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SNAP 19 Phase III Final Report

VOLUME I
POWER SUPPLY SYSTEM

MARTIN MARIETTA NUCLEAR DIVISION

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SNAP 19 Phase III Final Report

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May 1968

MARTIN MARIETTA CORPORATION NUCLEAR DIVISION

BALTIMORE, MD. 21203

LEGAL NOTICE

FOREWORD

This three-volume report, prepared by the Martin Marietta Corporation, is an account of the SNAP 19 radioisotope thermoelectric generator program performed under United States Atomic Energy Commission Contract AT(30-1)-3607.

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ABSTRACT

A. INTRODUCTION

Outlines the content and format of the three-volume report and describes evolution of the SNAP 19 power supply.

B. SNAP 19 POWER SUPPLY

This chapter describes the system and its modes of operation, evaluating system performance in orbit; describes single generators their performance characteristics; references classified data on the heat source; describes thermoelectric conversion modules, housing, instrumentation and wiring, thermal insulation, and miscellaneous components; and describes generator subsystem, power conditioner unit and telemetry signal conditioner unit.

C. INTERFACE WITH NIMBUS B SPACECRAFT

The mechanical, electrical and thermal interfaces between SNAP 19 and Nimbus B are discussed, along with nuclear radiation and its effect on the system.

D. TESTING

In this chapter are described the generator subsystem, power conditioner unit, telemetry signal conditioner unit and power supply system testing. Performance criteria are given. Prototype qualification and flight acceptance testing are defined and described. Mass properties and radiation measurements are reported. Appendixes A, B and C summarize system and subsystem test data.

E. POWER SUPPLY RELIABILITY

This chapter describes criteria for parts selection and screening, and also describes method of determining, identifying and handling parts critical to successful performance. Failure modes and effects, demonstrated reliability and reliability predictions are discussed.

F. AEROSPACE NUCLEAR SAFETY

The major points of the safety philosophy and the technical approach to safety are covered in this chapter, with references to documents in which details are given.

G. AEROSPACE GROUND EQUIPMENT

Descriptions of the ground support test console, power supply rack, portable monitor, capsule shipping casks, generator subsystem handling, shipping and storage equipment, technical manual preparation and verification, and generator subsystem transportation appear in this chapter.

H. SPACECRAFT INTEGRATION

Design of generator subsystem from transmissibility, thermal conductance, magnetic moments and spacecraft shroud cooling standpoints are discussed in addition to testing of the power supply system with the spacecraft and a description of launch site operations.

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SUMMARY

A. INTRODUCTION

This volume of the three-volume report covers the complete power supply system. Volume II reports the development of the heat sources (dispersal and intact re-entry), and Volume III covers significant developmental aspects of the SNAP 19 program.

Steps in evolution of the power supply were Phase I (generator design studies), Phase II (feasibility study and prototype design and construction), Phase III (flight-qualified unit design and construction) and the IRHS program (development of an intact re-entry heat source).

B. SNAP 19 POWER SUPPLY

The power supply system consists of a generator subsystem, a power conditioner unit (PCU) and a telemetry signal conditioner unit (TSCU). The PCU wave-shapes, transforms, rectifies and filters the generator output. The TSCU provides generator and PCU performance measurements compatible with the spacecraft telemetry system.

A single generator (two generators form a subsystem) produces approximately 30 watts. A single fuel capsule is in each generator. Six thermoelectric modules convert the fuel heat to electrical energy. The internal parts of the generator are housed in a cylindrical, finned case. Instrumentation consists of sensors for hot junction temperature, internal gas pressure, fin root temperature and output voltage.

The generator subsystem (two generators assembled in tandum) is mounted on a vibration-damping support base and standoff assembly.

The PCU is housed in a standard Nimbus 4/0 module. It contains two dc-to-dc converters, each in series with one of the generators. The 2.6 0.1-volt generator output is converted to -24.5 volts. Output switching from bus to dummy load is by ground command.

The TSCU is housed in a standard 2/0 Nimbus module. It provides 26 analog outputs as voltages in the range of 0 to -6.35 volts dc.

C. INTERFACE WITH NIMBUS B SPACECRAFT

The mechanical interface was dictated by size and weight limitations imposed by the spacecraft. Requirements of the spacecraft determined the power supply electrical output level and the characteristics of the output.

Power supply telemetry signals are supplied to the spacecraft telemetry system.

Conducted and radiated heat are within limitations imposed by the spacecraft.

Components of the power supply will not be affected by radiation up to five times that of the combined generator subsystem and space radiation.

D. TESTING

Generator subsystem parametric testing was conducted. Functional tests were performed on the power conditioner and telemetry signal conditioner units and on the power supply system. The system tests were conducted using the generator subsystem and the ground support test console to simulate the generator subsystem.

Prototype qualification tests (humidity, vibration, acceleration and thermal vacuum) and flight acceptance tests (vibration and thermal vacuum) were conducted. Mass properties and nuclear radiation were measured.

E. POWER SUPPLY RELIABILITY

Parts were selected from the NASA Preferred Parts List, or were procured to comply with Martin Marietta specifications. The NASA screening requirements were complied with. Parts critical to successful performance were given special handling.

Failure mode analyses were made, starting from the component level.

Endurance testing and the results of operation produced a demonstrated generator reliability of 0.95 at 50% confidence for a one-year mission.

Predicted reliability of both power channels for a one-year mission is 0.680 and, for at least one channel, 0.969.

F. AEROSPACE NUCLEAR SAFETY

The aerospace nuclear safety philosophy evolved from initial consideration of atmospheric dispersion of plutonium metal to the ultimately used intact re-entry of PuO_2 microspheres. The safety philosophy encompasses the transportation, launch pad operations, preorbital, orbital and post-mission phases of the mission profile.

The technical approach determined the effect to be expected on population groups as a result of using the SNAP 19 intact re-entry heat source generator system on the Nimbus B mission. Malfunction occurrence and potential hazards were defined and analyzed.

G. AEROSPACE GROUND EQUIPMENT

The ground support test console contains all equipment necessary to test the complete SNAP 19 system, the generator subsystem, the power conditioner unit and the telemetry signal conditioner unit. The console can also be used for calibration of the telemetry signal conditioner unit and for simulating the generators in a system test.

The power supply rack, using chassis from the console, provides a convenient method of supplying power to electrically heated generator subsystems.

The portable monitor is used to check generator subsystem temperature and pressure.

Shipping casks were built for the dispersal capsules, and four of these were modified for the intact re-entry capsules.

Handling equipment includes an adapter for lifting the generator subsystem, a hoist bar that attaches the adapter to a crane (thus providing clearance at installation on the spacecraft), a mobile carriage for transporting generator subsystems between work areas and a hoist for the carriage.

A paraffin-shielded shipping container is provided for fueled generator subsystems The container is shipped on a wooden skid. There is a special hoist sling for the container.

Instructions for system handling, storage, shipping and operation, and for use of the aerospace ground equipment are presented in the technical manual. The manual was prepared in general accord with military specifications, and accuracy was verified by use with SNAP 19 equipment.

A detailed loading, transporting and unloading procedure for the system was prepared.

H SPACECRAFT INTEGRATION

Elasticity and vibration damping is incorporated in the generator subsystem support structure. Heat conducted to the spacecraft through the structure was shown to be insignificant.

A magnetic moments test confirmed that the magnetic moment values will not be detrimental to the Nimbus flight.

Shroud cooling tests showed that cooling is adequate to maintain temperatures within the shroud to prescribed levels

Prototype level vibration tests and electrical systems tests were conducted using model spacecraft Other tests were conducted with the flight spacecraft

Launch site operation procedures were verified by exercises at General Electric Co , Valley Forge, and at the Air Force Western Test Range.

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LIST OF TABLES

I. INTRODUCTION

This report covers the major aspects of Phase III of the SNAP 19 radioisotope-fueled thermoelectric generator program, under which prototype-qualified and acceptance tested flight power supplies for the Nimbus B spacecraft were produced. Sources of more detailed information (such as the SNAP 19 Safety Reports and documents on previous phases of the SNAP 19 program) are referenced at appropriate points in this text.

The Phase III Final Report is in three volumes, of which this is Volume I. Section IA is a brief discussion of the three-volume format.

The report concentrates on the power supply configuration developed for Nimbus B under Phase III, including both the dispersal and intact re-entry heat source versions. However, the evolution of the SNAP 19 is described in Section IB to provide background for the Phase III effort report.

A. REPORT FORMAT AND CONTENT

Volumes I and III are unclassified and Volume II is classified. Each volume is divided into chapters, and each chapter is subdivided as appropriate to the subject. All references are grouped together in Chapter IX. A list of illustrations and a list of tables are in the front of each volume (for the illustrations and tables in that volume, only), following the table of contents.

1. Volume I

Volume I treats the entire power supply (all units), with particular emphasis on SNAP 19 as a power supply for the Nimbus B spacecraft. Aspects such as system qualification, support equipment and spacecraft integration are included.

2. Volume II

Volume II reports the development of the heat sources for SNAP 19 and covers both the dispersal and intact re-entry configurations.

3. Volume III

Volume III covers selected developmental aspects of the SNAP 19 RTG accomplished during Phase III. Despite the SNAP 19 activity not being originally programmed for technology development, development effort became necessary during the program. (The safety-heat source aspects required major development effort, reported in Volume II) Although the production RTG was constrained to thermoelectric technology available at the start of Phase II, limited development in this area and extensive RTG endurance testing was programmed. Other items of a developmental nature were realized in the process of compliance with the prime program objectives. These developments are discussed in Volume III.

B EVOLUTION OF THE SNAP 19 POWER SUPPLY

The SNAP 19 power supply configuration developed for the Nimbus B spacecraft was finalized during the Phase III program. The basic concept for the radioisotope thermoelectric generator (RTG) was developed in a program (Phase I) to meet the requirements of a different NASA spacecraft. In addition, initial fabrication experience on the RTG concept was obtained in development of a model for a flight safety test program. The work directed toward Nimbus requirements started with the Phase II program. The relationship of the programs which led to Phase III and the delivery of a SNAP 19 flight system for Nimbus B is shown in Fig. I-1. The programs are summarized below.

1. The Phase I Program

The basic SNAP 19 RTG design concept was derived from a design study, begun in February 1963, for the NASA Interplanetary Monitoring Probe (IMP) spacecraft (Ref. I-1). This study was later designated SNAP 19 Phase I.

The RTG design was based on fuel capsule and housing technology developed during the SNAP 9A program and a modular thermoelectric configuration from SNAP 11. The RTG for IMP was a cylindrical, finned design of 20 watts output Two boom-mounted units were required, as shown in Fig. I-2.

A complete RTG detail design and a limited effort on fabrication and test of thermoelectric modules were accomplished. The RTG design was selected as a SNAP RTG characteristic model for the Re-entry Flight Demonstration Number Two, RFD-2 (Refs. I-2 and I-3). A flight test model was built for RFD-2 (Ref. I-3), but the design did not proceed into hardware for IMP. The work for RFD-2 did, however, yield useful RTG fabrication experience, particularly in regard to the heat block, cold end hardware and assembly tooling and methods.

2. The Phase II Program (Ref. I-4)

In December 1963, a feasibility study was begun on a nuclear power supply for the Nimbus spacecraft (Ref. I-5) under development by NASA-Goddard Space Flight Center. The study showed that integration of an RTG system with the basic spacecraft structure was feasible and that the Phase I RTG concept could be utilized. A power supply consisting of two RTG's and a power conditioner was selected. Each RTG was to have an output of 30 watts and be basically a scaled-up version of the Phase I design

The RTG was designed for fuel burnup upon atmospheric re-entry. The impact strength of the capsule was improved over the SNAP 9A design; capsule qualification was accomplished.

Electrically heated prototype RTG's were built and tested. Measured beginning-of-life power output was 33 to 35 watts, with a thermal input of 610 watts. Liaison was conducted with Goddard Space Flight Center on integration of the RTG with the basic Nimbus sensory ring. A tandem generator configuration with a vibration-isolating support structure was developed. Environmental qualification testing (including humidity, vibration, acceleration and thermal vacuum) was performed on the RTG subsystem and the prototype power conditioner. This testing was completed in January 1965. The Phase II RTG subsystem being installed in thermal vacuum chamber is shown in Fig. I-3.

A preliminary safety analysis, which included hypersonic tunnel testing, was also performed.

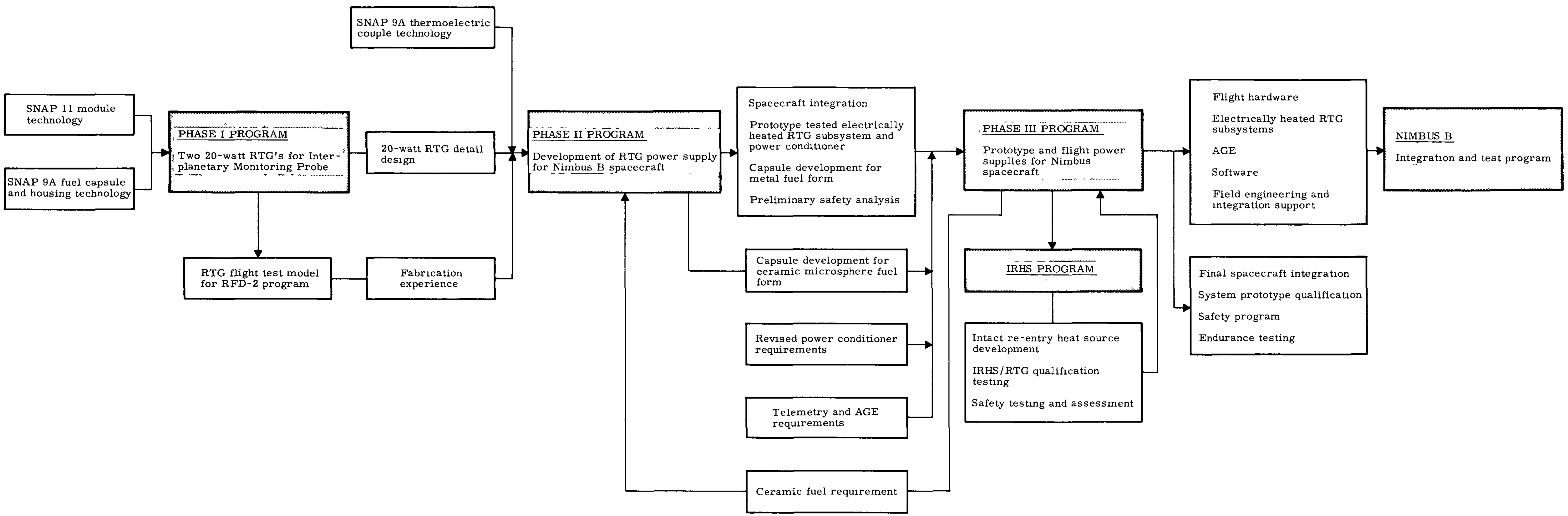


FIG. I-1. DEVELOPMENT OF THE SNAP 19 PROGRAM

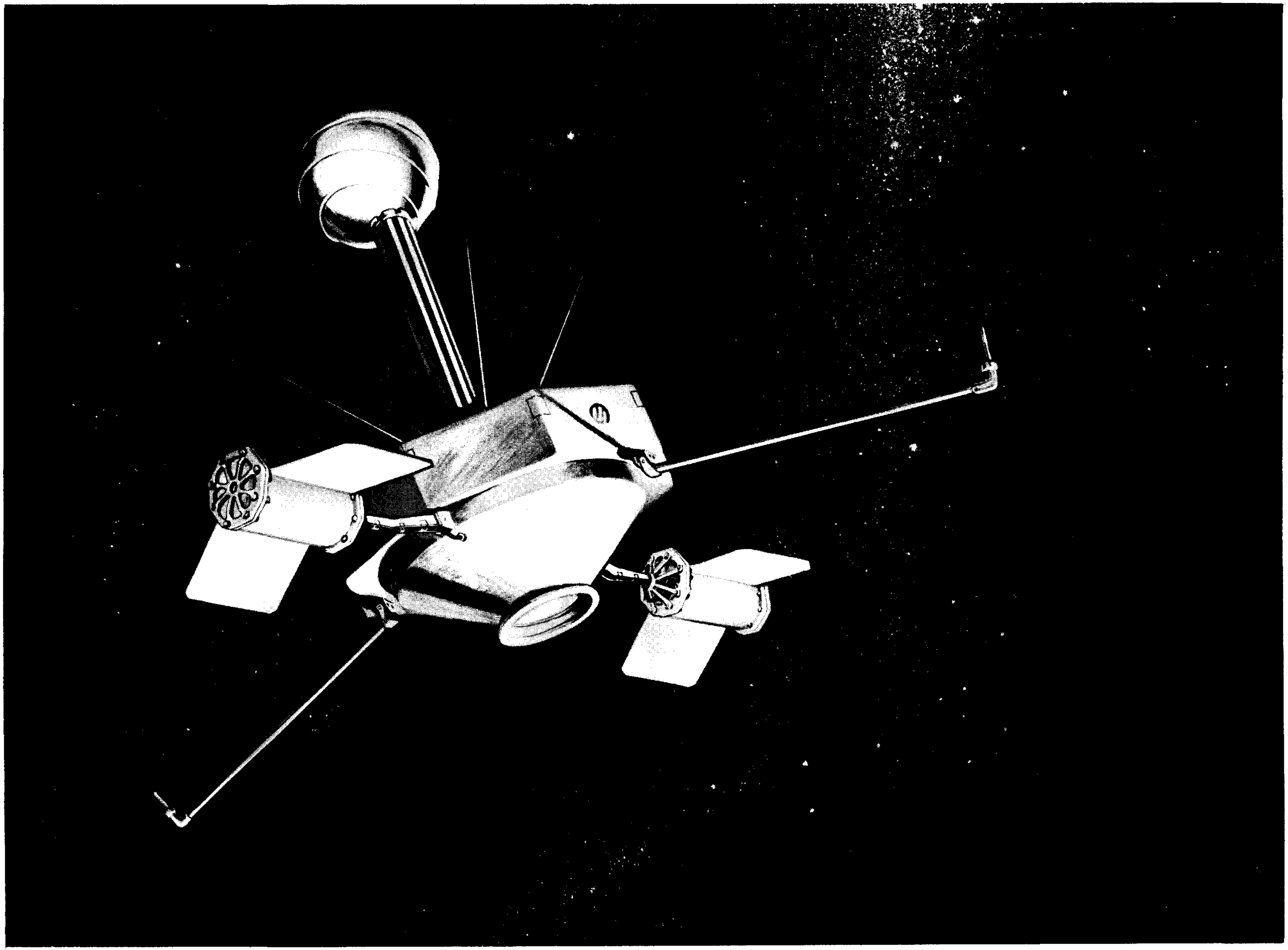


FIG. I-2. TWO TWENTY-WATT GENERATORS MOUNTED ON INTERPLANETARY MONITORING PROBE

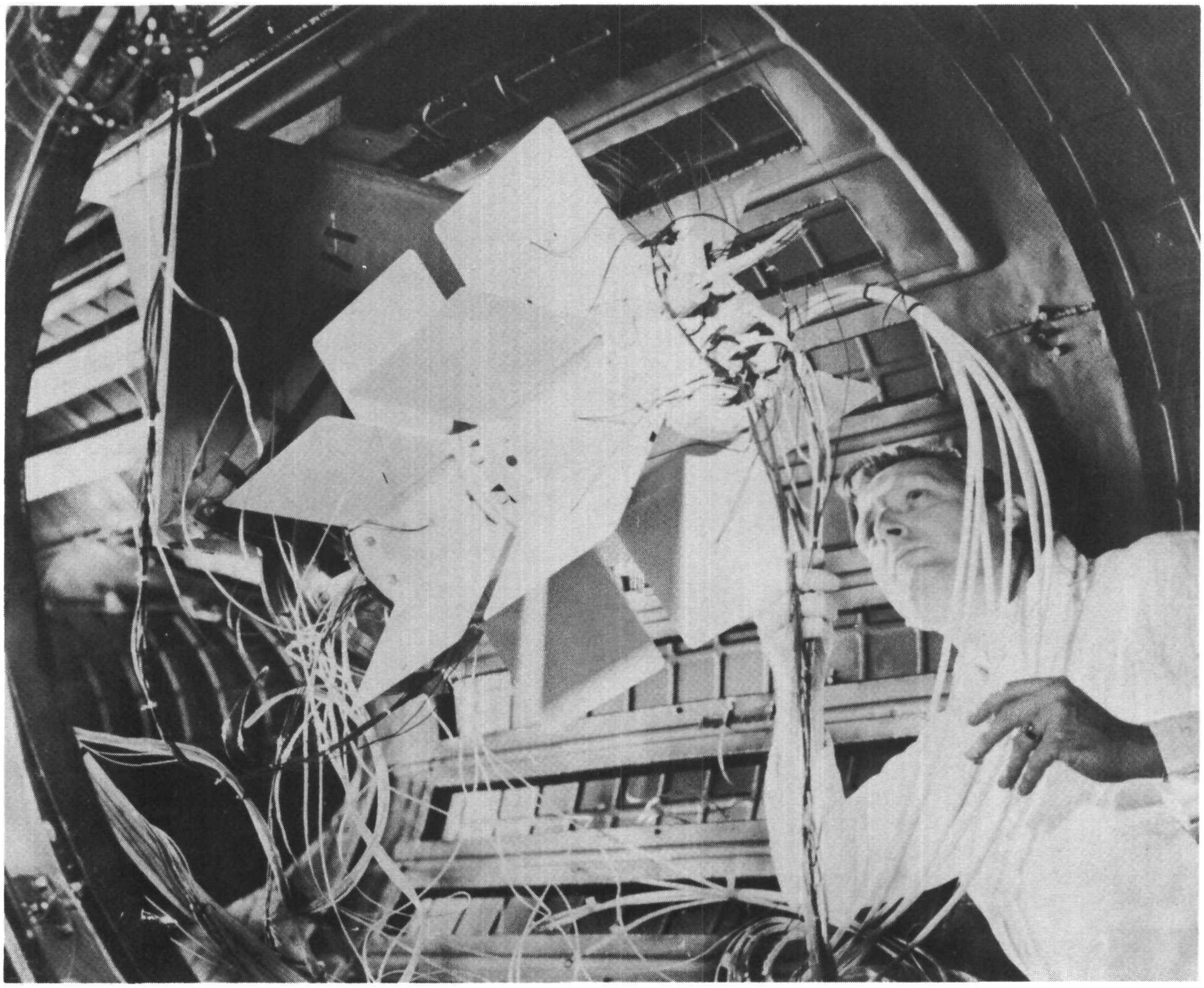


FIG. I-3. GENERATOR SUBSYSTEM INSTALLATION IN THERMAL VACUUM CHAMBER

3. The Phase III Program

The Phase III program, which is the subject of this report, started in September of 1965. The objective of Phase III was to build and qualify fueled prototype and flight RTG power supplies for the Nimbus B spacecraft.

Phase III involved some major changes which affected the system configuration relative to that of Phase II, including:

(1) Metallic fuel form change to ceramic

(2) Re-entry mode change from wide-area dispersion of submicron particles resulting from high altitude burnup of metallic fuel to limited-area dispersion of as-produced microspheres

(3) Reduction of RTG radiator area with consequent lower thermal inventory and output power

(4) Change in power conditioner design constraints

(5) More flight instrumentation and addition of telemetry conditioning.

After qualification and flight acceptance of SNAP 19 power supplies, the RTG heat source was changed to that of an intact re-entry heat source (IRHS). This affected the RTG subsystem as discussed below.

4. The IRHS Program

In the Spring of 1967, a development program was undertaken to provide a heat source for SNAP 19 which could prevent fuel dispersal during atmospheric re-entry. Design constraints were set up such that little or no modification to the RTG was required.

Upon heat source development, safety assessment and test in an RTG subsystem, the Atomic Energy Commission decided that IRHS would be used in the flight RTG subsystem. The IRHS activity was therefore integrated with the basic Phase III program for prototype requalification and flight acceptance testing and delivery of the RTG subsystem. The IRHS program is covered in this report.

The IRHS development represented the last change to the RTG configuration for the Nimbus B spacecraft.

II. SNAP 19 POWER SUPPLY

A. POWER SUPPLY SYSTEM

1. System Description

The SNAP 19 power supply system consists of a radioisotope thermoelectric generator (RTG) subsystem (Fig. II-1), a power conditioner unit (PCU) (Fig. II-2), and a telemetry signal conditioner unit (TSCU) (Fig. II-3). The system is configured for integration on the Nimbus B spacecraft. The generator subsystem is mounted on top of the spacecraft sensory ring and the TSCU and PCU are housed in Bay 18 of the ring (Fig. II-1). The mechanical, electrical, thermal and nuclear radiation interfaces with the Nimbus B spacecraft are discussed in Chapter III.

The radioisotope fueled generator subsystem has two generators, each of which is served by a separate dc-to-dc converter in the PCU and an essentially separate telemetry net in the TSCU.

Power produced by each generator is furnished to its respective dc-to-dc converter where the 2.6 input voltage is wave shaped, transformed to higher voltage, rectified and filtered. The combined output power of approximately 50 watts is supplied to the spacecraft bus, which is regulated at -24.5 volts.

The telemetry signal conditioner assesses generator and power conditioner performance parameters through connections to sensors in those units. The sensor analog signals are conditioned and furnished to the pulse code modulator of the spacecraft telemetry subsystems. The TSCU also provides digital signals indicating the PCU status.

The power supply system provides two power channels which are electrically in parallel. Each channel has a generator in series with a dc-to-dc converter.

A SNAP 19 power supply system block diagram is shown in Fig. II-4.

2. Modes of Operation

There are two operational modes of the SNAP 19 power supply system. In the normal mode, both converters supply power to the spacecraft regulated bus; in the standby mode, both converter outputs are connected to spacecraft dummy-load resistors.

The converter output switching between spacecraft power bus and dummy load is accomplished by a relay in series with the converter output. The relays, one in each of the two power channels, are actuated by three distinct commands which, when executed, can place each of the converters on the bus independent of the other, but can only remove them from the normal mode simultaneously.

During launch, the SNAP 19 power supply system will be in the normal mode and will remain in this mode for all usual flight conditions. The standby mode will be used to isolate the system from the spacecraft bus as necessary for experimental or diagnostic purposes.

3. Evaluation of Performance in Orbit

The operational status of the SNAP 19 RTG and PCU will be monitored by a set of 28 sensing circuits; 14 in each of the two power channels. Because the SNAP 19 power supply system is primarily an experiment on the Nimbus B spacecraft, assessment of system performance is of prime importance.

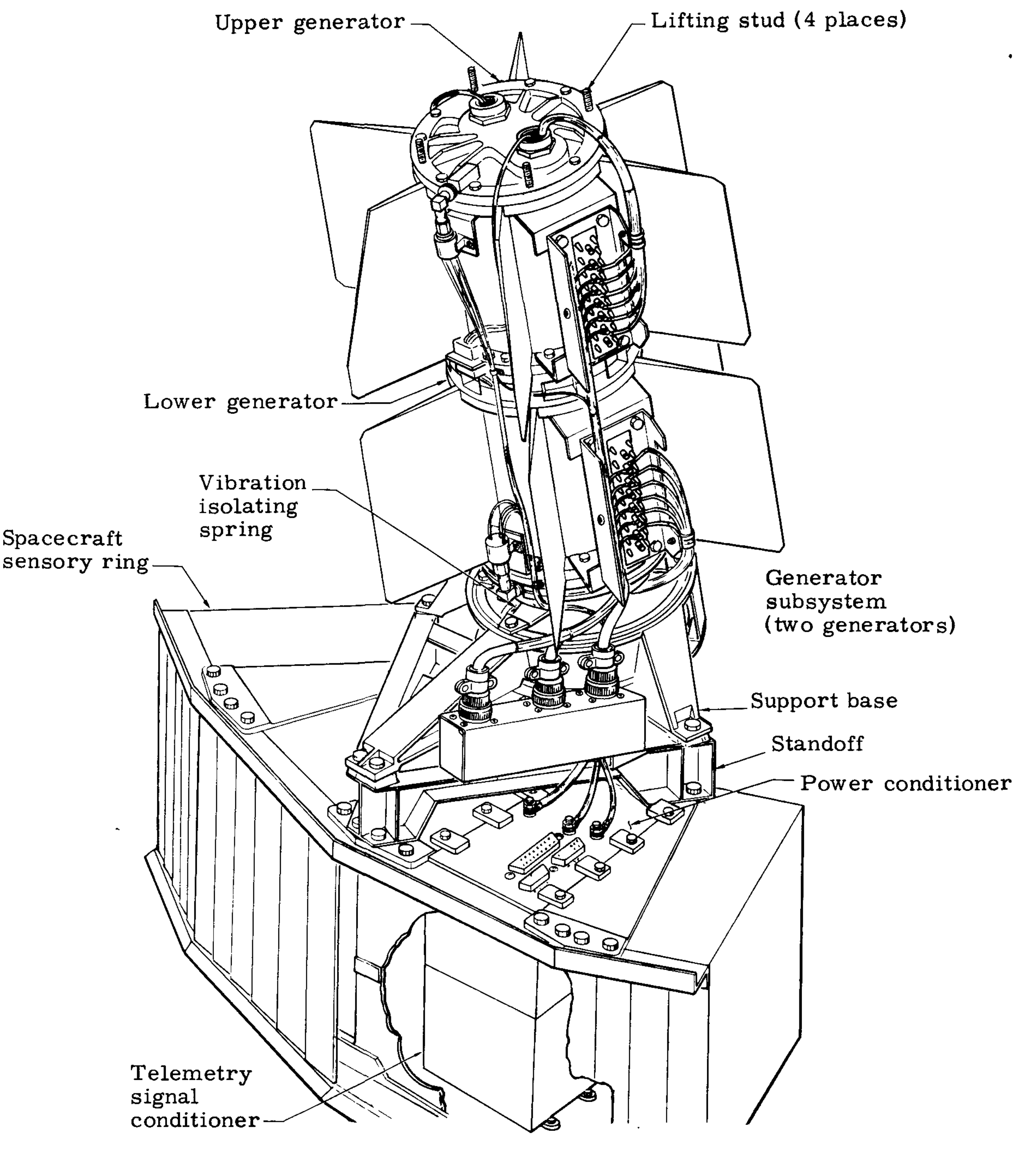


FIG. II-1. SNAP 19 ARRANGEMENT

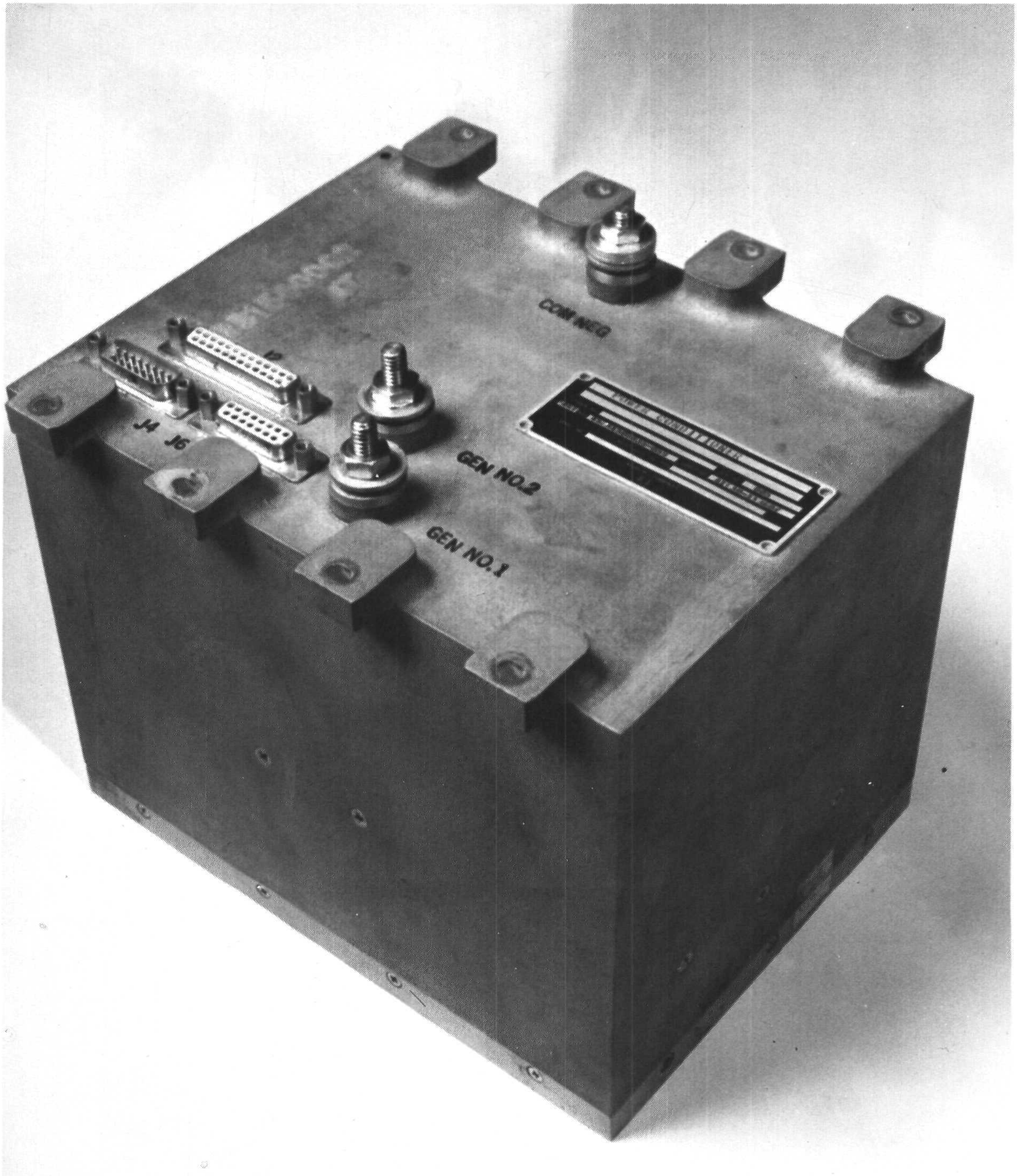


FIG. II-2. POWER CONDITIONER UNIT

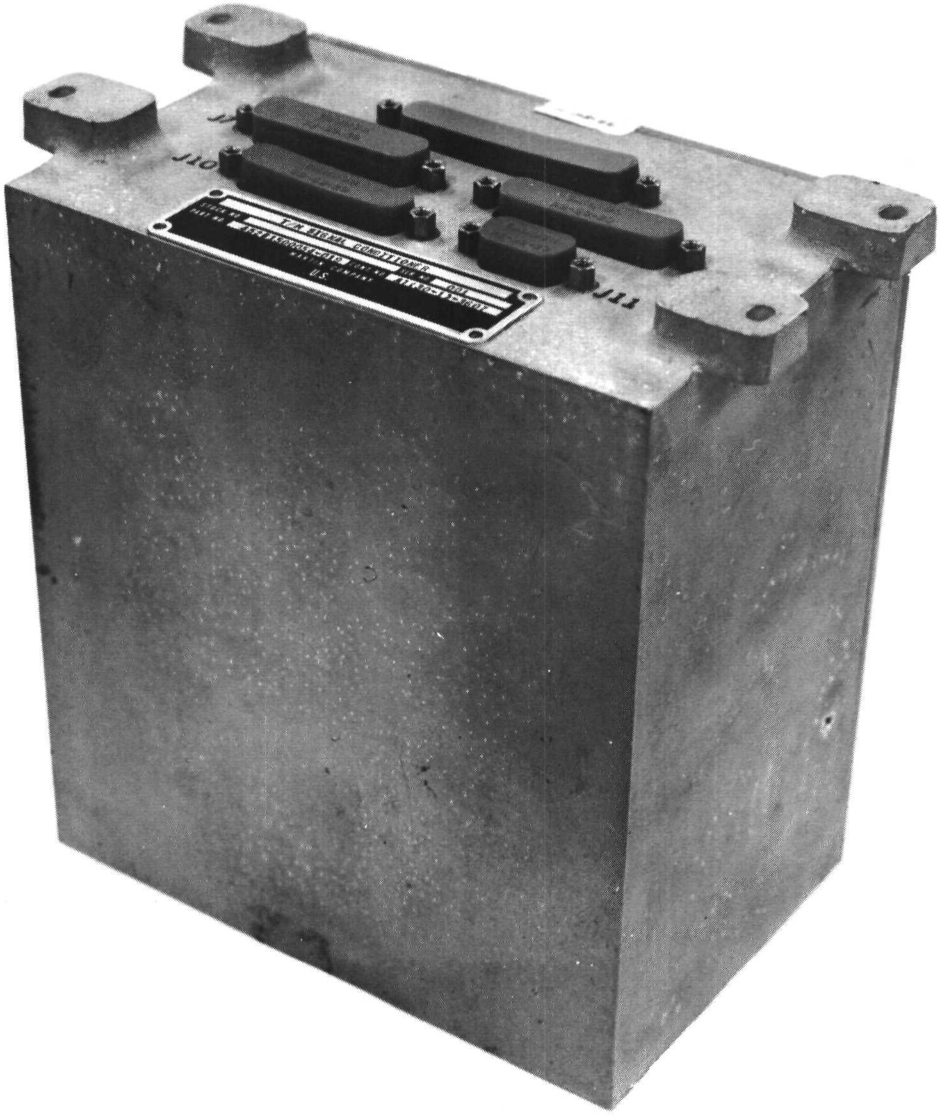


FIG. II-3. TELEMETRY SIGNAL CONDITIONER UNIT

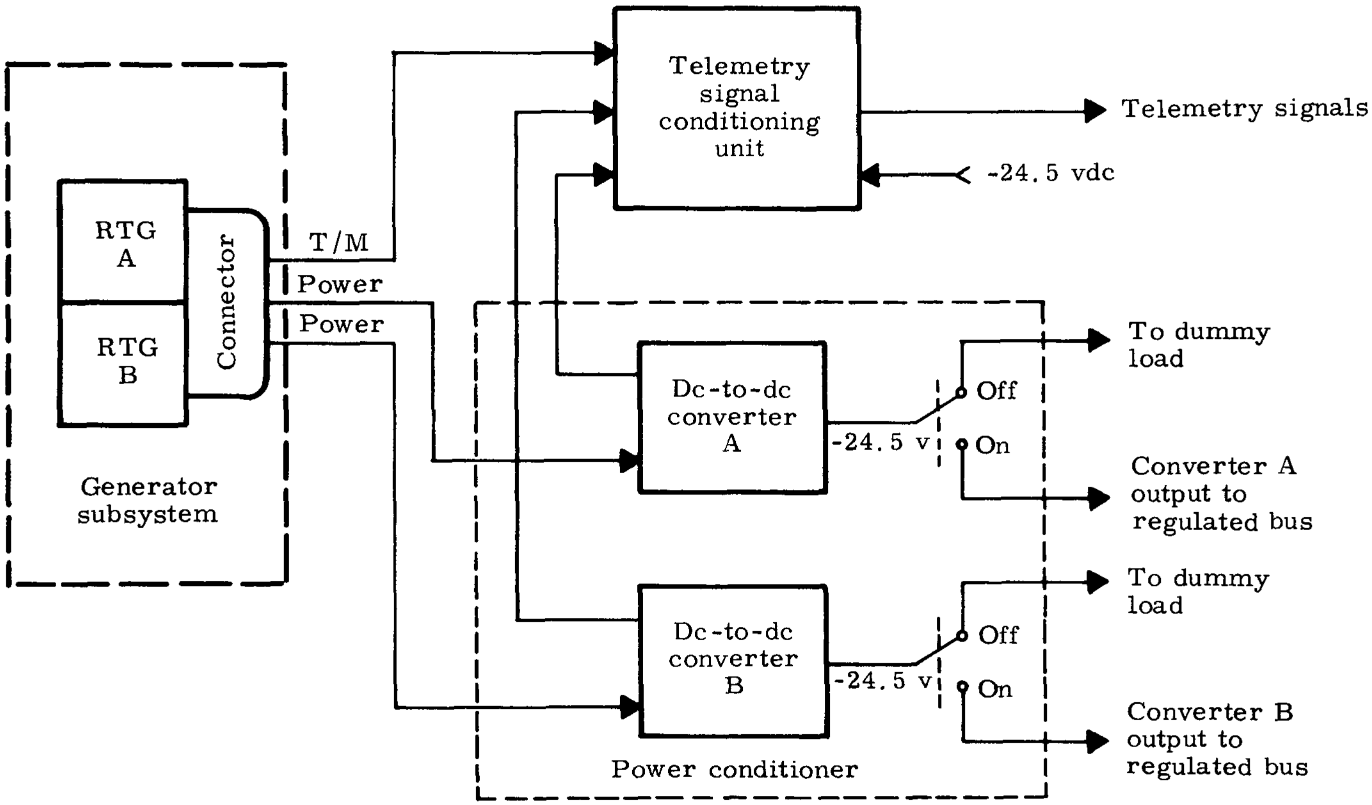


FIG. II-4. SNAP 19 POWER SUPPLY SYSTEM BLOCK DIAGRAM

The sensors and their corresponding conditioning circuits in the TSCU will provide data on the following system parameters:

Parameter	Data Points per Power Channel
Generator hot junction temperature	3
Generator fin root temperature	3
Generator internal pressure	1
Generator output voltage	1
Converter input voltage	1
Converter output voltage	1
Converter input current	1
Converter output current	1
Converter on-off regulated bus status	1
Converter internal temperature	1

The level of assessment of SNAP 19 performance in orbit will depend, in large measure, on the degree of effort and analytical sophistication applied to the task. Direct and derived performance characteristics will be available for evaluations ranging in scope from discrete point readings to interrelated, parametric, long duration, statistical studies.

