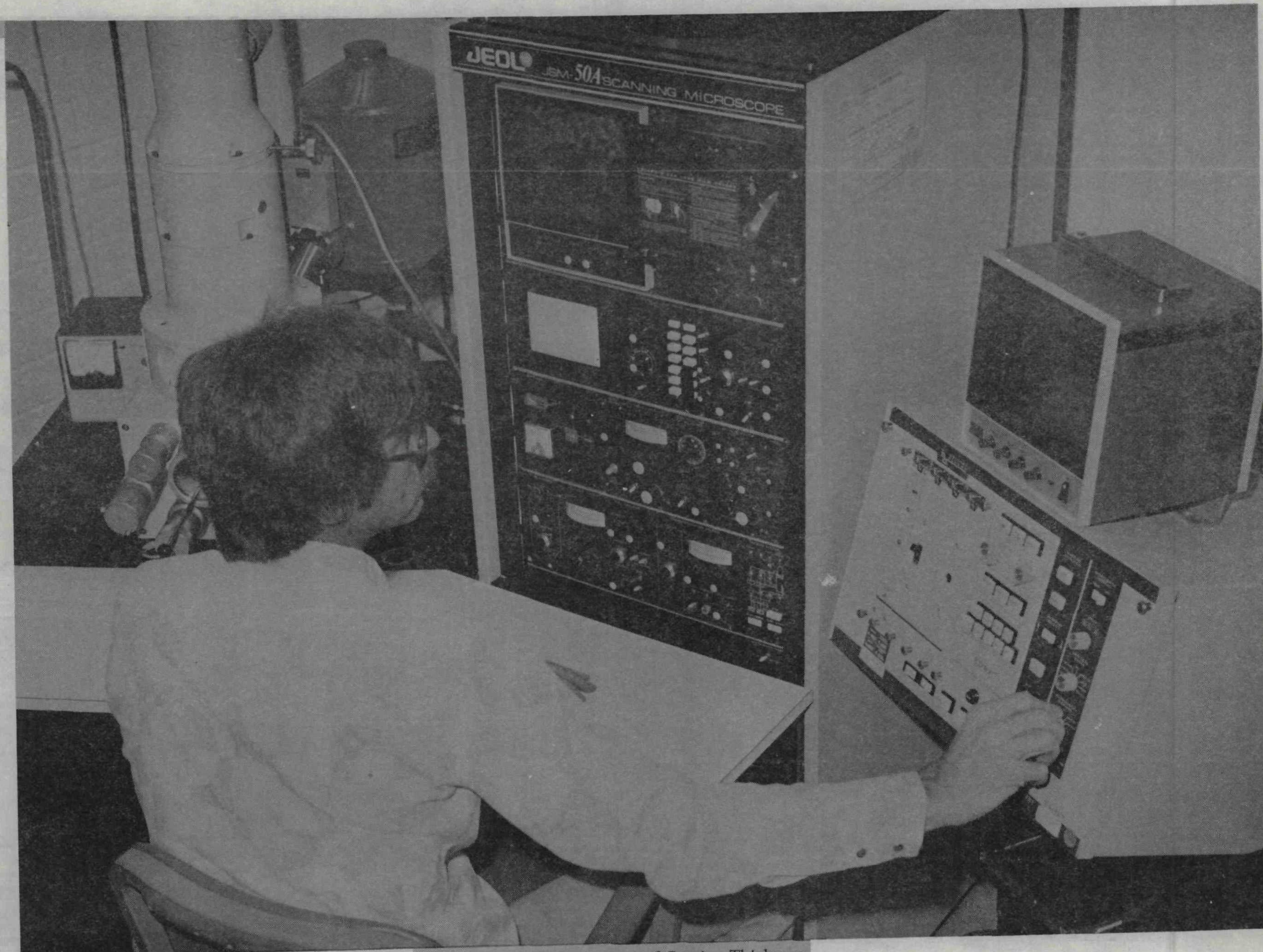

Figure 5. SEM Measurement of Coating Thickness

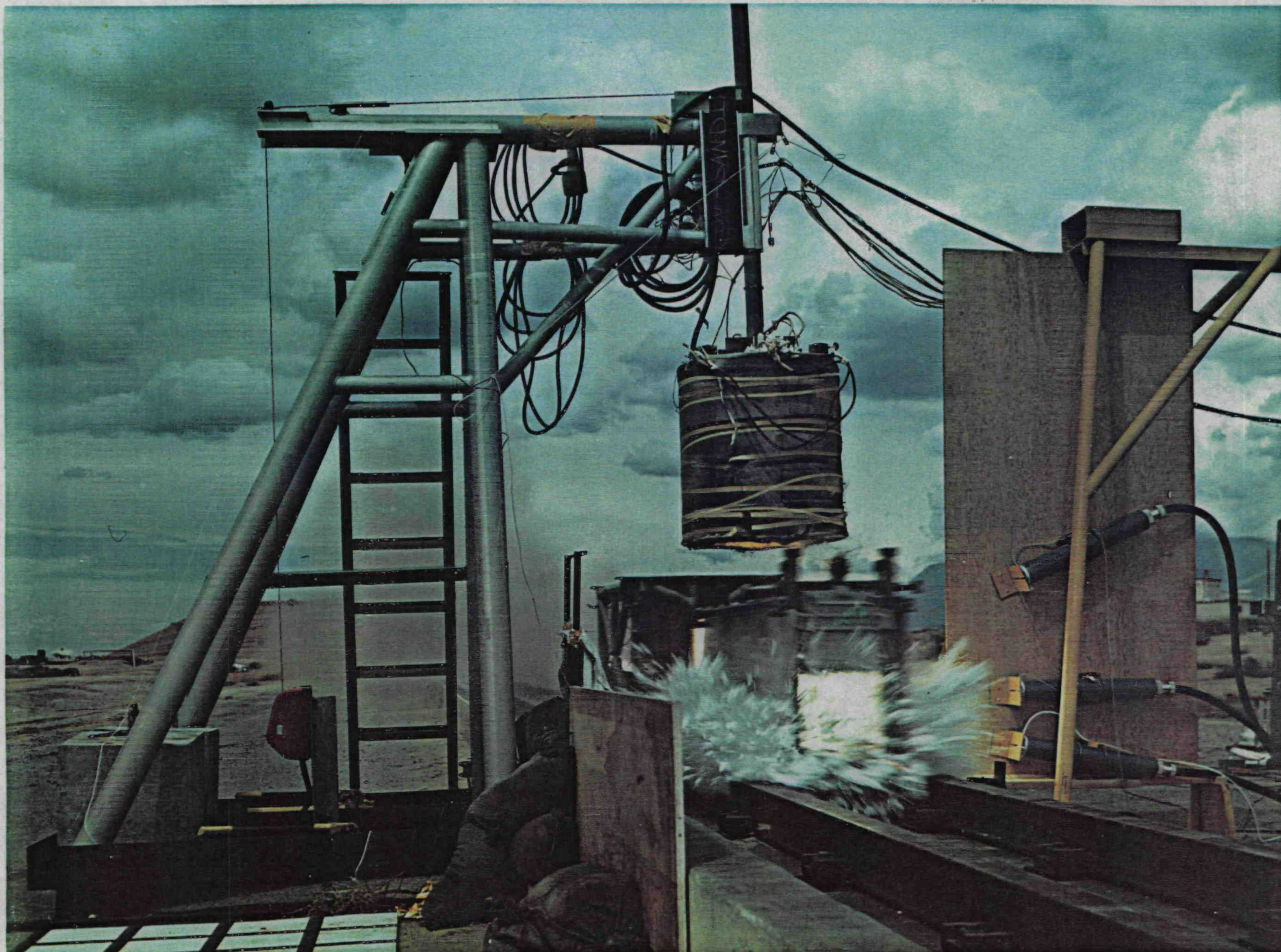

Figure 6. MHW Program Isotopic Heat Source Impact Test

Table 1. Major Contacts With Prime Contractors, Major Subcontractors, Support and Using Agencies

Programs	Prime Contractors	Subs. Support	Using Agencies
SNAP 19 Nimbus	Martin-Marietta	3M Co. GE	NASA-AMES
SNAP 27	General Electric	3M Solar Div. of IH Co. GE, Vallecitos NASA, Cape Kennedy	NASA, Johnson Space Center
Transit	TRW, Inc.	General Atomics Edler Mfg.	John's Hopkins Applied Physics Lab.
SNAP 19 Pioneer & Viking	Teledyne Energy Systems	3M Co.	NASA-AMES JPL
MHW – LES 8/9 Voyager	General Electic	RCA Speedring, Inc. Hitco GE, Evendale Cape Canaveral Oak Ridge National Labs Pressure Science Inc. Englehard	Lincoln Labs, MIT JPL
HPG-3	Teledyne Energy Systems	3M Co. GE	U.S. Navy
75mW	General Atomic	MRC LANL	U.S. Air Force
BIPS	AiResearch	Battelle Columbus Lab ORNL GE	None
KIPS	Sundstrand	BCL ORNL TES GE Solar	None
SIG	Teledyne Energy Systems 3M Co.	GE BCL ORNL	JPL
SIPS	General Electric	Phillips Labs	U.S. Navy
Isotopic Heat Source	MRC	GE TES LANL ORNL	
GPHS	General Electric	Speedring/Schiller Ind. Inc.	JPL
	MRC	Oak Ridge National Labs Savannah River	ESA

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 forties 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. RTGs to date have used a variety of semiconductor materials, including lead telluride, bismuth 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 fifties, with the obvious requirement for high reliability, light weight, and long life, forced a marriage between this power conversion principle and radioisotopic fuel. The emerging converter is appropriately called the Radioisotopic Thermoelectric Generator (RTG). The original QA effort was directed toward RTGs that were destined for space use. More recently radioisotopic heaters and terrestrial application RTGs have also entered the picture. The various RTGs for which Sandia had (or has) responsibility are described in the following sections. Table 2 provides a summary of selected design and performance characteristics.

SNAP 19 RTG

Nimbus III

In early 1968, two SNAP* 19 RTGs (Martin-Marietta Company) were launched to supplement solar power on the Nimbus B 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. Sandia (not QA) played a major role in the recovery of this capsule.

In April 1969, two more SNAP 19 RTGs were launched aboard a Nimbus III satellite. Initial power from these RTGs was approximately 28 watts each. These RTGs used 90 lead telluride (3M Company) thermocoules 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 RTGs 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.

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*System for Nuclear Auxilliary Power (SNAP) was an acronym applied to early devices. Heat for these devices was obtained from either small nuclear reactors (even numbered SNAPs) or from the decay of radioisotopes (odd numbers). With demonstrated reliability, RTGs were selected as the sole or main source of spacecraft power.