In addition to providing for detailed analyses of normal system operation, the comprehensive array of telemetry data will yield malfunction detection information in the event of partial or total system failure.

4. System Utilization Summary

Eight generator subsystems, five power conditioner units and five telemetry signal conditioning units were utilized on the SNAP 19 program as identified in Table II-1 and Fig. II-5. Not included in these charts are generator subsystems S/N 1 (generators S/N 1 and 2) and S/N 3 (generators S/N 5 and 6) because these assemblies were not configured to function as part of a power system that included a TSCU. Also excluded from this listing are single generators S/N 17, 18, 19, 20 and 21, which were built and tested as endurance generators.

B. RADIOISOTOPE THERMOELECTRIC GENERATOR

The SNAP 19 radioisotope thermoelectric generator (Fig. II-6) is housed in a cylindrical shell 6-1/2 inches in diameter and approximately 10 inches long, with six tapered fins attached for radiating surface area. The unit produces approximately 30 watts, initially, and weighs about 30-1/2 pounds. Major components of the radioisotope thermoelectric generator (RTG) are the heat source, thermoelectric conversion system, housing assembly, instrumentation and wiring, and thermal insulation. Miscellaneous components are seals, getter assembly and assembly hardware items.

A Phase III generator utilization summary for subsystems is given in Table II-1. A discussion of each subsystem (Phases II and III) is given in Section IV-G, and endurance generator utilization is discussed in Chapter V of Volume III.

TABLE II-1

Phase III System Utilization Summary Chart

System No.	Type	Heat Source	Generator Subsystem S/N	Generator S/N	TSCU S/N	PCU S/N
2	Engineering development unit	Electrical	2	9, 10 (3, 4)[1]	2	3
4	Prototype	Dispersal	4	7, 8	5	6
5	Prototype	Electrical	5	15, 16[2]	4	4
6	Flight[7]	Dispersal	6	11, 12[3]	6	7
7	Flight backup[7]	Dispersal	7	13, 14	7	8
8	Engineering development unit	Intact re-entry	8	22, 23	--	6[5]
6A	Prototype	Intact re-entry	6A	11A, 12A[3]	--	--
8A	Flight	Intact re-entry	8A	22A, 23A[4]	--	6[6]

1. Generators S/N 3 and S/N 4 were built under Phase II, and were rebuilt under Phase III. Generators S/N 9 and 10 were transferred to system No. 2 from system No. 5. Generator S/N 3 was vibrated and diagnostically disassembled, and generator S/N 4 was placed on endurance test.
2. Generators S/N 15 and 16, which were to be endurance tested, were assigned to system No. 5, after generators S/N 9 and 10 were transferred to system No. 2.
3. Generators S/N 11A and 12A were transferred to system No. 6A from system No. 6 and were modified to accept the IRHS capsules.
4. Generators S/N 22A and 23A were transferred to system No. 8A from system No. 8.
5. PCU S/N 6 was transferred to system No. 8 from system No. 4 as a test tool only.
6. PCU S/N 6 was transferred to system No. 8A from system No. 8 as a test tool only.
7. This designation was dropped subsequent to selection of IRHS for the flight system.

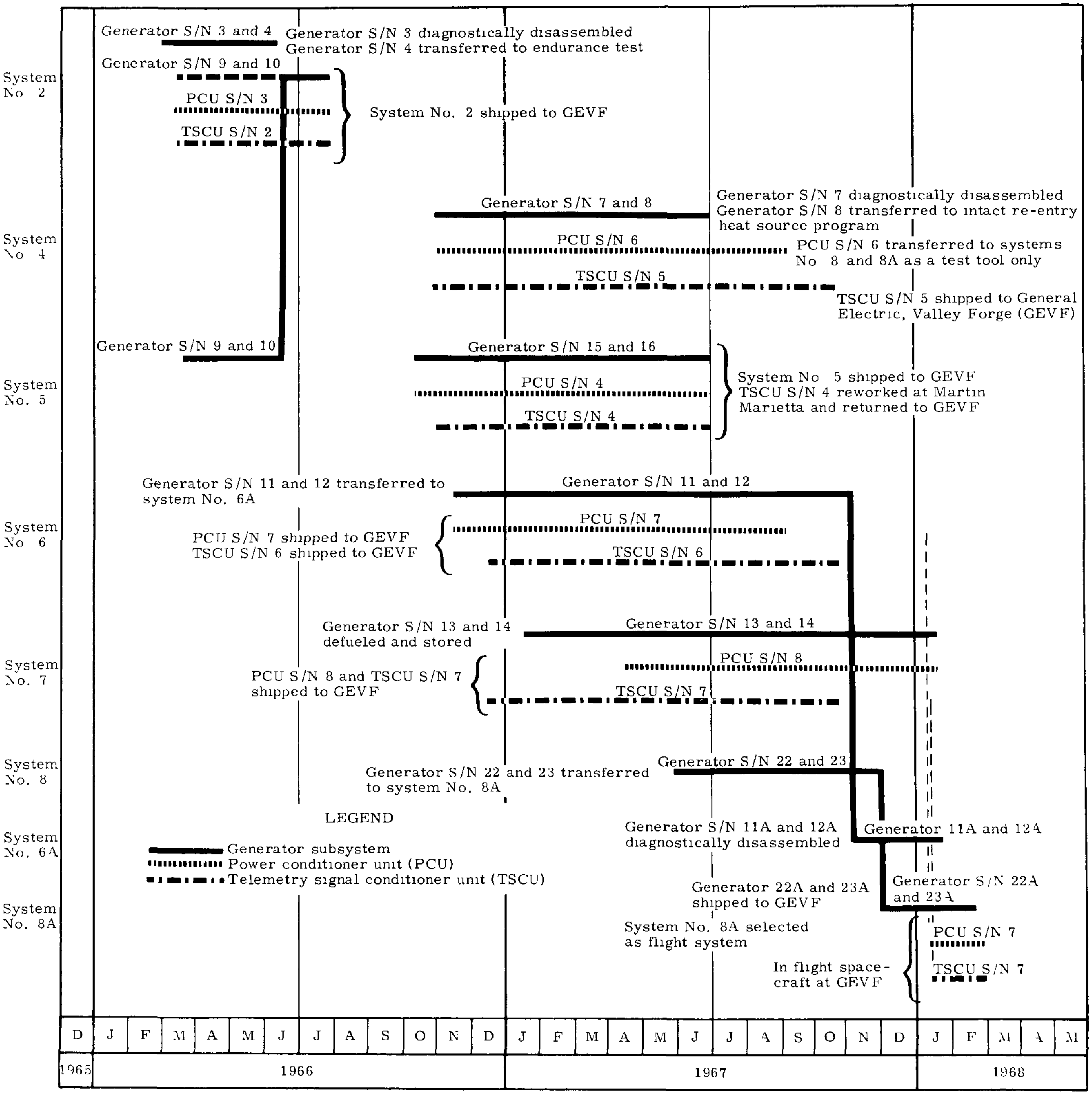


FIG. II-5. SYSTEM UTILIZATION SUMMARY BAR CHART

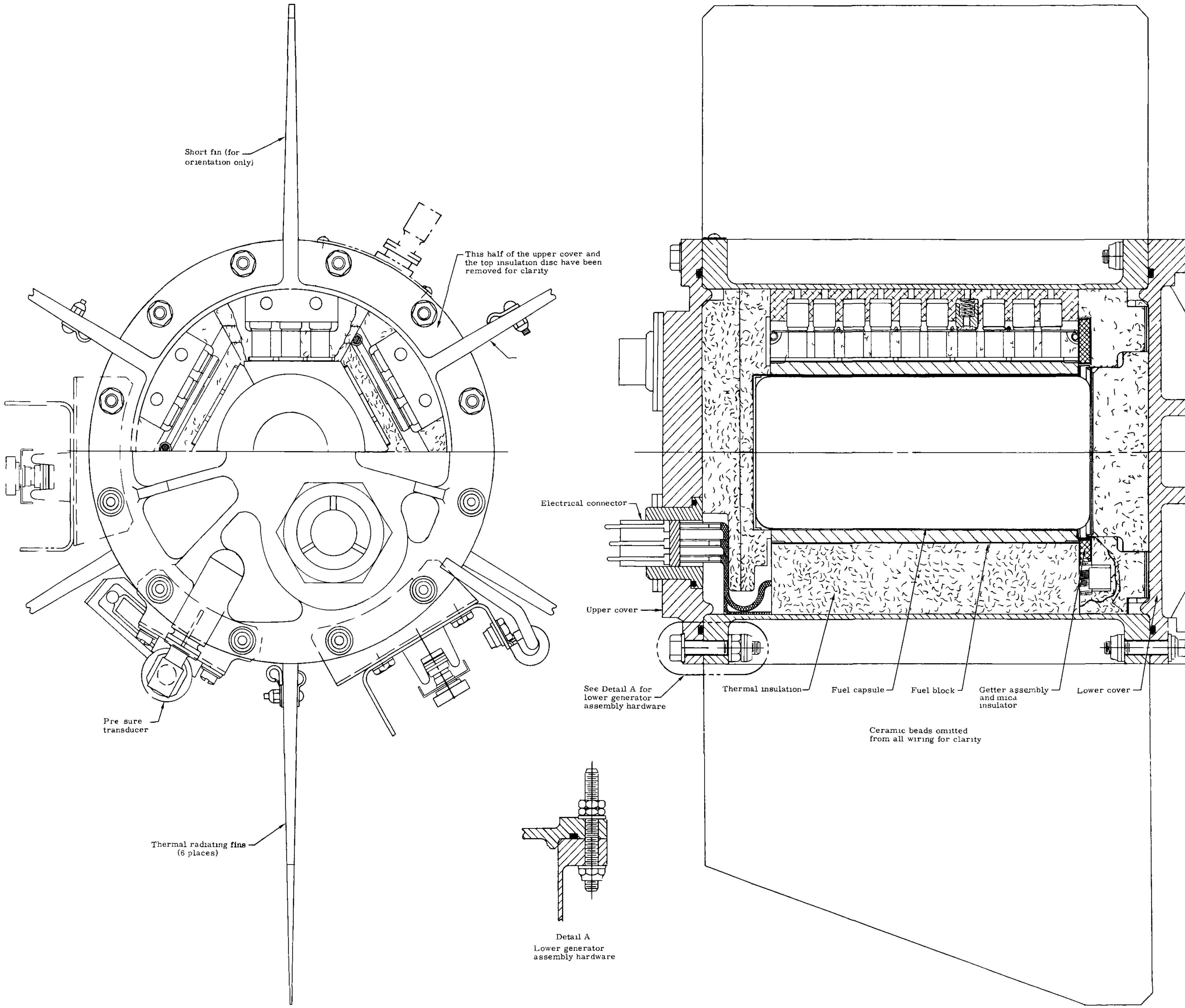


FIG. II-6. FUELED GENERATOR CONFIGURATION

1. Generator Characteristics

a. Thermal

The initial temperature profile of the generator is shown in Table II-2. Argon and vacuum cases are presented both in the electrically loaded and open circuited condition. All values cited are for the nominal 570-watt fuel loading per generator. The thermal efficiency of the generator is 90% (i.e., 10% parasitic heat losses).

TABLE II-2

Initial IRHS RTG Temperature Profile (°F)

Component	Argon, Normal Load	Vacuum,(1) Normal Load	Argon Open Circuit	Vacuum,(1) Open Circuit
Fin root	340	340	340	340
Cold junction	400	460	400	460
Hot junction	920	990	1160	1230
Heat distribution block	970	1090	1210	1330
Heat shield	1040	1280	1450	1460
Canister	1240	1730	1620	1840
Capsule	1430	1950	2960(2)	2030
Fuel centerline	2930(2)	(3)		(3)

(1) Assumes no sublimation damage to thermoelectric components

(2) Assumes argon fill gas only (essentially the case initially, after generator fueling)

(3) No thermal conductivity data available at low pressures.

At the end of one year in flight, all temperatures will be essentially the same as at the beginning, except that fuel centerline temperatures will be lower because of the presence of helium from the decay of plutonium.

In all cases, the 340° fin root temperature is an average value as experienced on the Nimbus B spacecraft. The fin root temperature will be ~360° F during maximum solar input and ~320° F in the absence of solar input. The corresponding Nimbus sensory ring temperature (on top of the mylar insulation) is -44° F and +170° F, with and without solar input. Thermal integration parameters used to determine these temperatures are listed in Table II-3.

TABLE II-3

Single RTG Thermal Integration Parameters

Casing diameter (in.)	6.5
Fin width (tip-to-root) (in.)	7.4
Fin height (in.)	8.9
Casing area (ft^2)	1.3
Perimeter area (ft^2)	3.9
Top cover area (ft^2)	0.2
Projected side area (ft^2)	1.3
Effective radiating area (ft^2)	3.6
Nimbus sensory ring top area (ft^2)	17.7

TABLE II-3 (continued)

View factor to sensory ring	0.25
Total view factor to Nimbus	0.40
View factor to space	0.60
Generator emissivity	0.85
Generator solar absorptivity	0.30
Sensory ring top surface emissivity	0.60
Sensory ring top surface solar absorptivity	0.30

b. Weights

The component weights for a fueled intact re-entry heat source (IRHS) generator are listed in Table II-4.

TABLE II-4

IRHS Generator Component Weights

Component	Weight (pounds)
Thermoelectric modules	4.57
Cold end hardware (less bars)	1.46
Heat sink bars	2.66
Housing and fins	7.00
Upper cover	2.11
Lower cover	1.44
Upper Min-K disk	0.39
Lower Min-K disk	0.41
Pressure transducer	0.19
Getter assembly	0.50
Nuts and bolts	0.47
Heat source (intact re-entry)	5.65
Heat distribution block	1.29
Heat source load distribution cups	0.16
O-rings	0.10
Miscellaneous (terminal board, 25-pin connector, wiring, etc.)	2.10
Total	30.5

c. Power-voltage-pressure

A SNAP 19 RTG with the 570-watt fuel loading produces about 29 watts as measured after fueling at orbital fin root temperature (~340° F). The power conditioner unit (PCU) input voltage is regulated to 2.6 ±0.1 volts dc by the Nimbus bus regulation of -24.5 ±0.5 volts dc and the turns-ratio of the transformer in the PCU. Wiring voltage drop back to the modules (just inside the feedthrough connector on the upper cover) causes the RTG to operate at 2.7 ±0.1 volt dc.

The power produced during storage and flight depends on the internal gas pressure and composition (which affect heat losses), the thermoelectric stability and time. Based on an exponential power-time model described by

$$P(t) = P(0) \exp\left[-\alpha' t\right]$$

where:

P = power (watts)

α' = thermoelectric degradation coefficient (hr^{-1})

t = time (hr),

thermoelectric degradation coefficients were determined for a number of generators at various hot junction temperatures. From these data and the pressure profile of the RTG (determined from the method described in Volume III under "Seal Performance"), power as a function of time was determined. Typical generator performance is shown in Figs. II-7 and II-8 for pressure and power, respectively. In this particular case, the leak rate is 1×10^{-4} scc/sec argon (normalized to 337° F fin root temperature and 14.7 psia pressure), storage time is six months (at a 260° F fin root temperature, typical of storage in the generator shipping container) and flight time is one year (at 337° F fin root temperature).

For all possible cases (various thermoelectric degradation rates and various leak rates), the powers in Table II-5 result. These values take into account the 1-watt Joulean line loss (per RTG) between the RTG and PCU and the minimum 89% PCU efficiency.

TABLE II-5

PCU Single-Channel Output Power Specifications

Time	Power
Acceptance (end of thermal vacuum test)	25 ± 4 watts
End of 6-month storage	92% ± 3% of power at acceptance
End of 12-month storage	85% ± 5% of power at acceptance
End of 1-year flight	77% ± 6% of power at end of storage

2. Heat Source

Each generator is fueled with about one kilogram of plutonium-238. The total fuel weight, including other isotopes of plutonium and impurities, is 1420 grams or 17,200 curies, which produces 570 thermal watts.

Heat source design objectives, development and supporting data are presented in Volume II (classified) of this report.

3. Thermoelectric Conversion Module

The thermoelectric conversion system initially converts approximately 6% of the thermal energy from the heat source to electrical power. Heat flows from the radioisotope fuel through lead telluride thermoelectric elements to effect the energy conversion. The thermoelectric circuit (Fig. II-9) consists of a total of 90 thermoelectric couples. The couples are arranged in 6 modules, each containing 15 couples. Each module is positioned adjacent to a flat surface of the heat distribution block, and the six modules are connected electrically in series. Within each module, the 15 couples are arranged in three electrically parallel circuits with five couples in each string.

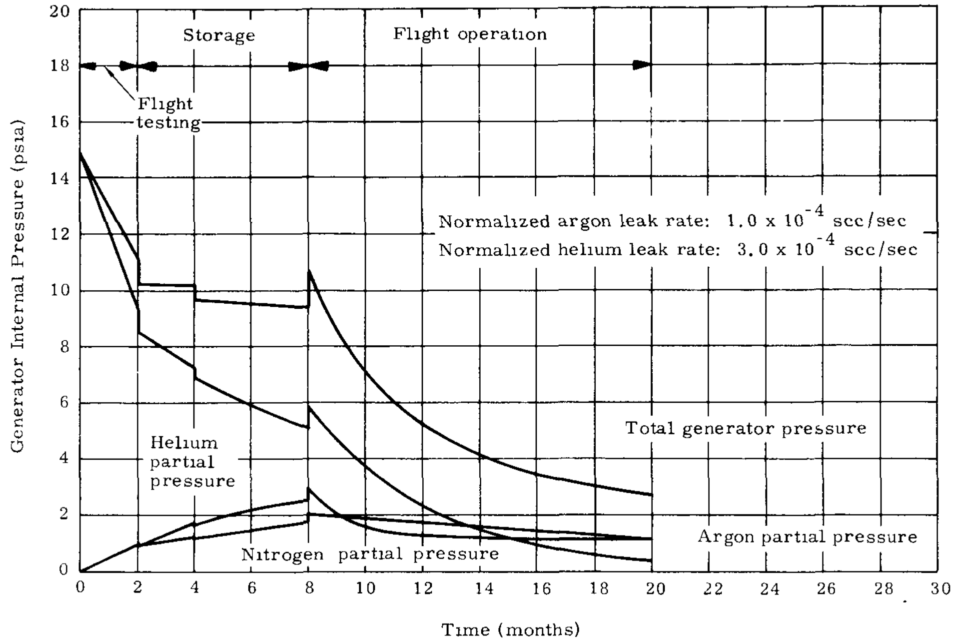


FIG. II-7. SNAP 19 IRHS GENERATOR INTERNAL PRESSURE PROFILE (SIX MONTHS STORAGE)--ARGON INITIAL FILL

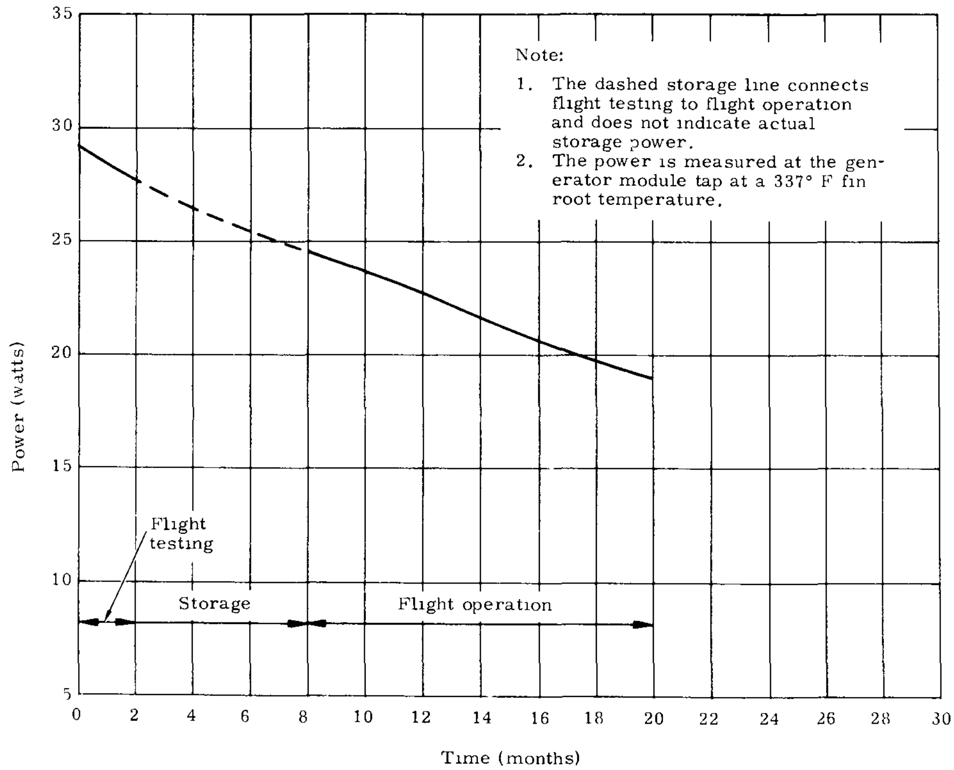


FIG. II-8. SNAP 19 IRHS GENERATOR PERFORMANCE PROFILE (SIX MONTHS STORAGE)--ARGON INITIAL FILL

The thermoelectric elements used in the SNAP 19 flight generators are cold-pressed and sintered lead telluride designated by 3M Company as TEGS-2N and TEGS-2P. The elements were sized, using a thermoelectric optimization computer program, and are 0.377 inch in diameter and 0.500 inch long. The elements (one N-type and one P-type) are metallurgically bonded to a common hot shoe and to individual cold shoes to form a thermoelectric couple. Additional information is given in Vol. III, Chapter II of this report. The couples are electrically interconnected on the cold side by gold-plated, oxygen-free copper straps after the individual couples are inserted into a block of Min-K thermal insulation to form a module. The six modules are connected in series by gold-plated, stranded copper wire. The hot shoes are electrically isolated from the heat distribution block by a 0.010-inch thick phlogopite mica strip. The thermoelectric couples are maintained in contact with the heat distribution block by spring-loaded cold end hardware.

The cold end hardware consists of alignment buttons, springs, pistons and heat sink bars (Fig. II-10). This hardware permits only compressive forces to act on the thermoelectric elements. An alignment button is adjacent to the copper connecting strap of each thermoelement. One side of the button is flat to permit radial movement and the other side is spherical to allow for angular misalignment. A spring-loaded piston with a concave surface bears on each alignment button to allow for axial movement and keeps the thermoelectric elements in compression. The springs and pistons are retained by a heat sink bar machined to match the generator housing inner diameter and to accept the pistons with minimal clearance to reduce thermal losses through this joint. The buttons, pistons and heat sink bars are made of 6061-T6 aluminum alloy, selected for its high thermal conductivity and light-weight characteristics, and are hardcoated (a Martin Marietta process which results in a thin oxide coating on the surface of the treated parts) to provide multiple electrical insulation barriers.

The thermoelectric element and couple specifications developed for the SNAP 19 program are discussed in detail in Vol. III of this report.

4. Housing Assembly

The generator housing assembly consists of a finned cylindrical case and top and bottom cover plates. The case is approximately 9 inches high by 6.5 inches in diameter and has a wall thickness of 0.093 inch. A flange is machined on each end of the case as an integral part of the housing. Each flange is 0.50 inch thick and 8.16 inches in diameter. Six fin stubs, also machined as an integral part of the housing, are located symmetrically around the case. The 0.30-inch thick stubs extend from the case outside diameter to the flange diameter. The heat-rejecting fins are welded to these stubs rather than to the casing to minimize weld distortion. The housing is machined from a 9.50-inch outer diameter by 5.75-inch inner diameter extruded tube of HM-31 magnesium-thorium alloy. Magnesium was chosen for the housing because it has low density, good structural characteristics and a high thermal conductivity.

The six fins are approximately 6.53 inches long, 8.86 inches high, and taper in thickness from 0.3 inch at the root to 0.03 inch at the tip. The fins provide approximately 5.5 ft^2 of surface area for heat rejection.

Final machining of the housing inner diameter and outer flange surfaces is accomplished after the six fins are welded in place. To provide spacecraft shroud clearance, the shape of four fins on the upper generator and two on the lower differ from the rectangular shape of the other fins.

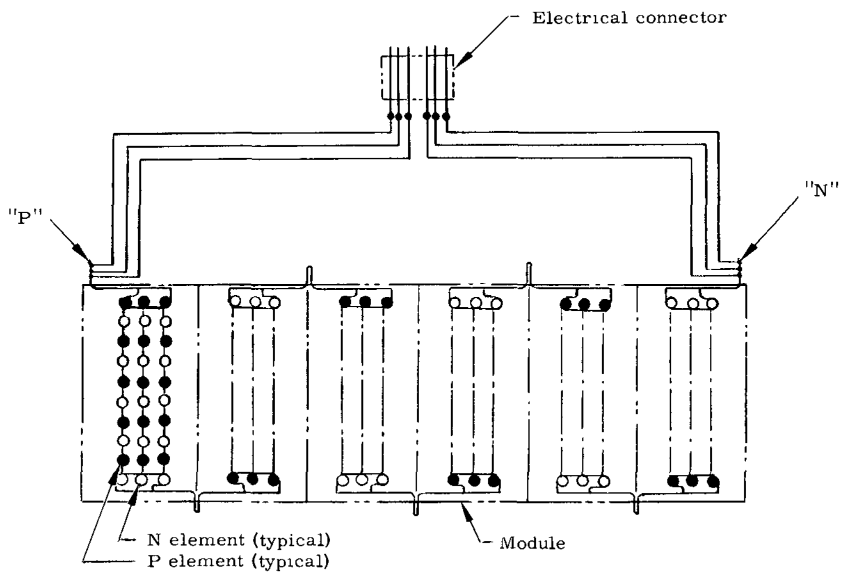


FIG. II-9. MODULE/GENERATOR ELECTRICAL SCHEMATIC

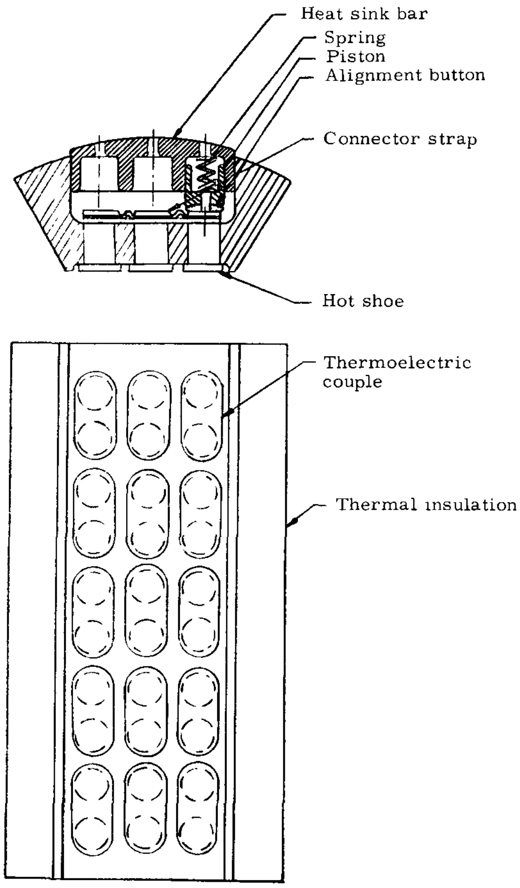


FIG. II-10. THERMOELECTRIC MODULE AND COLD END HARDWARE ASSEMBLY

Since the housing provides not only the heat rejection capability but also serves as a containment vessel to maintain an inert gas atmosphere for thermoelectric element protection, leakage must be minimized. O-ring seals are used for this purpose at the cover-housing interface. The O-ring grooves are machined in each cover, rather than the housing, to minimize the possibility of damaging the groove surfaces during the generator core assembly.

The upper and lower covers are fabricated from HM21A magnesium-thorium alloy, upset forged disks. The lower flight cover is a plain, ribbed disk with an O-ring groove. The ribbed design approaches the ultimate strength-to-weight ratio and the cover thickness in the area of the indentations is only 0.093 inch. When the unit is initially assembled, a variation of this lower cover--one containing an electrical connector and evacuation tube--is utilized to facilitate generator outgassing and conditioning. The flight lower cover is installed during the fueling operation after the outgassing cover is removed. Another function of the outgassing cover is to provide heater power during the fueling operation until the time of heat source installation to prevent an additional thermal cycle on the generator.

The upper cover is also a ribbed disk containing two raised bosses for electrical connector installation. The upper cover is fabricated with a machined port and welded elbow assembly, to which the pressure transducer for measuring generator internal pressure is attached. Each cover is bolted to the housing flanges by 12 titanium bolts.

All of these magnesium thorium details, after final machining, are grit blasted and deoxidized (or pickled) to prevent inherent chloride inclusions from reacting with environmental moisture. After pickling, the components are coated with a zirconium oxide--sodium silicate solution; this coating exhibits an emissivity of ~0.85 and a solar absorptivity of 0.2 to 0.3

5. Instrumentation and Wiring

Each flight generator contains instrumentation to provide the following data points:

(1) Five hot junction temperature indications--three by resistance temperature devices monitored during flight and two by chromel alumel thermocouples, for monitoring until time of launch.

(2) One generator internal gas pressure indication.

(3) Four generator fin root temperature indications--three to be monitored during the flight mission and one additional sensor for monitoring until time of launch.

(4) One generator output voltage indication.

Generator output current is also monitored, although no special sensors or wiring are provided in the RTG. (Transductors are provided at the input to the PCU.)

The resistance temperature device (RTD) is basically a hermetically sealed platinum coil whose resistance varies linearly with temperature at the rate of approximately 1 ohm per 5° F temperature change. The use of RTD's was predicated on the following characteristics:

(1) Small size

(2) Low power requirement

(3) No reference temperature junction required

(4) Extreme accuracy

(5) Fast response

(6) Good repeatability

(7) Radiation resistance

(8) Insensitivity to effects of space environment.

These units have an operating temperature range of from -250° F to +1800° F, with corresponding resistances of approximately 36 ohms and 432 ohms at those temperature limits. These units are attached by five spotwelds to an extension tab spotwelded to the underside of a thermoelectric couple hot shoe. Developmental aspects of the RTD's used in SNAP 19 are discussed in Volume III, Chapter VIII.

The hot junction thermocouples are formed using 26 gage chromel alumel premium grade thermocouple wire. The thermocouples are spotwelded to the thermoelectric couple hot shoe and are insulated with Al_2O_3 tubing in the high temperature area and with fiberglass sleeving elsewhere.

The generator internal gas pressure measuring instrument is a hermetically sealed, potentiometer-type absolute pressure transducer with a range of 0 to 60 psia. These stainless steel-housed units consist of three major parts: an input sensor (measurand), a measurand amplification system and an output system.

The pressure to be measured is applied to a port, which introduces the pressure to a capsule or measurand. The capsule is hermetically sealed by heliarc welding, except for the inlet orifice. Increasing the inlet pressure expands the capsule, which is designed so that it has only one degree of freedom (elongation, or capsule height increase). The capsule will expand linearly with increasing pressure, thus transforming pressure to linear mechanical motion. Movement of the capsule is generally insufficient to cover the entire resistance element employed in the output circuit. A unique multiplication system rotates a wiper arm through the required angle to sweep the resistance element. A potentiometric output is accomplished by angular displacement of the precious metal wiper arm traversing the precision wire-wound resistance element.

The fin root temperature sensing instruments are thermistors. The thermistors are thermally sensitive, resistor probe-type units with a negative temperature characteristic typical of semiconductor materials. The thermistor leads are platinum, and the sensing probe is sealed in a glass bead. The units have an operating range of -58° F to +572° F. The thermistors are installed at the generator fin root into an 0.060-inch diameter hole approximately 0.093 inch deep and are cemented in place. The cement has one of the highest thermal conductivities of any type adhesive and, since the sensing probe is sealed in a glass bead, a good dielectric is not required. The platinum lead wires are spliced and soldered to 24 gage, stranded copper, teflon-insulated wires. Each lead of the thermistor is insulated with fiberglass sleeving. The thermistor leads are clamped to the generator housing close to the splice joint and at other places to prevent inadvertent extraction and vibration damage to these sensors.

The voltage taps are a single strand of gold plated copper power lead wire attached at the crimp joints of the P and N module circuit legs; they exit the generator through the generator output power plug. Externally, the voltage tap wiring is teflon-coated, stranded copper, 24 gage wire.

The only other wiring internal to the generator is that used to interconnect the thermoelectric modules and to connect the module circuit to the electrical feed-through connector on the upper cover. This wiring is 14 gage, gold-plated, stranded, bare, oxygen-free copper wire. In the area from the module to the connector, the wire is insulated with alumina beads, over which fiberglass sleeving is installed. All electrical connections to the module circuit are crimped connections, which provide a mechanical joint superior to a solder connection.

All soldered connections at the electrical feedthrough connector (other than thermocouples) are made using 100% pure tin solder with a liquid soldering flux. The thermocouple wiring is pretinned with ASMC flux and solder, and washed with water to remove any excess flux or residue prior to soldering.

All external wiring (other than thermocouples) is stranded, silver-coated copper, unshielded wire insulated with polytetrafluoroethylene. The external thermocouple wiring is 24 gage, stranded, shielded, thermocouple extension wire.

The potting compound used at the connectors is a two-part silicone rubber mixture which has excellent stability at high temperature (350° F) and linear shrinkage of less than 0.2%. A primer is used to promote adhesion to the connector shell, and the teflon insulated wires are treated with an agent also to promote adhesion of the silicone potting compound.

The electrical connectors on the RTG upper cover, through which all internal wiring exits, are inserted from the underside of the cover and sealed with O-rings. This feature allows removal of the upper cover without disturbing internal wiring. The connector shells are stainless steel and the insulated insert is a special glass compound. The contacts are gold-plated copper, pretinned with pure tin solder and have a 50-megohm minimum resistance between contacts or between contacts and shell.

The power leads (Fig. II-11) from the upper cover terminate in an eight-stud terminal board. The four upper studs and the four lower studs are connected by copper straps to form two groups of four studs each. This arrangement provides four common connectors for the (+) leads and four common connectors for the (-) leads. Three of each are used for the six power-out leads, leaving one (+) and one (-) stud open. These connections are used to place the unit on short circuit while undergoing testing on an individual generator. Each power lead has a lug crimped on the stud and is retained by a washer and nut. This terminal board is mounted on the generator side, between the two end flanges.

All flight instrumentation externally terminates in a miniature, rectangular, 25-pin connector on a special bracket at the generator lower flange (Fig. II-11). The connector shell is gold-plated copper with an insert of diallyl phthalate and gold-plated copper contacts. A silastic sealing gasket is used between mating connectors retained with special mounting hardware.

6. Insulation

The primary thermal insulation used in a SNAP 19 generator is Johns Manville Min-K 1301. Min-K is a bonded structure reinforced with fibrous media and containing appreciable quantities of particulate matter, the ultimate structural elements

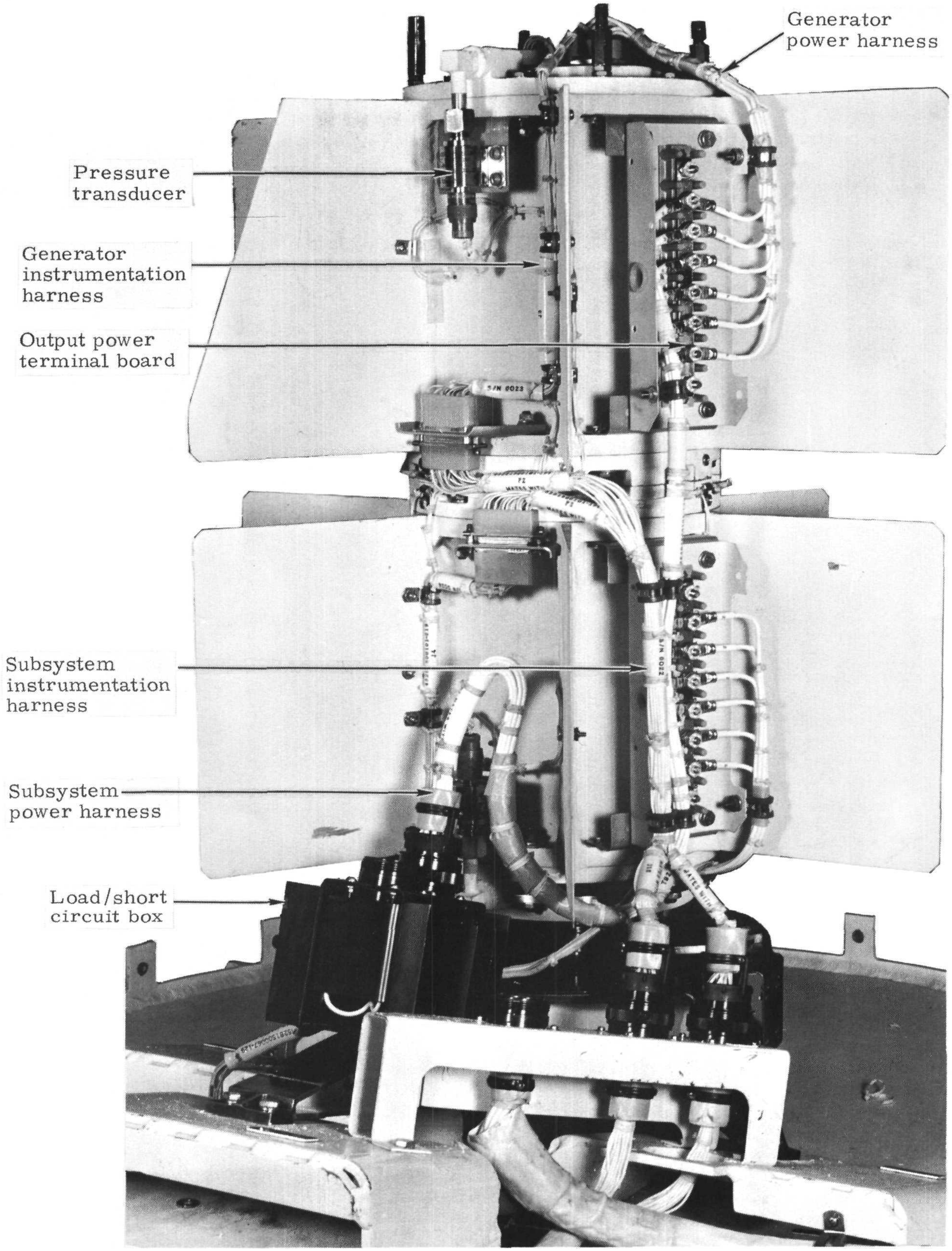


FIG. II-11. SUBSYSTEM WIRING AND CONNECTOR IDENTIFICATION of which are exceedingly small. This creates pores in the structure so minute that the amount of thermal energy transferred by molecular conduction is reduced well below that which would occur in conventional insulations where the pore sizes are orders of magnitude larger. Density of the material used in SNAP 19 is 20 pcf. The insulation used around the thermoelectric elements in each of the six modules is procured as a molded piece with hole locations for the 15 couples and the intricate outer periphery molded in the part. A plot of thermal conductivity of the material is shown in Fig. II-12.

Besides its exceptionally low thermal conductivity, the material possesses good compressive strength and is used in the RTG to provide a preload on the heat source. Since the manufacturer's structural properties data were rather limited, particularly in the area of dynamic characteristics, a test program was conducted at Martin Marietta in 1964 to determine the static and dynamic structural properties of Min-K 1301 as a function of both temperature and specimen restraint. The test results are reported in Ref. II-1.

From the tests run, an average spring constant was determined as 12,500 pounds/ inch and the modulus of elasticity as 5400 psi. These values, in conjunction with the ultimate strength and yield point, were used to establish the heat source preload.

To preload the IRHS heat source, the Min-K insulation is gaged to protrude 0.032 to 0.040 inch beyond the lower housing flange when the unit is in the heated condition in the fueling facility. The lower cover is installed, producing a preload on each end of the IRHS heat source (taking areas into account) of 323 to 398 pounds. This force is sufficient to withstand 108 to 132 g (well in excess of the 43-g maximum expected).

Prior to using Min-K details in the generator, they are outgassed or baked out in either an evacuable chamber or vacuum furnace at a temperature of 1050° F to drive off any organic binders or other contaminants that may be present in the material.

In addition to the Min-K insulation, the only other thermal insulation used is Refrasil, manufactured by H. I. Thompson Fiberglass Company. This material, procured in the form of fiber batting or felt, is used to fill void areas in the Min-K insulation, such as around instrument leads, connector cutouts, etc. This material, selected because of its flexibility, low thermal conductivity and low density properties, is composed of vitreous fibers nominally 0.00005 inch in diameter, and having up to 99% SiO_2 content. The material, commonly referred to as AAA or AAAA insulation, is white, and similar in appearance to glass textiles.

Electrical insulation used inside the generator is of two types. Ceramic beads of high-purity Al_2O_3 cover bare wiring in the generator hot zones, while woven unimpregnated fiberglass containing no organic resins is used for cooler areas.

7. Other Components

Among the more important of the miscellaneous generator components are the getter assembly and the seals.

The annular getter assembly absorbs any oxygen in the generator which may evolve during outgassing of various materials or which may permeate through the seals from surrounding air. The getter is contained in a Type 321 stainless steel annular cup, and an extremely fine (200 mesh) Type 316 stainless steel cloth is welded over the top of the cup. Approximately 0.30 pound of high purity zirconium sponge getter material is contained in each assembly. Since the getter is more effective at higher temperatures, it is located directly under the heat distribution block and is electrically isolated from the module circuit by 0.010-inch thick mica rings.

The generator cover seals are Viton O-rings. Viton is a synthetic elastomer consisting of a linear copolymer of vinylidene fluoride and hexafluoropropylene. The compound has good radiation resistance when exposed to levels less than 1 x 10^7 roentgens. Analytical and experimental data on the Viton seals are presented in Chapter VII, Volume III.

The only other seal used on the RTG is at the pressure transducer tube connection (Fig. II-13). The seal joint is achieved by use of commercially available mechanically compliant ferrules, as in a flareless tube connection. This configuration was developed for the SNAP 11 program and refined for SNAP 19 usage wherein the acceptable leak rate of 1 x 10^{-7} cm^3/sec of helium has been established. This leakage is negligible in comparison to the permeable Viton seals, where a leak rate of 1 x 10^{-5} cm^3 of argon in allowable.

All of the SNAP 19 flight generators are outgassed to assure the internal cleanliness of the unit, leak tested to demonstrate seal integrity and then backfilled at temperature with 99.95% pure argon. The argon provides an inert atmosphere for the thermoelectric elements and limits the parasitic heat losses through the Min-K insulation to approximately 10% of the fuel inventory (i.e., the RTG has a thermal efficiency of ~90%).

8. Generator Assembly Tool

The generator core assembly tool is a unique assembly which permits the complete core to be assembled and checked prior to insertion in the generator housing. (The core includes the heat distribution block; six thermoelectric modules; 180 pistons, alignment buttons and springs; six heat sink bars, and six mica insulating sheets.)

A complete generator core assembled on the tool is shown in Fig. II-14. A series of six radially retracting and expanding arms engage the heat sink bars at top and bottom in holes machined for this purpose. A center shaft positions the heat distribution block and, when rotated, causes the arms to retract, compressing all of the module springs until the diameter formed by the heat sink bars is less than the housing inner diameter. The Min-K between the heat sink bars is sanded until the complete assembly can be fitted through a ring gage. Stops in the retracting mechanism prevent overcompression of the springs. The core is then inserted into the housing and the tool positions the core the proper distance from the end flanges and aligns the heat sink bars so that they are centered on the generator radiating fins. The heat sink bar engaging arms are then expanded until the bars are in contact with the housing. The two end assemblies of the tool are then removed and the center shaft withdrawn. The module spring pressure then maintains all of the components in their relative positions until the RTG assembly is completed.

9. Electrically Heated Generator

The previous discussions on the fueled generator apply to an electrically heated generator, except for the heat source and external wiring. The discussion of external wiring for the electrically heated subsystem (Section II-C-5) also applies to a single generator. Two electrical heat source configurations were used in SNAP 19 generators. The first, developed during Phase II, was used in Phase II generator subsystems S/N 1 (generators S/N 1 and S/N 2), No. 2 (generators S/N 3 and S/N 4 from Phase II) and No. 3 (generators S/N 5 and S/N 6). The second type, developed during Phase III, was used in generator subsystems No. 2 (rebuilt generators S/N 3 and S/N 4, from Phase III, and generators S/N 9 and S/N 10), No. 5 (generators S/N 15 and S/N 16) and the remaining endurance test generators (S/N 17, 18, 19, 20 and 21). In addition, certain cartridge heater modifications discussed in detail in Volume III, Chapter IV were made to the heaters at generators S/N 5, 15, 16, 17, 18, 19, 20 and 21 to increase heater life. Further modifications, also discussed in Volume III, Chapter IV, were made to the heater block in generators S/N 15 and S/N 16 to enable these electrical heat sources to withstand the vibration environment for

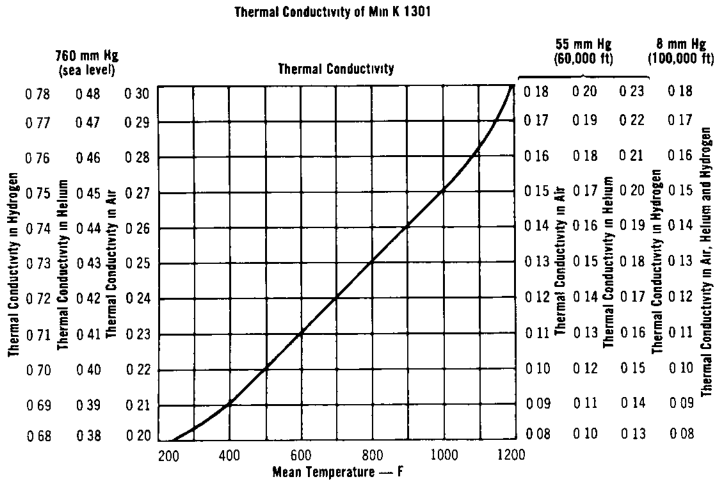


FIG. II-12. THERMAL CONDUCTIVITY OF MIN-K 1301

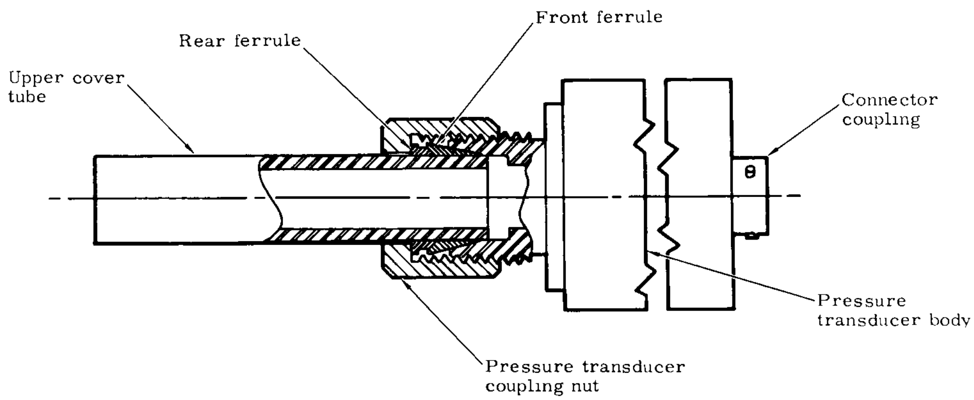


FIG. II-13. PRESSURE TRANSDUCER SEAL METHOD

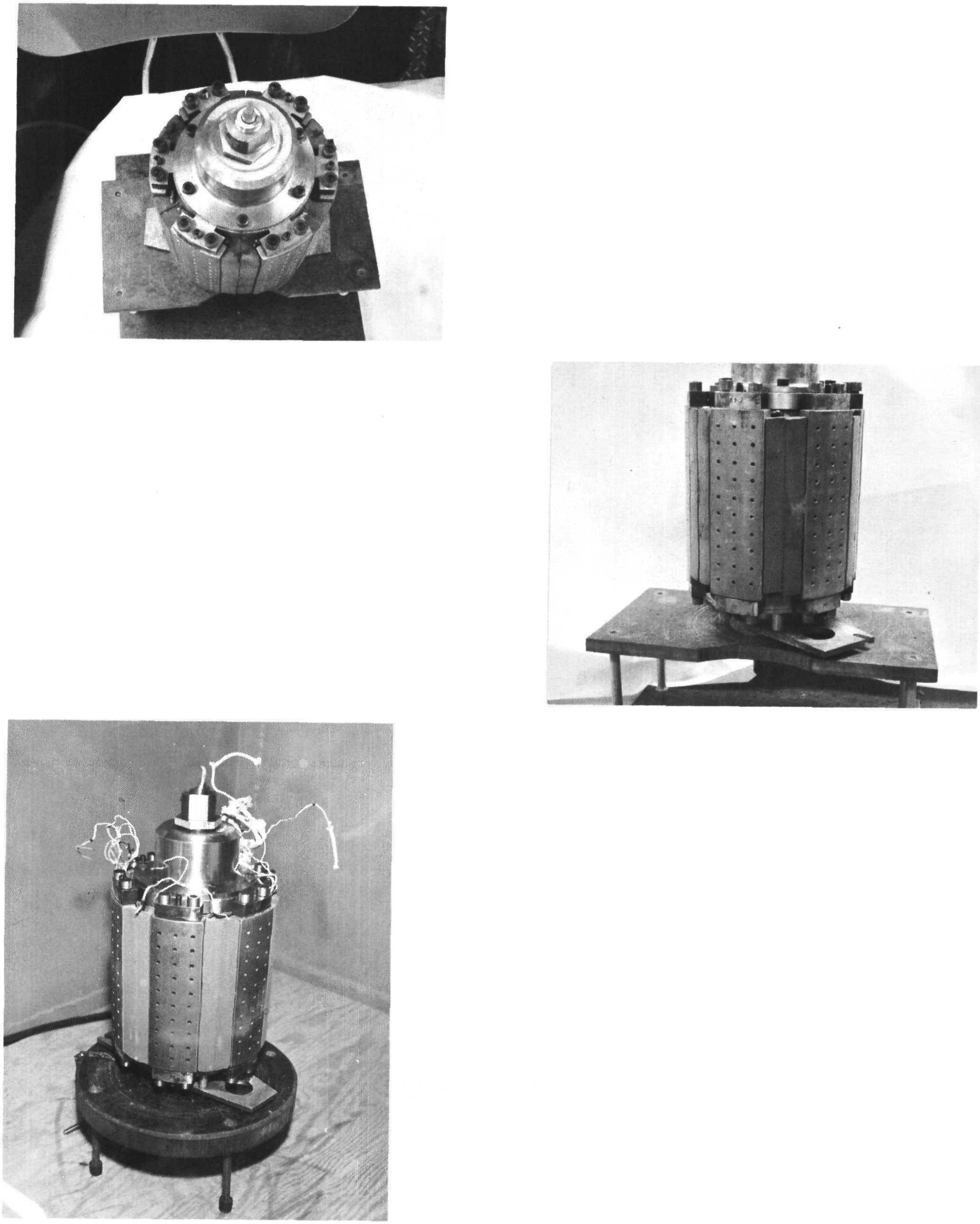


FIG. II-14. GENERATOR CORE ON ASSEMBLY TOOL those generators. These improvements included tack welding the cartridge heaters to the block, adding load distribution cups to each end of the heat source and restraining the primary input leads.

The Phase III electrical heat source is cylindrical steel block (Fig. IV-2, Volume III), housing six electrical heaters. This block and heater assembly simulates the size, weight, center of gravity and thermal inventory of the SNAP 19 dispersal fuel capsule. The heaters are Inconel-sheathed, with 15 AWG nickel leads at each end. The 6 heaters are wired in parallel, each capable of producing 225 watts at 115 volts ac. The heater leads are connected to the heater circuit by crimp-joining the solid lead to a stranded bundle close to the heater end. This type of joint permits thermal expansion without stressing the wiring connections at the bundle.

The Phase II heater block employes a seven-piece graphite block instead of the steel heater block. The cartridge heaters fit into small-diameter steel tubes inserted into the graphite block. In endurance generator S/N 5, which suffered a heater failure in Phase III, the old-type cartridge heaters were replaced with the modified versions, as discussed in Volume III, Chapter IV.

C. GENERATOR SUBSYSTEM

1. Subsystem Configuration

The generator subsystem consists of two radioisotope thermoelectric generators mounted in tandem on a support base and standoff assembly (Fig. II-15). The generator subsystem was designed to be compatible with the Nimbus spacecraft, its subsystems, the launch vehicle, and the launch and ground support equipment. (The interface design parameters are discussed in Chapter III of this report.) The ease of installation on and removal from the spacecraft makes generator subsystem removal after preshipment checkout practicable, thus avoiding transporting the spacecraft with fueled generators aboard.

A summary tabulation of Phase III generator subsystems built under the SNAP 19 program is given in Table II-1.

2. Mechanical and Electrical Connections

a. Mechanical connections

There are three principal sets of mechanical connections made in the assembly of a generator subsystem: joining one generator to the other, attaching the pair of generators to the support base and attaching the support base to the standoff.

The two generators are joined by six 1/4-inch diameter bolts secured by self-locking nuts bearing on the underside of the lower generator upper flange.

The generator pair is attached to the support structure by the 12 studs that secure the lower cover on the lower generator. A self-locking nut on the upper end of each stud bears on the generator flange. At the lower end of the stud, bearing on the generator cover, is a nonlocking nut which is jammed by another nonlocking nut. These two nuts, in addition to securing the cover to the housing, act as a spacer to reduce generator heat conductance to the spacecraft. That part of the stud projecting beyond the two nuts passes through the support base and is secured by a self-locking nut to attach the generators to the base.

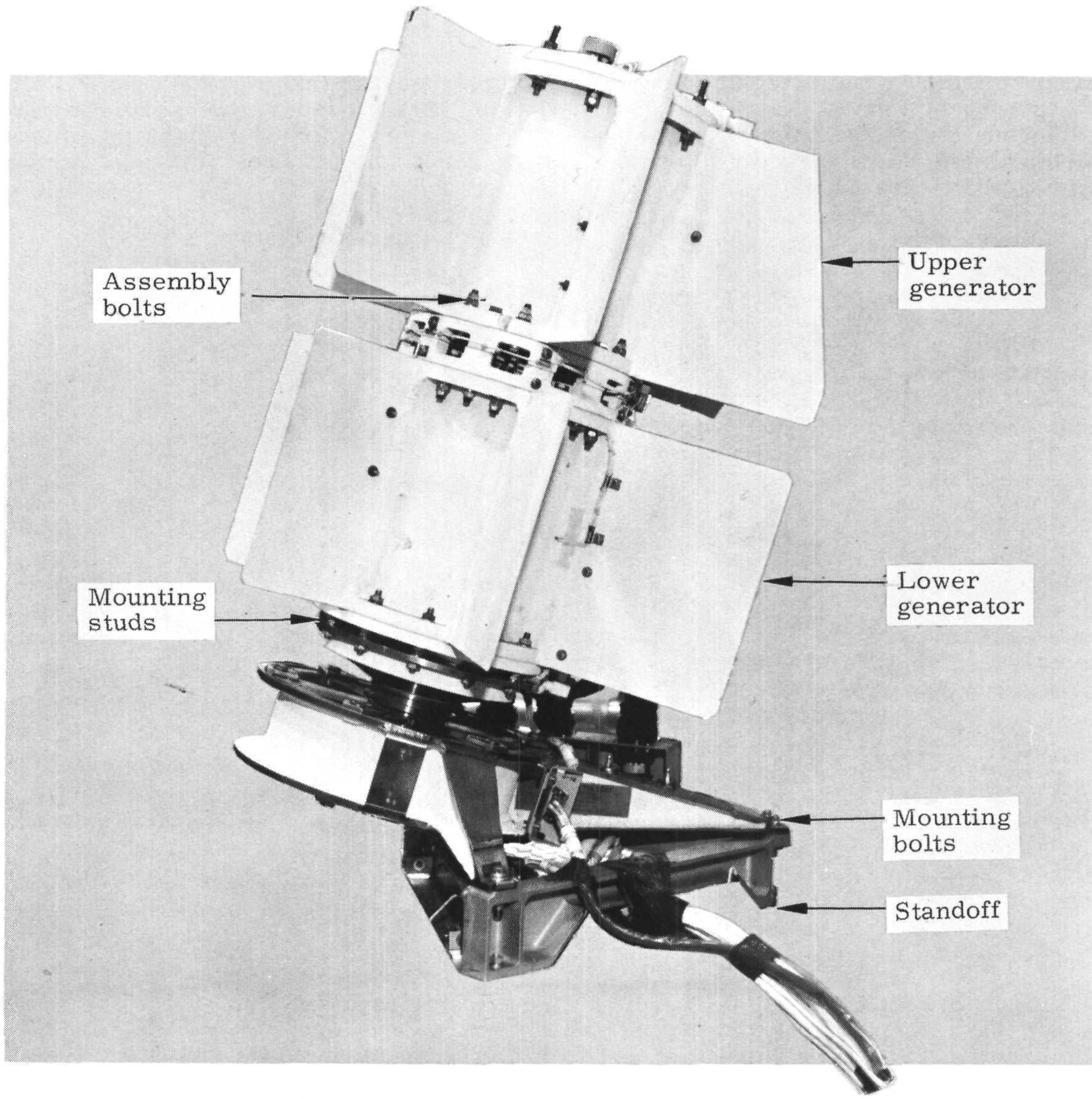


FIG. II-15. GENERATOR SUBSYSTEM CONFIGURATION

The support base (a tripod) is attached to the standoff by bolts engaging self-locking, elliptical anchor nuts on the underside of the standoff pads. Anchor nuts were used because there is no access to the underside of the standoff mounting surfaces when the spacecraft insulation is installed around the standoff. Locking torque in these all-metal nuts is produced by deformation of the reduced-diameter portion of the nut body (a turret-like section at the top of the nut). The deformation is caused by thread flank and crest contact as the bolt enters the restricted (elliptical-shaped) portion of the nut. The contact pressures depend upon the degree of ellipticity, the proportions of taper, metal hardness and bolt tolerances. Repeated mating and uncoupling of the subsystem and standoff causes reduction of the locking effect; therefore, the bolts are safety wired. The two forward bolts are wired together; the two rear bolts are wired to a special tab washer under the head of each bolt.

The assembled, fueled subsystem without the standoff weighs 86.1 pounds.

b. Electrical connections

The generator subsystem electrical connections are provided by four separate prewired harness assemblies. These harnesses and associated connectors (designated by P and J numbers) on a fueled subsystem are shown in Fig. II-16, and those on an electrically heated subsystem are shown in Figs. II-17 and II-18.

Two of the four cable assemblies carry the subsystem power output and two are for all of the subsystem instrumentation. One harness is wired for paralled connection of the 6 power-out leads from each generator and terminates in a 12-pin female plug (P1) with crimped joints to mate with the male plug (J17) on the standoff assembly (Fig. II-18). At the other end, this power harness terminates in crimped lugs connected to the generator terminal board studs. The lugs mate with the terminal board studs over the lugs and nuts that are already on the board from the generator unit. A locking nut holds the lugs in position. All of the wiring is 12 gage, teflon insulated, stranded copper wire; and the harness is formed by lacing the wires into a bundle.

The second power harness assembly mates with the generator output harness at the J17-to-P1 interface and terminates in three lugs (Fig. II-19) which mate with the power conditioning unit (PCU). The lugs, crimped to the power leads, are specially shaped to ensure correct connection to the PCU. The six positive leads (three from each single generator) are crimped into one lug, and the six negative leads are crimped into the two lugs (three from each generator per lug). This harness is a permanent part of the standoff assembly, with the J17 connector flange mounted on a bracket welded to the standoff.

The generator subsystem instrumentation cabling begins at the 25-pin miniature rectangular connector furnished with each generator and terminates in three other connectors. Two of these connectors, P8 and P9, contain 19 pins and mate with connectors J18 and J19 on the standoff assembly (Fig. II-19). All flight instrumentation wiring is routed through these two connectors. The third connector, J12, which is on the side of the support structure, is the termination point for the four hot junction thermocouples (two from each generator). This 9-pin miniature rectangular connector is the same type as the 25-pin connectors on the generators. There are no mates furnished with this connector, since thermocouples are not flight instrumentation. All joints on this cable are crimped connections. These five connectors and interconnecting wiring are fabricated as a single wiring harness.

A mating cable for the flight instrumentation (Fig. II-19) contains the two 19-pin crimped connectors, J18 and J19, and is a permanent part of the standoff assembly.

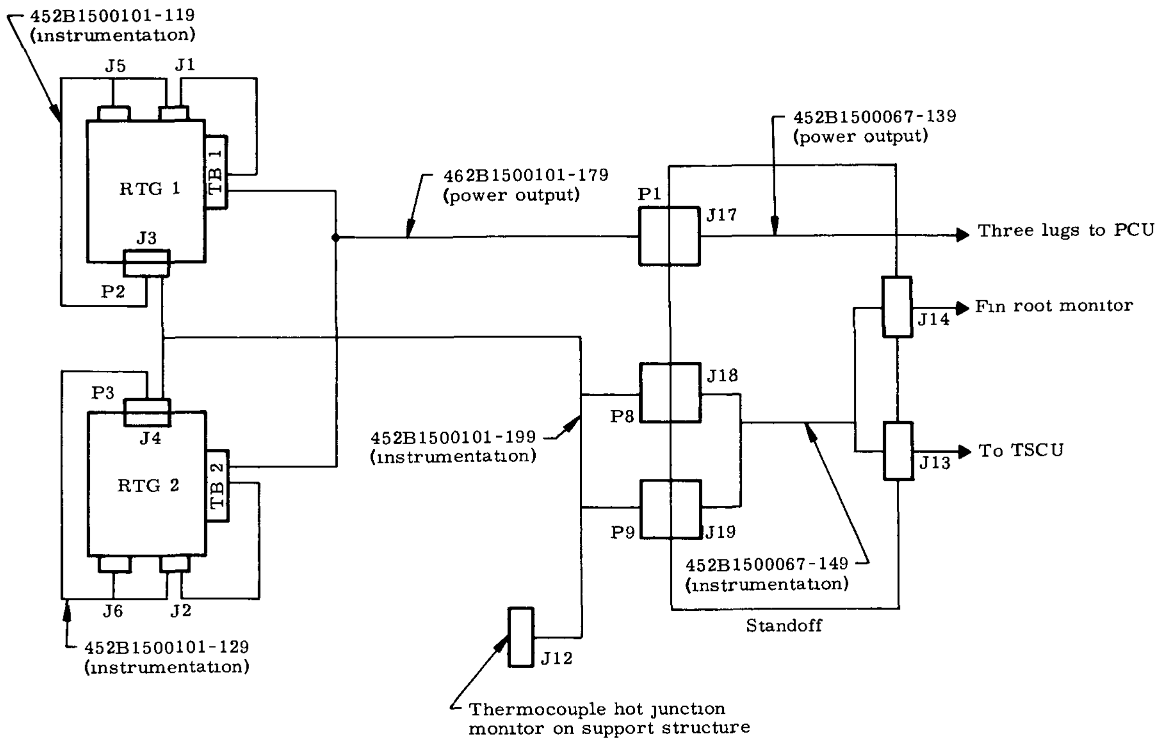


FIG. II-16. FUELED SYSTEM HARNESS SCHEMATIC

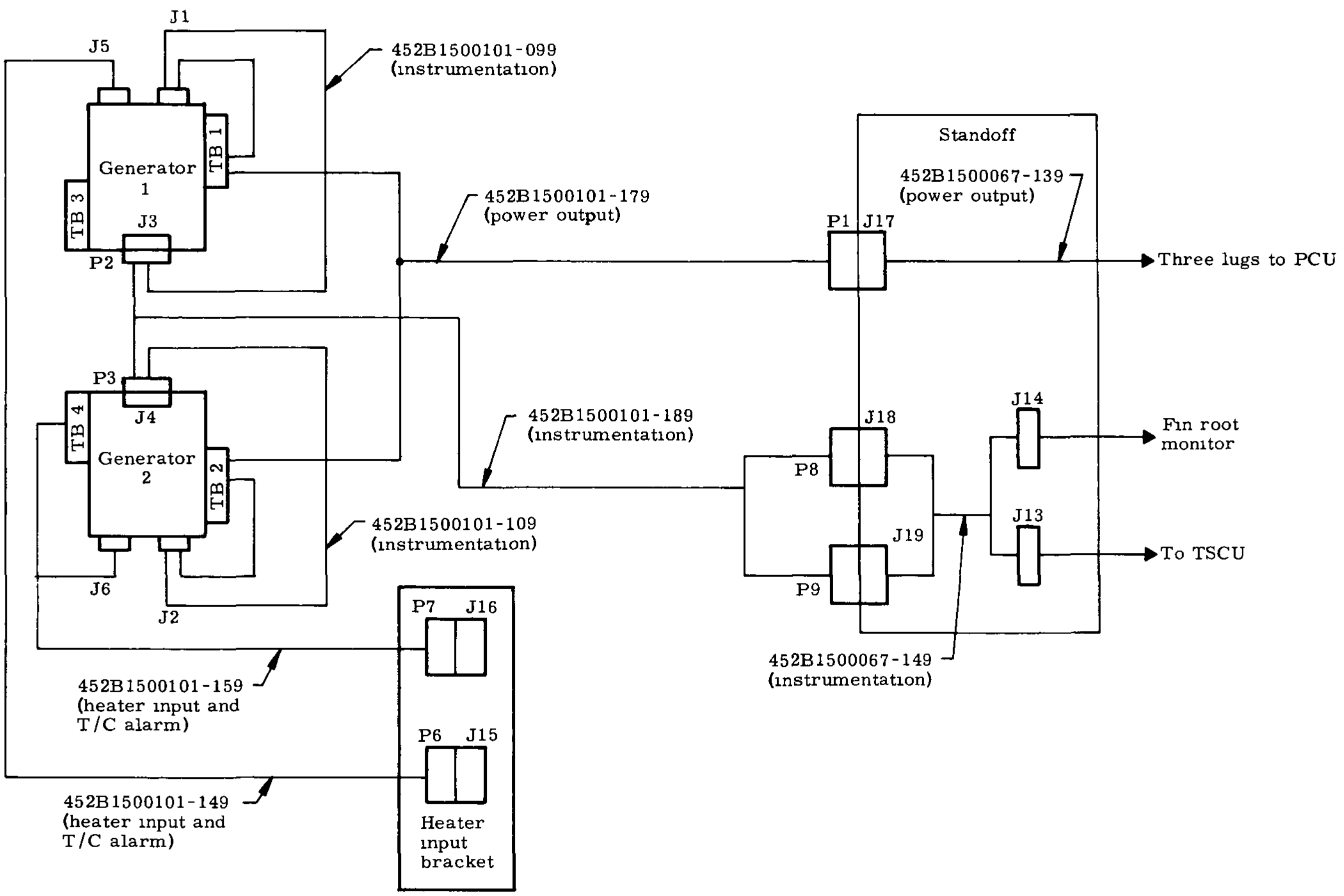


FIG. II-17. ELECTRICALLY HEATED SYSTEM HARNESS SCHEMATIC

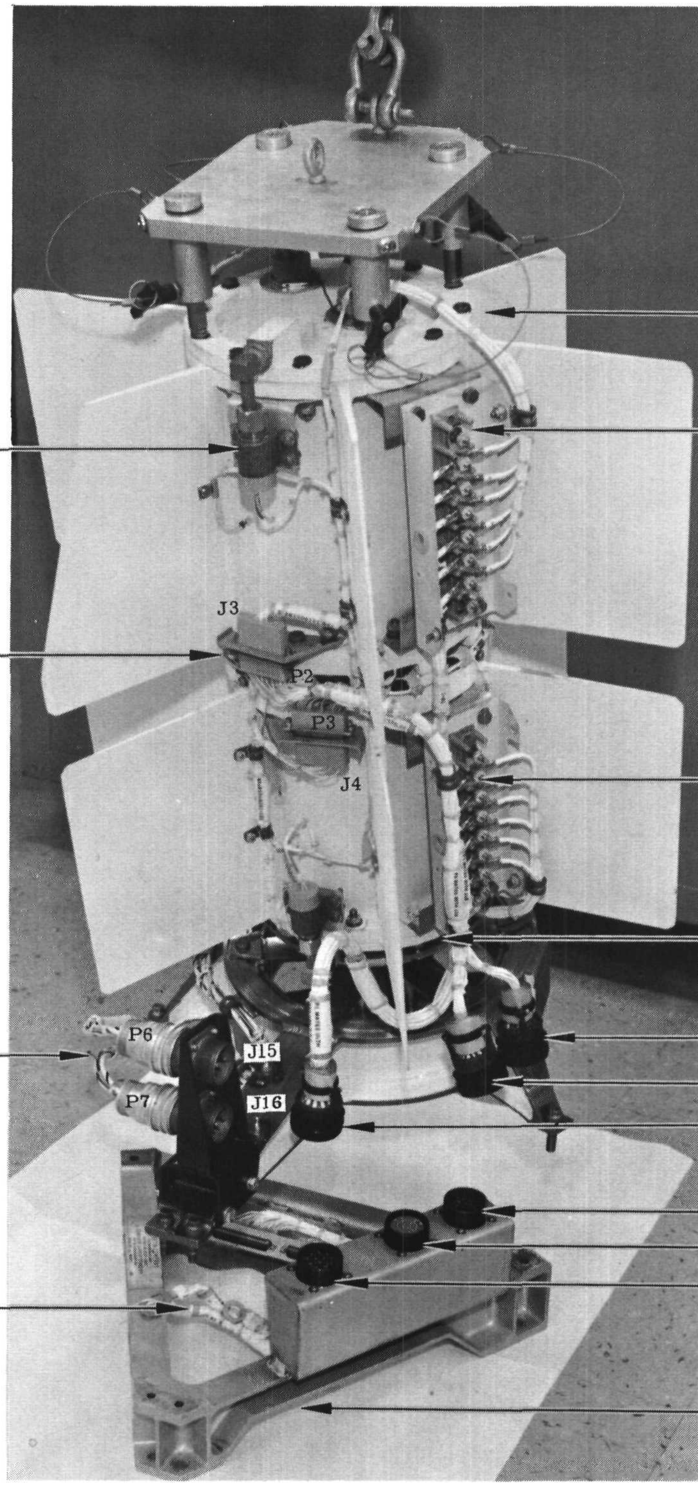


FIG. II-18. ELECTRICALLY HEATED GENERATOR SUBSYSTEM ELECTRICAL CONNECTOR IDENTIFICATION

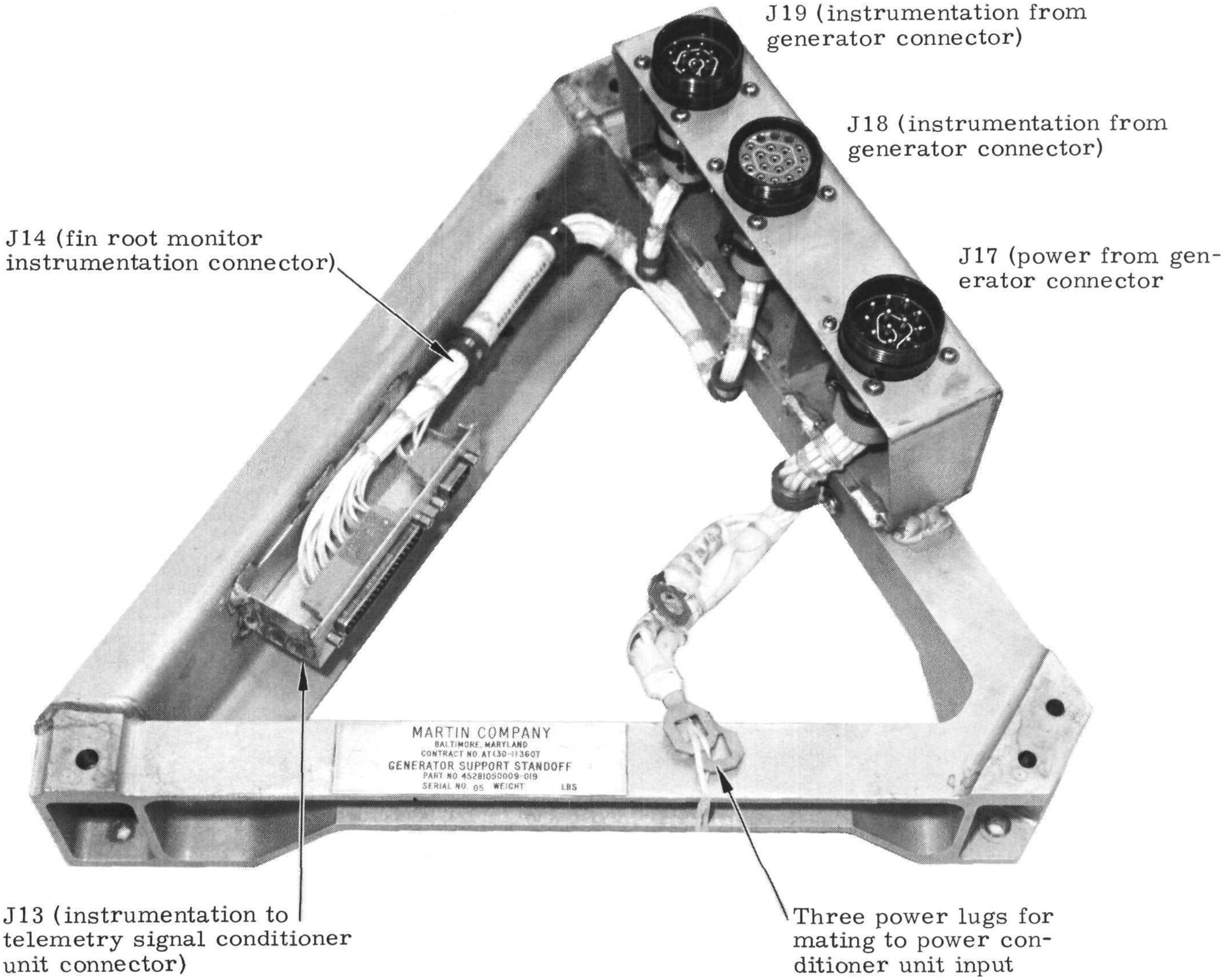


FIG. II-19. STANDOFF ASSEMBLY ELECTRICAL CONNECTOR IDENTIFICATION

Each of the two termination connectors is the miniature rectangular type, one being a 37-pin connector and other a 9-pin connector. All of the flight-monitored instrumentation terminates in the 37-pin connector, J13, and this connector is the instrumentation interface on the spacecraft. The 9-pin connector, J14, is the termination point for the two fin root temperature sensors (one from each generator) to be monitored at the launch pad.

3. Support Structure

The support structure (Fig. II-20) is a mechanical assembly (consisting of a support base and piston subassemblies) which performs the following functions:

(1) Adapts two tandem-mounted SNAP 19 generators to the sensory ring of the Nimbus B spacecraft (through the standoff assembly)

(2) Orients the generators at 16° from the spacecraft yaw axis. This was required for ejection of the generator from the spacecraft. Ejection requirements were later eliminated but the structural design was retained, since it had been qualified.

(3) Provides dynamic isolation of the generator subsystem from the spacecraft.

The support base subassembly is a tripod-mounted ring that houses upper and lower radial vibration-isolating springs joined by a cylindrical hub. The springs have six spokes and are retained in the ring by clamp plates bolted to the ring. The springs are machined from Ti-6 Al-4V, and the rest of the base support is made from 17-7 PH corrosion resistant steel.

The piston, fabricated from Type 416 steel bar, is a flanged saucer-shaped body on a hollow cylindrical shaft. The flange provides a mounting surface for attachment of the lower generator, and the piston shaft fits into the hub on the support base. The piston shaft is retained in the hub by a 3/8-inch diameter bolt and self-locking nut.