Table 2. RTG Design Description and Nominal Performance Characteristics

	SNAP 19 NIMBUS	SNAP 27 Apollo 12-16	SNAP 27 Apollo 17	Transit	SNAP 19 Pioneer	SNAP 19 Viking	MHW LES 8/9	MHW Voyager	HPG-3	75 mW	GPHS GLL	GPHS ISPM
Life (Yr)	2	1	2	5	2	90 days	5	4	4	15	4.2	4.7
Deployed Date	1968-69	1969-72	1972	1972	1972-73	1975	1976	1977	1977	1978	TBD	TBD
Pre Launch Pwr (W)	NA	NA	NA	NA	NA	NA	120 typ	105	NA	NA	220	220
BOM Pwr (W)	28	72 typ	75	35.6	40	41 to 47	150 typ	160	180	0.100	285	285
EOM Pwr Req (W)	15 (act)	63.5	63.5	30	30	35	125	128	150	0.075	255	250
Heat In (W)	630	1480	1520	850	645	675	2400	2400	2440	4.5	4405	4440
Efficiency (%)	4.4	4.9	4.9	4.2	6.2	6.5	6.3	6.7	7.4	2	TBD	TBD
Load Voltage	4.2	16	16	5.7	4.2	4.4	26.5	30	13	6	30	28
Thermocouples	90	442	442	432	90	90	312	312	280	200	576	576
TC's in Parallel	2	2	2	4	2	2	2	2	2	None	2+2	2+2
P Element	PbSnTe	PbSnTe	PbSnTe	PBSnMnTe	TAGS 85	TAGS 85	SiGe	SiGe	TAGS 85	BiTe	SiGe	SiGe
N Element	PbTe	PbTe	PbTe	PbTe	PbTe	PbTe	SiGe	SiGe	PbTe	BiTe	SiGe	SiGe
Hot Junc Temp (°C)	538	593	593	400	516	580	1000	1000	482	210	1000	1000
Cold/Fin Root (°C)	166	274	274	137	166	166	270	270	38	40	270	270
Fill Gas (Oper)	Ar	Ar	Ar	Vac	Ar	3He/1Ar	Vac	Vac	He/Ar	Xenon	Vac	Vac
Fill Gas (Gnd)	Ar	Ar	Ar	NA	Ar	3He/1Ar	Ar or Xe	Ar or Xe	He/Ar	Xenon	Ar or Xe	Ar or Xe
Case Seal	Vitron	Braze	Braze	NA	Weld	Weld	C-Seal Bolted	C-Seal Bolted	Weld	Weld	C-Seal	C-Seal
Dimensions (HtxDia)	11 x 19	18 x 16	18 x 16	18 x 25	11 x 19	18½ x 22	23 x 15.7	23 x 15.7	36 x 36	5.2 x 1.8	45 x 18	45 x 18
Weight (Lb)	25	43½ typ	44	30	29.5	32.5	84	84	450 Max	1.3	119	119
Insulation	Min K	Powder Min K	Powder Min K	A1/Al Op	Solid Min K	Solid Min K	Mo/Ast	Mo/Ast	Solid Min K	Kapton Coated Al foils	Mo/Ast	Mo/Ast
Number Deployed	4	4	1	1	8	8	4	6	4	4	2 (planned)	2 (planned)

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 RTGs. The Pioneer 10 mission to Jupiter was launched in March 1972 with four SNAP 19 RTGs providing the sole source of power. Successful Jupiter encounter occurred 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. In July 1981 the probe was at a distance of 25 A.U. from the sun. Figure 7 shows the performance of the RTGs on Pioneer 10 and 11.

The SNAP 19 Pioneer RTG was produced by Teledyne Energy Systems (TES). The 90 thermoelectric elements are the 3 M 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 the 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 RTGs again provided the sole source of electric power. Following the Jupiter encounter, this space probe was reprogrammed for a Saturn flyby which occurred in mid-1979.

The RTGs 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. The Viking RTG (Figure 8) is representative of the Pioneer RTG, except for the end dome which is unique to Viking.

Viking

Two Viking Spacecraft, each containing two SNAP 19 RTGs were launched in mid-1975. These craft arrived at the planet Mars in July 1976. Each spacecraft contained an "orbiter" and a "lander" (Figure 9) which in turn contained the RTGs. Design requirements for each RTG provided for a life (on Mars) of 90 days, with a minimum power output of 35 watts. Primary mission goals were to obtain data relative to the existence of life on Mars. Additionally, data on the atmospheric composition, wind velocity, ground movements, etc. were obtained.

The Viking SNAP 19 RTGs are modifications of those used for the Pioneer 10 and 11 missions. The Heat Source fuel loading was increased to a nominal 675 watts (thermal), the operating temperature of the hot junction was increased to 579°C and a unique dome reservoir was added for increased gas management control. To extend life, the RTGs were 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 the thermocouple hot junction and is used as a means to reduce hot junction sublimation. All flight RTGs are normally stored in the short-circuited condition.)

SNAP 27 RTG

Apollo

The SNAP 27 RTG (Figure 10) 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), Apollo 14 (January '71), Apollo 15 (July '71), Apollo 16 (April '72), and Apollo 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 prior to earth atmosphere reentry.

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 electrical watts. The SNAP 27 RTGs far exceeded this design goal. In September 1977 routine data transmissions and data processing were purposely terminated by NASA. Random monitoring continued. As late as July 1980, two Apollo Stations (14 and 16) were still operating.