Three major considerations in designing the support structure were:

(1) It had to be cantilevered because of space allocations.

(2) The lowest resonant frequency in each of the 3 mutually perpendicular axes had to be between 30 and 60 cps.

(3) Use of an 80 g equivalent static load, based on achievement of Item (2) above.

The design and structural analyses were performed in Phase II, using a comprehensive, three-dimensional Martin Marietta computer program. Design criteria are specified in Ref. II-2. The model was developed for both the static and dynamic analyses; program output included mode shapes, frequencies, individual shear flows, bending moments, internal loads in all elements and the deflection at all mass points. These are reported in Ref. II-2 for the static loading conditions investigated (1, 60, 80 and 100 g in X, Y and Z directions). The design was based on the 80 g static load factor and, inasmuch as the frequency requirement had apparently been met (as determined by the aforementioned computer program), the load factor has proved adequate. The complete subsystem structural analysis is discussed in Ref. II-3.

To minimize thermal inputs from the generator subsystem into the spacecraft, the inner surface of the piston is highly polished, and the exterior of the support ring is coated with an emissive coating similar to that used on the generators.

4. Standoff

The standoff (Fig. II-19) mates with the Nimbus sensory ring and raises the support structure above the spacecraft sensory ring insulation. Cables and connectors necessary to connect the generators to the remainder of the system are incorporated in the standoff.

The standoff, weighing 5-1/4 pounds, is a machined structure of 6061-T6 aluminum with a zee member welded into the rear of the structure and a connector mounting bracket welded to one side. The raised mounting pads on the upper surface are the support structure mating surfaces; the bottom surfaces interface with the Nimbus spacecraft. Machined channel-like sections in the two sides of the standoff provide access for spacecraft cable runs.

All of the mating surfaces are treated with Alodine 600, a product of Amchem Products, Inc., used as a protective coating for aluminum where a low dielectric resistance is desired. This characteristic ensures adequate grounding of the generator housing to the spacecraft. The remaining surfaces of the standoff are anodized for corrosion protection.

The self-locking anchor nuts are riveted under the upper mounting holes. The holes in the lower surface are close-tolerance holes, as specified by the Nimbus requirements. A master drill template was used to coordinate the hole pattern in the lower surface of the standoff with those on the spacecraft. An additional template was fabricated at Martin Marietta to mate with the template used to drill the lower holes and to coordinate the holes in the upper surface of the standoff with those in the support structure. This template also locates and orients the support structure with respect to the standoff. The standoffs are interchangeable with any support structure. Support structure location on a standoff, is repeatable within 0.007 inch.

5. Electrically Heated Subsystem

The preceding discussion is applicable to electrically heated subsystems, except for some differences in electrical wiring (Figs. II-17 and II-18) and the provision on electrically heated systems for input power to the heaters. A heater input bracket with two plugs (J6 and J7) is mounted on the long leg of the support structure to provide an interface with an external heater power supply. Each plug on the bracket contains five pins--two for input power, two for a hot junction thermocouple alarm and one spare. These connections are at one end of a harness that terminates at two points on each generator. The heater input power leads run to a four-post terminal board on the side of each generator and then to the J2 header on the upper cover of each generator. The thermocouple alarm wiring runs directly from the plug on the bracket (J6 or J7) to J2. The 9-pin connector (J12) for hot junction thermocouples that is on the fueled system support structure is eliminated on electrically heated subsystems because of pin limitations associated with using the heater input leads and the thermocouple alarm.

Four electrically heated subsystems were built under the SNAP 19 program: S/N 1, 2, 3 and 5. Subsystem S/N 1 was built in Phase II and used for numerous engineering investigations (transmissibility studies, vibration tests at General Electric Co., transient thermal response tests, shipping container thermal tests, etc.). Subsystem S/N 2 was built during Phase II with generators S/N 3 and S/N 4. These units, after testing at Martin Marietta, were sent to NASA Goddard for additional testing (including thermal vacuum). Generators S/N 3 and S/N 4 were returned to Martin Marietta for Phase III redesign and rebuilding (including replacement of thermoelectric modules). Generators S/N 3 and S/N 4 were then put into system No. 2, and were subsequently reassigned to a test program. Generator S/N 3 was used for vibration tests, and was subsequently disassembled. Generator S/N 4 was placed on endurance test (Ref. Volume III). Generators S/N 9 and S/N 10 replaced S/N 3 and S/N 4 in system No. 2. System No. 2 generators (S/N 9 and S/N 10) were sent to GE as an engineering model for spacecraft integration tests. Subsystem S/N 5, built during Phase III, consisted of generators S/N 15 and S/N 16. This was also an engineering model but, unlike subsystem S/N 2, was used for complete prototype testing, including humidity, vibration, acceleration, and thermal vacuum environments.

D. POWER CONDITIONER UNIT

The power conditioner unit (PCU), which is electrically in series with the generator subsystem, conditions the output voltage of the generators (RTG) to that required by the spacecraft bus. The PCU includes output switching circuits for on-bus and off-bus operations. Instrumentation signals indicating converter status and performance are provided to the SNAP 19 telemetry signal conditioner unit (TSCU). A simplified functional schematic of the PCU is shown in Fig. II-21.

1. Configuration

The PCU circuits are packaged in a machined magnesium alloy housing of standard Nimbus 4/0 module configuration (Fig. II-2). The 13.6-pound unit is 8 x 6 x 6-1/2 inches (excluding connectors and mounting lugs). The housing finish is Dow 23 plus a conformal coating that is applied after final assembly. Adequacy of the packaging was verified during environmental testing (humidity, acceleration and three-axis vibration, discussed in Chapter IV) of the prototype units.

The PCU contains two dc-to-dc converters, each in series with one of the generators in the RTG subsystem. Small components in the PCU are mounted on a 1/8-inch thick printed circuit board bolted to the housing. All other components and subassemblies are mounted in the power conditioner by lugs and bosses integral with the housing.

The three input terminals are gold-plated beryllium copper feedthroughs, electrically isolated from the case by laminated epoxy bushings and keyed to ensure proper connection during system assembly. The output and telemetry connectors have brass shells and gold-plated contacts.

2. Performance Characteristics

The 2.6 ±0.1-volt input to the PCU from the generators is converted to -24.5 volts for delivery in parallel from the converters to the spacecraft bus. Voltage regulation is provided by the spacecraft. The output of each converter is connected to the spacecraft bus through a switching system that permits removal of the output (from either or both converters) from the bus by ground command. On removal from the bus, the output is switched to a dummy load provided by the spacecraft. Because the dummy load impedance is similar to that of the spacecraft bus, output switching does not result in significant transients in the RTG operating parameters.

The PCU efficiency is approximately 90%. Thus, for a 60-watt RTG subsystem input, about 6 watts will be dissipated as heat in the PCU module.

The PCU is equipped with sensors for the monitoring of performance, status and temperature. The input and output voltage and current for both dc-to-dc converters

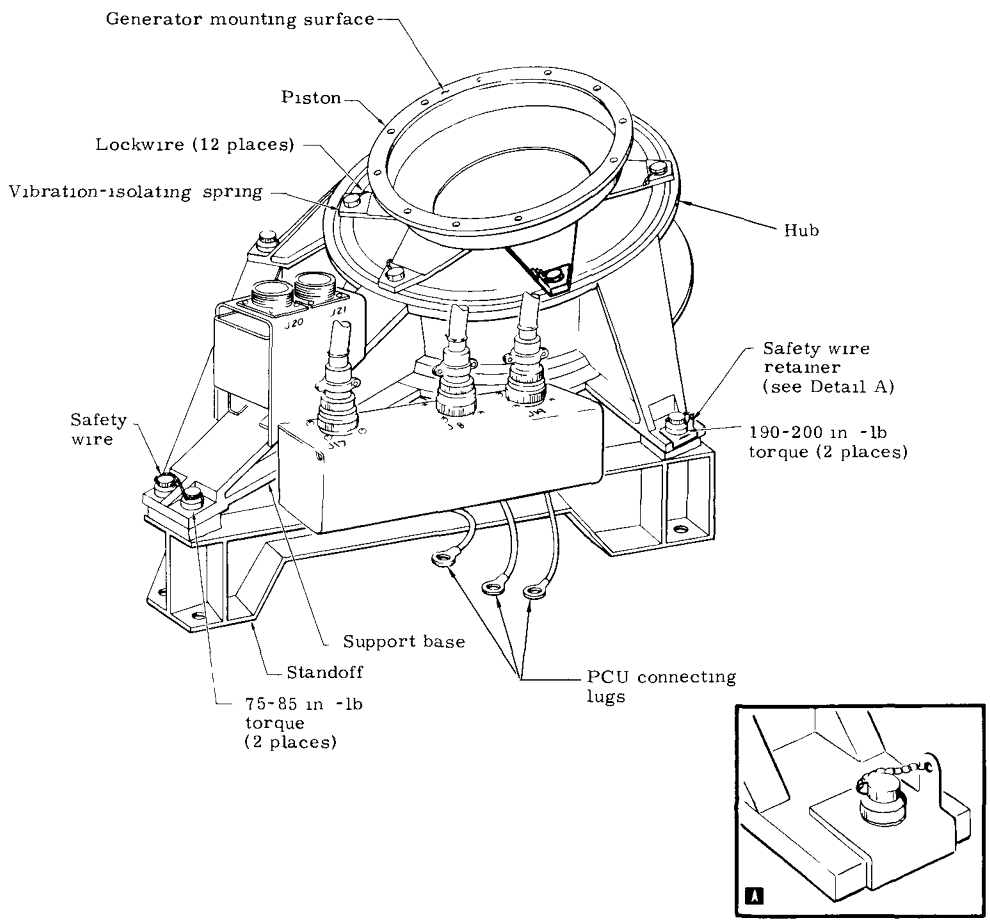


FIG. II-20 GENERATOR SUBSYSTEM SUPPORT STRUCTURE AND STANDOFF

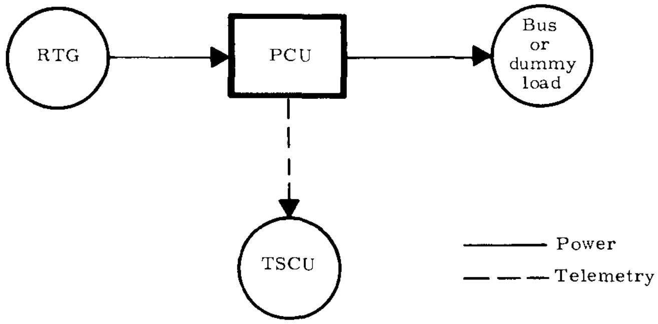


FIG. II-21 POWER CONDITIONER FUNCTIONAL SCHEMATIC DIAGRAM are measured. These measurements also offer redundancy for other instrumentation, since the input voltage is similar to the RTG subsystem output voltage and the output voltage is similar to the bus voltage. The output relays have contacts to ascertain converter on-off bus status, and each converter has one thermister to indicate internal housing temperature.

Performance characteristics are summarized in Table II-6.

TABLE II-6

Power Conditioner Performance Characteristics

Input voltage	2.6 volts dc
Output voltage	-24.5 volts dc
Maximum output ripple	50 millivolts
Maximum design output power	75 watts
Efficiency	0.90
Maximum power dissipation, short-circuit output	13 watts
Maximum power dissipation, open-circuit output	11 watts
Output relay response	5 millisec

3. Circuits

Each of the two converters (Figs. II-22 and II-23) consists primarily of a current feedback-driven oscillator with base peaking inductors feeding a power transformer, the output of which is full-wave rectified and then filtered.

To obtain the required system efficiency, the oscillator utilizes germanium transistors as switching elements because they exhibit minimum losses during conduction, and thus approach an ideal switch. The power loss in the transistors varies nonlinearly with collector current; therefore, two transistors are parallel-connected for each side of the oscillator to obtain further gains in efficiency. The base peaking inductors are employed to decrease the turn-on and turn-off times of the power switching loss and thus increase the converter efficiency. A nickel-iron alloy torroidal core was used for the power transformer to provide high initial permeability and low losses.

The oscillator output is stepped up to a higher voltage level by the power transformer and then full-wave rectified. The rectifiers are base-collector junctions of germanium transistors with a forward voltage drop approximately 50% lower than the conventional silicon rectifiers (a further improvement of efficiency). The rectified voltage is filtered by an LC filter. The capacitors are series-connected with shunt resistors to divide the voltage imposed on them. The series connection enhances the reliability of the circuit since the capacitor failure mode is a short circuit.

To ensure reliable starting of the converter circuit, a blocking oscillator is employed. The blocking oscillator is capable of starting the power oscillator with a generator voltage as low as 0.8 vdc and is maintained inoperable as long as the power oscillator is operating.

A protection circuit was incorporated on the output of each converter circuit to ensure that a generator will not undergo a no-load condition. The protection circuit

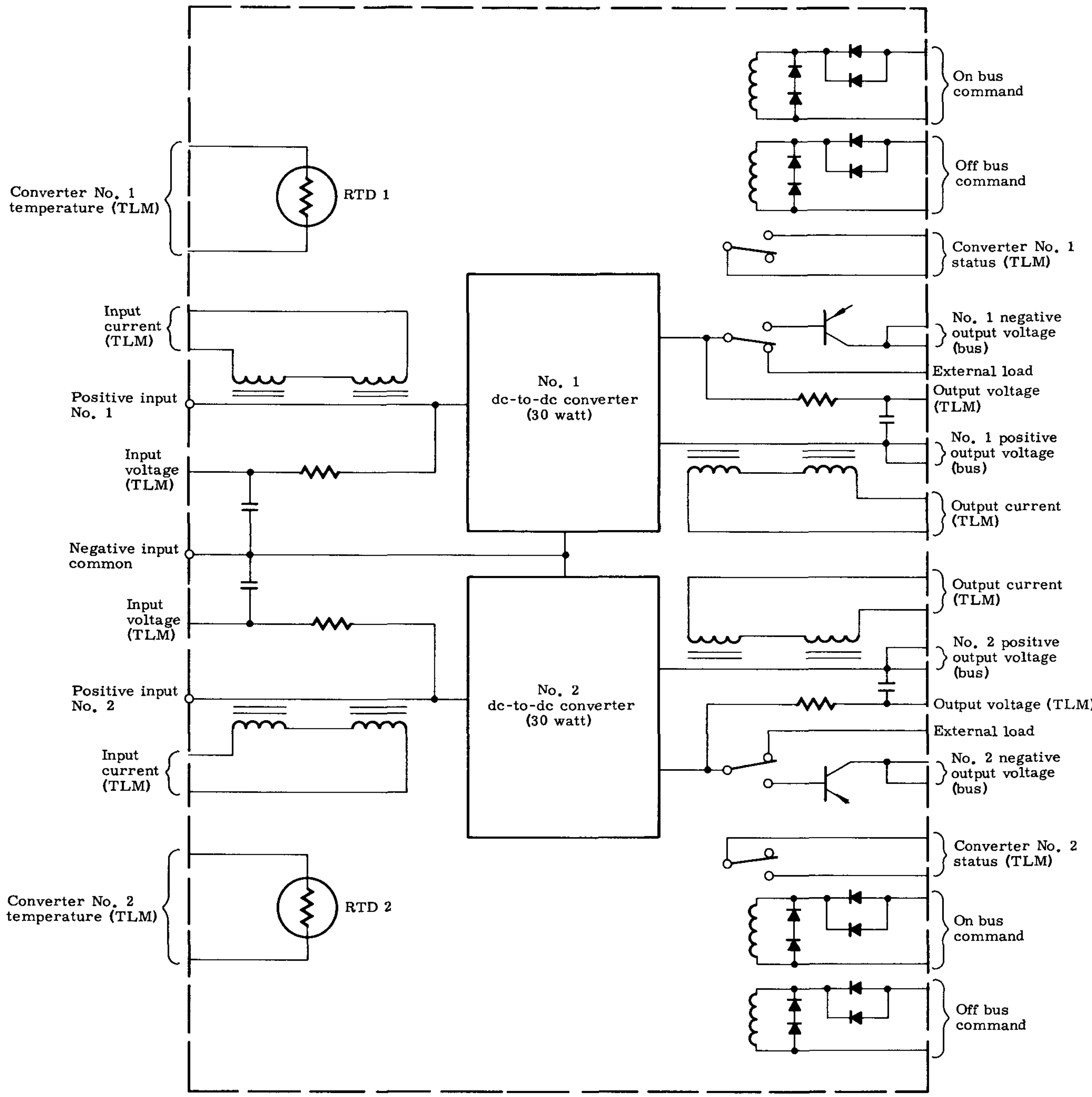
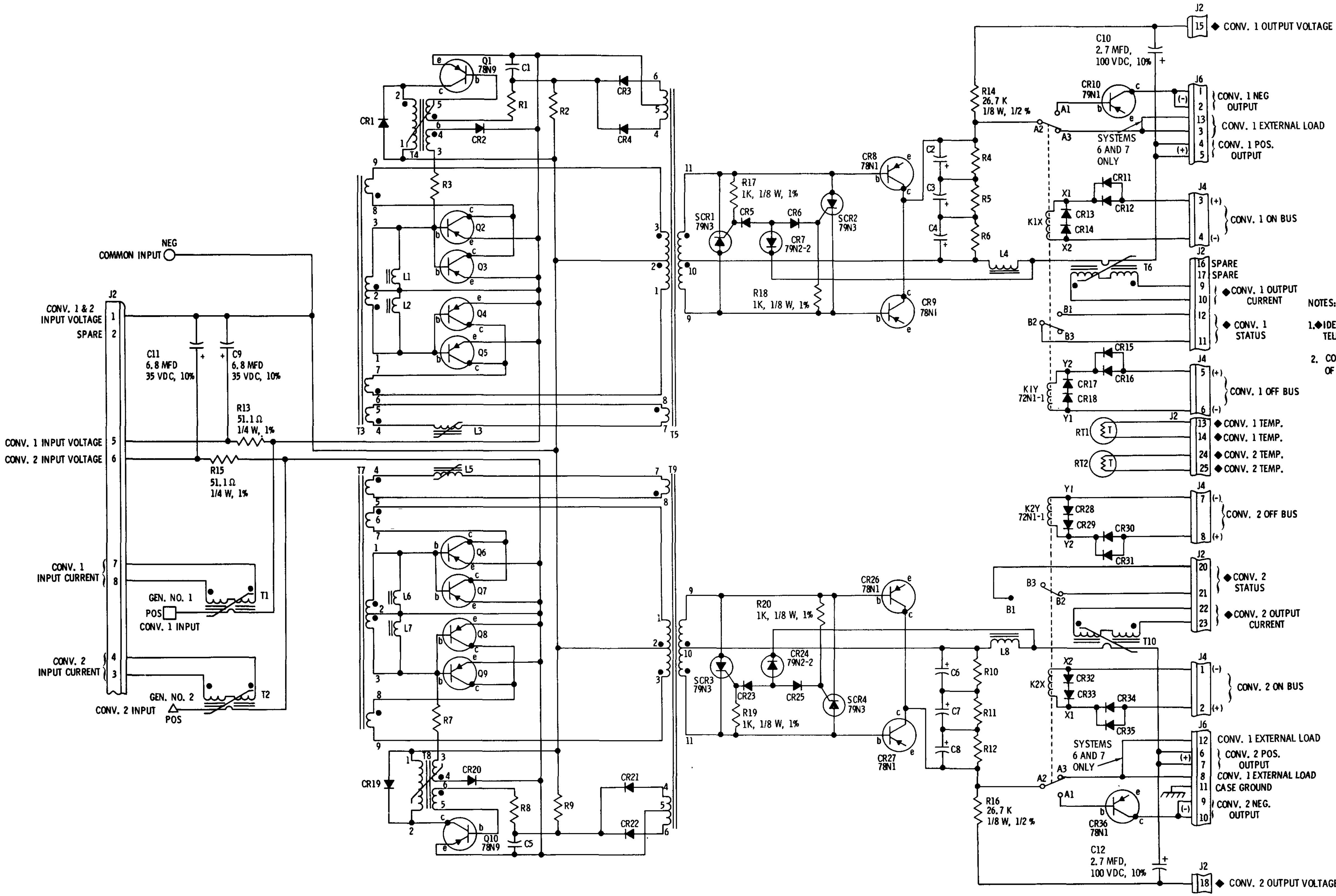


FIG. II-22. POWER CONDITIONER UNIT BLOCK DIAGRAM



NOTES:

1. ◆ IDENTIFIES SIGNALS TO TELEMETERING PACKAGE.

2. COMPONENT VALUES (AND NOTED IN FIELD OF DRAWING):

C1, C5	.15 MF, 200V, ± 10%
C2, C3, C4, C6, C7, C8	47 MF, 35V, ± 10%
R1, R8	220 Ω, 1/8 W, ± 1%
R2, R9	10K, 1/8 W, ± 1%
R3, R7	18 Ω, 1/8 W, ± 1%
R4, R5, R6, R10, R12	1M, 1/4 W, ± 1%
RT1, RT2	92N3-1

FIG. II-23. POWER CONDITIONER UNIT SCHEMATIC DIAGRAM consists of two silicon-controlled rectifiers (SCR) and a zener diode connected across the output of the power oscillator. When the power oscillator output voltage exceeds the breakdown voltage of the zener diode, the SCR is turned on and remains on for the duration of a half cycle, constituting an effective short circuit to both the converter and the generator. A converter no-load or short-circuit condition can exist for an indefinite period of time with no adverse or permanent effects.

Each converter has a latching relay in series with its output to provide the capability of placing either or both converters on or off the spacecraft bus. External command signals are required to operate the two latching relays and place the converters in the desired mode. In addition, each relay has a second set of contacts utilized by telemetry as a monitor for the on-off bus status of the converters. Transductors are for use with telemetry excitation circuits to monitor converter input and converter output current. Voltage taps are supplied for monitoring converter input and converter output voltage.

The outputs of the PCU are provided with diode isolation when the output relays are in the on-bus mode.

4. Utilization

A total of eight power conditioners were built during Phase III. The utilization of the units is summarized in Table II-7.

TABLE II-7

Power Conditioner Utilization

Serial No.	Utilization
1	Initial circuit functional testing and environmental evaluation
2	Endurance testing*
3	System level functional tests
4	Prototype qualification; verification of technical manual procedures
5	Environmental overtesting
6	Prototype qualification
7	Flight unit
8	Flight unit backup

*See Section V-D, Demonstrated Reliability

E. TELEMETRY SIGNAL CONDITIONER UNIT

The SNAP 19 telemetry signal conditioner unit (TSCU) conditions the SNAP 19 system sensor signals, received from the generators (RTG) and power conditioner (PCU), for compatibility with the Nimbus B telemetry system. The TSCU output signals are connected to the Nimbus B pulse code modulator (PCM), which converts the analog signals to digital form. Power to operate the TSCU is obtained from the spacecraft bus. (See Fig. II-24 for a functional schematic of the TSCU connections.)

The TSCU is discussed in summary fashion below; for further details, refer to Ref. II-4.

1. Configuration

The TSCU circuits are housed in a machined magnesium alloy casting which conforms to the dimensions of a standard 2/0 Nimbus B module and is coated with Dow 23. The unit (Fig. II-3) weighs 3-1/2 pounds and (excluding connectors and mounting lugs) is 4 by 6 by 6-1/2 inches. The package has five electrical connectors: a 9-pin connector for input power from the spacecraft bus, a 25-pin connector for input signals from the power conditioner, a 36-pin connector for input signals from the generators and two 25-pin connectors for output signals.

The components in the unit are mounted on four printed circuit boards. The total electronic assembly can be tested before it is installed in the housing. Adequacy of the packaging was verified by environmental testing.

The TSCU circuits are powered by two auxiliary power supplies within the TSCU. Each power supply accommodates essentially one half of the instrumentation circuits. The total bus power required is less than 2 watts. (See Fig. II-25 for a block diagram of the circuit configuration.)

2. Measurements

The TSCU provides a total of 26 analog outputs as voltages in the range of 0 to -6.35 volts dc. The analog measurements are summarized in Table II-8.

TABLE II-8

TSCU Analog Measurements

Measurement	Quantity	Range	Tolerance
PCU converter temperature	2	0° to 150° F	10° F
RTG hot junction temperature	6	700° to 1100° F	20° F
RTG fin root temperature	6	200° to 500° F	10° F
RTG pressure	2	0 to 60 psia	5%
RTG output voltage	2	0 to 6.6 vdc	5%
PCU input voltage	2	0 to 6.6 vdc	5%
PCU output voltage	2	0 to 33 vdc	5%
PCU input current	2	0 to 26 adc	5%
PCU output current	2	0 to 2.4 adc	5%

Calibration curves for the analog outputs are provided for each of the TSCU's. The curve for each output is obtained from calibration data based on simulated inputs provided by the ground support test console (GSTC, Section VII-A-1) or an equivalent test tool. Calibration data books which contain both subsystem and system level curves were provided for each SNAP 19 power supply.

3. Circuits

a. Temperature

Generator housing (fin root) and power conditioner temperatures are sensed by thermistors. The thermistor is characterized by low power consumption because of

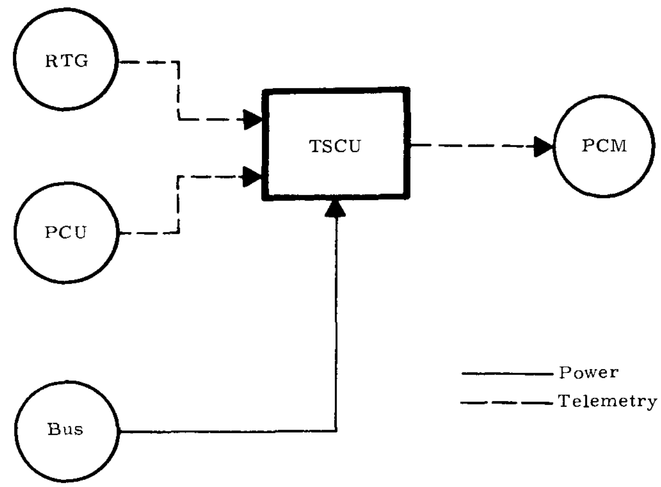


FIG. II-24. TELEMETRY SIGNAL CONDITIONER UNIT FUNCTIONAL SCHEMATIC DIAGRAM

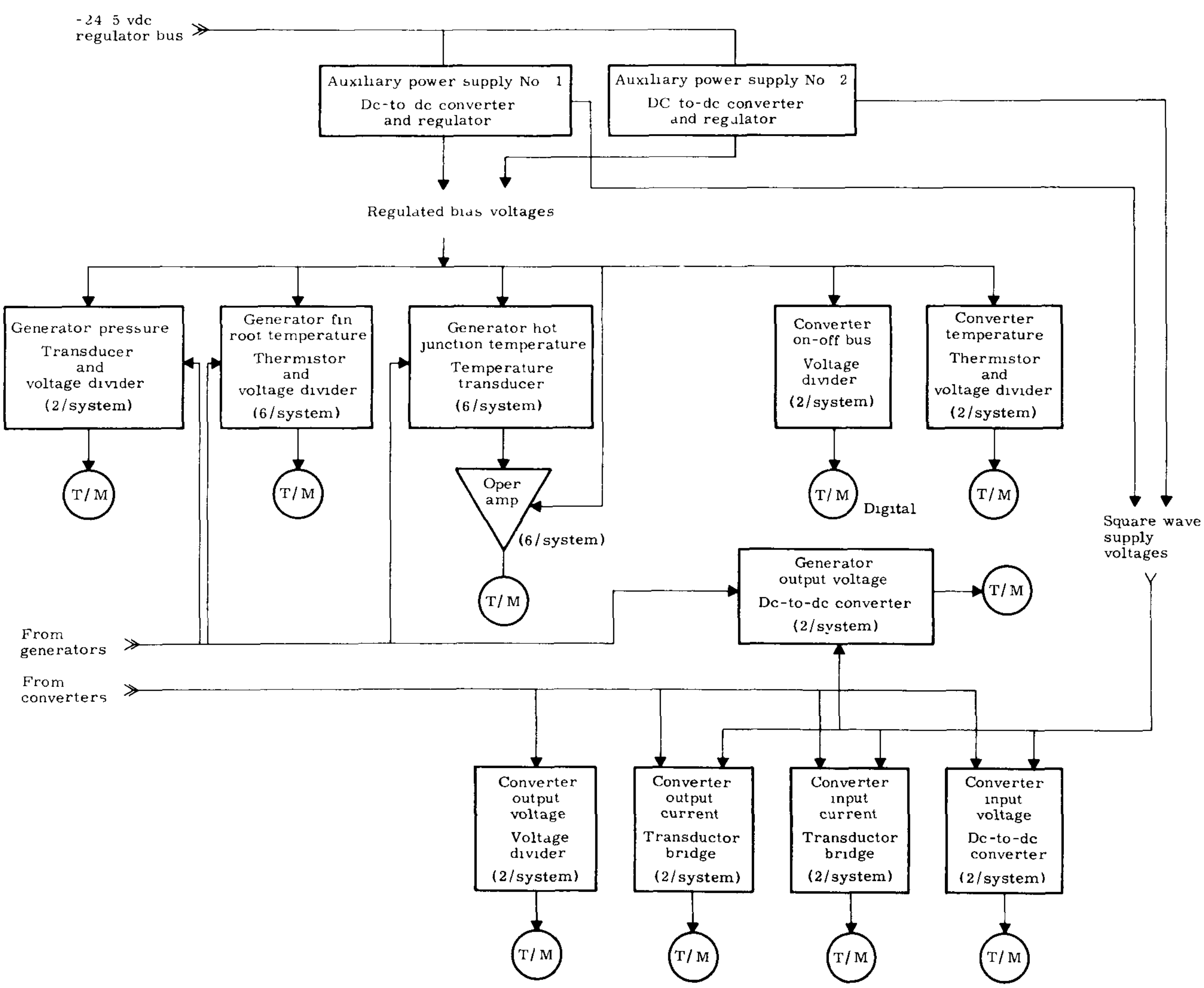


FIG II-25. TELEMETRY SIGNAL CONDITIONING UNIT BLOCK DIAGRAM its high resistance. It also gives excellent resolution, since it exhibits large resistance changes for small changes in temperature. This allows the thermistor signals to be conditioned by a simple voltage divider circuit as shown in Fig. II-26.

Generator hot junction temperatures are sensed with resistance temperature devices (RTD's). In this device, the resistance of a platinum sensing element is proportional to temperature. The resistance change is converted to a proportional voltage change by a bridge circuit in the TSCU. The output of the bridge is amplified to the 0-to-6.3 vdc range by an operational amplifier. The hot junction temperature measuring and conditioning circuit is shown in Fig. II-27.

b. Generator internal pressure

Generator internal pressure is measured with a transducer which gives a potentiometer output signal. The TSCU limits the voltage supplied to the transducer, allowing the transducer signal to be fed directly to the spacecraft PCM.

c. Voltage

The output voltages of the PCU are conditioned by a voltage divider circuit. The circuit provides isolation as well as the required ranging.

The output voltages of the generators and the input voltages of the PCU are measured and conditioned with a dc-to-dc converter circuit (Fig. II-28). Conversion is needed since the generator output is required to be isolated from the spacecraft bus.

d. Current

The PCU input and output currents are measured and conditioned by a transductor circuit (Fig. II-29). The output voltage is nearly linear with the current being measured.

e. On-off bus status

The PCU output status is indicated by a contact which is part of the on-off bus relay circuit. The TSCU provides a voltage divider circuit for status monitoring. When the PCU is on-bus, the contact is closed and the TSCU output voltage is ~0 vdc; when off-bus, the contact is open and the output voltage is ~-7 vdc.

f. Auxiliary power supplies

The d-c bias voltages for the amplifiers, bridges and voltage dividers and the a-c driving voltage for the voltage and current measuring circuits are obtained from two auxiliary power supplies in the TSCU. These power supplies are connected to the TSCU circuits such that, if one supply fails, a representative number of system performance parameters is obtained. This is illustrated in Fig. II-30, the functional block diagram for one of the power supplies.

g. RF filtering circuitry modifications

System testing at Martin Marietta showed excessive noise on the power input side of the TSCU. Further tests by the spacecraft integrator confirmed this and also highlighted RF noise on some of the outputs.

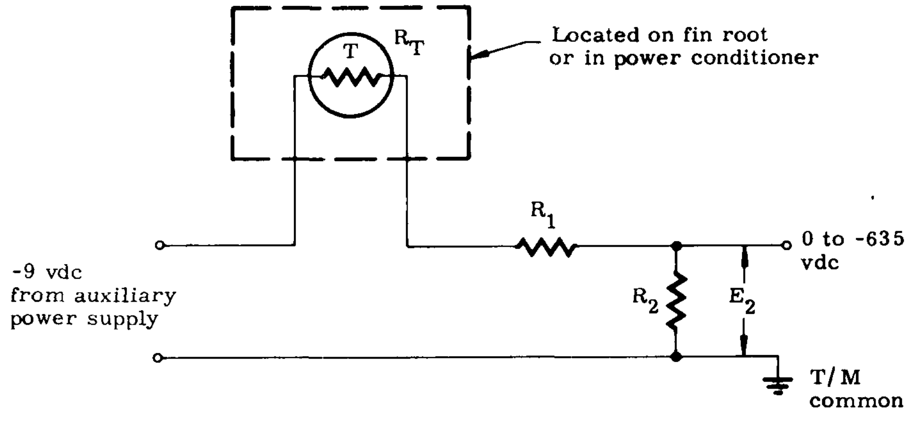


FIG. II-26. FIN ROOT AND POWER CONDITIONER TEMPERATURE MEASUREMENT AND CONDITIONING CIRCUIT

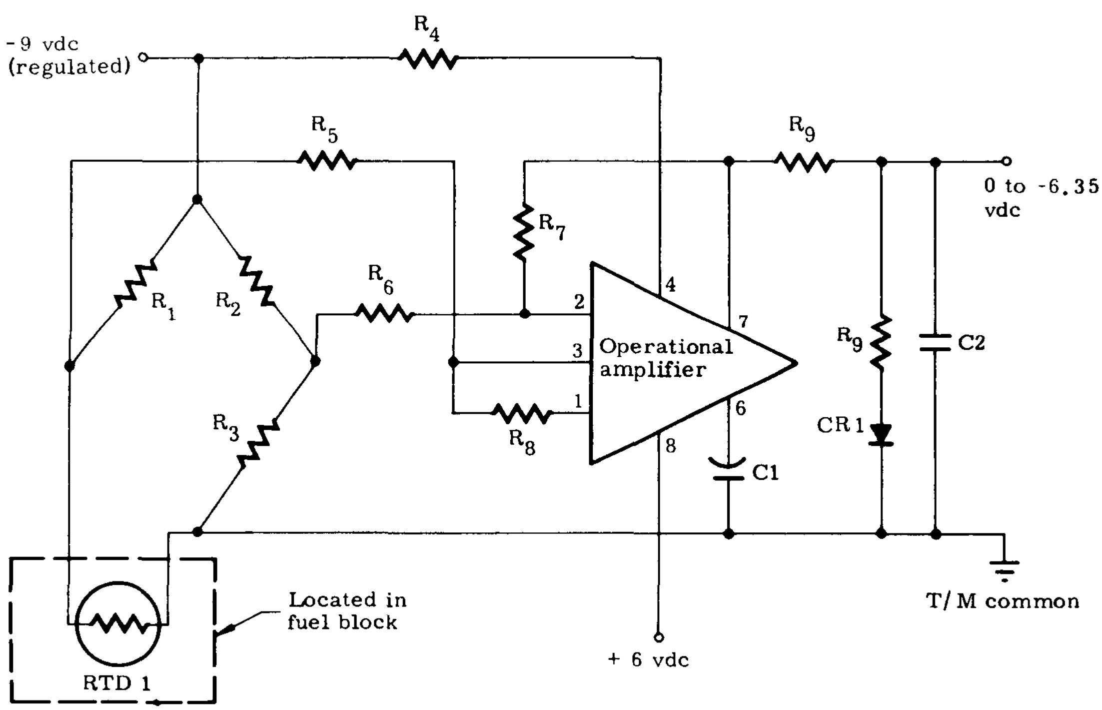


FIG. II-27. JUNCTION TEMPERATURE MEASUREMENT AND CONDITIONING CIRCUIT

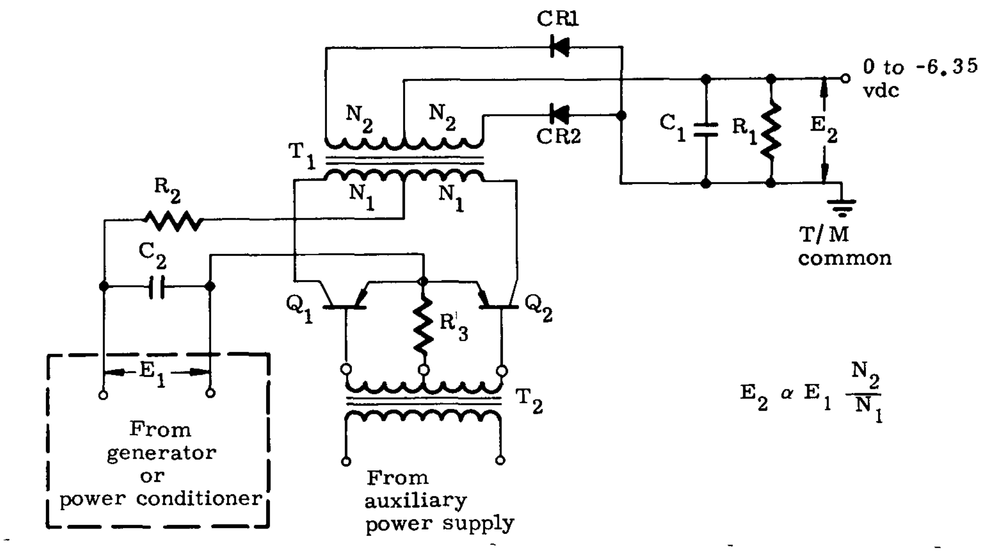


FIG. II-28. GENERATOR OUTPUT VOLTAGE AND POWER CONDITIONER INPUT VOLTAGE MEASUREMENT AND CONDITIONING CIRCUIT

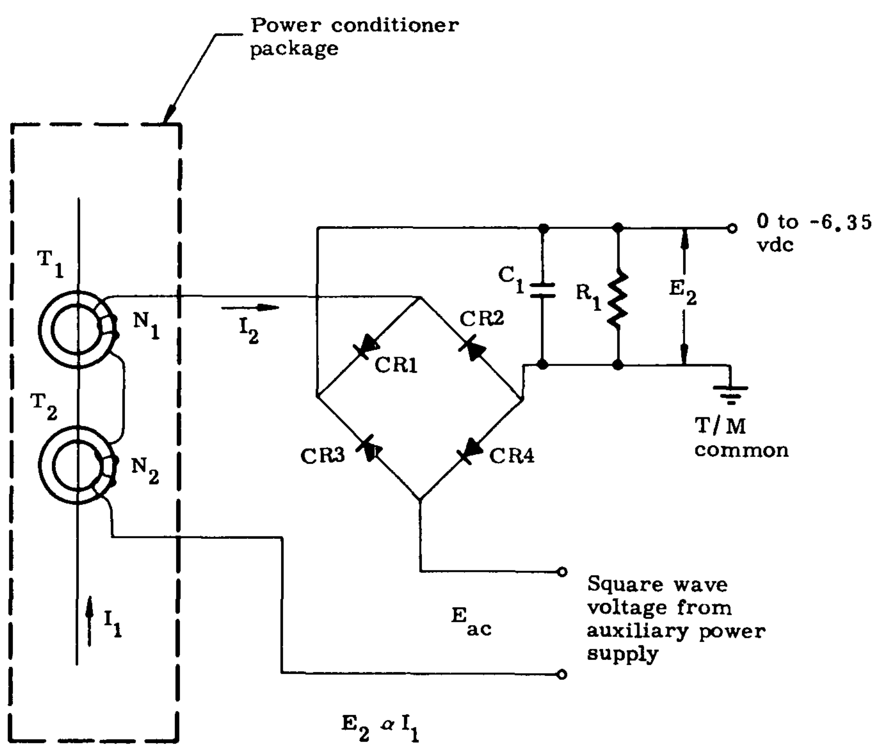


FIG. II-29. POWER CONDITIONER INPUT AND OUTPUT CURRENT MEASUREMENT AND CONDITIONING CIRCUIT

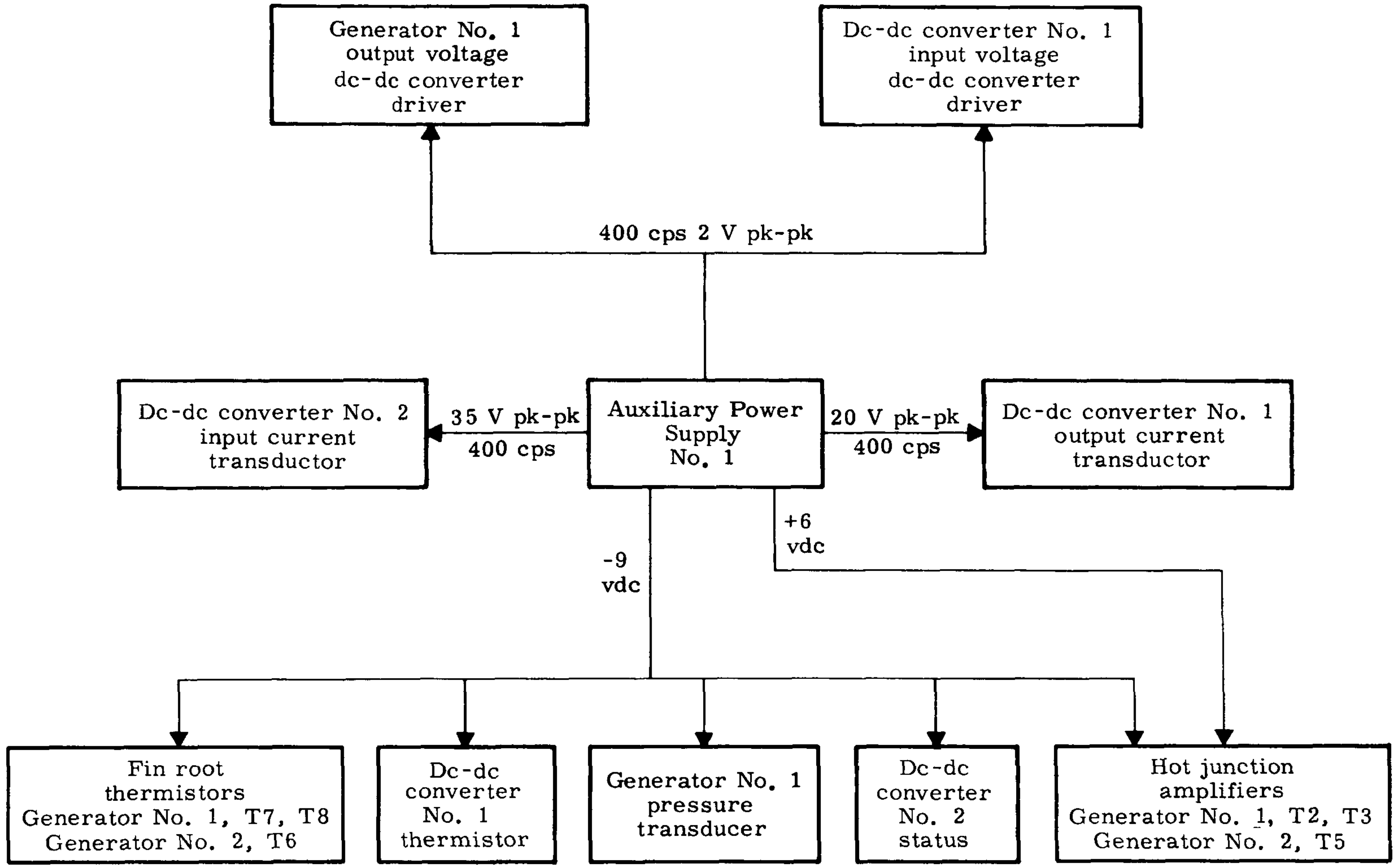


FIG. II-30. AUXILIARY POWER SUPPLY NO. 1 FUNCTIONAL BLOCK DIAGRAM

Filtering was developed by Martin Marietta, which resolved the noise problem at the input. This also tended to reduce the output noise. Further effort at Martin Marietta showed that RF improvements realized in the lab were not necessarily reproduced at the spacecraft level. This was due to the coupling between the unit and the spacecraft. It was decided that output RF attenuation could best be done by the integrator in conjunction with spacecraft testing. Further effort and evaluation at the integrator's facility resulted in acceptable output noise attenuation.

4. Utilization

Seven telemetry signal conditioners were built. Three units were used for engineering evaluation and four for prototype qualification and flight acceptance testing. A summary of TSCU utilization is given in Table II-9.

TABLE II-9

Telemetry Signal Conditioner Unit Utilization

Serial No.	Utilization
1	Circuit functional testing and environmental test evaluation
2	System level functional testing
3	GSTC functional testing; RFI evaluations
4	Prototype qualification; technical manual procedure verification
5	Prototype qualification; 30-day system thermal vacuum test.
6	Flight unit backup
7	Flight unit.

III. INTERFACE WITH NIMBUS B SPACECRAFT

The SNAP 19/Nimbus B interface requirements, including mechanical, electrical, thermal and nuclear radiation compatibility, were dictated by power and data network needs; launch and space environmental loads; spatial limitations; thermal radiation, conduction and dissipation limitations; and sensitivity of spacecraft components to generator nuclear radiation. This chapter discusses these various interfaces. The following applicable documents describe in detail the SNAP 19/Nimbus B interface requirements.

Contractor/ Agency	Document	Title
Martin Marietta	MN-10210B	Specification for SNAP 19/Nimbus Radioisotope Thermoelectric Power Supply System
	452B0100002	Power Supply System Mechanical Interface Drawing
	452B0100003	Power Supply System Electrical Interface Drawing
GE	207704	Interface Agreement for the SNAP 19 Radioisotope Thermoelectric Generator Subsystem and Nimbus B Spacecraft
	47J207704	Mechanical Interface Drawing
	47J209960	Electrical Interface/Schematic Drawing
	47J209963	Electrical Interface/Schematic Drawing
NASA	S-320-N1-2	GSFC Environmental Test Specification, Nimbus B Spacecraft, Subsystems and Experiments
		Nimbus B Experimenters Handbook
	ME 2116	Nimbus Module Mechanical Interface Requirements

A. MECHANICAL INTERFACE

Installation of the SNAP 19 power supply on the Nimbus B spacecraft is illustrated in Fig. II-1. The generator subsystem, with a spatial envelope approximately 22 inches in diameter and 32 inches high, is mounted atop bays 18 and 1 of the spacecraft sensory ring. (Complete mechanical interface dimensions are presented in Martin Marietta Drawing 452B0100002.) A standoff support structure is employed to mate the generator subsystem with the spacecraft. The major axis of the generator subsystem is at a 16-degree ±0.5 angle* to the yaw (thrust) axis and is within ±0.5 degree of the spacecraft yaw-roll plane.

The power conditioner unit (PCU) interfaces with the spacecraft sensory ring in the upper half of Bay 18. The PCU, housed in a 6- by 6-1/2- by 8-inch standard 4/0 Nimbus B module, is mounted on the top support rails of the sensory ring by eight slotted lugs.

*To accommodate requirement for ejection capability; requirement was subsequently eliminated.

Mechanical interfacing of the telemetry signal conditioner unit (TSCU) with the spacecraft is in the bottom half of bay 18 of the sensory ring, where it is mounted by four slotted lugs. The TSCU is housed in a 6- by 6-1/2- by 4-inch standard 0/2 Nimbus B module.

A port in the spacecraft shroud provides access to the generator terminal strip, the three-connector bracket (J17, J18 and J19) and the dummy load box. It can also be used for the harness feedthroughs of the electrically heated generators.

Measurement and/or calculation of mass properties (i.e., weight, center of gravity, mass moments of inertia, and mass products of inertia) are program requirements. The total flight system weight and the maximum allowable subsystem weights are tabulated as follows:

	Weights (lb)	
Component	Maximum Allowable	System No. 8A Actual
Generator subsystem	96.0	88.33
PCU	15.0	14.01
TSCU	4.0	3.55
Total	115.0	105.89

No design limit was placed on the location of the center of gravity or on magnitude of mass moments of inertia and mass products of inertia. Weight, center of gravity and mass moments of inertia were measured as described in Section IV-E. Mass moments and products of inertia are required for the generator subsystem only and were obtained from previously collected data. The weight of the flight generator subsystem S/N 8A was measured; the cg of the entire spacecraft, including the SNAP 19 power system was determined by the integrating contractor using a Palton machine.

B. ELECTRICAL INTERFACE

The electrical interface between the SNAP 19 power supply system and the Nimbus B spacecraft is schematically illustrated in Fig. III-1. The PCU output power is delivered to the spacecraft bus, and the TSCU conditioned signals are transmitted to the spacecraft telemetry subsystem.

1. Power Requirements

The output for each power channel, as determined at the output of the PCU, must meet the requirements specified in Table III-1.

TABLE III-1[1]

Power output at acceptance	25 ±4 watts
Power output after six months storage and test[2]	92% ±3 power output at acceptance
Power output after one-year storage and test[2]	85% ±5 power output at acceptance
Power output after one year in orbit[2]	77% ±6 power output at acceptance

(1) All values are for single-channel operation as measured at fin root temperature of 337° F ±5.

(2) Based on not more than two full months of operation at other than short circuit for all integration tests and during which the number of cycles, short to load to short, does not exceed 12.

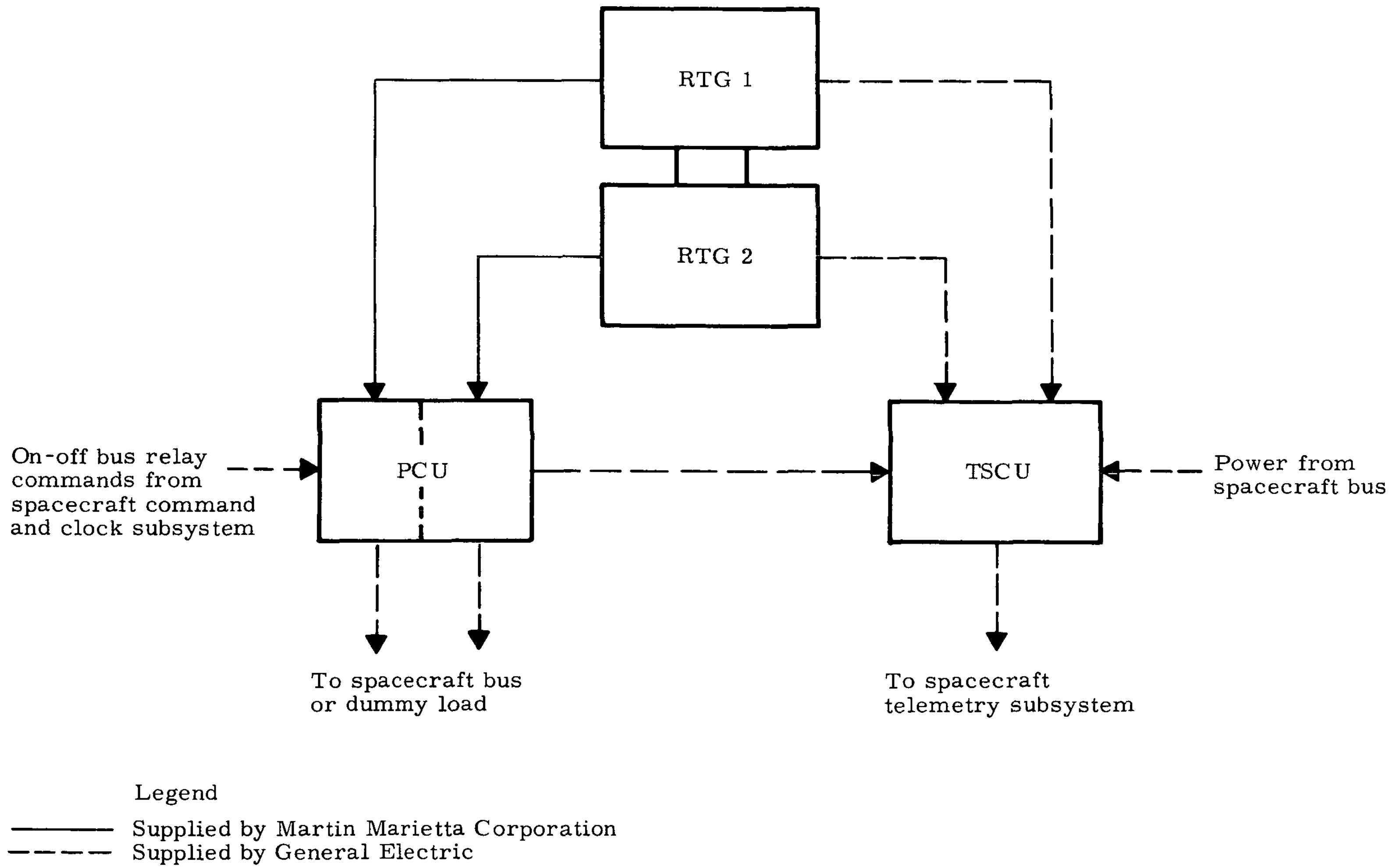


FIG. III-1. ELECTRICAL INTERFACE BETWEEN SNAP 19 POWER SUPPLY AND NIMBUS B SPACECRAFT

The power allotment from the spacecraft bus for operation of the TSCU is two watts, maximum.

2. Spacecraft Regulated Bus Interface

The spacecraft regulated bus interfaces with the power supply system at the PCU power output connectors. The bus characteristics are defined in Table III-2.

TABLE III-2

Nimbus B Electrical Bus Characteristics

Voltage regulation (volts)	-24.5 ±0.5 dc
Voltage ripple (mv)	≤50 peak-to-peak
Power distribution voltage drop (volts)	≤0.15 dc
System output circuits	Isolated from system structure
Stepload application limits[(1)]	Varies from 2 amp/μsec to 9 amp/10 msec
Output impedance[(1)]	Varies irregularly from 5 mΩ at 10 cycles to 80 mΩ at 3×10^5 cycles

[(1)]Detailed variation shown on appropriate graphs in Interface Agreement Document 20774 dated June 22, 1967.

Transients which might be produced by the PCU are prevented from reaching the spacecraft regulated bus by diode isolation in the PCU. Fuses for the power supply system are in the solar power subsystem control module. Fuse sizes, determined by the spacecraft integrator, are five amperes for the PCU and one ampere for the TSCU.

3. Command and Clock Subsystem Interface

Commands are required by the power supply system to actuate the on-off bus relay in the PCU. The spacecraft command and clock subsystem supplies redundant encoded commands to the SNAP 19 power supply system. The command comes from either of two redundant clocks; hence, the commands are also redundant.

4. Spacecraft Telemetry Subsystem Interface

Twenty-eight instrumentation sensor signals are supplied to the spacecraft telemetry subsystem by the TSCU. The telemetry subsystem transmits these signals to ground stations for evaluation. Twenty-six of the signals are analog signals, and two (the PCU on-off bus) are digital signals. The instrumentation monitored is discussed in Section II-E. The TSCU conditions all analog signals to a range +0.7 to -1.0 volt dc for the on-bus condition and -5.0 to -10.0 volts dc for the off-bus. The analog signals, as received by the ground stations, are converted to real data utilizing calibration curves and evaluated by comparison to the nominal ranges.

5. Power Management Subsystem Interface

The power management subsystem includes the spacecraft dummy loads and the auxiliary load controller. This subsystem interfaces with the PCU in the off-bus mode. Two dummy loads of 20 ±0.5 ohms each are provided, one for each of the PCU channels. Both channels of the PCU are transferred off the regulated bus and on the dummy load by one command from the spacecraft command and clock subsystem. This single command is transferred into two commands, one for each PCU channel, by a transfer relay of the auxiliary load controller.

C. THERMAL INTERFACES

Integration of SNAP 19 power supply systems with the Nimbus B spacecraft required consideration of thermal constraints. From 1050 to 1120 watts(t) are radiated from the surface and fins of the generator subsystem. This range of thermal radiation complies with the maximum allowable of 1120 watts(t) and depend on the initial fuel inventory, the time after fueling and the performance of the generators. Heat conducted through the generator support structure to the sensory ring was limited to 15 watts. A test conducted at General Electric, Valley Forge, using generator subsystem No. 1, determined that the heat conducted to the sensory ring was between 10 and 15 watts. Further, actual heat flows from the PCU and TSCU to the sensory ring are limited to maximum allowable 13 watts and 2 watts, respectively.

Forced air cooling for thermal control of the generator subsystem while the spacecraft shroud is in place will be supplied by NASA/GSFC. A detailed discussion of this subject is presented in Section VIII-A.

D. NUCLEAR RADIATION

The nuclear radiation interface for the generator subsystem was defined as the as-measured total dose rate. Total dose rate measurements were obtained as a function of distance from the side, top and bottom of the RTG subsystem. These data can be used to establish dose rates at any spacecraft component and for health physics purposes.

Total dose rates for the exposed flight generator subsystem and for the subsystem in the shipping container are given in Chapter IV.

Information on energy distribution and magnitude for neutron and gamma radiation is given in Ref. III-1. Experimental data were obtained with a SNAP 19 prototype generator subsystem.

A radiation damage analysis was performed for the power and telemetry conditioners (Ref. III-2). For radiation damage analysis purposes, the units are typical of spacecraft electronics. Sensitivity to the combined effects of the generator subsystem and space radiation was considered. The safety margin is about a factor of five in radiation level; that is, if the exposure was five times higher, some semiconductors and organic materials would require further investigation to assure satisfactory performance.

IV. TESTING

A. PRE-ENVIRONMENTAL FUNCTIONAL TESTING

Functional testing of all SNAP 19 subsystems prior to environmental testing was performed. This was required to assure satisfactory operation of the as-built hardware.

Pre-environmental functional testing at the system level was performed on an optional basis only. Initial system testing had shown that subsystem functional testing assured subsequent system compatibility.

1. Generator Subsystem Testing

All generators were leak checked prior to assembly into a generator subsystem. In addition, each fueled unit was power checked before and after fueling.

Generator subsystem parametric testing was performed with the subsystem in the shipping container. Both generators were performance tested at load voltages of 1.5, 2.0, 2.6 and 3.0 volts. These data yielded the current-voltage and power characteristics for each generator. Typical parametric plots of current and power as functions of load voltage are given in Figs. B-1 and B-2 in Appendix B for the flight generators. During parametric testing, other parameters, such as hot junction temperatures, fin root temperatures, open-circuit voltage and internal pressure were also acquired.

Parametric testing, on a system level, was performed as part of thermal vacuum testing and is discussed later.

2. Power Conditioner Unit Testing

The power conditioner unit (PCU) converts and conditions the generator output power and interfaces with the spacecraft bus. Therefore, the PCU functional test consisted of duplicating the generator output power as an input to the PCU and measuring the output parameters against the required conditioning tolerances and conversion efficiencies. The PCU was tested under varying load conditions, including full load, partial load, overload, open circuit and short circuit.

The on-off bus relay was also checked in several load conditions. Ripple voltage was measured on the PCU output power.

The power inputs were supplied by a generator simulator. Output parameters were read through a power conditioner test tool and/or standard laboratory equipment. Ripple voltage was measured with an oscilloscope.

Performance characteristics of the PCU are given in Table II-6.

3. Telemetry Signal Conditioner Unit Testing

The telemetry signal conditioner unit (TSCU) conditions the signals produced by the generator and PCU instrumentation sensors to a voltage range compatible with the spacecraft telemetry system. Functional evaluation of the TSCU requires duplicating of the various sensor signals as inputs to the TSCU and comparison of the output, or conditioned signals, against the known inputs. Calibration curves were used in making the necessary voltage-to-parametric conversions for output signals. A breadboard test tool and standard laboratory instrumentation were used in the testing. The signals duplicated for this functional test include:

Generator hot junction temperature

Generator fin root temperature

Generator internal pressure

Generator output voltage

Power conditioner input voltage

Power conditioner input current

Power conditioner output voltage

Power conditioner output current

Power conditioner temperature

Power conditioner status (on- or off-bus).

4. System Testing

The power supply system can be functionally tested with the GSTC. The functional tests verify nominal system operation or identify an anomaly. For convenience, the GSTC can also simulate the RTG subsystem so that the PCU and TSCU can be checked out under simulated system conditions.

System checkout was conducted in accordance with either a functional procedure (Ref. IV-1) or the technical manual (Ref. IV-2). The system (either fueled or electrically heated) was assembled and connected to the GSTC. A load was applied, and the system was monitored until it achieved thermal stability. A complete set of data was then recorded and converted to real data utilizing calibration curves. The real data were evaluated by comparison with the criteria of Refs. IV-1 or IV-2.

The procedure for system functional test with simulated generators is given in the technical manual (Ref. IV-2). The test was conducted with the PCU and TSCU and utilizes the GSTC to simulate the generator subsystem. The PCU and TSCU were connected to the GSTC. Regulated spacecraft bus voltage was applied to the PCU and TSCU and simulated generator subsystem signals were applied by the GSTC. Thermal stability of the PCU was achieved, and a complete set of data was recorded by the GSTC. These data were converted to real data and evaluated by comparison with the known simulated generator subsystem input data.

This test provides a means of checking the PCU and TSCU when the generator subsystem is not available, and provides a quick means of troubleshooting the system without resorting to the longer procedure required when the generator subsystem is used.

B. PERFORMANCE CRITERIA

Criteria were developed for the parameters measured in the system and subsystem performance and acceptance tests. These criteria are presented in the procedures listed on Table IV-1 along with the system or subsystem effectivity to which each document is applicable. Criteria are applicable to the power supply system in-air functional test, 452B1900018; fueled power check, parametric test, post-vibration functional test and post-acceleration functional test, 452B1900073; and system and subsystem functional, simulation and verification tests, Ref. IV-2.

TABLE IV-1

List of Procedures Containing System/Subsystem Performance/Acceptance Criteria

Martin Marietta Procedure/ Document No.	Title	Effectivity Systems	Effectivity Subsystems
452B1900018	SNAP 19/Nimbus B Power Supply System Functional Test Procedure	6, 7 and 8	
452B1900036	Radioisotope Fueled Thermoelectric Generator System Thermal Vacuum Test/Performance Test Procedures	4, 6, 7 and 8	
452B1900043	Thermal Vacuum Test Electrically Heated System	5	
452B1900073	SNAP 19/Nimbus B Power Supply System Performance/Acceptance Criteria	4, 5, 6, 7 and 8	8, 6A and 8A
452B1900104	Radioisotope Fueled Thermoelectric Generator Thermal Vacuum Test/ Performance Test Procedures		8, 8A
452B1900109	RTG Fueled Subsystem Thermal Vacuum Test Procedure Utilizing Laboratory Instrumentation		6A
MND-3607-80	SNAP 19 Technical Manual--Operation and Field Maintenance	All	All
MN-10210B	Specification for a SNAP 19/Nimbus B Radioisotope Thermoelectric Power Supply System	All	All
452B1900026	Telemetry Signal Conditioning Unit Functional Acceptance Test Procedure		All
452B1900021	Power Conditioner Functional Acceptance Test Procedure		All

System performance and acceptance criteria (452B1900036) are presented in Table IV-2. These system criteria are applicable to thermal vacuum testing which was normally the last environmental test conducted. The first four columns on the left in Table IV-2 deal with system performance requirements immediately prior to application of thermal vacuum conditions. The middle four columns present the itemized system requirements immediately after attaining normal average orbital conditions, and the four remaining columns pertain to the same orbital condition at the completion of the testing cycle. Each of the corresponding columns in each of the three sets deals with a different combination of the two power channels in the on-/off-bus modes.

TABLE IV-2

SNAP 19 System Performance and Acceptance Criteria

Measurement	Type	GSTC Channel	Initial Air Test Step 6.1 (13) PC On Bus 6.1.29 (13)	Initial Air Test PC 1 Off Bus 6.1.38 (13)	Initial Air Test PC Off Bus 6.1.40 (13)	Initial Air Test PC 2 Off Bus 6.1.42 (13)	Initial System Performance Test Step 6.3 (13) PC On Bus 6.1.29 (13)	Initial System Performance Test PC 1 Off Bus 6.1.38 (13)	Initial System Performance Test PC Off Bus 6.1.40 (13)	Initial System Performance Test PC 2 Off Bus 6.1.42 (13)	Final System Performance Test Step 6.10 (13) PC On Bus 6.1.29 (13)	Final System Performance Test PC 1 Off Bus 6.1.38 (13)	Final System Performance Test PC Off Bus 6.1.40 (13)	Final System Performance Test PC 2 Off Bus 6.1.42 (13)
PC 1 input volts	Direct	01	2.6 ± 0.1 vdc	2.55 ± 0.1 vdc	2.55 ± 0.1 vdc	2.6 ± 0.1 vdc	2.6 ± 0.1 vdc	2.55 ± 0.1 vdc	2.55 ± 0.1 vdc	2.6 ± 0.1 vdc	2.6 ± 0.1 vdc	2.55 ± 0.1 vdc	2.55 ± 0.1 vdc	2.6 ± 0.1 vdc
PC 2 input volts	Direct	02	2.6 ± 0.1 vdc	2.6 ± 0.1 vdc	2.55 ± 0.1 vdc	2.55 ± 0.1 vdc	2.6 ± 0.1 vdc	2.6 ± 0.1 vdc	2.55 ± 0.1 vdc	2.55 ± 0.1 vdc	2.6 ± 0.1 vdc	2.6 ± 0.1 vdc	2.55 ± 0.1 vdc	2.55 ± 0.1 vdc
PC 1 input volts	TM (12)	03	← Within 5% of direct reading (channel 1) →											
PC 2 input volts	↑	04	← Within 5% of direct reading (channel 2) →											
RTG 1 output volts		05	← Within 6% of (direct PC input volts (channel 1) + 0.1 vdc) →											
RTG 2 output volts		06	← Within 6% of (direct PC input volts (channel 2) + 0.1 vdc) →											
RTG 1 hot junction temp T2		07	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)
RTG 1 hot junction temp T3		08	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)
RTG 1 hot junction temp T5		09	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)
RTG 2 hot junction temp T2		10	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)
RTG 2 hot junction temp T3		11	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)
RTG 2 hot junction temp T5		12	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)
RTG 1 fin root temp T6		13	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)
RTG 1 fin root temp T7		14	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)
RTG 1 fin root temp T8		15	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)
RTG 2 fin root temp T6		16	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)
RTG 2 fin root temp T7		17	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)
RTG 2 fin root temp T8		18	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)
RTG 1 pressure		19	> 9 psia	> 9 psia	> 9 psia	> 9 psia	> 10 psia	> 10 psia	> 10 psia	> 10 psia	> 10 psia	> 10 psia	> 10 psia	> 10 psia
RTG 2 pressure		20	> 9 psia	> 9 psia	> 9 psia	> 9 psia	> 10 psia	> 10 psia	> 10 psia	> 10 psia	> 10 psia	> 10 psia	> 10 psia	> 10 psia
PC 1 input current		21	10.5 ± 2.5 amp	11.0 ± 2.5 amp	11.0 ± 2.5 amp	10.5 ± 2.5 amp	10.5 ± 2.5 amp	11.0 ± 2.5 amp	11.0 ± 2.5 amp	10.5 ± 2.5 amp	10.5 ± 2.5 amp	11.0 ± 2.5 amp	11.0 ± 2.5 amp	10.5 ± 2.5 amp
PC 2 input current		22	10.5 ± 2.5 amp	10.5 ± 2.5 amp	11.0 ± 2.5 amp	11.0 ± 2.5 amp	10.5 ± 2.5 amp	10.5 ± 2.5 amp	11.0 ± 2.5 amp	11.0 ± 2.5 amp	10.5 ± 2.5 amp	10.5 ± 2.5 amp	11.0 ± 2.5 amp	11.0 ± 2.5 amp
PC 1 output volts		23	(4)	(5)	(5)	(4)	(4)	(5)	(5)	(4)	(4)	(5)	(5)	(4)
PC 2 output volts		24	(6)	(6)	(7)	(7)	(6)	(6)	(7)	(7)	(6)	(6)	(7)	(7)
PC 1 output current		25	(8)	(9)	(9)	(8)	(8)	(9)	(9)	(8)	(8)	(9)	(9)	(8)
PC 2 output current		26	(10)	(10)	(11)	(11)	(10)	(10)	(11)	(11)	(10)	(10)	(11)	(11)
PC 1 temperature		27	90 ± 20° F	90 ± 20° F	90 ± 20° F	90 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F
PC 2 temperature		28	90 ± 20° F	90 ± 20° F	90 ± 20° F	90 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F	80 ± 20° F
PC 1 on-off bus status	↓	29	0 to -0.1 vdc	-7.3 ± 0.1 vdc	7.3 ± 0.1 vdc	0 to -0.1 vdc	0 to -0.1 vdc	-7.3 ± 0.1 vdc	-7.3 ± 0.1 vdc	0 to -0.1 vdc	0 to -0.1 vdc	-7.3 ± 0.1 vdc	-7.3 ± 0.1 vdc	0 to -0.1 vdc
PC 2 on-off bus status	TM (12)	30	0 to -0.1 vdc	0 to -0.1 vdc	-7.3 ± 0.1 vdc	-7.3 ± 0.1 vdc	0 to -0.1 vdc	0 to -0.1 vdc	-7.3 ± 0.1 vdc	-7.3 ± 0.1 vdc	0 to -0.1 vdc	0 to -0.1 vdc	-7.3 ± 0.1 vdc	-7.3 ± 0.1 vdc
RTG 1 hot junction temp T9	Direct	31	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)
RTG 1 hot junction temp T10	↑	32	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)
RTG 2 hot junction temp T9		33	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)
RTG 2 hot junction temp T10		34	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	790 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)	890 ± 70° F (1)
RTG 1 fin root temp T13		35	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)
RTG 2 fin root temp T13		36	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	245 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)	337 ± 35° F (2)
PC 1 output current		37	0.90 to 1.17 amp	0 ± 0.01 amp	0 ± 0.01 amp	0.90 to 1.17 amp	0.92 to 1.19 amp	0 ± 0.01 amp	0 ± 0.01 amp	0.92 to 1.19 amp	0.88 to 1.17 amp	0 ± 0.01 amp	0 ± 0.01 amp	0.88 to 1.17 amp
PC 2 output current		38	0.90 to 1.17 amp	0.90 to 1.17 amp	0 ± 0.01 amp	0 ± 0.01 amp	0.92 to 1.19 amp	0.92 to 1.19 amp	0 ± 0.01 amp	0 ± 0.01 amp	0.88 to 1.17 amp	0.88 to 1.17 amp	0 ± 0.01 amp	0 ± 0.01 amp
PC 1 output volts		39	-24.5 ± 0.5 vdc	NA	NA	-24.5 ± 0.5 vdc	-24.5 ± 0.5 vdc	NA	NA	-24.5 ± 0.5 vdc	-24.5 ± 0.5 vdc	NA	NA	-24.5 ± 0.5 vdc
PC 2 output volts		40	-24.5 ± 0.5 vdc	-24.5 ± 0.5 vdc	NA	NA	-24.5 ± 0.5 vdc	-24.5 ± 0.5 vdc	NA	NA	-24.5 ± 0.5 vdc	-24.5 ± 0.5 vdc	NA	NA
PC 1 dummy load current		41	0 ± 0.01 amp	0.95 to 1.22 amp	0.95 to 1.22 amp	0 ± 0.01 amp	0 ± 0.01 amp	0.97 to 1.24 amp	0.97 to 1.24 amp	0 ± 0.01 amp	0 ± 0.01 amp	0.93 to 1.22 amp	0.93 to 1.22 amp	0 ± 0.01 amp
PC 2 dummy load current		42	0 ± 0.01 amp	0 ± 0.01 amp	0.95 to 1.22 amp	0.95 to 1.22 amp	0 ± 0.01 amp	0 ± 0.01 amp	0.97 to 1 24 amp	0.97 to 1.24 amp	0 ± 0.01 amp	0 ± 0.01 amp	0.93 to 1.22 amp	0.93 to 1.22 amp
PC 1 dummy load volts		43	NA	-23.75 ± 0.5 vdc	-23.75 ± 0.5 vdc	NA	NA	-23.75 ± 0.5 vdc	-23.75 ± 0.5 vdc	NA	NA	-23.75 ± 0.5 vdc	-23.75 ± 0.5 vdc	NA
PC 2 dummy load volts		44	NA	NA	-23.75 ± 0.5 vdc	-23.75 ± 0.5 vdc	NA	NA	-23.75 ± 0.5 vdc	-23.75 ± 0.5 vdc	NA	NA	-23.75 ± 0.5 vdc	-23.75 ± 0.5 vdc
PC output load volts		45	-23.0 ± 0.5 vdc	-22.75 ± 0.5 vdc	22.75 ± 0.5 vdc	-22.75 ± 0.5 vdc	-23.0 ± 0.5 vdc	-22.75 ± 0.5 vdc	-22.75 ± 0.5 vdc	-22.75 ± 0.5 vdc	-23.0 ± 0.5 vdc	-22.75 ± 0.5 vdc	-22.75 ± 0.5 vdc	-22.75 ± 0.5 vdc
TSCU input current		46	← 60 ± 10 ma →											
TSCU 1 input volts		47	← 24.5 ± 0.5 vdc →											
TSCU 2 input volts		48	← -24.5 ± 0.5 vdc →											
Press. 1 excitation	↓	49	← -6.34 ± 0.3 vdc →											
Press. 2 excitation	Direct	50	← -6.34 ± 0.3 vdc →											
System power (direct)														
Single channel	Direct	NA	22.5 to 28.0 w (3)	NA	NA	NA	23.0 to 28.5 w (3)	NA	NA	NA	22.0 to 28.0 w (3)	NA	NA	NA
Both channels (total)	Direct	NA	46.5 to 54.0 w	NA	NA	NA	47.5 to 55.0 w	NA	NA	NA	46.0 to 54.0 w	NA	NA	NA
Ripple	Direct	NA	< 50 mv (p-p)	NA	NA	NA	< 50 mv (p-p)	NA	NA	NA	< 50 mv (p-p)	NA	NA	NA

NOTES:

1. For a given fuel inventory and ambient temperature, all hot junction measurements on a single generator must agree within 80° F.
2. For a given inventory and ambient temperature, all thermistor measurements must agree within 50° F.
3. System power on a single channel by direct measurement (on bus) is the product of GSTC channels 37 and 39 for PC channel 1 and GSTC channels 38 and 40 for PC channel 2.
4. Within 5% of direct reading (channel 39).
5. Within 5% of direct reading (channel 43).
6. Within 5% of direct reading (channel 40).
7. Within 5% of direct reading (channel 44).
8. Within 5% of direct reading (channel 37).
9. Within 5% of direct reading (channel 41).
10. Within 5% of direct reading (channel 38).
11. Within 5% of direct reading (channel 42).
12. Telemetered
13. Related paragraph in 452B1900036, Radioisotope Fueled Thermoelectric Generator System Thermal Vacuum Test/Performance Test Procedure

C. PROTOTYPE QUALIFICATION

Prototype qualification included four separate environmental tests· humidity, vibration, acceleration and thermal vacuum. The prototype vibration test levels were more severe than those of the flight acceptance in terms of magnitude of g-level and time duration of run. Further, the prototype thermal vacuum test differed from the flight acceptance version only in the temperature extremes, the hot and cold temperature soaks were increased by a nominal 9° F.

System and subsystem operational characteristics were measured after each environmental test, and the data were compared to applicable performance criteria to determine compliance with requirements.

1. Humidity Testing

Each subsystem, in an operating mode, was subjected to 24 hours of humidity testing at 86° F and 95% relative humidity. Functional tests were performed on each subsystem at the completion of the humidity exposure, and critical parameters were monitored throughout the test. The generator subsystems were fully assembled for the test, ensuring that all flight connectors received adequate exposure and testing

A complete visual examination was performed immediately after the test articles were removed from the humidity environment. Particular attention was given to the condition of the emissive coating on the generator subsystem. This coating, when cold, is susceptible to water damage. In the operating mode, however, the isotopic decay heat maintains the coated surfaces above 212° F and prevents condensate from forming. Figure IV-1 shows subsystem S/N 4 installed in an environmental chamber.

2. Vibration Testing

Each prototype subsystem was subjected to the sinusoidal vibration spectra shown in Table IV-3 and the random vibration spectra shown in Table IV-4.

Functional tests were performed at the completion of each vibration axis test to ensure satisfactory post-test performance. A vibration axis is defined as one sine sweep plus one random sweep. During the testing, the generator subsystems were mounted on a shaker adapter fixture. Yaw axis vibration was performed directly on the shakerhead (see Fig. IV-2) Roll and pitch axes vibration tests were performed on an oil film slip table (see Fig. IV-3).

The fixtures for the PCU and TSCU were supplied by NASA/GSFC and are representative of their mountings in the spacecraft sensory ring.

3. Acceleration Testing

Each subsystem was subjected to a 30 g sustained acceleration in the positive yaw axis for 5 minutes The generator subsystems were maintained on nominal load in an operating condition and underwent functional tests at the completion of the acceleration test. The tests were performed on a centrifuge with the specified levels applied at the calculated center of gravity of the specimen. Figure IV-5 shows generator subsystem S/N 4 mounted in the centrifuge for testing. Due to nuclear safety considerations, the sides and top of the centrifuge were removed, and the area was bunkered with sand bags.

TABLE IV-3

Vibration Levels (Sinusoidal)--
Prototype Qualification Tests

Direction	Frequency Range (cps)	Amplitude, 0 to Peak g (in.)
Generator subsystem		
Z (yaw) axis	10 to 14	0.5 double amplitude
	14 to 40	5.0
	40 to 80	7.0
	80 to 450	5.0
	450 to 2000	7.5
Y (pitch) axis	5 to 10	2.0
	10 to 70	3.0
	70 to 250	1.5
	250 to 400	3.0
	400 to 2000	7.5
X (roll) axis	5 to 10	2.0
	10 to 30	3.0
	30 to 40	0.065 double amplitude ΔConstant displacement
	40 to 60	5.5
	60 to 250	1.5
	250 to 400	3.0
	400 to 2000	7.5

ΔConstant displacement from 3 g at 30 cps to 5.5 g.