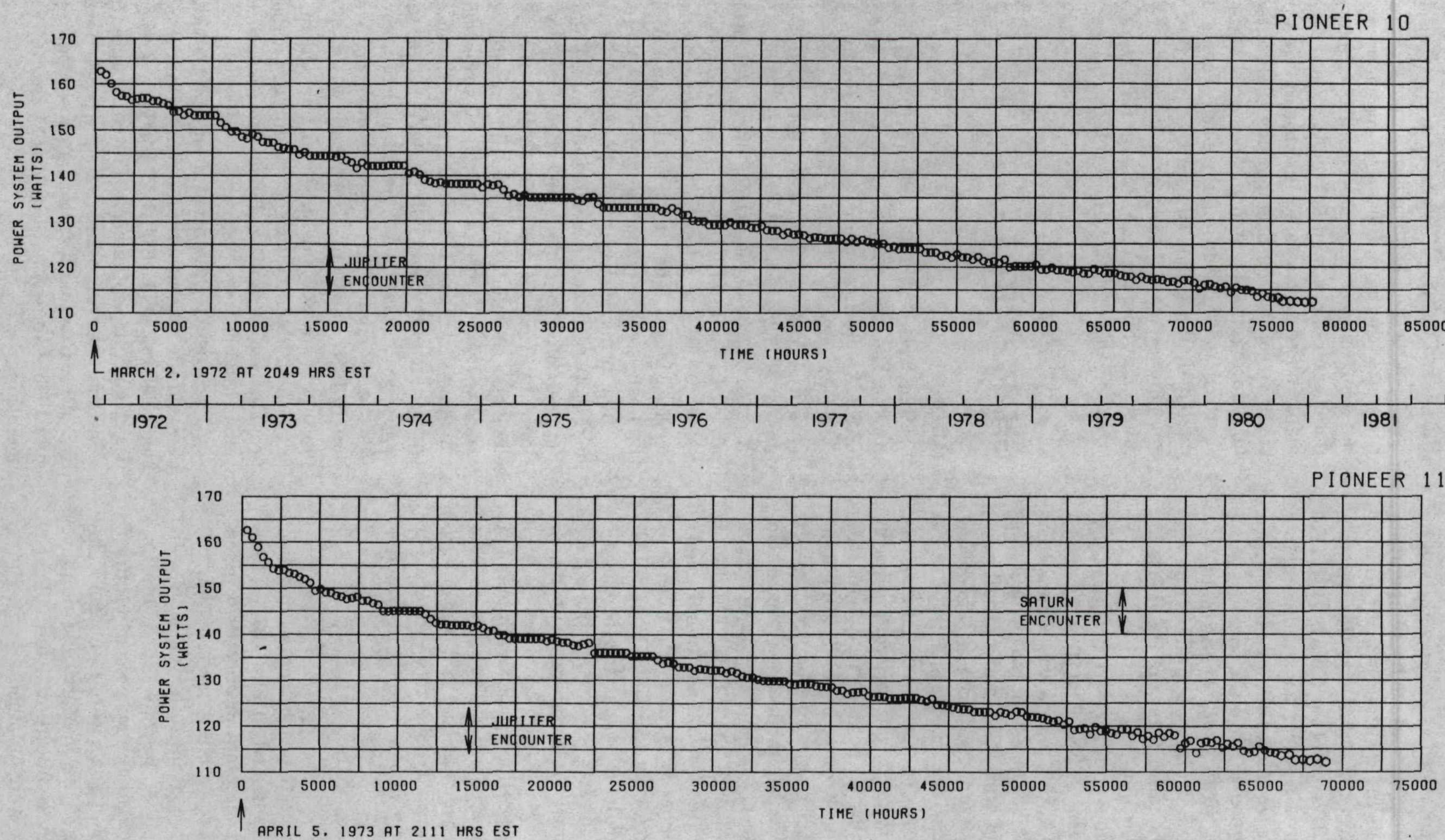

Figure 7. RTG Flight System Performance, Pioneer 10 and 11

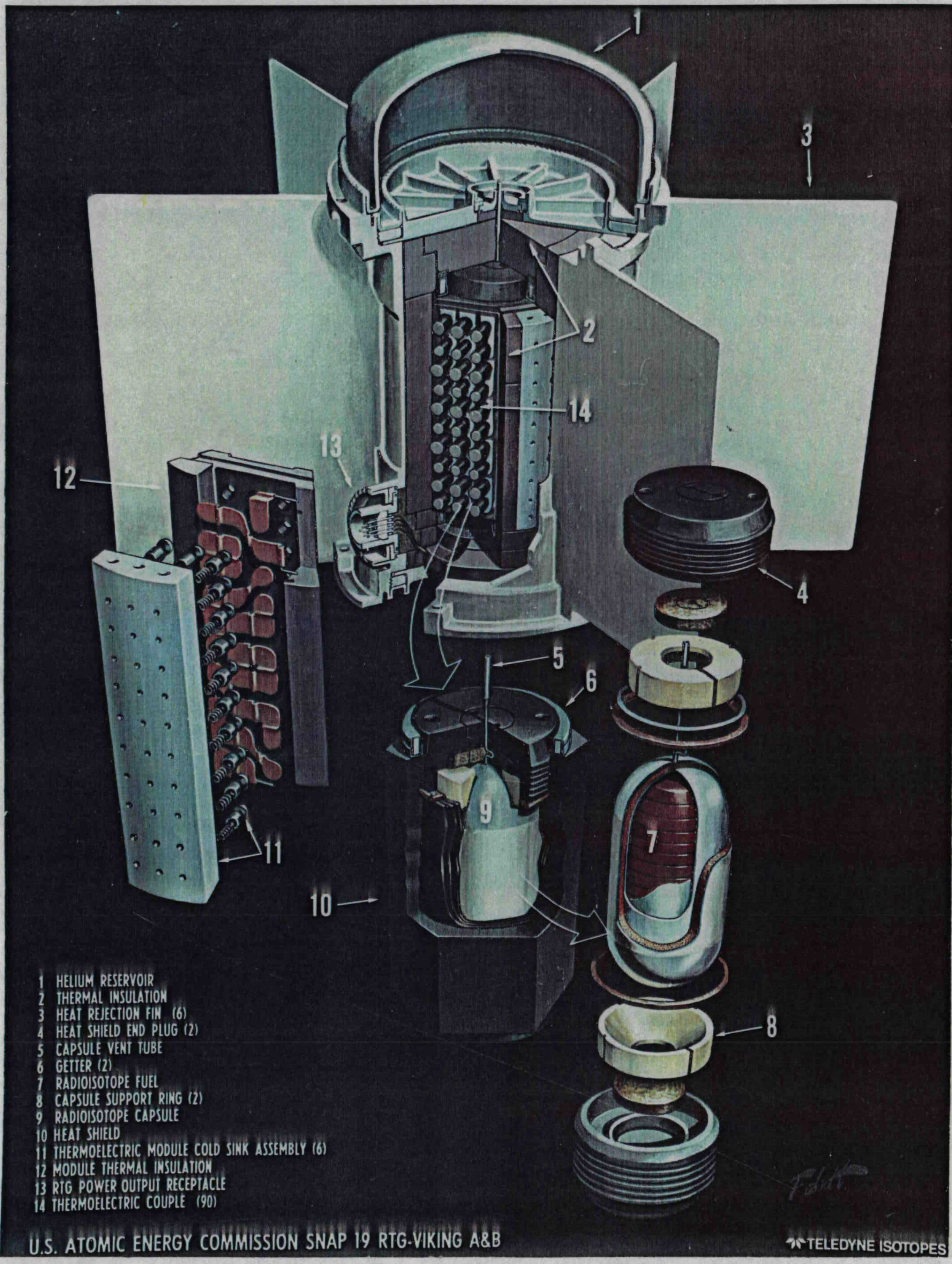

Figure 8. Viking (SNAP 19) RTG

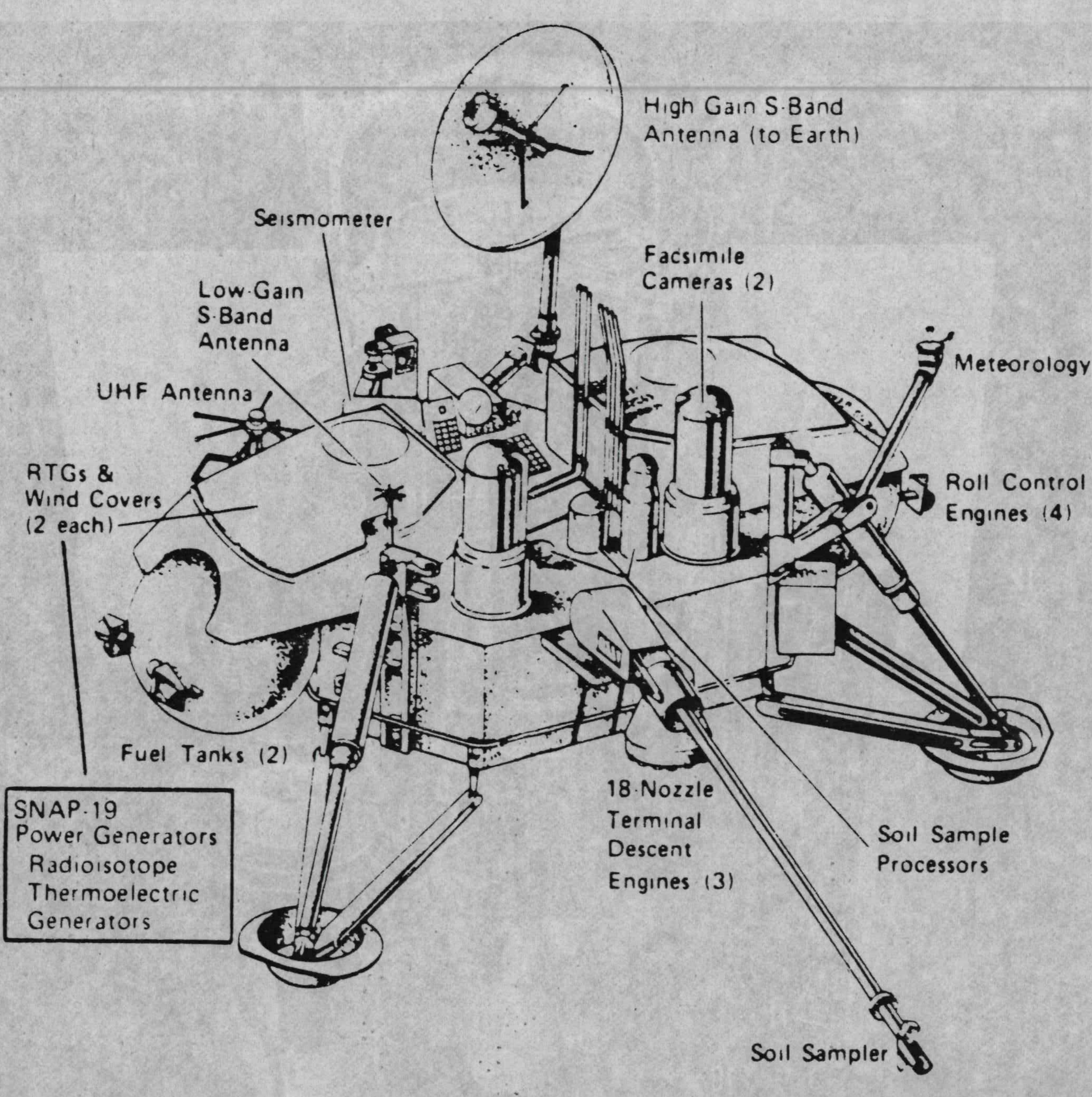

Figure 9. Viking Mars Lander

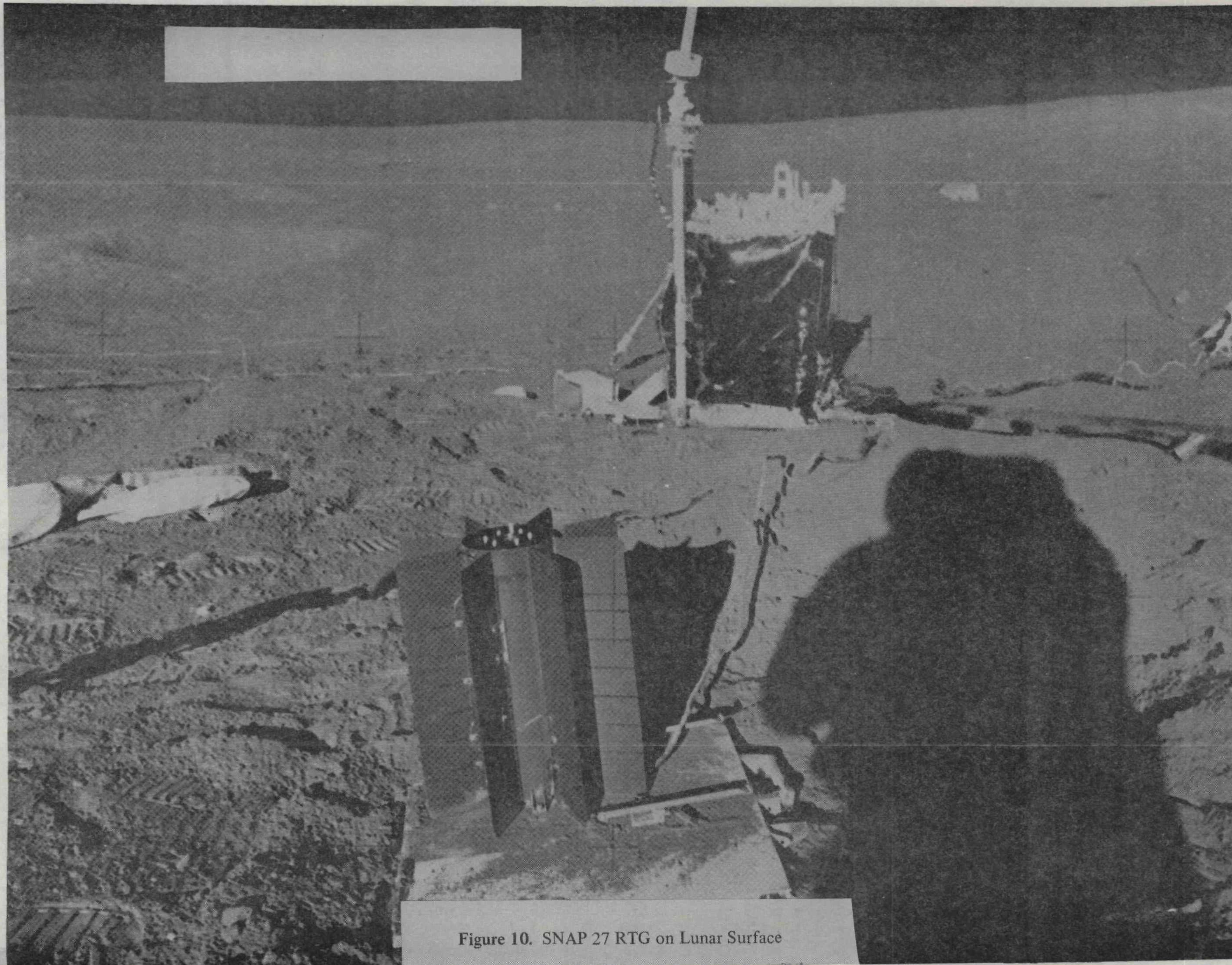

Figure 10. SNAP 27 RTG on Lunar Surface

Transit RTG

Transit Mission

The purpose of the Transit program was to provide accurate navigational location data. The first Transit satellite used 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 (Figure 11) which had no SNAP designation was launched aboard the Triad OI-1 spacecraft via the Scout launch vehicle in September 1972.

The Transit RTG (TRW prime contractor/General Atomics major subcontractor) was most unique. It relied on modular construction which was an outgrowth of the Gulf General Atomics Isotec technology. A basic module (or panel) consisted of 36 lead telluride (3M Company) couples arranged in a series parallel network and were contained in a multilayer 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 were controlled by the use of 6-mil thick silicon-dioxide mirrors which were attached to the outer surface of each panel. Twelve such panels were used. These were structurally interattached to Mg-Th corner posts and a honeycomb reinforced base. A heat source and removable honeycomb top cover completed the assembly. The Transit heat source used plutonium moly cermet fuel. A molybdenum rhenium liner isolated the fuel and the T111 strength member. Between these two members was a Ta10W liner, while outside was a platinum-rhodium clad. Partially surrounding this clad was a pyrolytic-graphite sleeve to inhibit the influx of heat during reentry. A POCO graphite outer shield served as the ablator during reentry. Surrounding this assembly was the super alloy (Inconel) metallic case. Attached to this case was a length of capillary tubing which managed the internal atmosphere.

The Transit satellite is no longer operational. Spacecraft telemetry was lost after approximately one month in orbit. The program yielded significant RTG performance data before the loss prevented any further 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 spacecraft power needs.

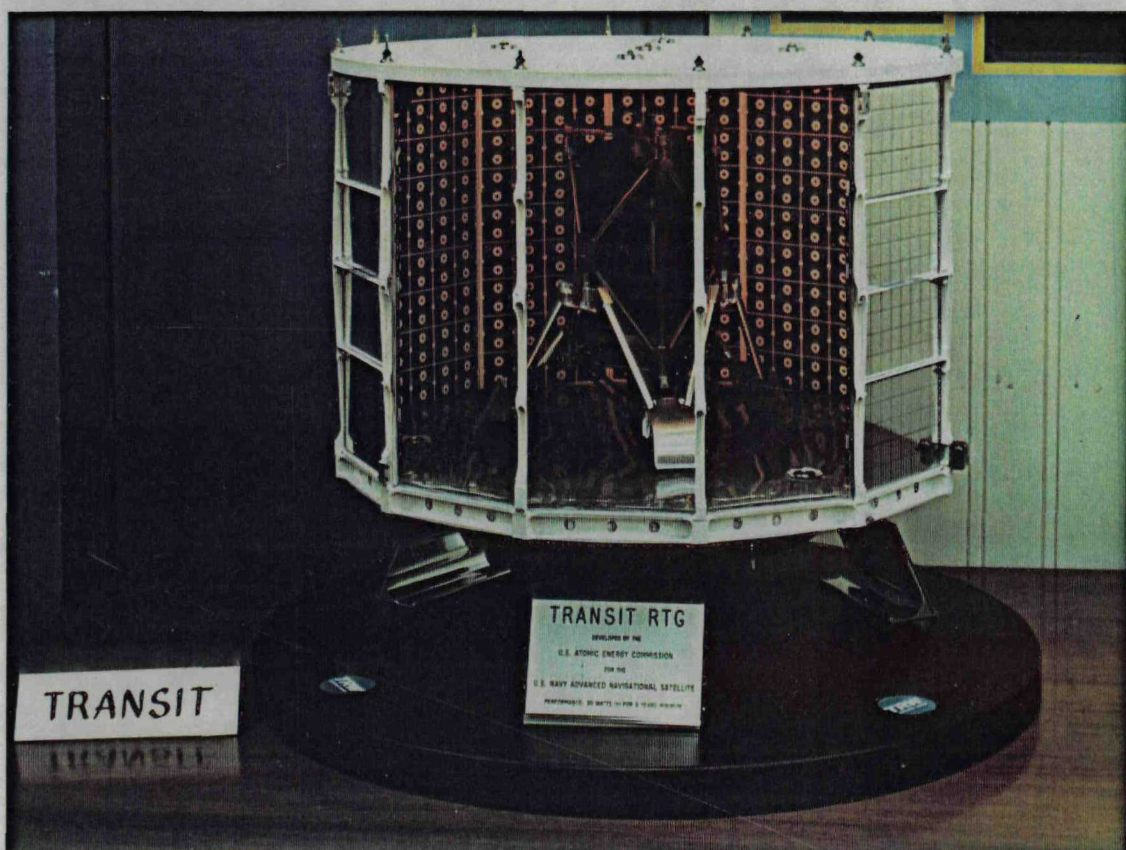

Figure 11. Model of Transit RTG for Navigational Satellite

Multi-Hundred Watt RTG

Lincoln Experimental Satellites 8 and 9

These satellites (Figure 12), designed to provide increased survivability, are experimental communication systems developed by Massachusetts Institute of Technology's Lincoln Laboratory. They have been placed in synchronous earth orbit and are intended to provide communication with each other as well as earth stations. RTGs, rather than solar cells, were chosen because of their spacecraft integration simplicity and because of their ability to survive hostile environments.