Power conditioner and telemetry modules		
Yaw axis	5 to 2000	10
Pitch axis	5 to 2000	10
Roll axis	5 to 2000	10

Notes:

Vibration limited to 0.25 inch single amplitude, ±0.025 inch

Sweep rate: 1 octave/minute

Single sweep per axis

Axis orientation is defined in Figs. IV-2, IV-3 and IV-4.

TABLE IV-4

Vibration Levels (Random)--Qualification Tests

Direction/Duration	Frequency Range (cps)	Level (g^2/cps)
Generator subsystem 4 minutes each axis; total 12 minutes	20 to 2000	0.11 (14.7 g-rms)
Power conditioner and T/M modules 4 minutes each axis; total 12 minutes	20 to 2000	0.2 (20 g-rms)

Note:

Axis orientation is defined in Figs. IV-2, IV-3 and IV-4.

The PCU and TSCU were mounted in the same test fixture as was used for vibration testing and their performance was monitored during the test.

4. Thermal Vacuum Testing

During thermal vacuum testing, each system or subsystem was thermally cycled 2-1/2 times over a period of about 284 hours. The required cycles are shown in Fig. IV-6 for the generator subsystems and in Fig. IV-7 for the PCU and TSCU subsystems.

To test the generator subsystem, PCU and TSCU as a system in a single chamber required the use of a secondary shroud around the PCU and TSCU. The secondary shroud, filled with a recirculated saline solution, approximated the thermal environment which the PCU and TSCU will experience when mounted within the spacecraft sensory ring. The generator subsystem is completely exposed to space once the spacecraft shroud is jettisoned and, for this test, was suspended in the center of the vacuum chamber. To further simulate the thermal interface between the generator subsystem and the spacecraft, a mylar blanket, or thermal shield, was installed between the standoff and the generator subsystem support structure.

During thermal vacuum testing, two system performance evaluations were conducted, one at the beginning of the test and the other just before completion. The first test was a parametric evaluation of system performance. Three load points, 50%, 75% and 100% of the PCU output voltage, were employed and a system performance power map was prepared from the resultant data. The system parametric evaluation was the first test performed under thermal vacuum conditions.

The system performance/acceptance test was the last test performed. This test was essentially the same as the system parametric except that a single load, 100% of nominal, was employed. The data from the final system test was considered record data for final acceptance of the system.

Residual gas analyzer (RGA) equipment was used during thermal vacuum testing to obtain data for calculation of generator subsystem argon leak rate; the equipment analyzed vacuum chamber exhaust gas for argon content. These values were compared to results derived from the generator internal pressure sensors. The two

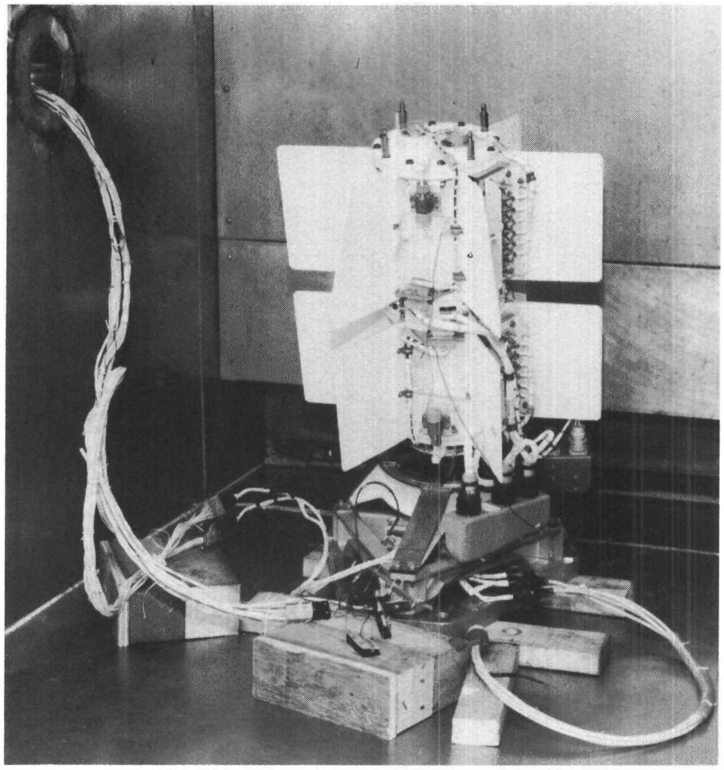


FIG. IV-1. GENERATOR SUBSYSTEM S/N 4 IN ENVIRONMENTAL TEST CHAMBER

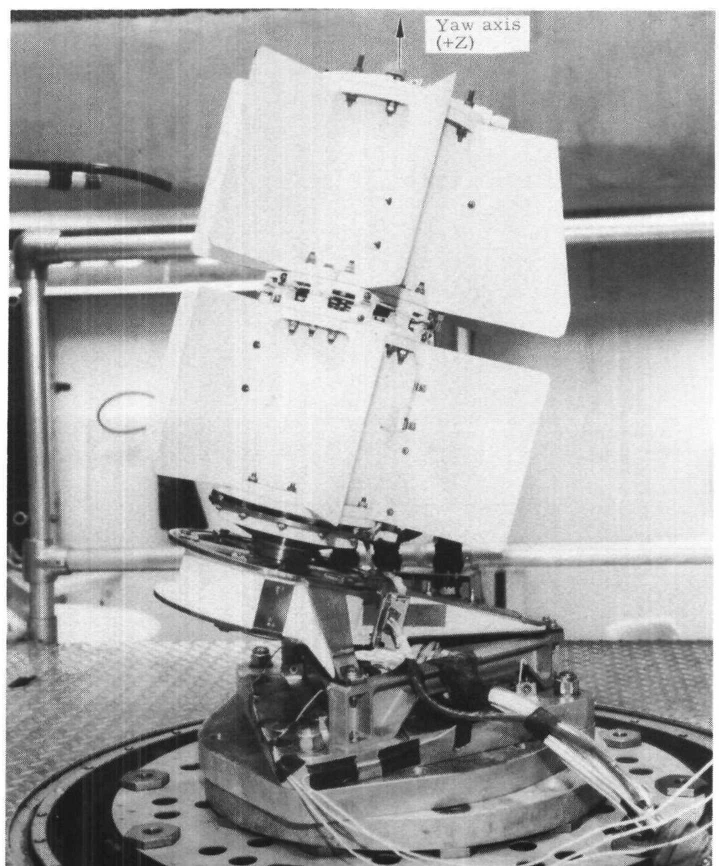


FIG. IV-2. GENERATOR SUBSYSTEM MOUNTED FOR YAW AXIS VIBRATION TEST

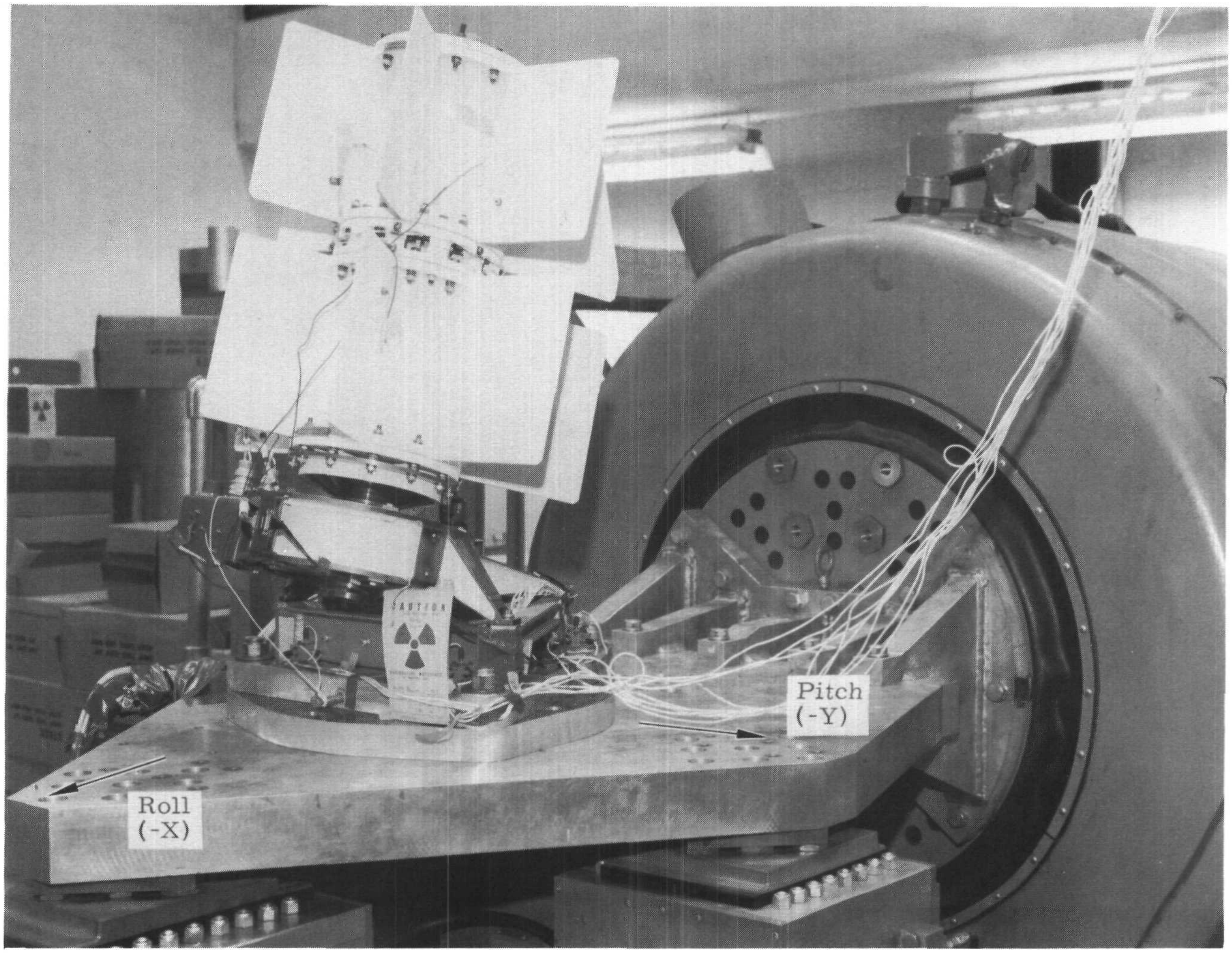


FIG. IV-3. GENERATOR SUBSYSTEM S/N 4 MOUNTED ON TEAM TABLE FOR PITCH AND ROLL AXES VIBRATION

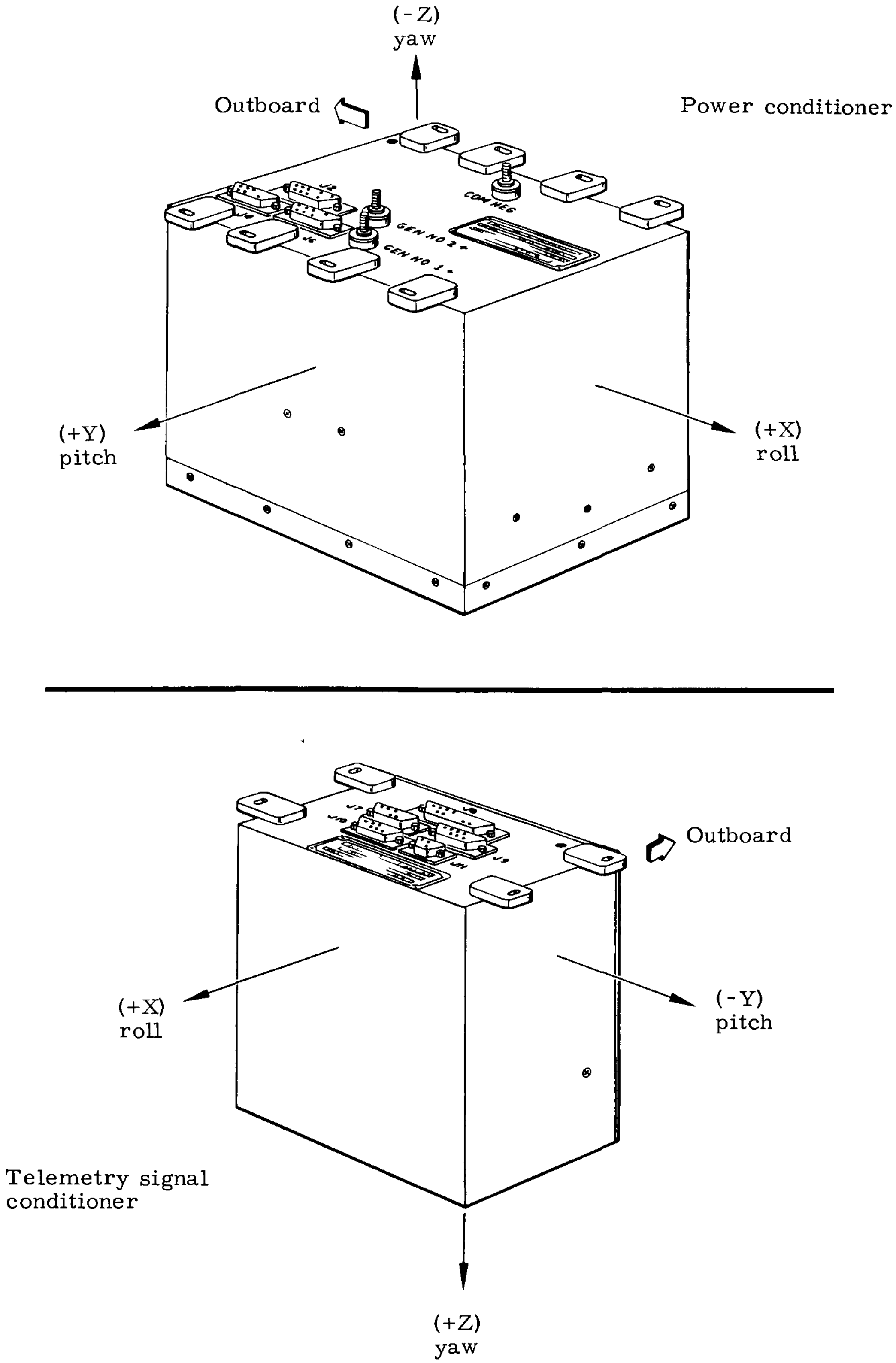


FIG. IV-4. POWER CONDITIONER AND TELEMETRY SIGNAL CONDITIONER VIBRATION TEST AXES

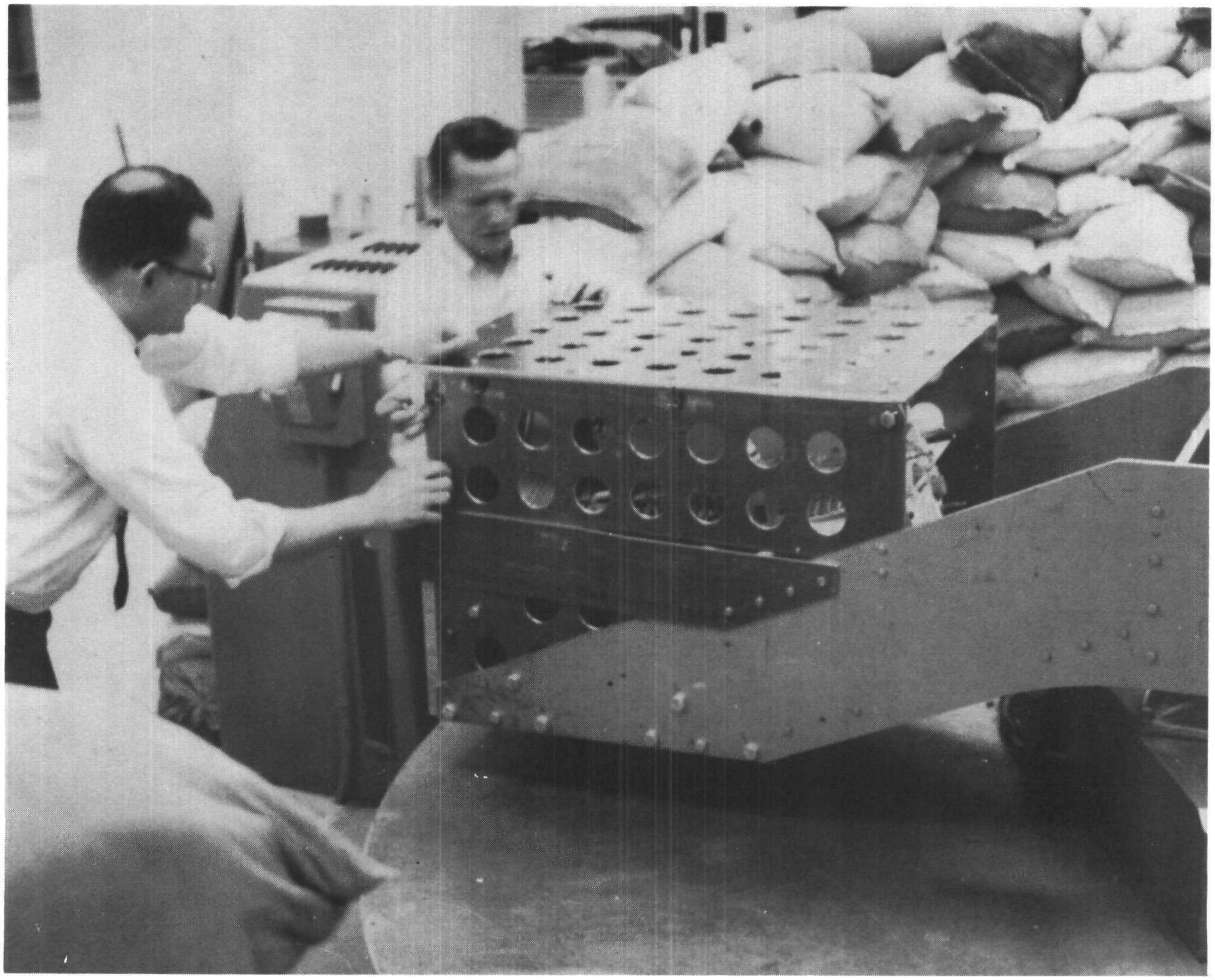
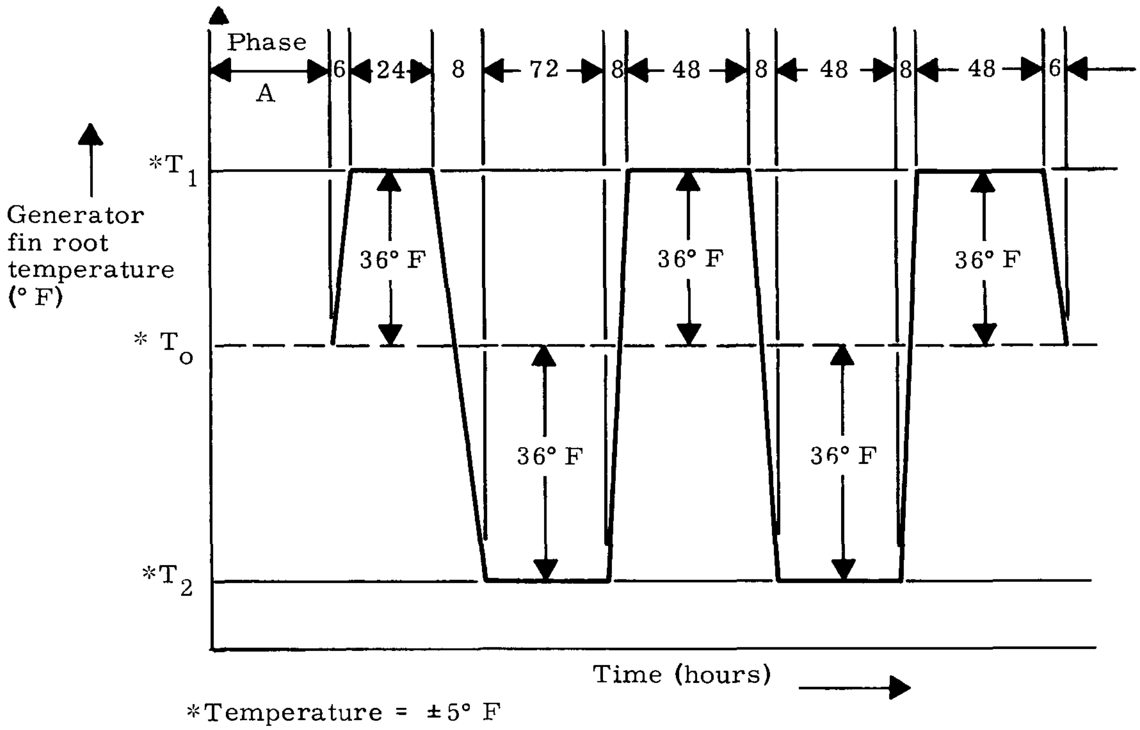


FIG. IV-5. GENERATOR SUBSYSTEM S/N 4 MOUNTED IN CENTRIFUGE FOR ACCELERATION TESTING

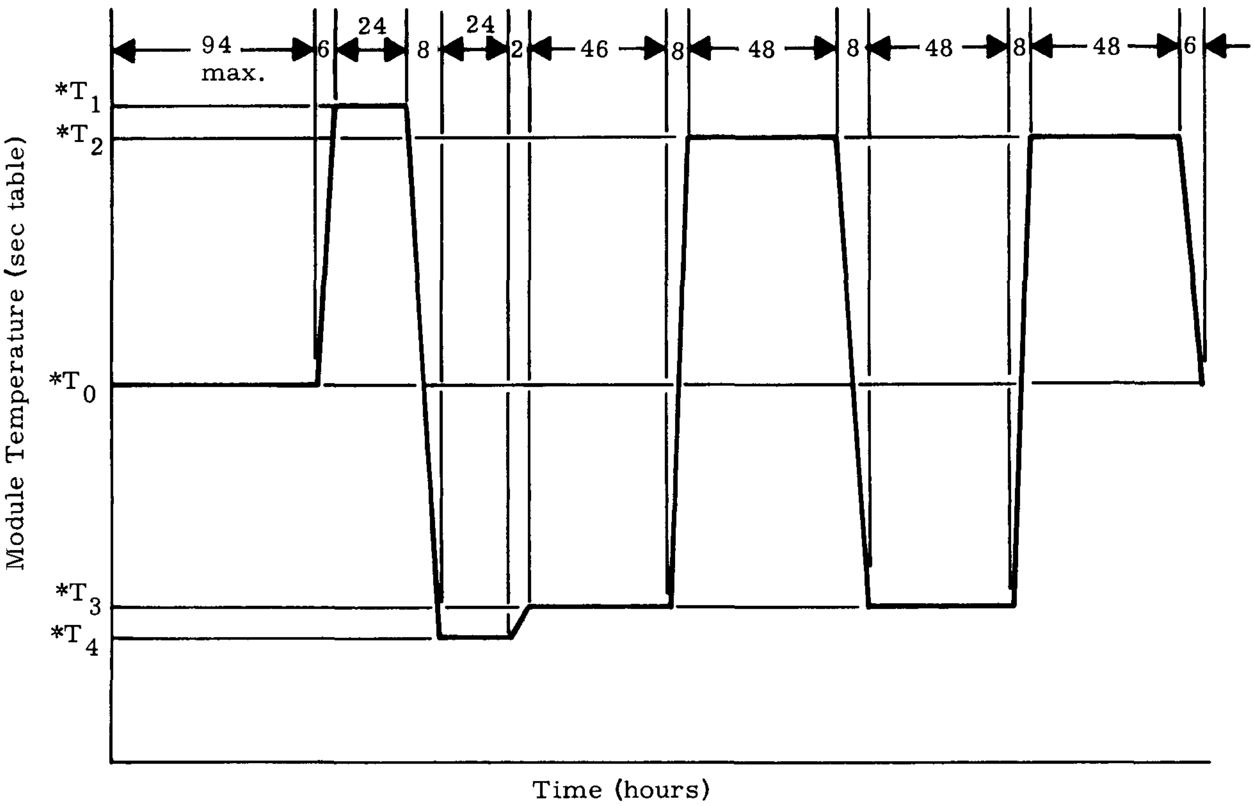


Temperature (° F)

Prototype	
T_o	337
T_1	373
T_2	301

▲In Phase "A," input power shall be held constant and the output power level shall be varied.
Phase "A," the average orbit temperature test, shall not exceed 94 hours duration.

FIG. IV-6. THERMAL-VACUUM CYCLE TEMPERATURE-TIME PROFILE GENERATOR SUB-SYSTEM (PROTOTYPE LEVEL)



Temperature (° F)	Prototype
T_1	131
T_2	122
T_0	Room ≈ 77
T_3	32
T_4	23

*Temperature ± 5°

FIG. IV-7. THERMAL-VACUUM CYCLE TEMPERATURE-TIME PROFILE PCU AND TSCU (PROTOTYPE LEVEL) methods of evaluating leak rates produced answers that were in general agreement for those tests conducted in the smaller of the two vacuum chambers available at the Martin Marietta Corporation. RGA scan data acquired from the larger chamber were characterized by variations sufficient to preclude their use. The chamber size is used to identify the source of useful data, not to infer that the larger volume was the total problem. The reliability of RGA data is largely dependent on the relative magnitude of the measured leak to the chamber argon background (i.e., signal-to-noise ratio). The smaller chamber provided an acceptable test situation for use of RGA techniques.

D. FLIGHT ACCEPTANCE

Flight acceptance testing included two environmental tests: vibration and thermal vacuum. As in prototype qualification, the test article operational characteristics were measured after each environmental test, and the data were compared to applicable performance criteria to determine compliance with requirements.

The specification requirements for flight acceptance were incorporated into the applicable test procedure.

1. Vibration Testing

Flight subsystems were subjected to the sinusoidal vibration spectra listed in Table IV-5, and the random vibration spectra are listed in Table IV-6. Each subsystem was operating and on nominal load throughout the test. Functional tests were performed at the completion of each vibration axis, i.e., one sinusoidal sweep and one random vibration.

The generator PCU and TSCU subsystems were mounted in fixtures and attached to the shaker as described in Section IV-C-2.

2. Thermal Vacuum Testing

In thermal vacuum testing, each system or subsystem was thermally cycled 2-1/2 times during a period of approximately 284 hours. The temperature profile for the generator subsystems is shown in Fig. IV-8 and the corresponding temperature profile for the PCU and TSCU subsystems is shown in Fig. IV-9. Other than the differences in temperature excursions, the discussion in Section IV-C-4 is also applicable to flight acceptance testing.

Figure IV-10 shows a system installed on the external railing of the thermal vacuum chamber. The secondary shroud prevents a direct view of the PCU and TSCU.

TABLE IV-5

Sinusoidal Vibration Levels Flight Acceptance Test

Direction	Frequency Range (cps)	Amplitude, 0 to peak g (in.)
Generator subsystem		
Z (yaw) axis	10 to 14	0.5 double amplitude
	14 to 40	3.3
	40 to 80	4.7
	80 to 450	3.3
	450 to 2000	5.0
Y (pitch) axis	5 to 10	1.4
	10 to 70	2.0
	70 to 250	1.0
	250 to 400	2.0
	400 to 2000	5.0
X (roll) axis	5 to 10	1.4
	10 to 40	2.0
	40 to 60	3.7
	60 to 250	1.0
	250 to 400	2.0
	400 to 2000	5.0
Power conditioner and telemetry signal conditioner units		
Z (yaw) axis	5 to 2000	5
Y (pitch) axis	5 to 2000	5
X (roll) axis	5 to 2000	5

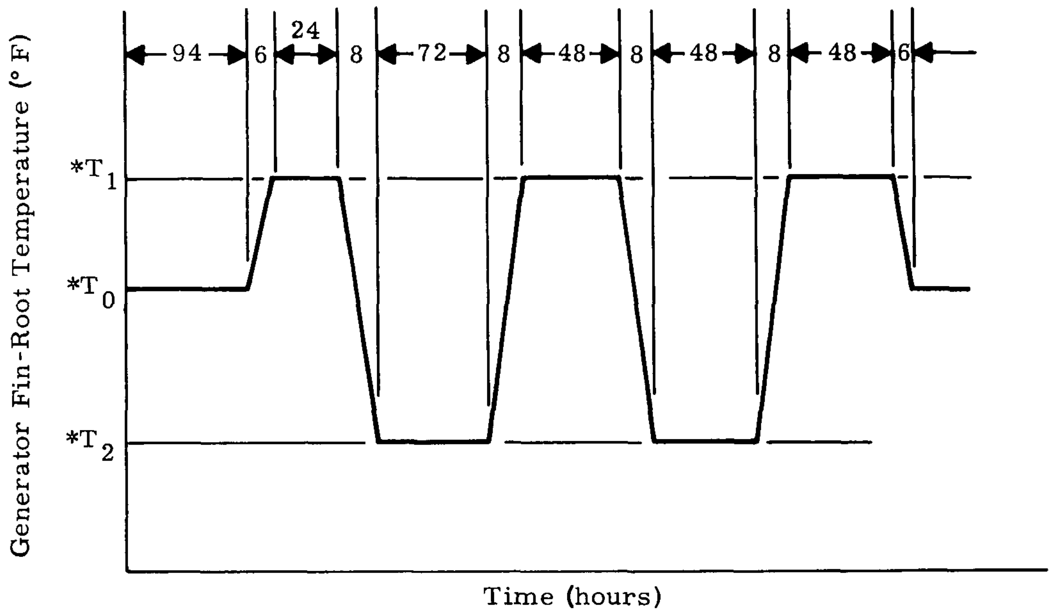
Notes:

Vibration limited to 0.25-inch single amplitude, ±0.025 inch

Sweep rate: 2 octaves/minute

Single sweep per axis

Axis orientation is defined in Figs. IV-2, IV-3 and IV-4.



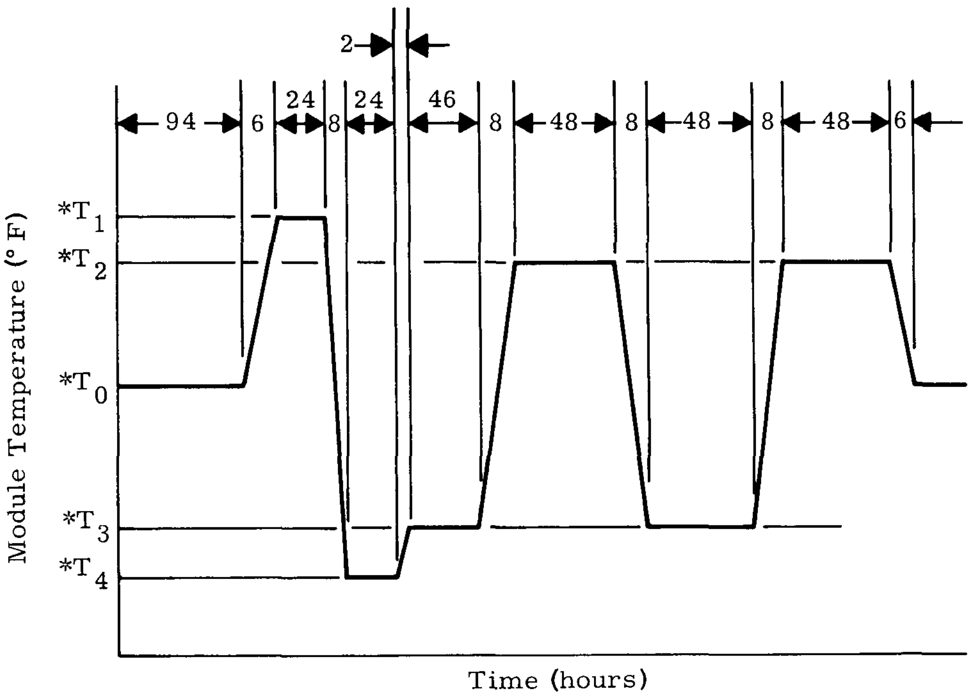
Temperature (° F)

Flight Article

*	Average of Sensors	Single Sensor
T_0	337 ± 5	
T_1	364 ± 5	$376 \, {}^{+0}_{-5}$
T_2	310 ± 5	$322 \, {}^{+5}_{-10}$

—— Flight article

FIG. IV-8. GENERATOR SYSTEM (FLIGHT LEVEL) THERMAL VACUUM CYCLE TEMPERATURE-TIME PROFILE



*Temperature ± 5° F

	Flight
T_1	122
T_2	113
T_0	77
T_3	41
T_4	32

FIG. IV-9. PCU AND TSCU (FLIGHT LEVEL) THERMAL VACUUM CYCLE TEMPERATURE-TIME PROFILE

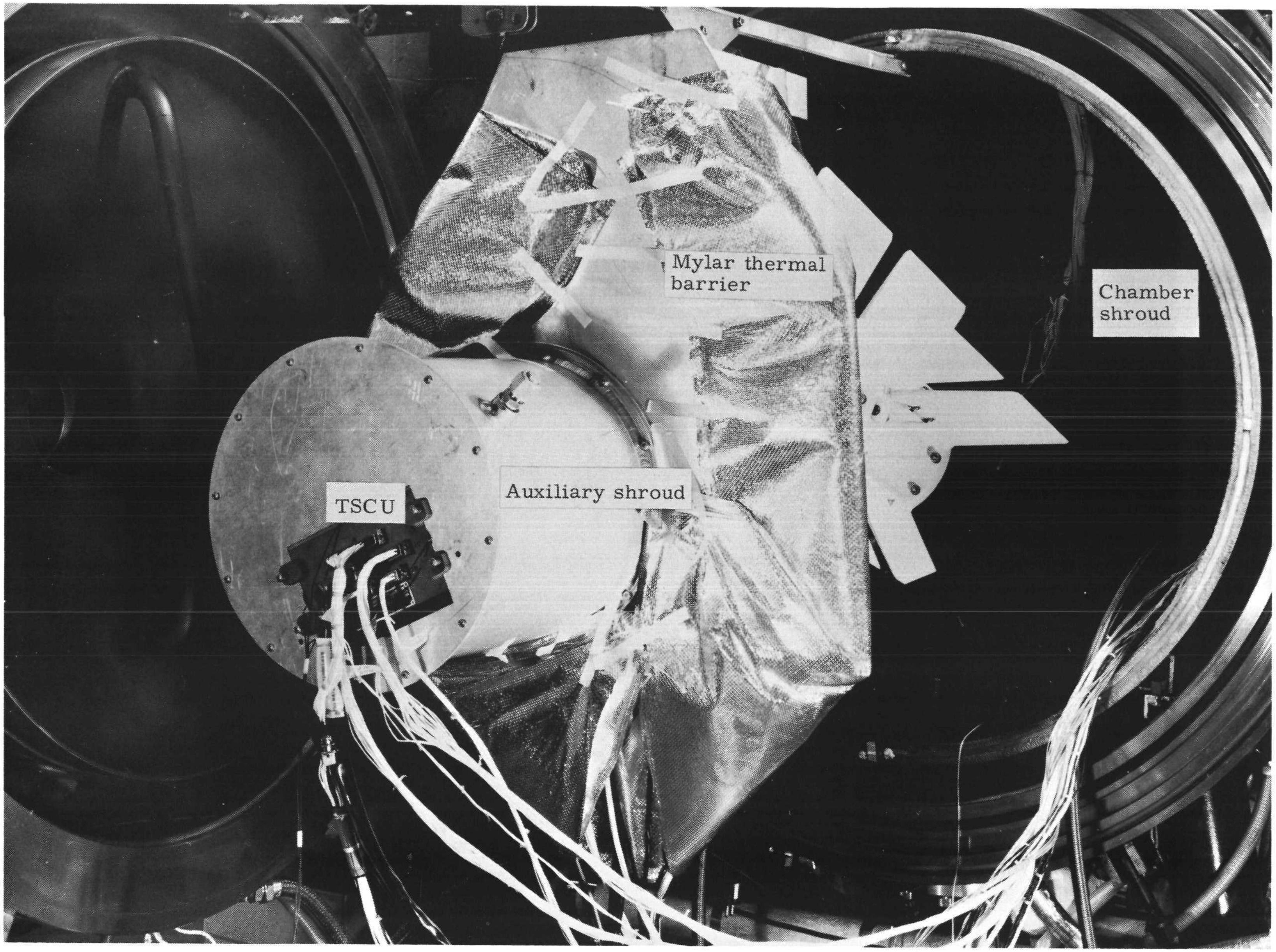


FIG. IV-10. SYSTEM MOUNTED FOR INSERTION INTO THERMAL VACUUM CHAMBER

TABLE IV-6

Random Vibration Levels Flight Acceptance Test

Direction/Duration	Frequency Range (cps)	Level (g^2/cps)
Generator subsystem		
Z (yaw) and transverse axes 2 minutes each axis; total 6 minutes	20 to 2000	0.05 (10 g-rms)
Power conditioner and telemetry signal conditioner units		
Z (yaw) and transverse axes 2 minutes each axis; total 6 minutes	20 to 2000	0.07 (11.7 g-rms)

Note:

Axis orientation is defined in Figs. IV-2, IV-3 and IV-4

E. MASS PROPERTIES MEASUREMENTS

Mass properties measurements were performed on the generator, PCU and TSCU subsystems. Weights and centers of gravity were determined for each unit. Also, mass moments of inertia were required for the generator subsystem.

Weight properties were established for all flight subsystems and one prototype subsystem. Center of gravity (cg) was measured for one prototype generator subsystem, one flight generator subsystem and all PCU' s and TSCU' s. Mass moment of inertia (MI) properties were determined for one prototype and one flight generator subsystem only.

Special techniques were developed for each unit. A developmental study made it evident that the accuracy requirements for generator subsystem cg location (±0.1 inch in Z axis and ±0.03 inch in X and Y axes) were only marginally obtainalbe in the X and Y axes with the special techniques. For this reason, MI and cg measurements were discontinued on generator subsystems subsequent to S/N 6. The techniques employed for the measurements prior to the discontinuation are discussed in the following paragraphs.

1. Generator Subsystems

Mass properties measurements were carried out on the generator subsystem to:

(1) Demonstrate that the subsystem was within the weight requirement

(2) Determine the centers of gravity and mass moments of inertia relative to a specified set of coordinate axes.

Weight measurements were performed with either a calibrated load cell or a calibrated balance scale. The center of gravity of subsystems S/N 5 and S/N 6 were determined about the three major spacecraft axes by the compound pendulum method. This method uses the principle which relates the cg of a compound pendulum to the change in period and the change in pivot distance along a line connecting two pivot points with the cg. The derivation and proof of principle for this method are presented in Ref. IV-3.

The test setup involved suspending the generator subsystem from a cross fixture, swinging the article through a known angular displacement and accurately measuring the period of pendulum swing. After this, the pendulum length was changed by relocating the pivot point, and the measurements were repeated. The measurements were made in an altitude chamber at about 1.05 psia to minimize air drag effects. Period measurements were taken at 2-, 3-, 4- and 5-degree angular displacements. Since this measurement technique is theoretically insensitive to small changes in angular displacement for small angles, the variation helped in establishing accuracy limits. Figure IV-11 shows generator subsystem S/N 6 suspended in the roll axis. Comparable measurements were taken in both the pitch and yaw axes.

Separate sets of measurements were made for the subsystem with the support standoff attached and for the standoff alone. The additional flexibility gained through the second determination permits the spacecraft integrator to consider the spacecraft both with and without the generator subsystem aboard.

When completed, the measurement data were processed with an IBM 1130 computer code, programmed to account for the various test fixture components and geometric relationships which required numerous tare determinations. Moment of inertia and center of gravity calculations were performed independently of each other. This was done to reduce the error potential which would exist in a sequential calculation. Final data employed in the calculations were based on 5° amplitude for cg and 3° amplitude for moment of inertia. The accuracy of the cg measurements was established as less than ±0.050 inch error in any axis.

2. Power Conditioner and Telemetry Signal Conditioner Units

Mass properties measurements were carried out on the PCU and TSCU to:

(1) Demonstrate that the subsystems were within the weight requirement

(2) Determine the cg relative to a specified set of coordinate axes.

Each unit was weighed on a balance scale. Because the PCU and TSCU each provide three flat, mutually perpendicular surfaces, a simple knife-edge balance technique was used to determine the center of gravity location.

F. RADIATION MEASUREMENTS

Fueled generator subsystem nuclear radiation measurements were made with the subsystem inside the shipping container and with the subsystem exposed (not enclosed in any manner). Measurements were made as a function of distance from the exposed subsystem and from the external surface of the shipping container containing a subsystem.

Neutron measurements were made with a neutron dosimeter, and gammas were measured with a Geiger-Mueller survey meter. The data were plotted as total dose rate in millirem/hour as a function of distance in feet.

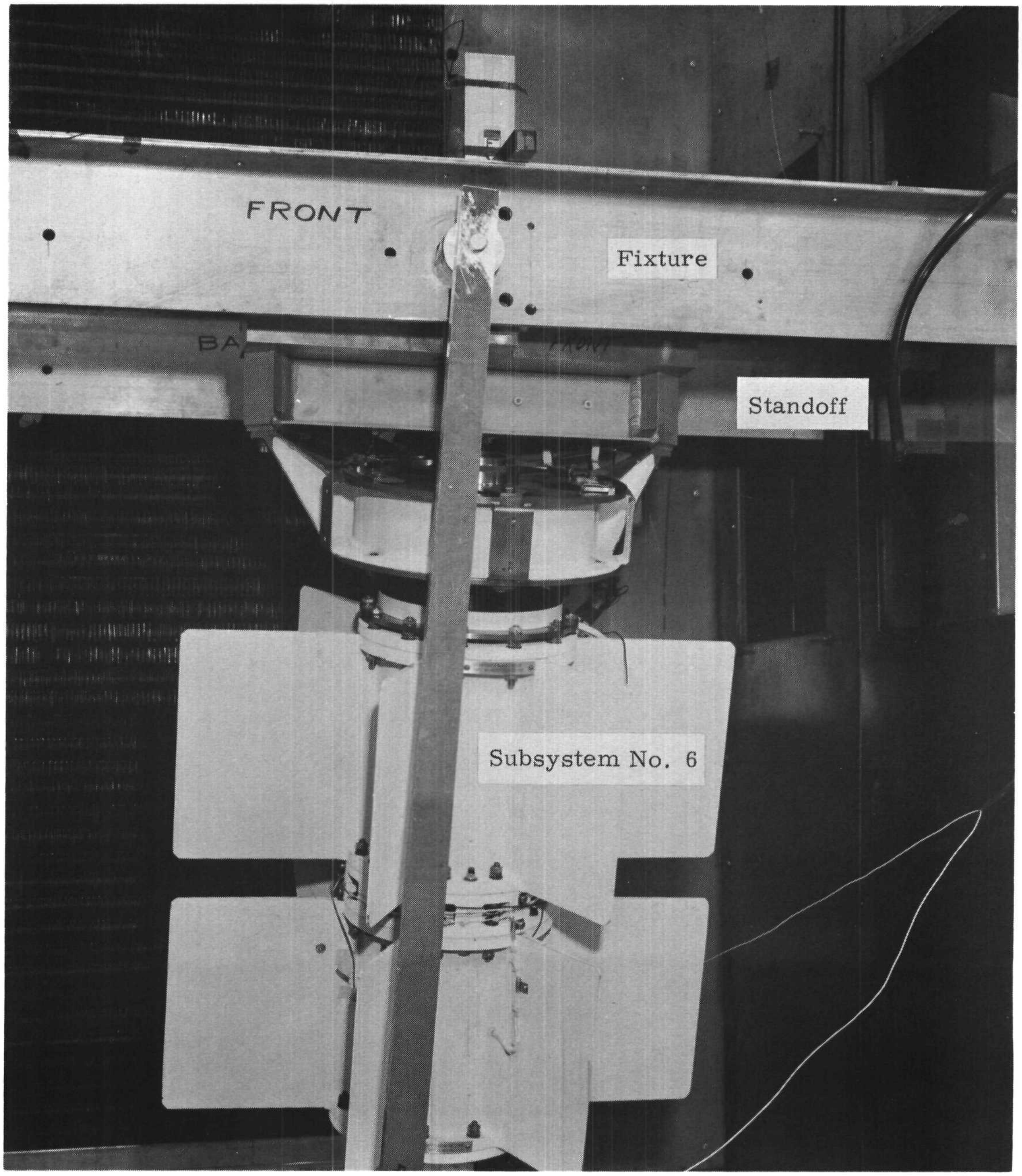


FIG. IV-11. GENERATOR SUBSYSTEM S/N 6 INSTALLED FOR ROLL AXIS MASS PROPERTIES TEST

Total doses for the flight generator subsystem are given in Figs. IV-12 through IV-14. Dose rates for the shipping container with the RTG subsystem installed are given in Figs. IV-15 and IV-16.

Energy spectra for both the neutron and gamma radiation were measured for a prototype subsystem, S/N 4. These data are available in Ref. IV-4.

G. SUBSYSTEM AND SYSTEM TEST SUMMARY

Chronologies of major events in testing systems Nos. 2, 4, 5, 6, 7, 8, 6A and 8A are presented in Appendix A. In addition to test events, these chronologies also include manufacturing events, program decisions and other items that affected testing.

Appendix B summarizes generator subsystem S/N 4, 5, 6, 7, 8, 6A and 8A test data, and Appendix C summarizes power supply system Nos. 4, 5, 6, 7, 8, 6A and 8A test data. Appendix C also includes a list of procedures used in system testing.

Because the components assigned for use as systems Nos. 1 and 3 were not assembled as systems under Phase III, the chronologies in Appendix A do not include these systems. Following is information on utilization of the generators from systems Nos. 1 and 3, and amplification of significant, unplanned events identified in the chronologies.

1. Generator Subsystem S/N 1 Utilization

Generator subsystem S/N 1, designed and fabricated during Phase II, became an engineering test unit during Phase III and was used in the following activities:

(1) Thermal conductance to spacecraft test (GE)

(2) Transmissibility and vibration tests on spacecraft (GE)

(3) Spacecraft shroud thermal test (GE)

(4) Shipping container thermal test (MMC)

(5) Transient thermal response to load voltage variations (MMC)

(6) "Walk-through" practice (GE and AFWTR)

(7) Capsule burst test (MMC).

2. Generator Subsystem S/N 3 Utilization

Generator subsystem S/N 3, consisting of generators S/N 5 and S/N 6, was fabricated during Phase II. These generators were used for endurance testing (refer to Volume III, Chapter V) during Phase III.

3. Generator Subsystem S/N 4 Event Detail

Though it was not considered relevant at the time, there were changes in the generator S/N 7 hot junction temperature characteristics during and after the prototype vibration. These changes were later determined to be the result of a relaxation of heat source preload. Subsequent motion of the heat source during vibration had

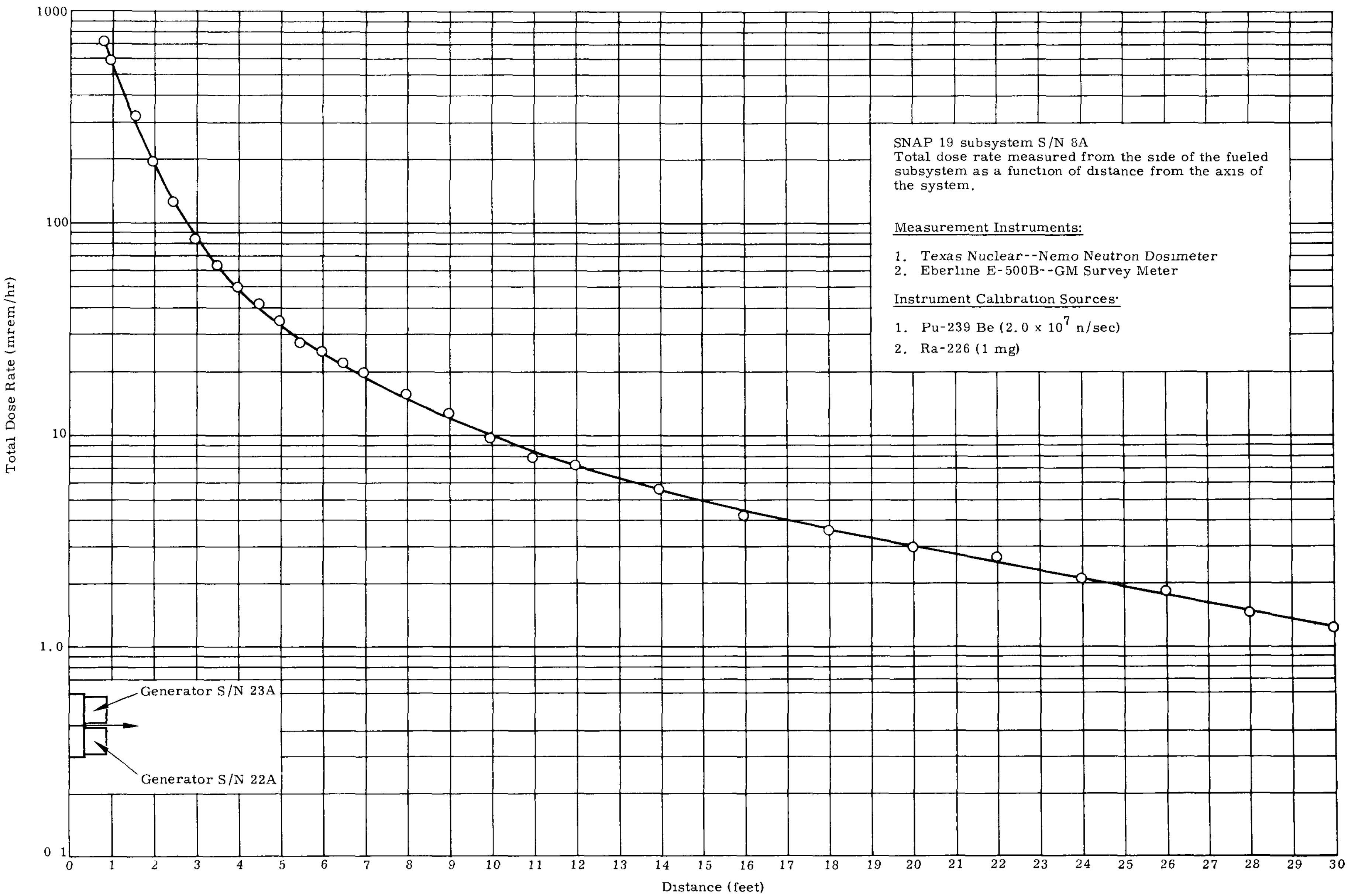


FIG IV-12 TOTAL DOSE RATE TO THE SIDE OF EXPOSED SUBSYSTEM

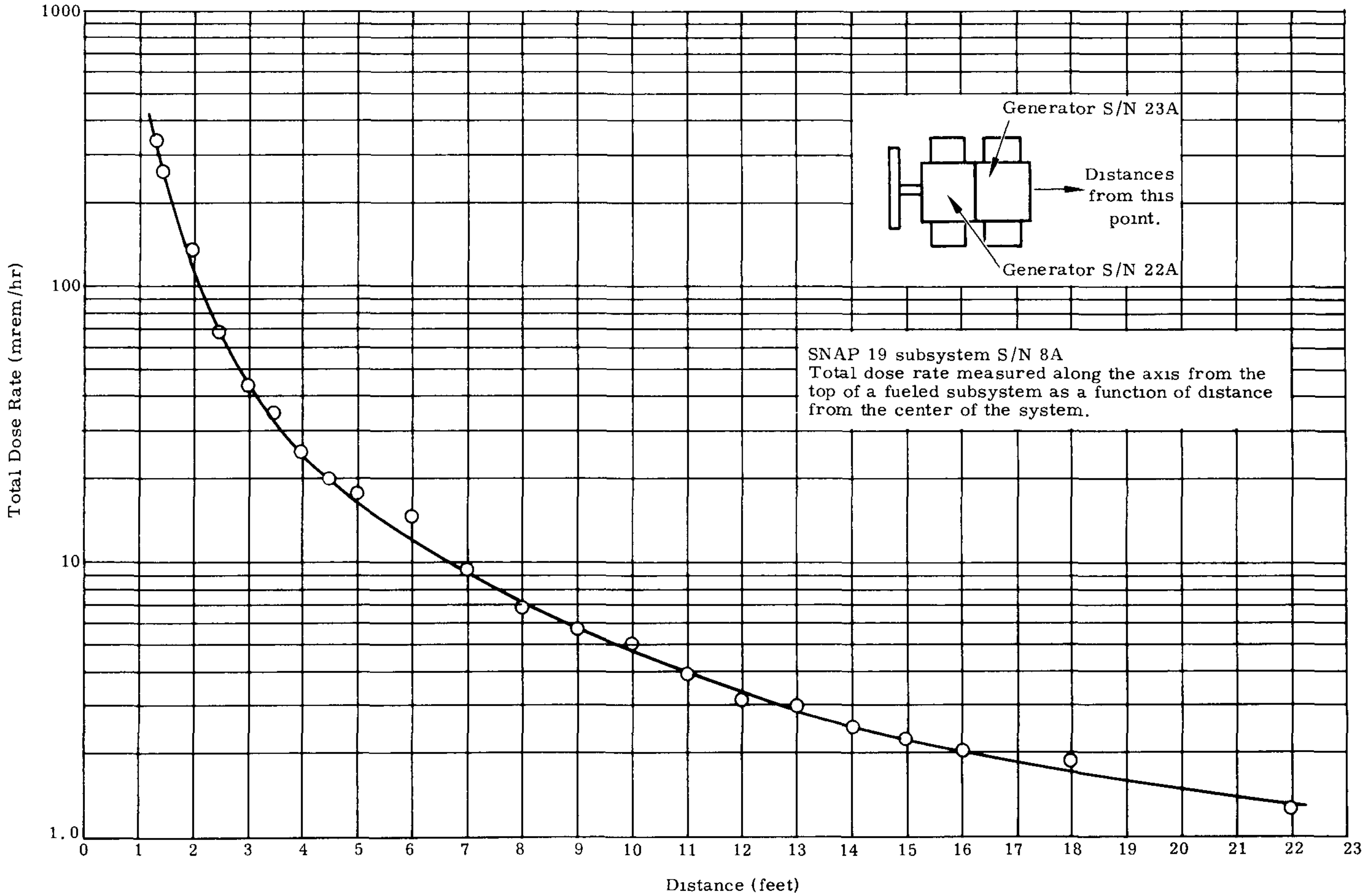


FIG. IV-13. TOTAL DOSE RATE ABOVE EXPOSED SUBSYSTEM

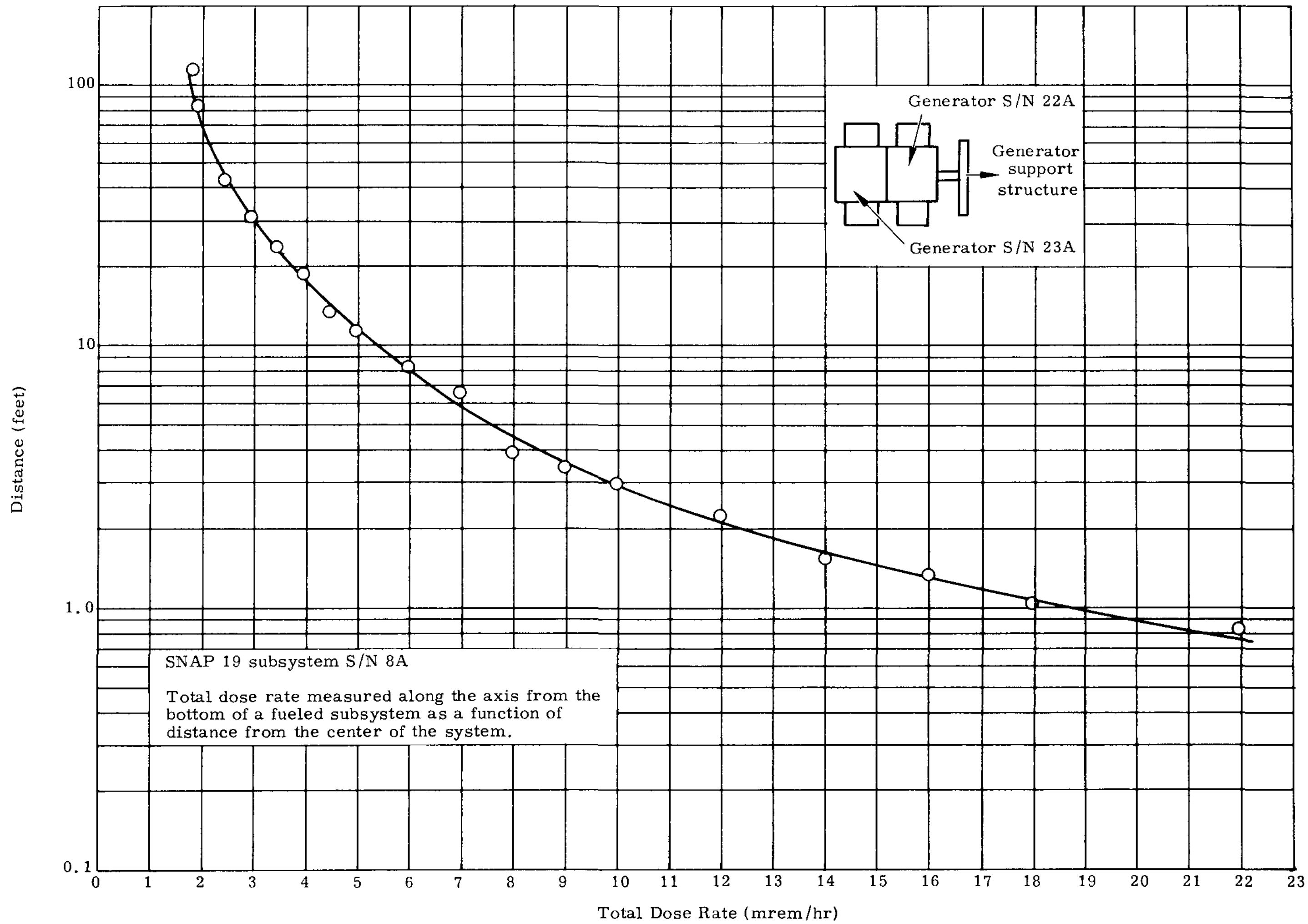


FIG. IV-14. TOTAL DOSE RATE BELOW EXPOSED SUBSYSTEM

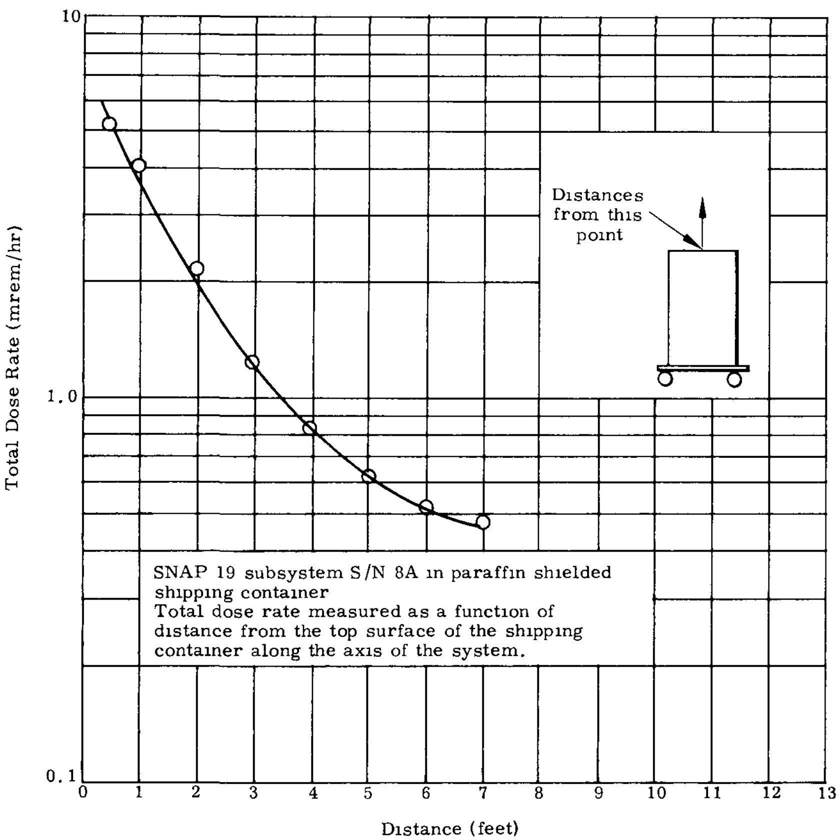


FIG. IV-15. TOTAL DOSE RATE TO THE SIDE OF SHIPPING CONTAINER WITH SUBSYSTEM

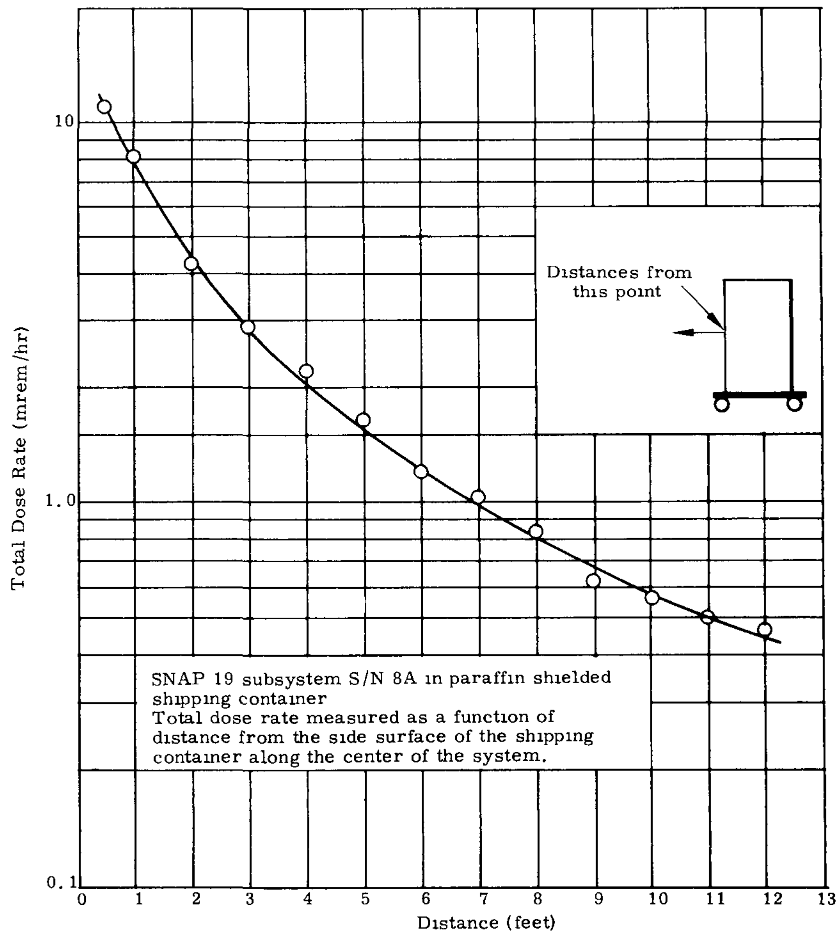


FIG. IV-16. TOTAL DOSE RATE ABOVE SHIPPING CONTAINER WITH SUBSYSTEM damaged some generator instrumentation. A modification was incorporated in the loading technique for flight system No. 7 which eliminated this as a potential problem area. (See Volume III, Chapter X.)

4. Generator Subsystem S/N 5 Event Detail

Generator subsystem S/N 5, an electrically heated prototype subsystem, included generators S/N 15 and S/N 16. During the first axis vibration testing, in the sinusoidal sweep, a power failure inside generator S/N 15 was manifested by a 50% drop in heater line voltage. The subsystem was disassembled for diagnosis of both generators, even though only one had failed. The diagnostic disassemblies revealed that the heaters and heater blocks were not adequately supported. A development program was undertaken to establish improved design. Detailed discussions of the program and the modifications are presented in Volume III, Chapter IV, and in Ref. IV-5. During this development period, the fueled prototype subsystem successfully completed prototype vibration. In view of this, and considering the fact that generator subsystem S/N 5 would experience only flight level vibration testing at the spacecraft level, it was decided to test the heater block modification at flight level vibration. The acceleration test was deleted in accordance with the reduced test requirements.

5. Generator Subsystem S/N 6

Generator subsystem S/N 6, the first flight subsystem with dispersal heat sources, consisted of generators S/N 11 and S/N 12. At the completion of thermal vacuum testing, a generator overtemperature incident occurred during repressurization of the chamber. This required a partial retest of the generator subsystem as a demonstration that no significant damage had occurred. The subsystem was first placed on an extended bench functional power check (seven days) at average orbital temperatures. After seven days, the subsystem was revibrated at flight acceptance levels in the yaw axis and again placed on an extended power check for 11 more days. These tests showed that the overtemperature had not resulted in significant degradation.

V. POWER SUPPLY RELIABILITY

The SNAP 19 Reliability program (Ref. V-1) was conducted in general accord with NASA publication NPC 250-1 (Ref. V-2). The NPC 250-1 was particularly appropriate since it aims to achieve reliability by monitoring and controlling small production lot items. The reliability activity was reported throughout the Phase III program in SNAP 19 monthly and quarterly reports. Four aspects of the work (parts and materials, failure modes and effects, reliability predictions and demonstrated reliability) are summarized below.

A. PARTS AND MATERIALS

1. Parts Selection and Screening

Electrical parts were selected from the NASA Preferred Parts List (Rev. V-3). Semiconductor aging and parts screening were performed to the requirements of Goddard Space Flight Center (GSFC) (Refs. V-4 and V-5). When the desired part was not available on the Preferred Parts List, the part was screened to the GSFC requirements.

In some few instances, the GSFC screening requirements were not in agreement with the manufacturer's practice. These instances were discussed and resolved with GSFC reliability personnel. Component derating factors were specified by GSFC in Ref. V-6. (See Volume III, Chapter II for a discussion of the thermoelectric element specification.)

Thermoelectric elements, special parts, structural materials, etc., were obtained to Martin Marietta specifications. Nonstandard parts, for example, were defined in the manner of similar standard parts, and test data were required where applicable.

These parts and specifications for test of standard parts were examined for prior experience under conditions similar to the operational and environmental requirements for SNAP 19.

2. Controlled Parts (Ref. V-7)

Selected parts which were critical to successful performance were designated controlled parts. These items received special handling, storage and testing, and in most cases the parts were serialized. One hundred percent inspection and functional testing were required for all controlled parts; when destructive testing was required statistic sampling techniques were employed. In addition, all semiconductors were X-rayed for evidence of internal defects, debris, and lead defects.

3. Failure Rate Data

Failure rate data for electrical parts were determined from the generic data and methods of MIL-HDBK-217A (Ref. V-8). Data for other parts, such as thermoelectric elements, were obtained from in-house tests.

B. FAILURE MODES AND EFFECTS

Failure modes and effects analyses were made, starting from the component level. These were used to ascertain critical failure areas and to influence the design to minimize failure susceptibility. The analyses were necessary for the development of reliability mathematical models and were helpful in malfunction detection and identification. (See, for example, Ref. V-9.)

Failure modes and effects are tabulated for each subsystem and the intrasystem hardware in Ref. V-10.

C. RELIABILITY PREDICTION

A reliability stress analysis (Ref. V-10) of each part of the system was made, using MIL-HDBK-217A as a guide, to provide data points for the reliability characteristics. Predictions were based on catastrophic failure modes.

1. Power

Predicted power reliability for a one-year mission is summarized in Table V-1. The generator value includes all power wiring connections through the RTG subsystem to the power conditioner terminals. There are two identical dc-to-dc converters in the power conditioner. A power channel is defined as one generator in series with one dc-to-dc converter (see Chapter II). Reliability block diagrams are presented in Fig. V-1. Each power channel has a predicted reliability of 0.825. The system is, in a sense, redundant in regard to a half-power capability. Therefore, predictions for having at least one operational power channel (1/2 power) and both channels operational (full power) are of interest. These values are 0.969 and 0.680, respectively, for one year. Figure V-2 shows the variation with mission duration.

TABLE V-1

Predicted Reliability for One-Year Mission

Item	Predicted Reliability
Generator *	0.990
Dc-to-dc converter	0.833
Each power channel	0.825
At least one power channel	0.969
Both power channels	0.680

Includes power wiring through RTG subsystems to power conditioner terminals.

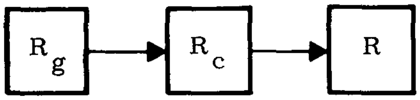
The controlling factor in the power system reliability is the prediction for the dc-to-dc converters. This is shown as a function of time in Fig. V-3.

2. Telemetry

The SNAP 19 telemetry signal conditioner unit contains two power supplies. Each power supply accommodates one-half of the system instrumentation, and each half is independent. For one-year operation, the probability of success is 0.792 for an individual discrete half of a conditioner. For at least one operational half, the probability is 0.957 and, for a fully operational unit, the probability is 0.627. Reliability as a function of mission duration is given in Fig. V-4.

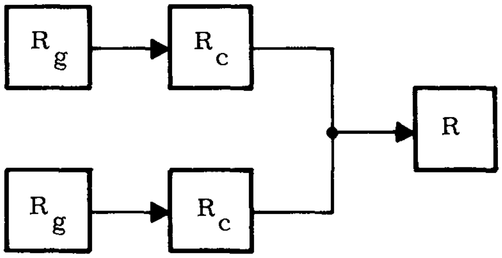
D. DEMONSTRATED RELIABILITY

During the program, operating time was accumulated on the power supply and subsystems. Included are endurance, operational and environmental testing. Operational time for the calculation of demonstrated reliability is accumulated as of December 31, 1967.



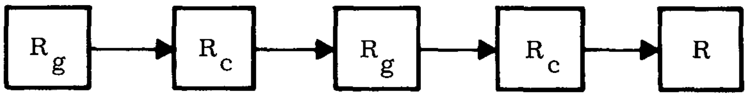
$$R = R_g R_c$$

Each Power Channel



$$R = 2R_g R_c - (R_g R_c)^2$$

At Least One Power Channel



$$R = (R_g R_c)^2$$

Both Power Channels

R_g = generator reliability

R_c = converter reliability

FIG. V-1. POWER CHANNEL RELIABILITY BLOCK DIAGRAMS

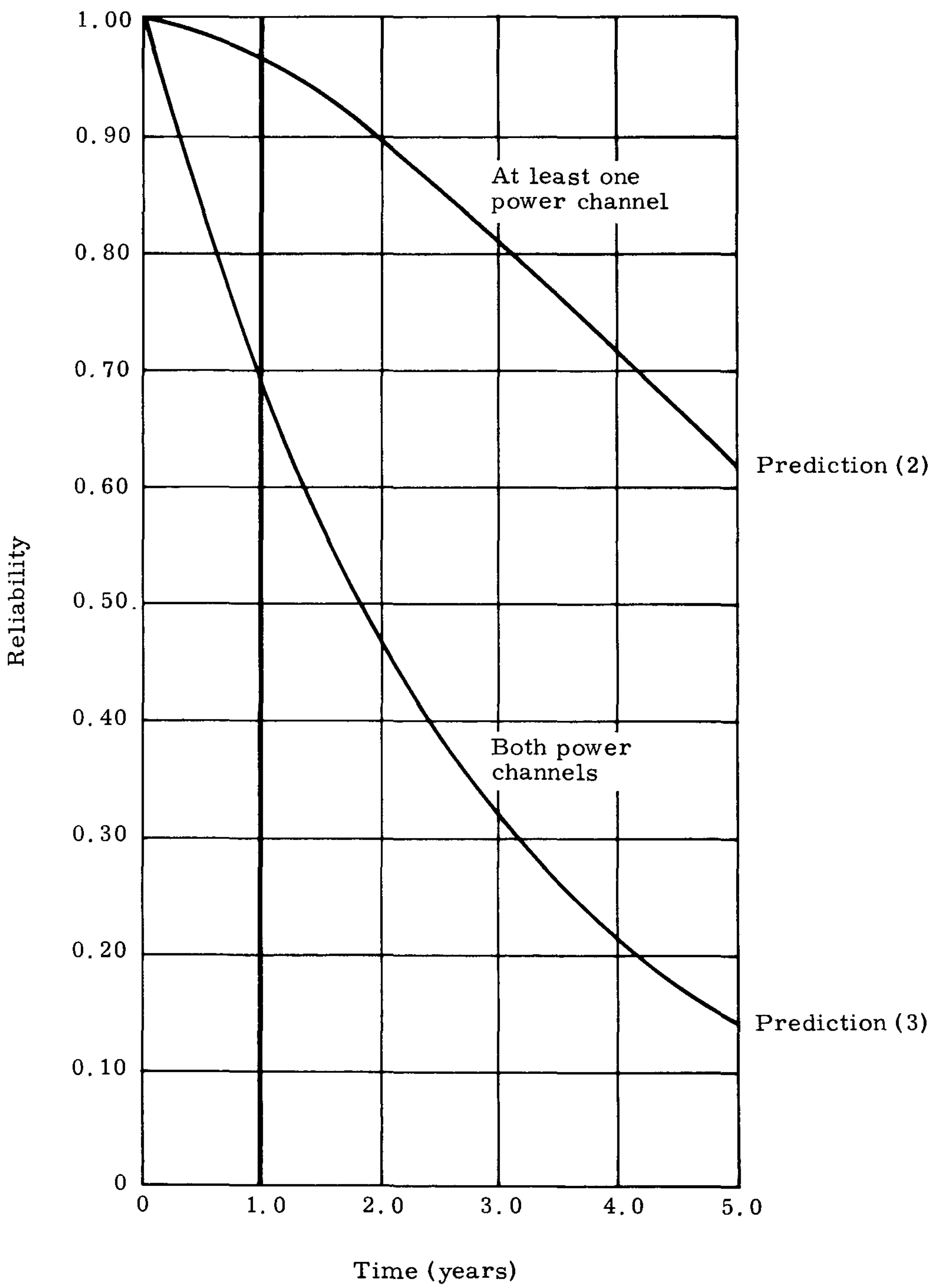


FIG. V-2. POWER SYSTEM RELIABILITY VERSUS TIME CHARACTERISTICS

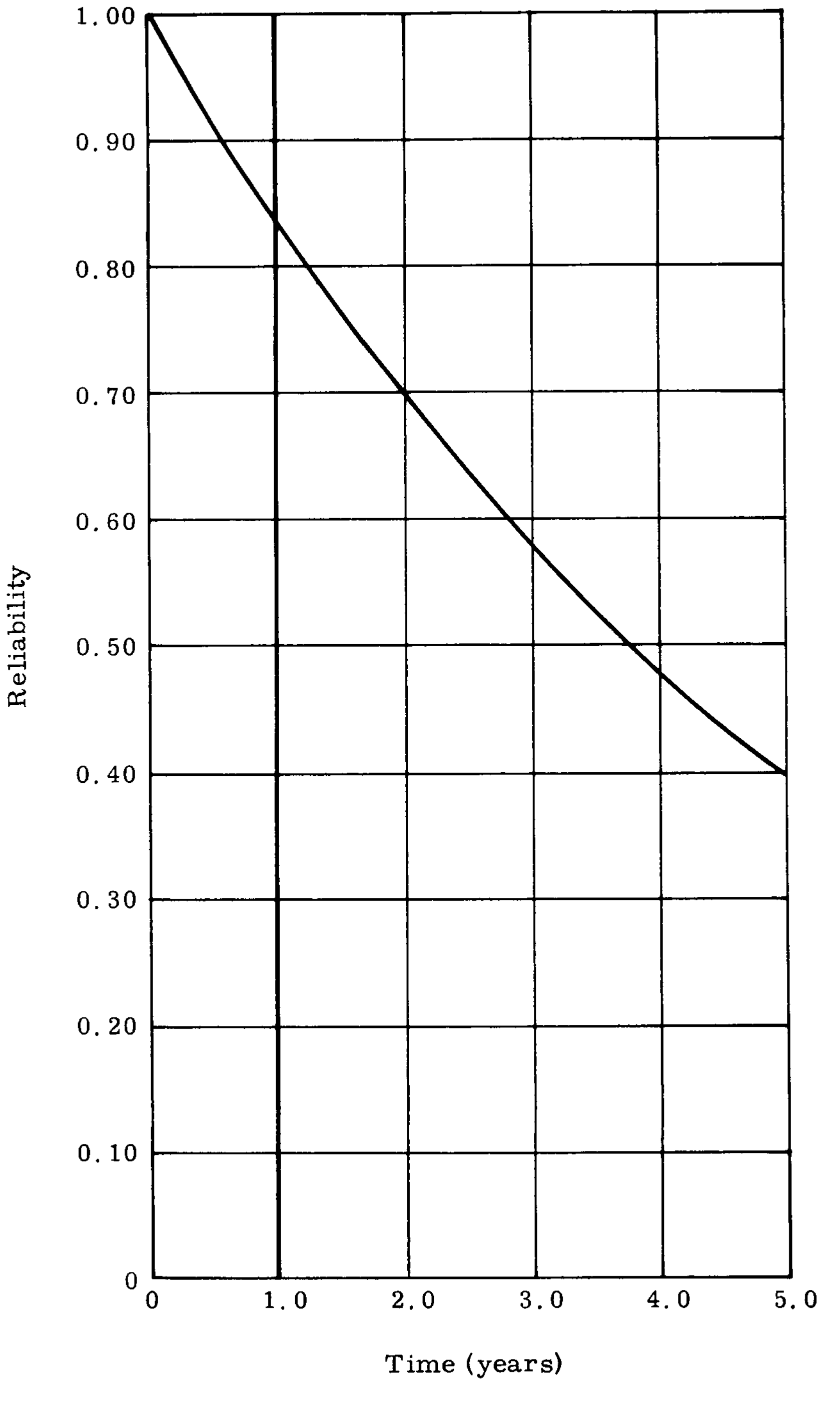


FIG. V-3. DC-DC CONVERTER RELIABILITY VERSUS TIME CHARACTERISTICS

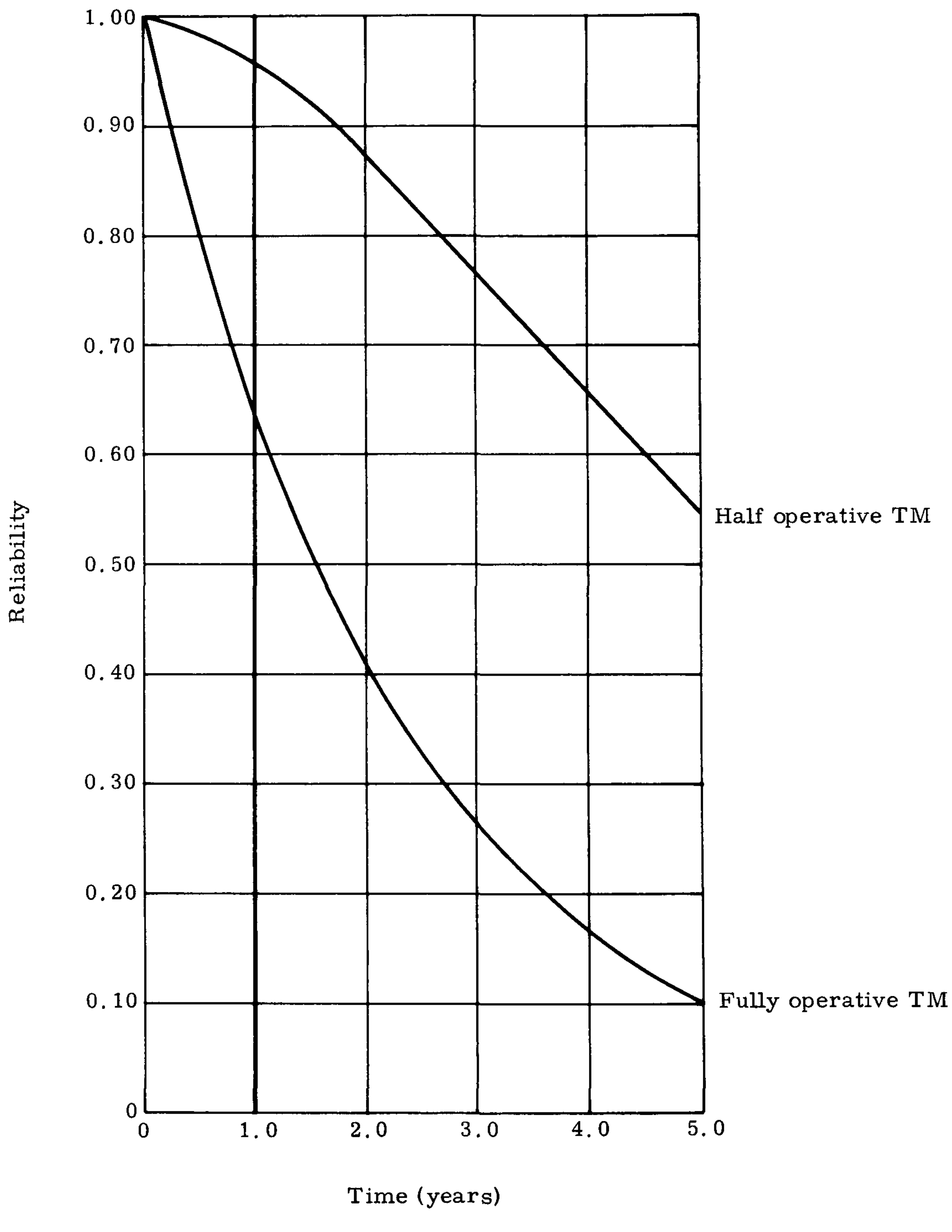


FIG. V-4. TELEMETRY CONDITIONER RELIABILITY VERSUS TIME CHARACTERISTICS

1. Power System

Of particular significance was the endurance testing of generators. (See Vol. III and Ref. V-11.) Applicable SNAP 19 generator operating time (endurance plus operations) exceeded 100,000 hours at the end of 1967. As shown in Table V-2, the generator demonstrated reliability is 0.95 at 50% confidence for a one-year mission.