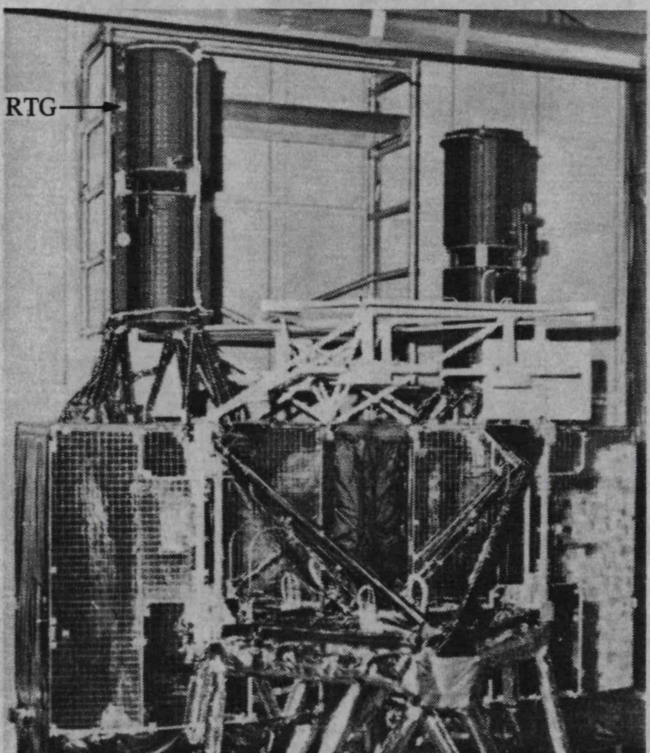

Figure 12. MHW RTGs on LES 8/9 Spacecraft

The Multi-Hundred Watt (MHW) RTG (Figure 13) developed by the General Electric Company, uses 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.

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 requirement 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 RTGs (two on each satellite) were launched in early March 1976. The five-year power level prediction is approximately 130 watts per RTG. Figure 14 shows power performance on the LES 8/9 RTGs.

Early prelaunch power requirements for the Lincoln Experimental Satellites were set at 80 watts minimum. Prior to launch, the need for increased on-the-pad power became evident and was met by exchanging the RTG internal argon atmosphere with xenon. The use of the lower thermal conductivity gas increased the RTG prelaunch power by approximately fifty percent.

Voyager

This Jet Propulsion Laboratory mission (formerly called MJS77) involved two identical spacecraft launched in 1977. These craft (Figure 15) are more sophisticated than the Pioneer 10 and 11 probes. The Jupiter encounter occurred in March and July 1979; the Saturn encounter occurred in November 1980 and August 1981. Data returned concerns atmosphere, surface features, physical properties, etc. The Voyager II trajectory is programmed for a Uranus flyby in January 1986 and Neptune flyby in August 1989. Figure 16 shows power performance for the Voyager RTGs. Figure 17, 18 and 19 are representative of the spectacular photographs from Voyager 1 and 2 spacecraft.

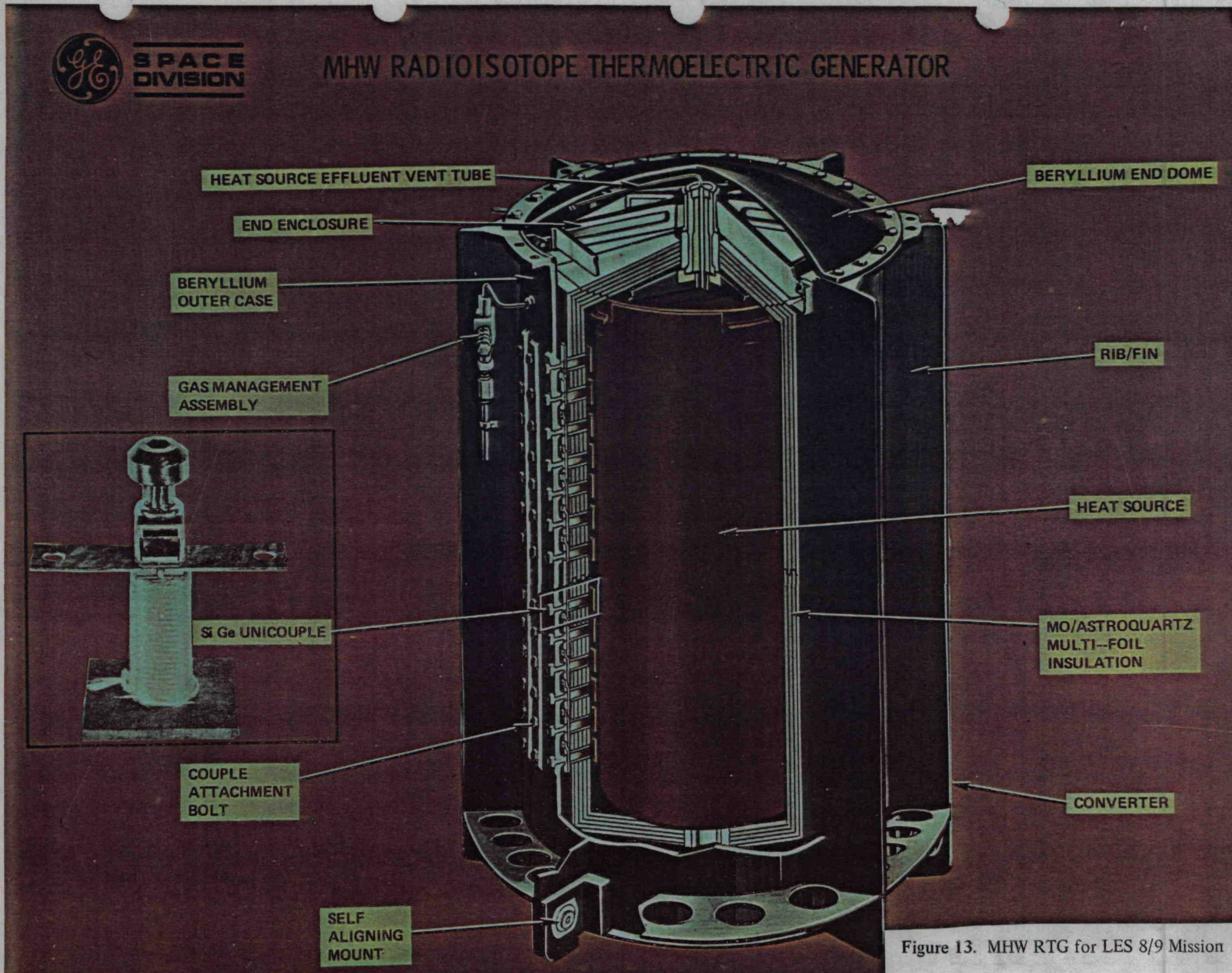

Figure 13. MHW RTG for LES 8/9 Mission

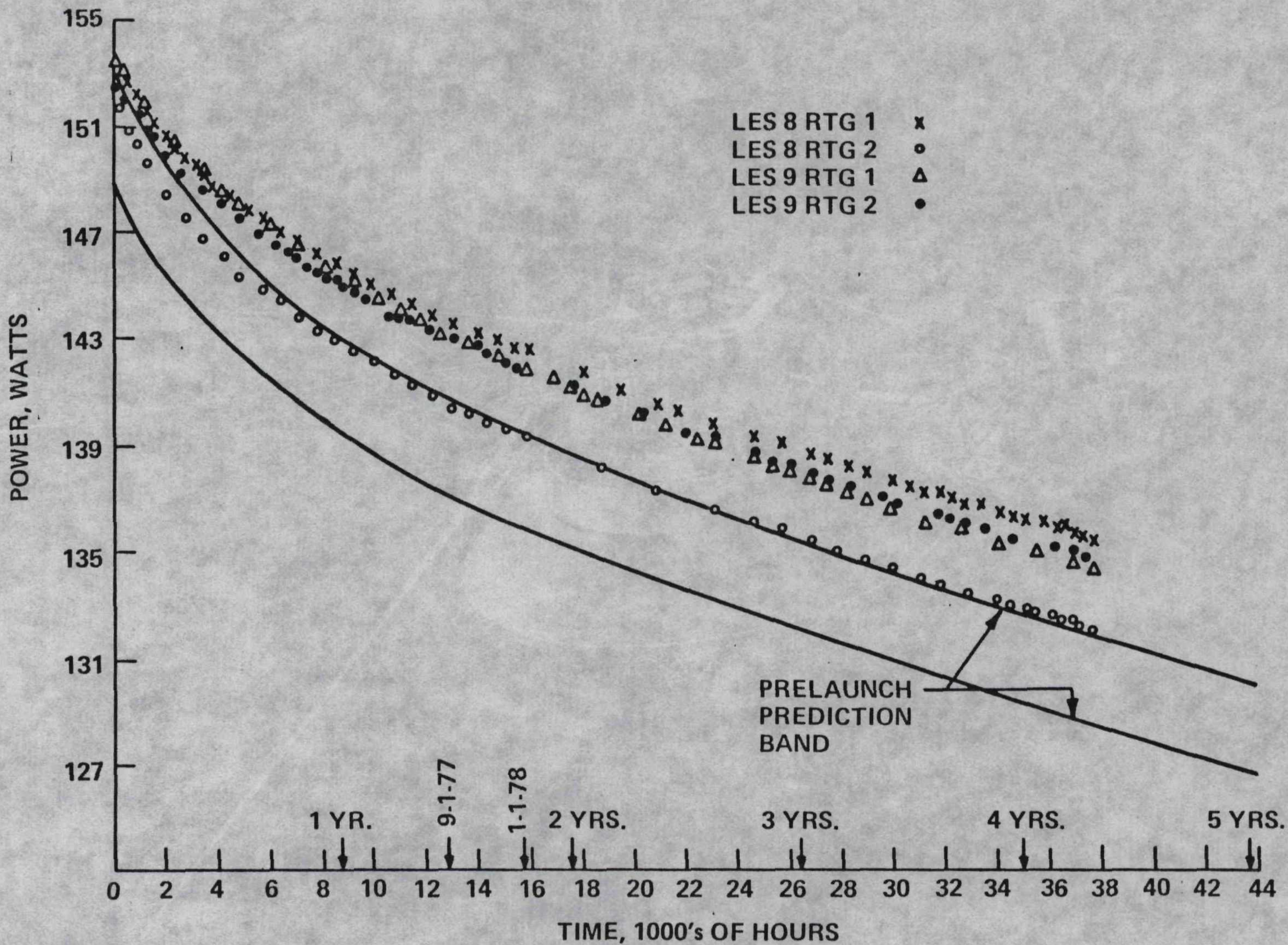

Figure 14. MHW LES 8/9 RTG Power Output During Mission

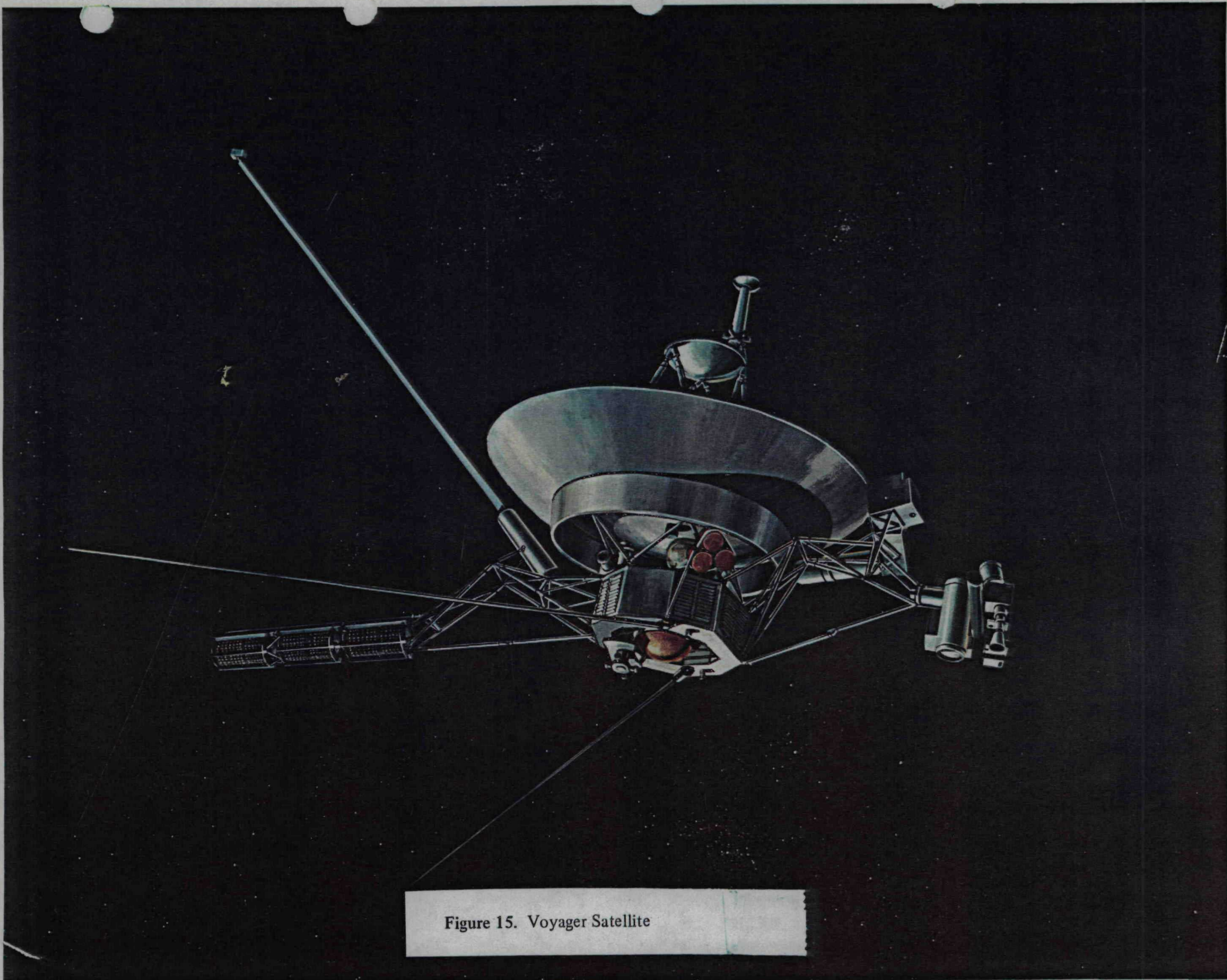

Figure 15. Voyager Satellite

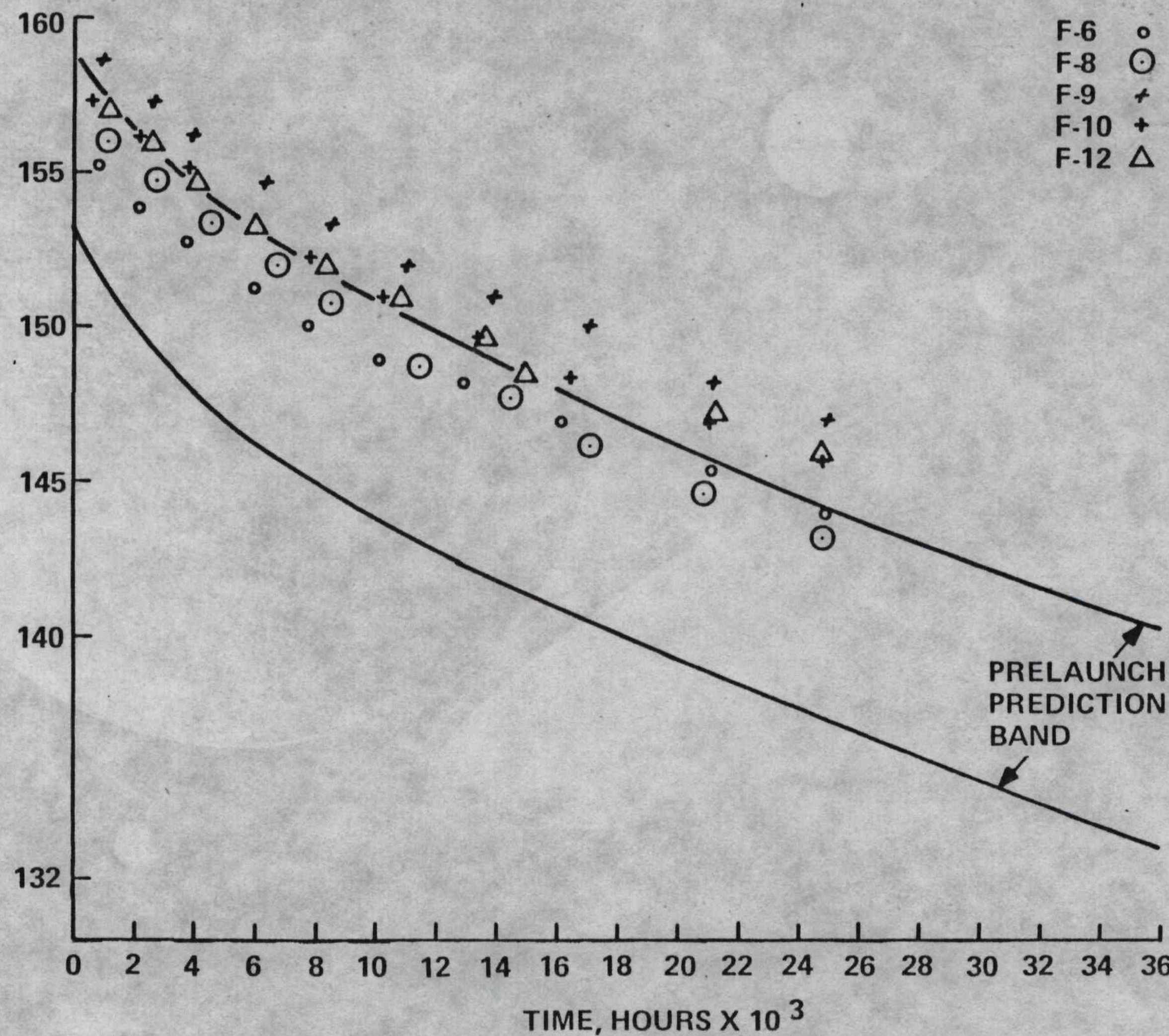

Figure 16. Voyager RTG Output During the First Three Years of its Mission

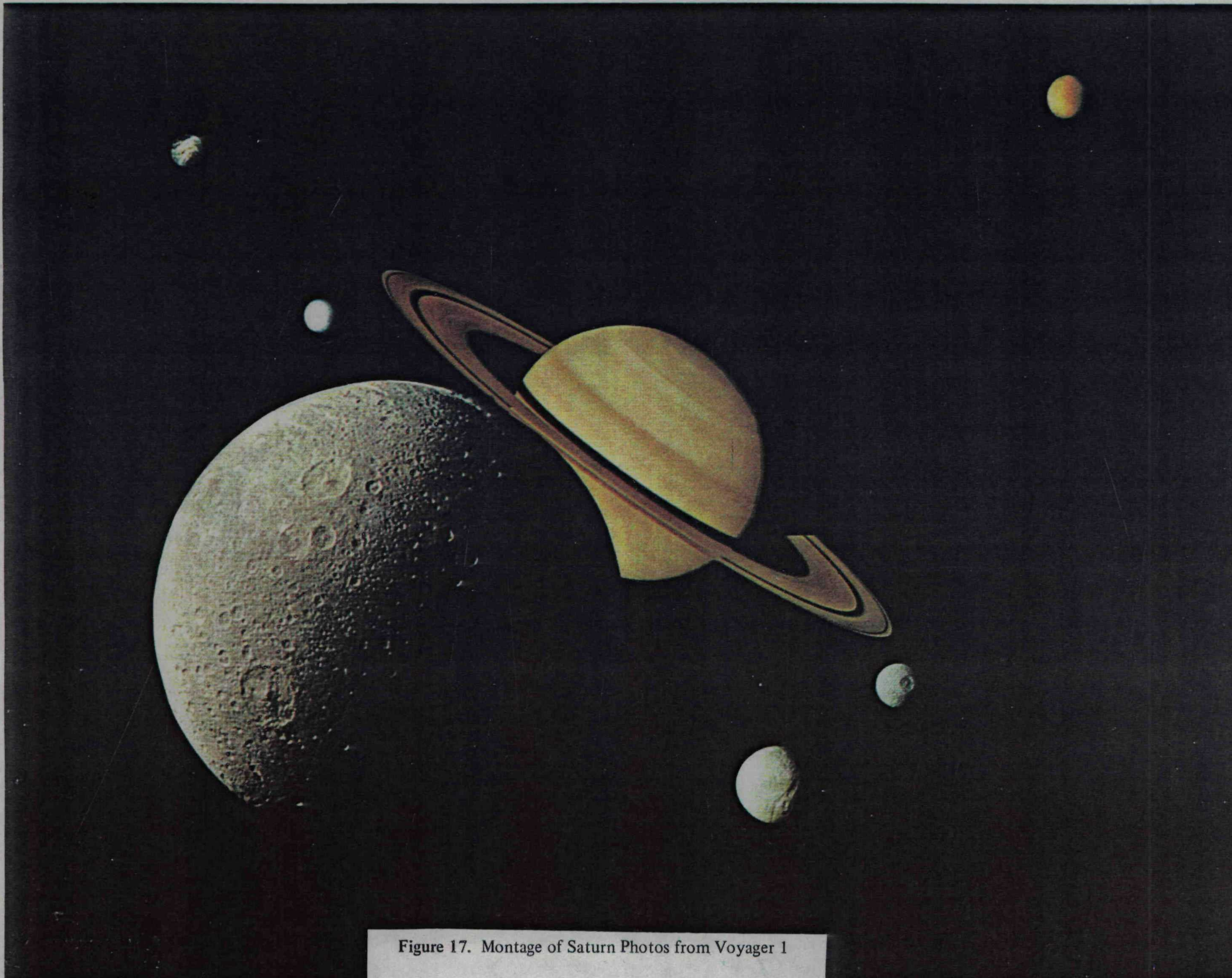

Figure 17. Montage of Saturn Photos from Voyager 1

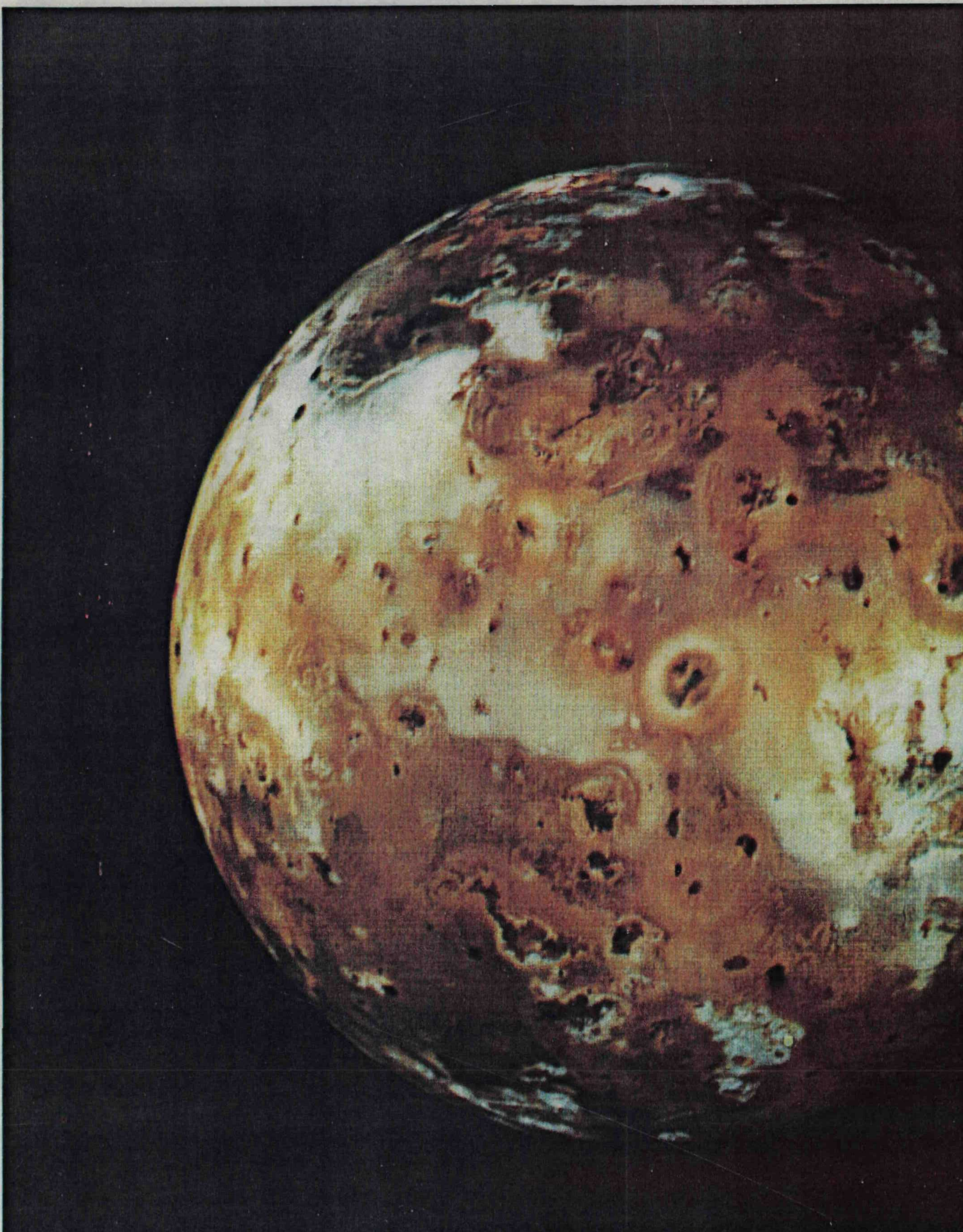

Figure 18. Voyager 1 Picture of Jupiter Satellite Io

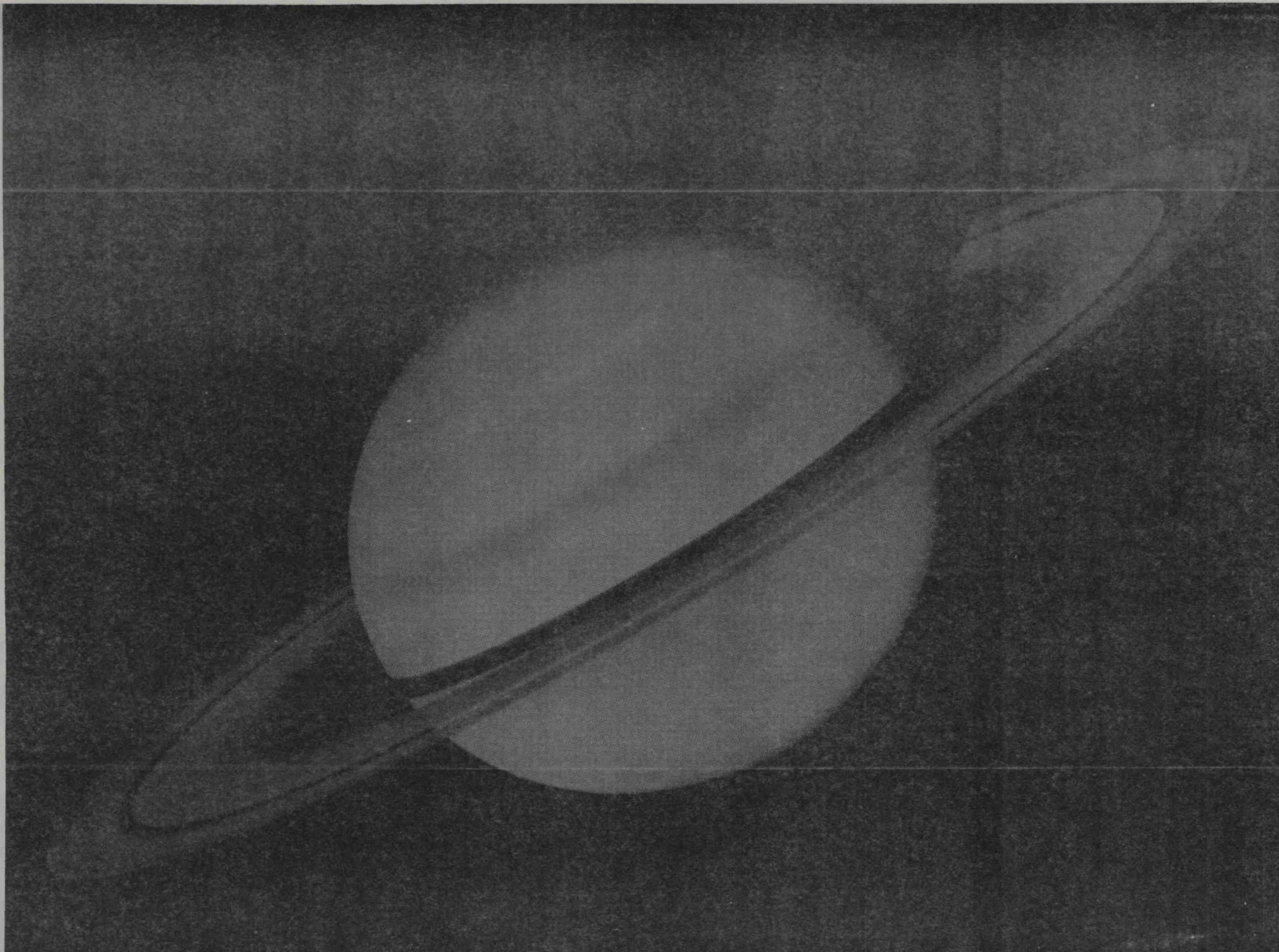

Figure 19. Voyager 1 Photo of Saturn

Changes from the RTGs used on the Lincoln Experimental Satellites 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 eight RTGs, the final generator to be delivered by the end of 1981. This system, designed for terrestrial application, uses the Multi-Hundred Watt Isotopic Heat Source. The design utilizes 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 450-pound maximum weight. General Electric is responsible for the Isotopic Heat Source which Monsanto Research Corporation will assemble and ship as GFE to Teledyne. Figure 20 shows the general configuration of the HPG-3 RTG. One fulltime SQAR was in residence at Teledyne starting in May 1976. Delivery schedules were such that for the past several years, SQAR coverage at Teledyne has been on a part-time, as needed, basis.

75 Milliwatt RTG

This RTG for terrestrial use is manufactured by General Atomic Company, San Diego, California and provides 75 milliwatts of dc power at a matched load voltage of 6 volts after 15 years. Physical dimensions are about 1.8 inches in diameter and 5.2 inches in length. Weight is 1.3 pounds. The thermoelectric material is doped bismuth telluride. Seven have been delivered since this program began in late 1977. The current order of eight units will be delivered about November 1981. Figure 21 shows the configuration of the 75 mW RTG.

GPHS RTG

The GPHS RTG (General Electric, Valley Forge) is now under development in support of two new NASA missions: (1) Galileo to Jupiter (GLL) and (2) the International Solar Polar Mission (ISPM).

Galileo (Figure 3), originally planned for a January 1982 launch, has twice been delayed to 1984 and now to 1985. The Galileo mission will use two spacecraft: an Orbiter and a Probe. The Orbiter will carry the Probe to Jupiter. Launch is now planned for April 1985 by the Space Shuttle using a Centaur upper stage. The Orbiter will relay the Probe's data as the Probe descends into the Jupiter atmosphere. The Orbiter will perform remote sensing studies of Jupiter and its satellites and direct measurements of the magnetosphere. The planned mission will last twenty months and will allow for 11 orbits around Jupiter with one close satellite encounter for each orbit.

The United States, through NASA, and the European Space Agencies (ESA) each planned to provide a spacecraft for investigation of the polar regions of the sun. (Recent budget constraints have placed the NASA spacecraft in jeopardy). Also, due to budget constraints and space shuttle delays, a great deal of uncertainty exists with regard to the currently planned launch date. For RTG manufacturing purposes we are, however, proceeding on a 1985 date. Plans are for a single Space Shuttle launch toward Jupiter whereupon the spacecrafts will double back (slingshot) on a trajectory toward the sun's poles (a 3 1/2 year flight time). Figure 22 is an artist's rendition which depicts this mission. The spacecraft trajectory and momentum will be such that they will circle the sun and arrive at opposite poles approximately one year later. The science package for these spacecraft provides for measurements of cosmic dust, intersteller gas, magnetic field, etc.

The GPHS RTG (Figure 23) is modeled after the MHW converter design. A tight early planning schedule was the main driving force for this approach. The heat source, developed by LANL, is new.

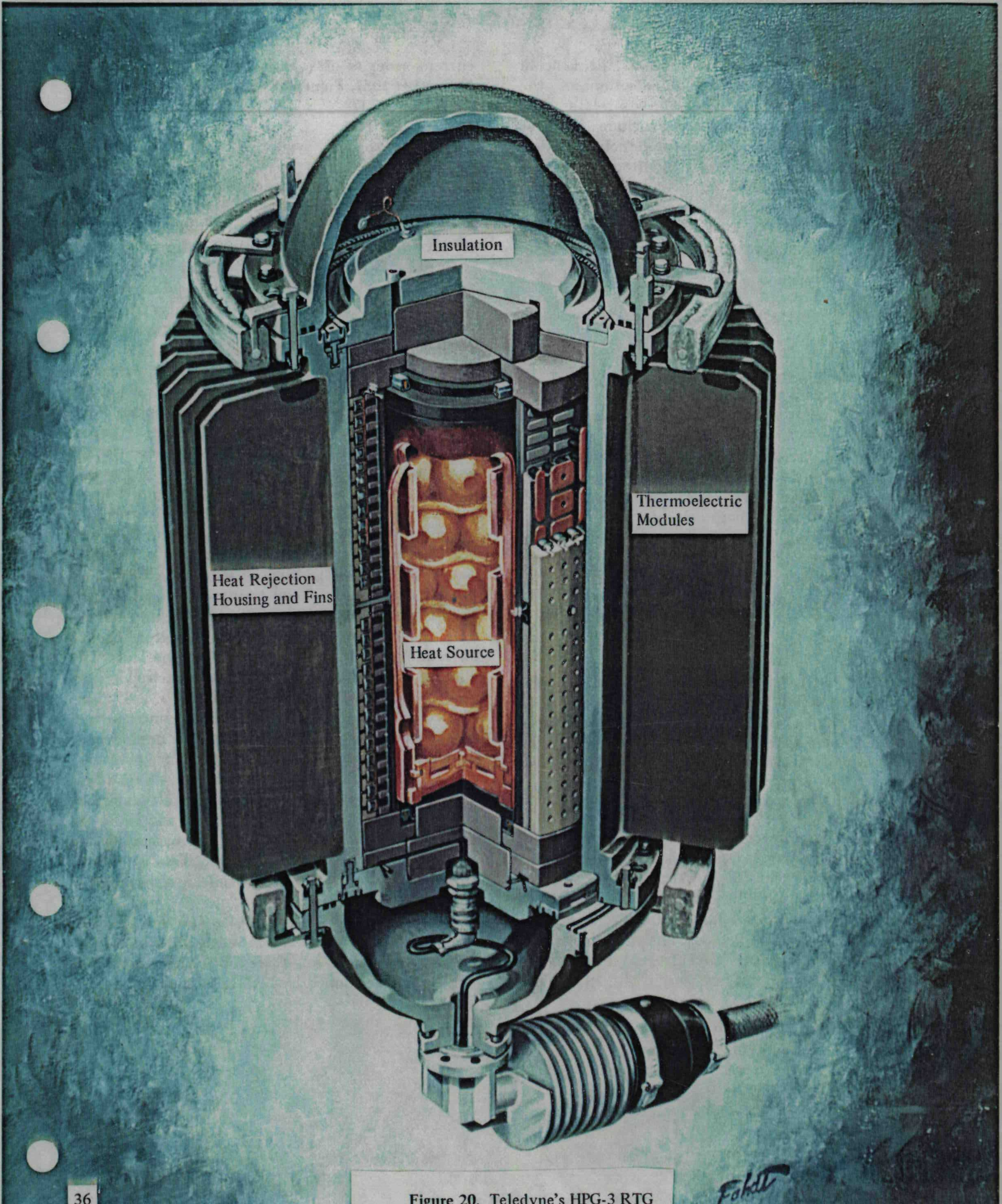

Figure 20. Teledyne's HPG-3 RTG

NUCLEAR BATTERY ASSEMBLY MB– M75B

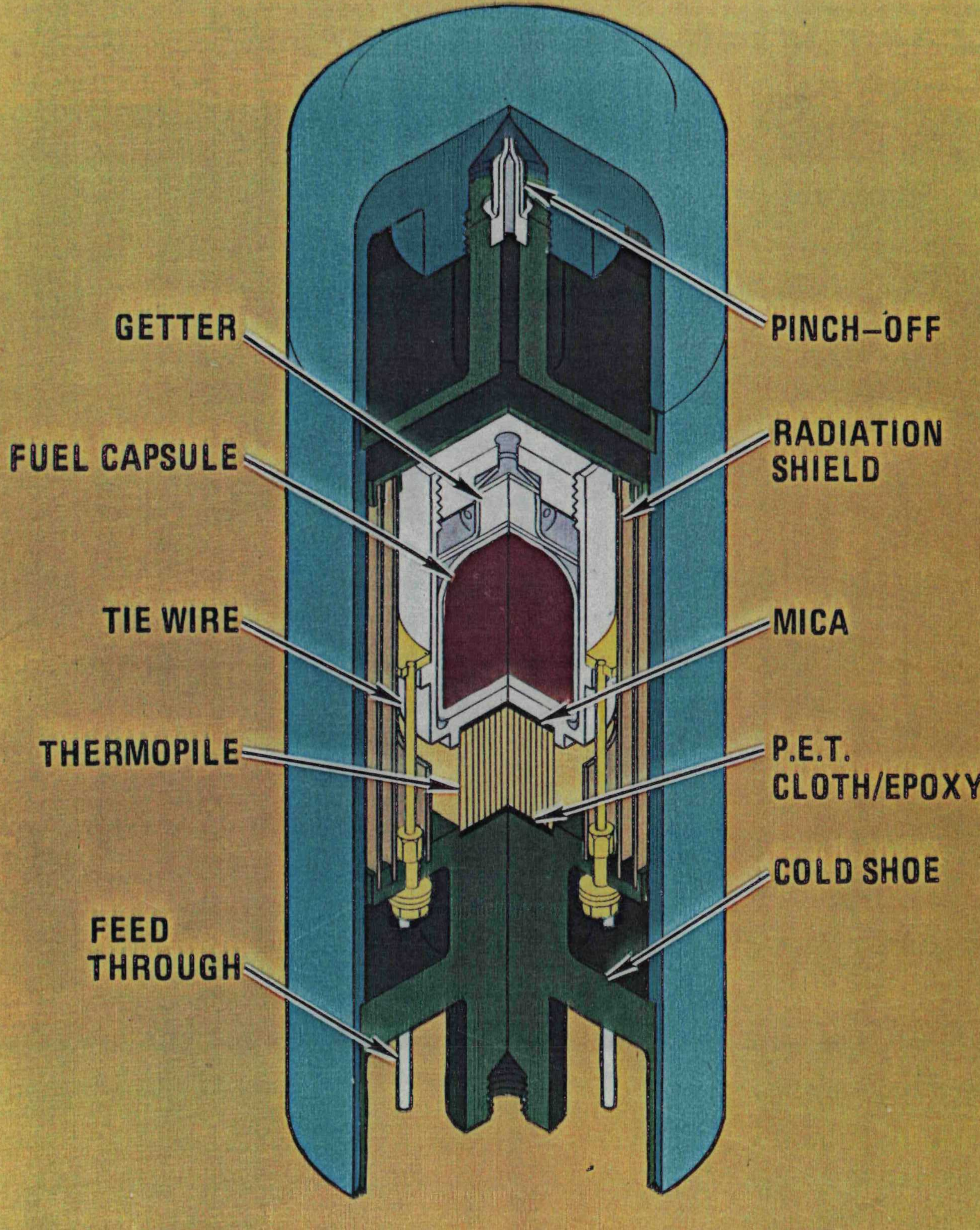

Figure 21. General Atomic's 75 Milliwatt RTG

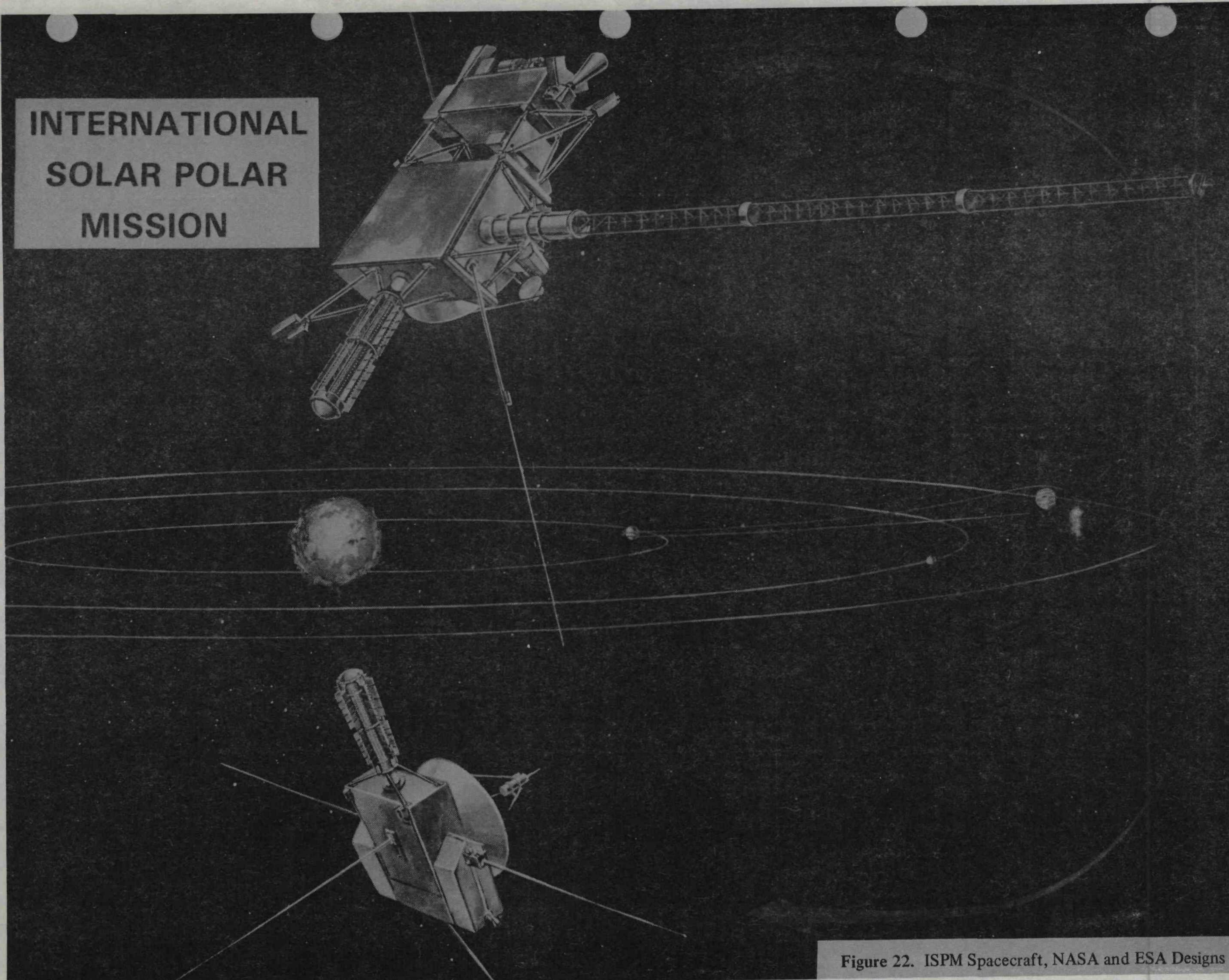

Figure 22. ISPM Spacecraft, NASA and ESA Designs

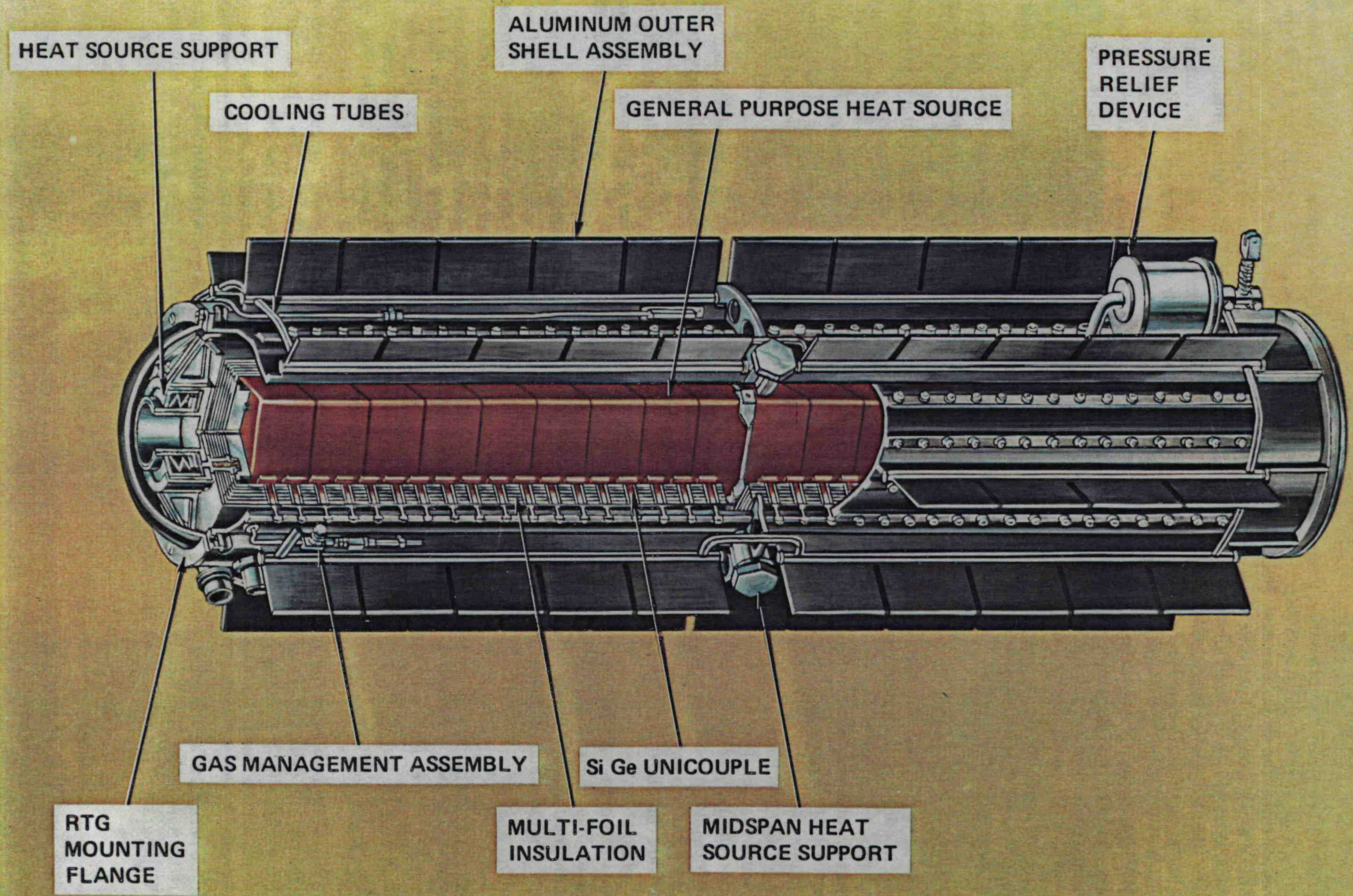

Figure 23. GPHS/RTG Converter for Galileo and Solar Polar Missions

At the close of the MHW manufacturing program, cost considerations dictated the dismantling of the RCA Unicouple-converter production line. Delays in development of a new family of selenide thermoelectric materials expected to be used in an RTG for this program dictated reestablishment of the RCA Unicouple line at General Electric, Valley Forge. The GPHS converter will use 576 of the silicon-germanium type of MHW Unicouples. These will be arranged in a mechanically complex double-parallel arrangement that was uniquely designed to minimize the generation of magnetic fields. This arrangement eliminates the need for a separate degaussing loop. These couples are contained in a multi-layer molybdenum-astroquartz thermal blanket very similar to that used for the MHW converter. RTG structural integrity, gas management and heat rejection is, to repeat, very similar to MHW except that an aluminum outer shell is now used. In addition, safety constraints imposed through the use of the Space Shuttle launch vehicle have limited the outer shell temperature. To meet this limit, water cooling passages have been added to the aluminum outer shell.

The LANL General Purpose Heat Source is based on a modular approach (Figure 24). Eighteen such modules are required for each GPHS RTG. Each module contains plutonium dioxide fuel pellets encapsulated in an iridium membrane (Post Impact Shell) two of which are contained in a graphite impact shell. At the time of pressing, each pellet contains a nominal 62.5 thermal watts of fuel. A GPHS module consists of two such assemblies encased in a 3D (Avco) graphite aeroshell. The total thermal inventory at the time of manufacture is approximately 4500 watts.

VII. Outlook

As of late 1981, three RTG programs were active:

1. HPG-3 — The last RTG, S/N 308, will be fueled and ready for delivery by the end of the year.
2. 75 mW — The last of eight RTGs in the current contract will be delivered by late 1981.
3. GPHS — RTGs for the Galileo and Solar Polar missions will be needed in the 1984 to 1985 time frame.

During the period 1982 through at least 1986, the major effort by Sandia QA is expected to be on the GPHS/RTG program. This, plus other assignments from DOE/OCSP, are expected to result in a reasonably stable workload of $500-600K and 4 to 4.5 men per year per FY. Examples of several "other assignments" where Sandia has supported DOE/OCSP in the recent past, or will in the future, include:

- Acceptance on behalf of the government of a number (65 or more) of Light Weight Radioisotopic Heat Sources to be assembled by Los Alamos National Laboratory. These small heater units, approximately 1 inch in diameter and 1 1/4 inches long, contain just over 1 thermal watt of Pu 238, and are used to heat instrumentation and devices on the Galileo and Solar/Polar spacecraft.
- Participating as task force members on special investigations on (a) Iridium production and forming problems at Oak Ridge National Laboratories and Mound Facility, (b) a heat source-shipping container interference problem at Teledyne, (c) investigation of a failure in a test module on a space reactor power supply under development by LANL, and (d) silicon-germanium thermoelectric couple coating investigations at General Electric Company, Valley Forge.
- Assistance in formulating and editing and publishing of system quality and reliability specifications.
- Review of specifications for fueling and testing GPHS/RTG converters at Mound Facility, and participation in "walk-throughs" of testing and assembly facilities and operations.
- Sandia QA was involved in a DOE-sponsored program to develop a Dynamic Isotope Power System for extended space missions. Two contractors were selected to develop competitive designs; AiResearch developed a Brayton cycle system and Sundstrand designed a Rankine cycle system. Demonstration systems were to produce 1300 watts, using MHW-type heat sources for thermal input. In April 1978, the Sundstrand Kilowatt Isotope Power System (Figure 25) was selected for further development, including life testing. Shortly thereafter the planned mission for the dynamic isotope power system was cancelled, and the development work terminated until such time as a mission is established. Sandia QA also participated in the contractor selection process as advisors to the evaluation board.

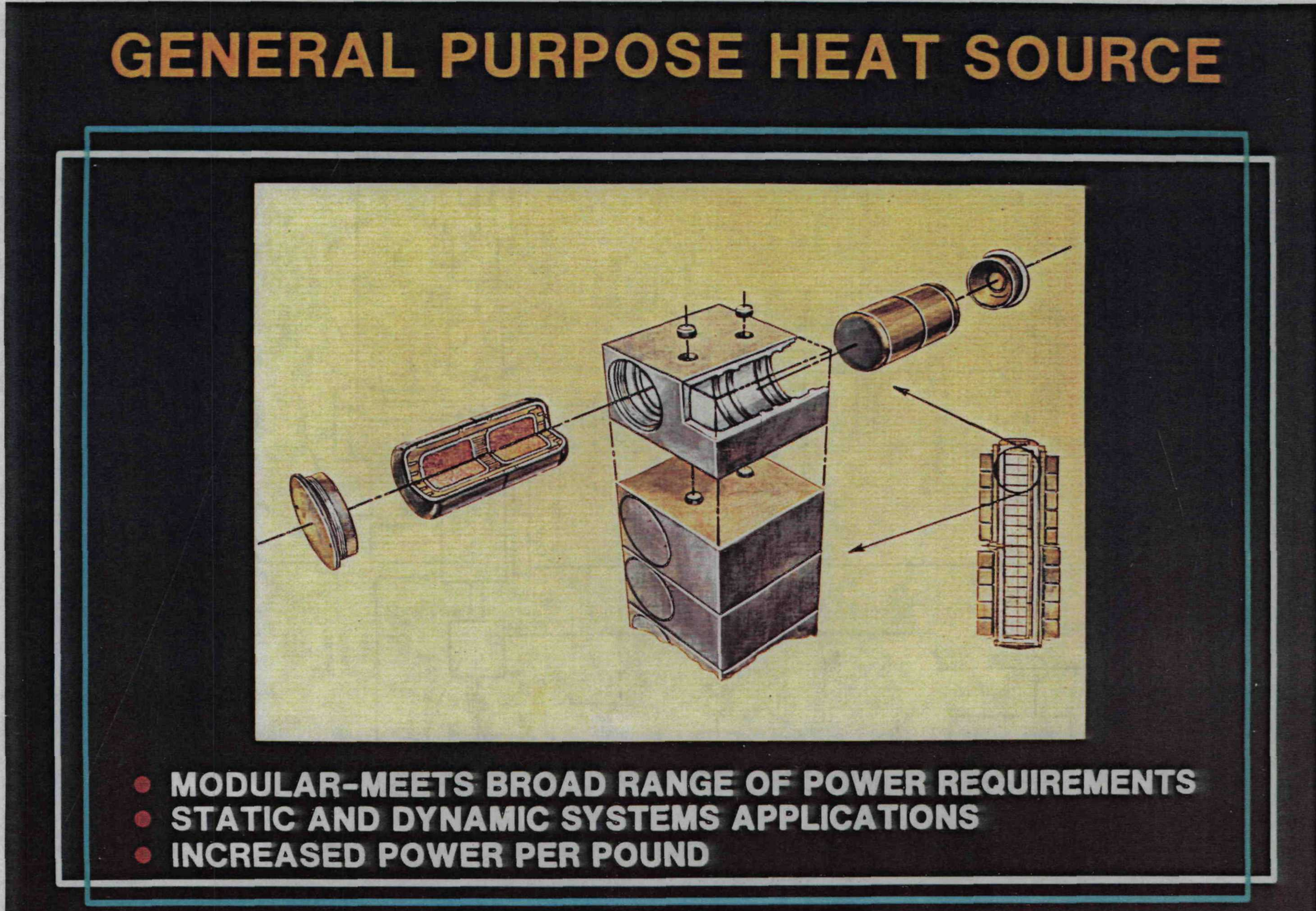

Figure 24. Isotopic Heat Source for GPHS/RTG

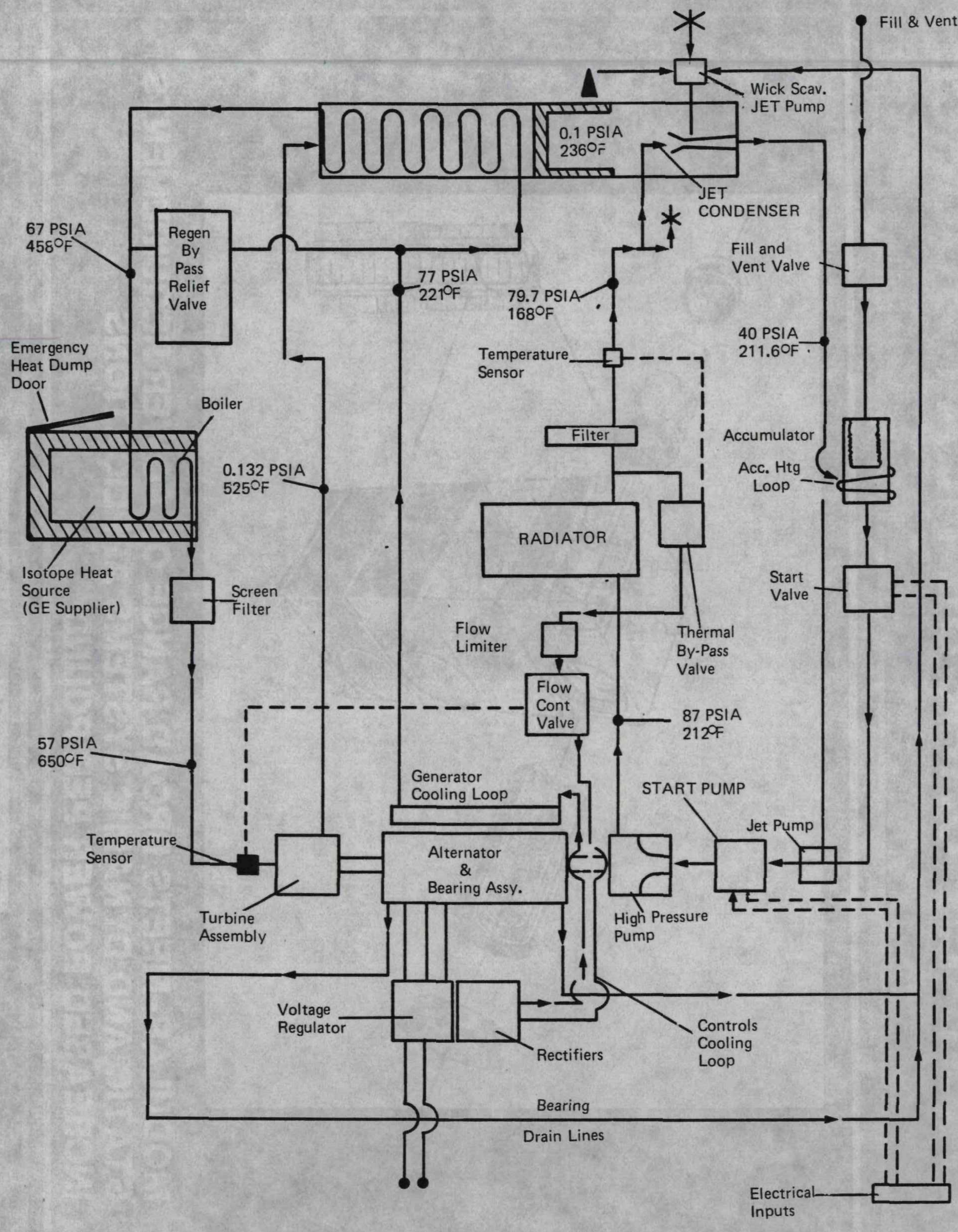

Figure 25. Kilowatt Isotope Power System

- Sandia QA was also involved in a program to develop an isotope power system based on the Stirling engine principle for a terrestrial application. General Electric, Valley Forge, was the prime integration contractor, and Phillips Laboratories was the converter subcontractor for the system which was to develop 1000 watts at 100 volts. The heat source was based on the MHW heat source design. Again, cancellation of the proposed mission necessitated termination of the Stirling isotope power system. (General Electric carried the development work on to the point where an electrically-heated system was running.)

VIII. Conclusion

In reviewing Sandia's 15-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 National Laboratories. Sandia has enjoyed an excellent interface relationship with the U. S. Atomic Energy Commission, and its successors, the Energy Research and Development Administration and the Department of Energy. The Laboratories has provided the U. S. Government with a quality program which has helped assure 100 percent success with RTGs deployed thus far. The RTG QA program reimbursable budget has increased 10-fold over this 15-year period. The fascinating nature of these space power programs has been a good growth experience, particularly for SQARs who often worked long and unusual hours during test operations.

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