A limited endurance test of one power conditioner was performed. Additional operating time was accumulated in subsystem and system testing. Since each conditioner contained two identical dc-to-dc converters, the accumulated time on converters is twice that of power conditioners. This gave a converter demonstrated reliability of 0.61.

The product of the generator and converter reliabilities gives 0.58 demonstrated reliability for each power channel. For at least one operational power channel, the demonstrated reliability is 0.82; and for both power channels, 0.34. No post-qualification or acceptance test power channel failures have been encountered. Demonstrated reliability continues therefore to increase as usage time accumulates. The largest gains will be achieved by power conditioner operating time.

TABLE V-2

Demonstrated Reliability at 50% Confidence for One-Year Mission

Item	Demonstrated Reliability
Generator	0.95
Dc-to-dc converter	0.61
Each power channel	0.58
One power channel	0.82
Both power channels	0.34

2. Telemetry Signal Conditioner Unit

Endurance testing was not conducted for the telemetry signal conditioner unit. Total accumulated operating time was insufficient to give a significant reliability demonstration.

VI. AEROSPACE NUCLEAR SAFETY

The aerospace nuclear safety assessment of the SNAP 19 power system is documented in the Safety Analysis Report (SAR), which is in compliance with procedures established by the United States Atomic Energy Commission. The Safety Analysis Report embodies five documents: Reference Design Document, Volume I (Ref. VI-1), Accident Model Document, Volume II (Ref. VI-2), Safety Analyses Document, Volume III (Ref. VI-3), Safety Analyses Report Addendum (Ref. VI-4) and the Safety Analysis Report IRHS Supplement (Ref. VI-5).

Volume I describes facilities, systems and operating profiles necessary for the safety analyses. It also assures that the analyses are based on a common body of data.

Volume II provides a complete description of the malfunction and accident spectra and identifies those yielding the greatest nuclear hazard potential based on the combined probability of occurrence and severity of the accident.

Volume III provides an evaluation of the response of the SNAP 19/Nimbus B system to normal and abnormal environments and the resulting interaction between the radioisotope fuel and people. Volume III provides the reviewer with a basis for judgment of the dispersal system capability to meet applicable radiation dose criteria.

The SAR Addendum reviews each phase of the mission profile and indicates where results that were previously presented in the SAR had been influenced by analyses and tests conducted after its issuance.

The supplement to the SAR presents a safety assessment of the intact re-entry heat source (IRHS). This assessment was developed employing the same approach utilized for the evaluation of the dispersal system.

A summary of the safety philosophy and technical approach contained in the five SAR volumes is presented in the following.

A. SAFETY PHILOSOPHY

The initial design approach for disposition of fuel upon re-entry of a SNAP 19 was high altitude release and burnup of plutonium metal. However, potential capsule compatibility problems involved with the use of Pu metal in the SNAP 19 heat source dictated the use of a different fuel form (Volume II, Chapter III). A decision was made to use plutonium dioxide microspheres which in addition to solving the compatibility problems also lowered the potential inhalation and ingestion hazards. The microspheres were still to be released at high altitude, but were to be sized above the minimum inhalation size. Subsequent investigation raised numerous questions concerning the behavior of microspheres during and after re-entry, and it appeared that an intact re-entry system would enhance safety. Consequently, the SNAP 19 heat source was redesigned for intact re-entry.

The Pu-metal dispersion system was characterized by fuel containment for one year after launch in all environments encountered until the system is exposed to significant aerodynamic heating (i. e., heating having detrimental effects on the fuel container) and fuel dispersion in all environments encountered after exposure of the system to significant aerodynamic heating.

The development of PuO_2 microspheres, resulted in a fuel form change which moderated the consequences of fuel release. The lower power density of the microsphere fuel form resulted in the need for a single, large-diameter capsule.

The nuclear safety philosophy selected for the Nimbus B/SNAP 19 (IRHS) mission is to minimize the occurrence probability of fuel release and the consequence of such releases to the population. The intact re-entry concept is predicated on fuel containment during exposure of the heat source to the aerothermodynamic re-entry environment, but not necessarily at earth impact. The philosophy was based on making use of the combined attributes of the heat source structural design and the SNAP 19 fuel form.

An intact re-entry system requires a fuel form which, by virtue of its physical and chemical properties, will result in a minimum of radioactive material being introduced into the ecological cycle upon release. Therefore, the fuel form must be insoluble, chemically inert, and sized to be nonrespirable. The heat source must also be designed so it does not cause detrimental changes in these fuel properties. In addition, the fuel form must possess a high degree of structural integrity when subjected to re-entry aerothermodynamic conditions, impact on the Earth's surface and subsequent terrestrial environment. Therefore, a high melting point compound in a physical form possessing a high crush strength is desirable.

The Pu-238 dioxide plasma-fired microspheres, 50 to 250 microns in diameter, were specified as the fuel form. This size range presents a relatively small probability of ingestion and inhalation of the microspheres. A fundamental aspect of the safety study was the assessment of the capability of the plutonium dioxide to meet the required chemical and physical criteria.

The key elements in the safety analysis are microsphere disposition and the biological effects of the microspheres when the SNAP 19/Nimbus B (IRHS) system is exposed to the operational abort aspects of the mission. The SNAP 19-IRHS system design approach was formulated with respect to the various operational phases of the mission profile, namely.

(1) Transportation

(2) Launch pad operations

(3) Pre-orbital

(4) Orbital

(5) Post-mission.

1. Transportation

For the prelaunch phase of operation, the heat source and shipping container assemblies were designed to:

(1) Provide sufficient radiobiological shielding to comply with Federal (ICC) regulations for shipment of radioactive materials.

(2) Endure prolonged storage at an ambient temperature of 120° F without the exterior surface temperature exceeding 180° F.

(3) Endure the standard transportation fire.

2. Launch Pad Operations

The principal heat source design criterion was fuel containment if the SNAP 19 IRHS system is exposed to credible accident conditions. These conditions are:

(1) Shock overpressure and thermal flux resulting from the explosion of missile propellants on the launch pad.

(2) Impact on typical media present at the Air Force Western Test Range at impact velocities characteristic of launch aborts.

3. Pre-Orbit

Fuel release from the heat source is permitted subsequent to impact on the Earth's surface, whether land or water, after exposure to significant aerothermodynamic heating.

4. Orbital

The heat source design is such that the fuel will be contained during the SNAP 19-IRHS/Nimbus B mission time and beyond. If there is a low orbit abort, the fuel will be contained at least until impact on the Earth.

5. Post-Mission

The nominal orbital lifetime of the SNAP 19-IRHS/Nimbus B spacecraft while in a 600-nautical mile orbit is estimated to be greater than 1600 years. As the fuel decays, helium is generated in the fuel cavity but vents from the heat source through a vent filter. Ideally, the fuel will be contained within the heat source for an extremely long time, until materials degradation in space occurs.

B. TECHNICAL APPROACH

The objective of the investigation was to determine the effect to be expected on population groups as a result of using the SNAP 19-IRHS generator system for the Nimbus B mission. Recent papers published by investigators at Martin Marietta Corporation and at other laboratories have emphasized the nondeterministic nature of both cause and effect of incidents involving radiobiological exposures. The need, therefore, is to assess within the present limits of knowledge the risk involved in the aerospace nuclear application. A summary of the methodology employed in the assessment of the risk is presented.

The approach employed requires definition of the occurrence of malfunctions and the potential initiation of hazards. These events were analyzed sequentially and in detail for two reasons. The first is that this is a true representation of a chronological process culminating in radiobiological exposure. The second is that confidence in the results of a probability determination depends on the use of experimental data or, lacking these, a believable physical model. It is difficult to obtain such confidence for composite events occurring with frequencies of one in a million, for example, unless these events are realistically describable in terms of sequenced events, each having probabilities of one in a hundred or so.

Following initiation of the hazard in terms of uncontrolled release of fuel or heat sources, the location of the fuel as a function of space and time coordinates must be determined. If the fuel remains encapsulated, its location must be determined with respect to population groups so that its external radiation may be taken into account properly in evaluating public exposure. In the case of released fuel, the surface and volume densities of particles must be determined so as to evaluate both external and internal radiative exposures. This portion of the analysis is referred to as the transport phase, dealing primarily with resuspension and subsequent diffusion from a land release, or, alternately, shallow water diffusion.

A specific concern during the transport process deals with changes in the physical state of the fuel. Nominally, the fuel particles are confined to between 50 and 250 microns in diameter and are relatively insoluble. If the particles remain in this size range, the chief hazards are expected to be from external radiation and exposures to the gastro-intestinal (GI) tract from direct ingestion and impaction-inhalation of the particles. However, size degradation due to impact or chemical effects and by crushing of particles lying on the ground can result in potentially more serious pulmonary and lymph exposures. There are few experimental data available predicting size degradation and consequential particle size distributions resulting from imposed physical stresses. Semi-empirical representations have been formulated to evaluate the change-of-state phenomena.

The next phase of the investigation is that of determining the probabilists of public exposure. For external radiation from a localized source, the roving receptor model developed under the Rover program (Ref. VI-6) was used. External radiation from small particles was treated in a straightforward manner by determining the average dose rate at one meter above a fallout field for particles of a given size, and therefore involved here, motion of people was irrelevant; only the total number of people affected was considered.

Realistic representation of the inhalation exposure hazard was one of the initial tasks. Preliminary evaluations indicated that the mean numbers of particles inhaled tended to be small compared with unity. The probabilistics of one-particle dose consequences cannot be evaluated conveniently using standard techniques (Ref. VI-7) which deal with the distribution of activity continuously throughout the body, rather than contained in a single, discrete particle. A Monte Carlo technique was developed, therefore, to treat the motion and residence time of particles in the body regions. Results of the Monte Carlo study were obtained in the form of the probability (per particle deposited in specified regions of the body) of exceeding any given dose.

In evaluating ingestion exposures, results were obtained for the consumption of contaminated fish and for particles deposited on leafy vegetables. In the former case, probabilistics were defined in terms of variations from the mean consumption rate and with the dependence of population density on distance from fishing ports.

The final task was that of combining the results of occurrence probabilities, activity transport and subsequent radiative exposure to determine the expected number of people to be exposed in excess of a given dose and the biological response to this dose.

The hazard phases are discussed in more detail in Ref. VI-4. No attempt is made in this report to summarize the voluminous results of calculations presented in Ref. VI-1 through VI-5 on activity transport and public exposure phases.

VII. AEROSPACE GROUND EQUIPMENT

A. TEST EQUIPMENT

1. Ground Support Test Console

The ground support test console (Fig. VII-1) contains all equipment necessary for complete functional testing of the SNAP 19 system. In addition to the overall system test capability, the console provides for the following:

(1) Testing of radioisotope or electrically heated thermoelectric generator subsystems

(2) Testing of power conditioner unit

(3) Testing of telemetry signal conditioner unit

(4) Calibration of the telemetry signal conditioner unit

(5) Testing of the system with the generators simulated.

Consisting of four racks of equipment integrated to form a single unit, the console is mounted on casters for limited mobility. It is designed for indoor use in a protected area, such as a launch complex assembly building or an industrial environment.

Accessories furnished with the console include 75 patchcords (45 patchcords, 24 inches long and 30 patchcords, 12 inches long), two 40-foot cables for connection to an electrically heated generator subsystem, a set of 25-foot cables for connections to a power supply system or subsystem under test and all cables necessary to interconnect subsystems under test. An oscilloscope camera is supplied to enable permanent recording of oscilloscope indications. There are two storage spaces in the console, one at the bottom of each of the outside equipment racks. Cables are also provided for interconnection of the oscilloscope and Eput (internal timer) to the monitor panel. There are two vertical input amplifier plug-ins supplied for the oscilloscope. One is a high gain unit with a differential input and the other is a dual trace unit.

A source of 120/208-v, ac, 3-phase (4-wire), 60-cps power rated at 12.5 kva is required for power input to the console.

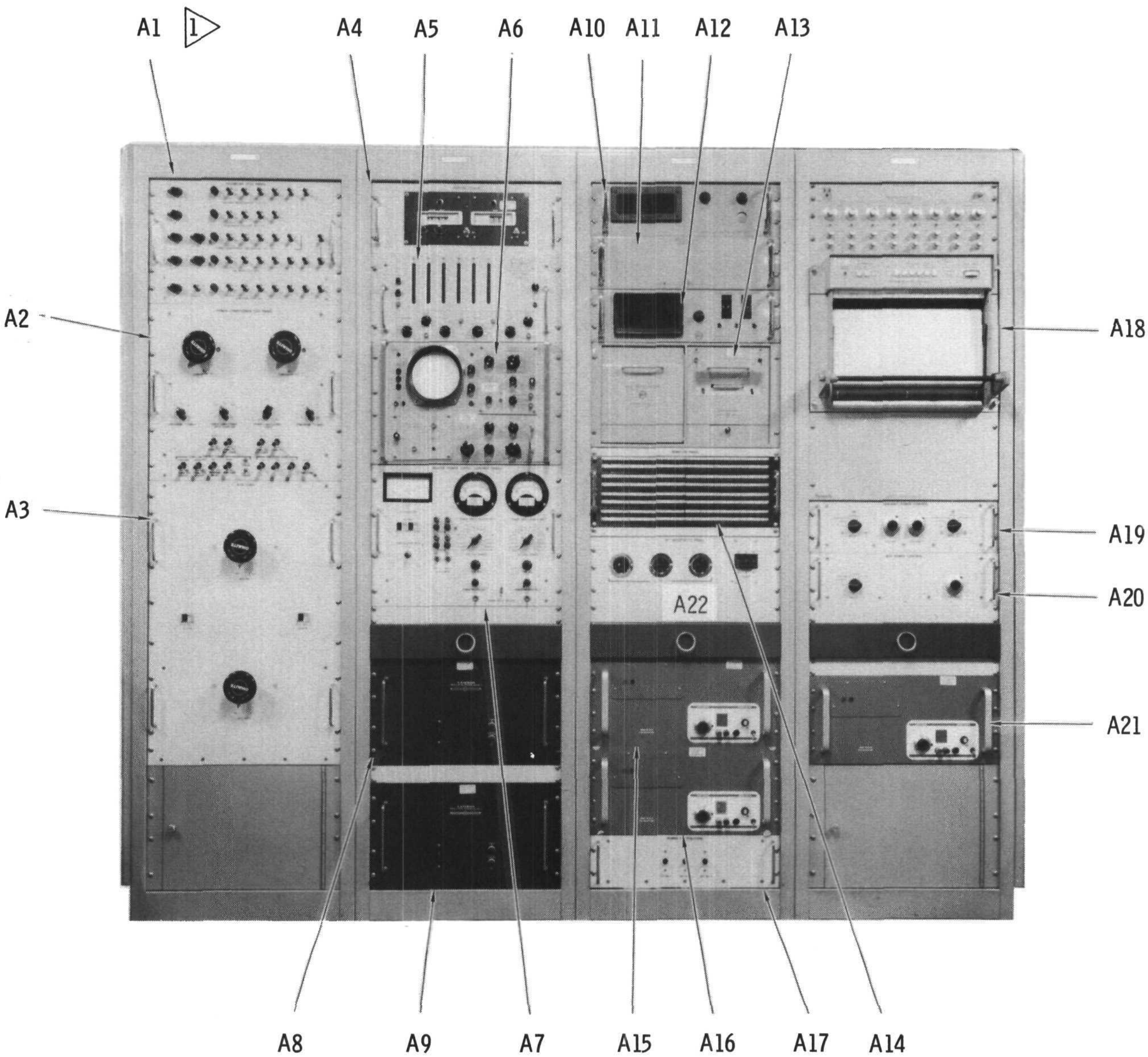
Each panel of the console is described individually in the paragraphs that follow.

a. Telemetry test panel

The telemetry test panel (A-1, Fig. VII-1) provides for complete testing and calibration of a telemetry signal conditioner unit independently of the rest of the system. In general, the test panel provides these capabilities by simulating all inputs to the telemetry signal conditioner unit and providing measurements of these inputs to the monitor panel (A-14, Fig. VII-1) for comparison with the telemetry signal conditioner unit (TSCU) outputs.

b. Power conditioner test panel

The power conditioner test panel (A2, Fig. VII-1) provides for complete testing of a power conditioner unit, either independently of the rest of the system or as part of a complete system. In general, the test panel provides these capabilities by simulating all inputs to the power conditioner, providing measurements of these inputs



NOTE

1 NUMBERS ARE DESIGNATORS USED FOR IDENTIFICATION IN TEXT.

FIG. VII-1. GROUND SUPPORT TEST CONSOLE ARRANGEMENT to the monitor panel, simulating loads for the power conditioner outputs and providing measurements of the outputs to the monitor panel.

c. RTG load panel

The RTG load panel (A3, Fig. VII-1) contains two 1-kilowatt, 2-ohm rheostats and two overtemperature alarm indicators. Each of the 2-ohm rheostats is a variable load for one radioisotope thermoelectric generator (RTG) under test. Two 25-foot cables, one for each generator, are supplied to connect the generators to the panel.

Measurement signals supplied by the RTG load panel include the output voltage and current of each RTG. (The output currents are expressed in millivolt form, 0 to 100 mv representing 0 to 20 amperes.) These outputs are available to the data acquisition system through the monitor panel.

d. Digital clock

A 24-hour clock (A4, Fig. VII-1) is provided for convenience in determining stabilization time and unit operating time for the power supply system or subsystem under test. The clock provides a digital indication of hours, minutes and seconds. The clock is started or stopped when desired by operating the clock switch on the front panel.

e. Universal Eput and timer

The universal Eput and timer (A5, Fig. VII-1) is used to measure the operating time interval of the on bus/off bus relays in a power conditioner under test. For this function, the instrument is used in the TIM (time-interval-meter) mode, with one input jack on the front panel connected to the stop jack on the monitor panel and the second input jack connected to the start jack on the monitor panel.

f. Oscilloscope

The oscilloscope (A6, Fig. VII-1) is used during power conditioner tests for measurement of output ripple voltages. Connections between the oscilloscope and the measurement point are made by connecting a cable from the vertical input jack on the front panel directly to a jack on the monitor panel.

An oscilloscope camera is supplied as an accessory to the oscilloscope. It provides for permanent recording of the oscilloscope trace.

g. Heater power supply control panel

The heater power supply control panel (A7, Fig. VII-1) controls the output of two regulated power supplies (A8 and A9, Fig. VII-1) which provide power to electrically heated thermoelectric generators. Each power supply furnishes heating power to one generator. The heater power supply control panel also provides for monitoring of generator temperatures, and includes an alarm which is actuated if the temperature of either generator exceeds 975 ± 25° F. An alarm condition results in automatic cutback of heater power to the generator.

h. Regulated power supply

Two power supplies (A8 and A9, Fig. VII-1) are included in the test console. Each supply furnishes power to one electrically heated thermoelectric generator. If there is a thermal overload of either supply, the thermal overload indicator lamp is energized and the supply itself is de-energized. After the trouble has been corrected, the thermal overload device is reset by pressing the thermal overload reset button on the back of the power supply.

i. Digital data acquisition system

The digital data acquisition system consists of the digital voltmeter, input converter, input scanner and data printer (A10, A11, A12 and A13, Fig. VII-1, respectively). The system sequentially scans up to 60 inputs (voltages and resistances intermixed) and prints out each measurement on paper tape. The system can also be used in a manual mode to display a single measurement on the digital voltmeter. The primary purpose of the system is to facilitate logging the many measurements required during power supply system and subsystem testing. The data acquisition system measures d-c voltages from 0 to ± 200 volts and resistances from 0 to 999.9 K ohms.

Each of the 60 input channels to the system is terminated at a jack on the monitor panel. The signals that require measurement are also terminated at jacks on the monitor panel. Signals that are to be measured for any particular test are connected to input channels of the system by patchcords. The input jacks accept a three-wire signal (i.e., signal high, signal low and ohm command). The signal jacks to be measured provide either a two-wire signal for voltage measurements (signal high or signal low) or a three-wire signal for resistance measurements (signal high, signal low and ohm command). Thus, the system scans and prints out both resistive and voltage measurements.

The input scanner sequentially scans the selected inputs and supplies them to the converter as a resistive or voltage measurement. The voltage measurement signal is routed directly to the digital voltmeter for display. The converter interrupts resistive measurement signals and applies them to a bridge-type measurement circuit. This circuit develops a corresponding voltage and transmits it to the digital voltmeter for display.

The data printer prints out on paper tape the channel measurement, when desired. The printout format is shown in Fig. VII-2.

j. Monitor panel

The monitor panel (A-14, Fig. VII-1) containing 384 jacks arranged in 8 rows, 48 jacks to a row, is used to connect by patchcords, the indicating and recording instruments to measurement points. All measurement points in the various test panels and the system or subsystem under test are terminated at specific jacks on the monitor panel. Two adjacent jacks are provided for each measurement point to permit use of two indicating instruments simultaneously if desired. Each of the eight input channels to the chart recorder is terminated at one jack on the monitor panel, and each of the 60 input channels to the data acquisition scanner is terminated at one jack.

All measurements are in terms of either ohms or volts. When an input channel of the data acquisition system is patched to an ohm measurement jack, the digital readout and printout for that channel is in terms of ohms, the readout and printout for each channel that is patched to a volt measurement jack is in terms of volts. The switching function (volts/ohms) is accomplished automatically.

k. Power supply

Three power supplies (A-15, A-16 and A-21, Fig. VII-1) are included in the test console and supply power for the various electronic chassis in the GSTC. Each of these units supplies regulated voltage, manually adjustable from 2.5 to 36 volts d-c, at 0 to 30 amperes.

The outputs of these power supplies are controlled at two separate panels in the test console. The bus power control panel (A20, Fig. VII-1) controls the output voltage and distribution of the A21 unit, and the variable power control panel (A19, Fig. VII-1) controls the output voltages and distribution of the A15 and A16 units.

With the outputs controlled from other panels, operation of the power supply front panel controls is not normally desired. However, the controls on each of the three power supplies must be preset for normal operation.

l. Power distribution panel

In the power distribution panel (A-17, Fig. VII-1), the power input line to the test console branches out to three 120-v, a-c, 60-cps, single-phase circuits which supply power to the various panels of the console. Each circuit is protected and controlled by a 35-ampere circuit breaker on the front panel. All power is removed from the console when the circuit breakers are off.

m. Recording system

The recording system (A-18, Fig. VII-1) consists basically of an eight-channel chart recorder with associated pre-amplifier, drive amplifier and system power panels. The system provides the capability of simultaneously recording up to eight signal voltages consisting of inputs to and/or outputs from the unit(s) under test. Each of the eight input channels to the recording system is terminated at a jack on the monitor panel. These jacks are connected to the desired measurement points by patchcords supplied with the console.

n. Variable power control panel

The variable power control panel (A19, Fig. VII-1) controls the output of two power supplies (A15 and A16, Fig. VII-1).

o. Bus power control panel

The bus power control panel (A20, Fig. VII-1) controls the output of the power supply.

p. A-c receptacle panel

The a-c receptacle panel (A22, Fig. VII-1) contains the main power switch for the console. This switch is effective only when the related circuit breakers on the power distribution panel (A17, Fig. VII-1) are on. The panel also contains three 120-v, a-c receptacles for use with auxiliary equipment.

2. Power Supply Rack

The caster-mounted power supply rack (Fig. VII-3) provides a convenient method of supplying power to the electrically heated generator subsystems and may be used instead of the ground support test console for this purpose. To use the rack, the power supplies and the heater power supply control panel are removed from the console and installed in the rack. With these units installed in the rack, operation is the same as for the console.

The rack contains a circuit breaker, a power light, two a-c receptacles, a mechanical clock, a fan and internal cabling.

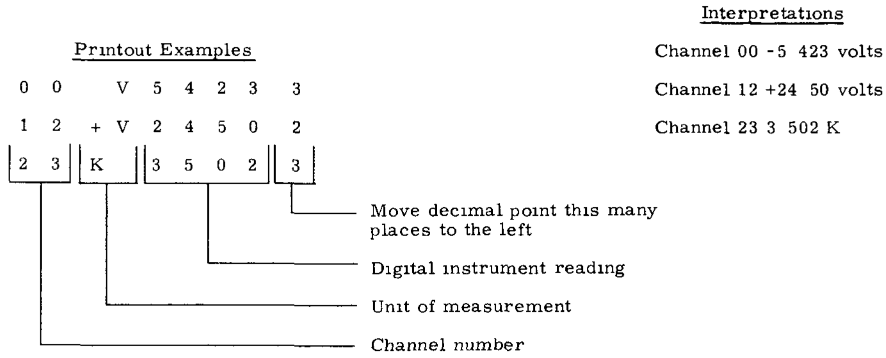


FIG VII-2 MEASUREMENT PRINTOUT FORMAT

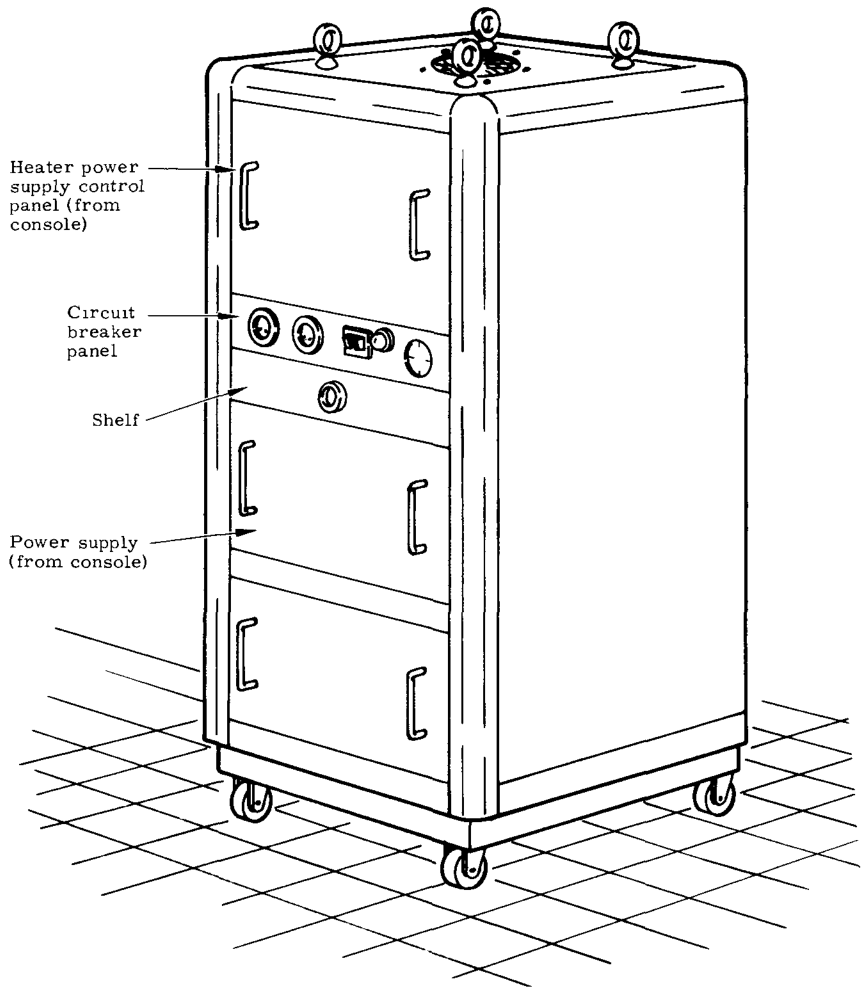


FIG VII 3 POWER SUPPLY RACK ARRANGEMENT

3. Portable Monitor

The portable monitor (Fig. VII-4) is used to check generator subsystems temperature and pressure when the generators are mounted on a standoff or in the shipping container. The portable monitor is intended for use when the GSTC is not available or when its use is impractical. The monitor can be powered by either an external 115-volt, 60-cycle source, or by its internal batteries. External power should be used whenever feasible in order to conserve the internal battery supply. The portable monitor will operate approximately 240 hours on its battery supply.

The unit monitors:

(1) Hot junction temperatures (three RTD's and two thermocouples in each generator)

(2) Generator pressure (for each generator)

(3) Fin root temperatures (four on each generator).

B. HANDLING AND STORAGE

1. Fuel Capsule Shipping Casks

a. Dispersal-type capsule cask

The dispersal fuel capsule shipping cask ensures safety during transportation of a single SNAP 19 dispersal fuel capsule from the fueling facility at Mound Laboratory in Miamisburg, Ohio to the Martin Marietta plant at Middle River, Maryland where the capsule is installed in a generator. The shipping cask (Fig. VII-5) meets ICC, BOE and AEC specifications and regulations. The bulk of all the design requirements is specified in the Code of Federal Regulations, Section 10, Part 71 (quoted in Ref. VII-1). In addition to these criteria, the AEC and ICC have imposed the following.

(1) The cask surface must not exceed 180° F in a 120° F environment.

(2) No material in the cask may be heated to within 300° F of its failure temperature during transport.

The design was completed late in 1965, and on December 20, 1965, the Bureau of Explosives granted permit No. 1317 to cover the Phase III containers.

The cask is fabricated from sections of six-inch thick 6061-T6 aluminum alloy plate. Aluminum was selected on the basis of its strength-to-weight ratio and thermal conductivity. The bulk aluminum surrounding the capsule is 5-3/4 inches thick on the sides and 6 inches thick on top and bottom. Eighty aluminum fins 1/8 inch thick, 5-1/2 inches wide and 13 inches long are furnace-brazed in place before final machining of the cask is completed. A compliant pad of Johns Mansville Min-K 1301 insulating material is in the bottom of the cavity to cushion normal transportation vibration loads. The cavity and plug sizing result in an approximately 0.032-inch Min-K deflection when the capsule is installed. This deflection provides the capsule preload.

The top cover, with a plug which protrudes down into the fuel capsule cavity to provide adequate radiation shielding, is bolted to the cask with eight 1/2-inch diameter hex-head bolts. An eyebolt through this cover is used to remove the cover and to lift the cask. Three transportation tie-down lugs are attached to the cover plug. The loaded cask weighs 325 pounds.

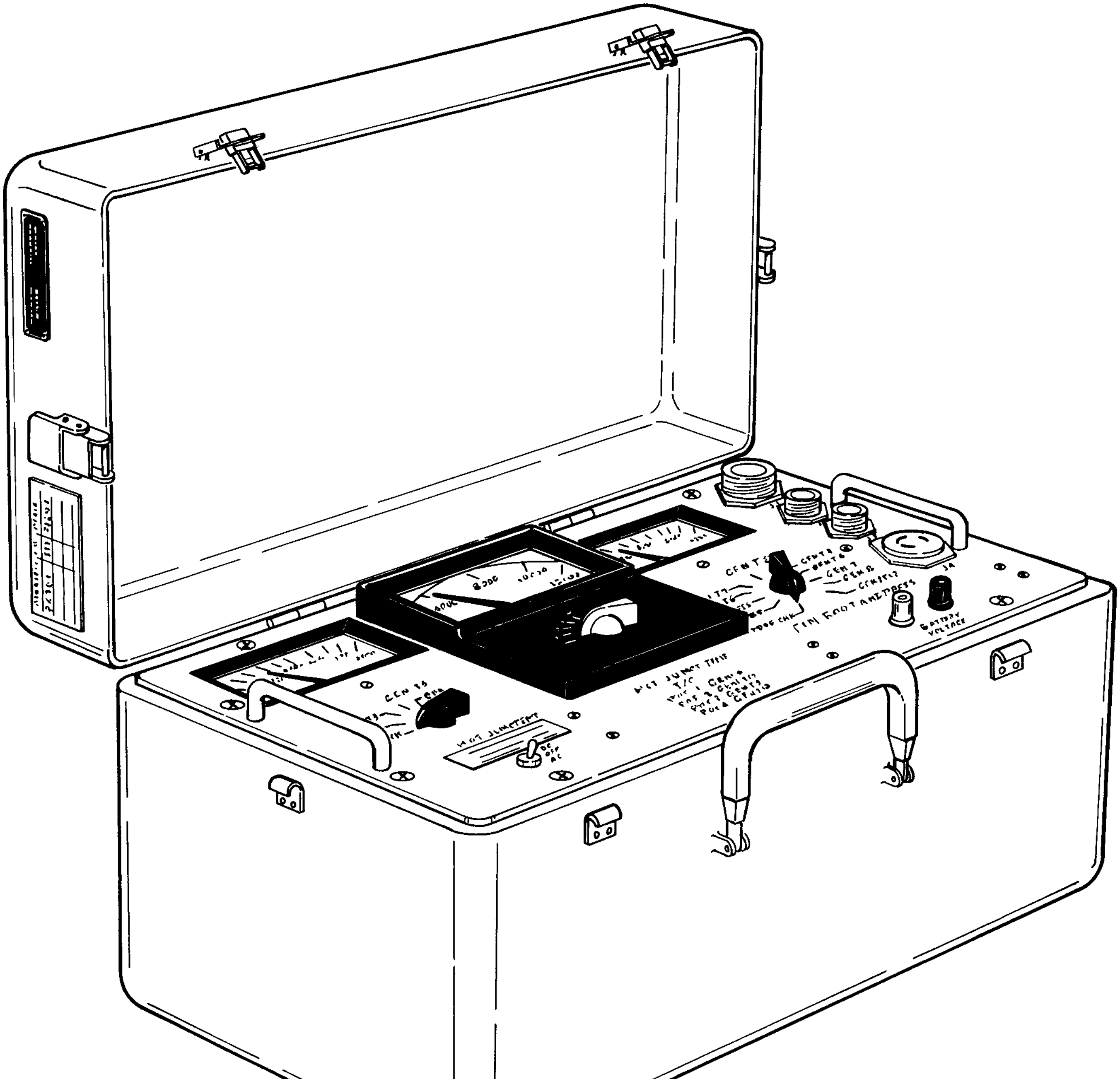
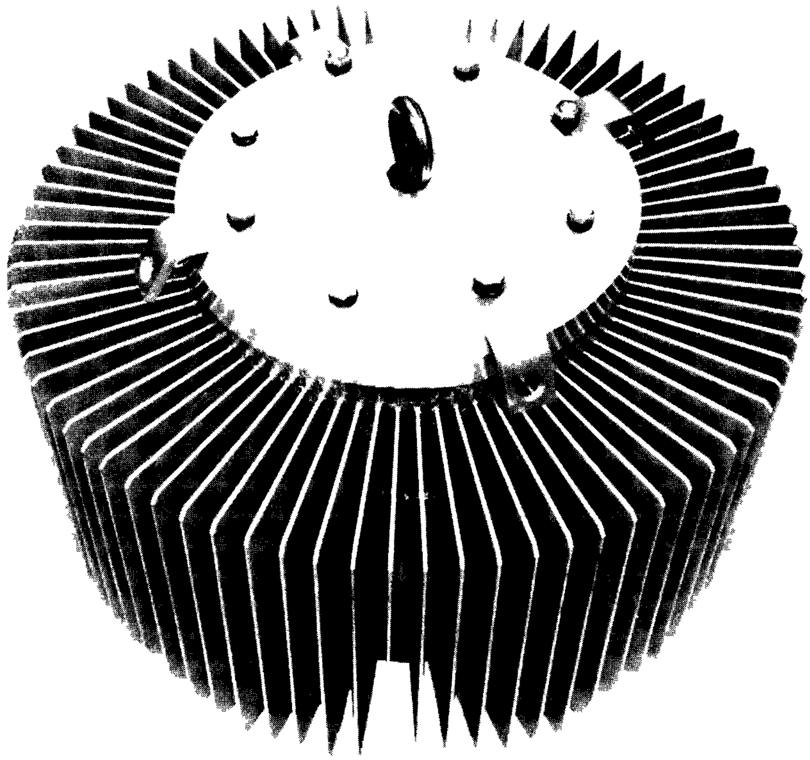


FIG. VII-4. PORTABLE MONITOR PACKAGE



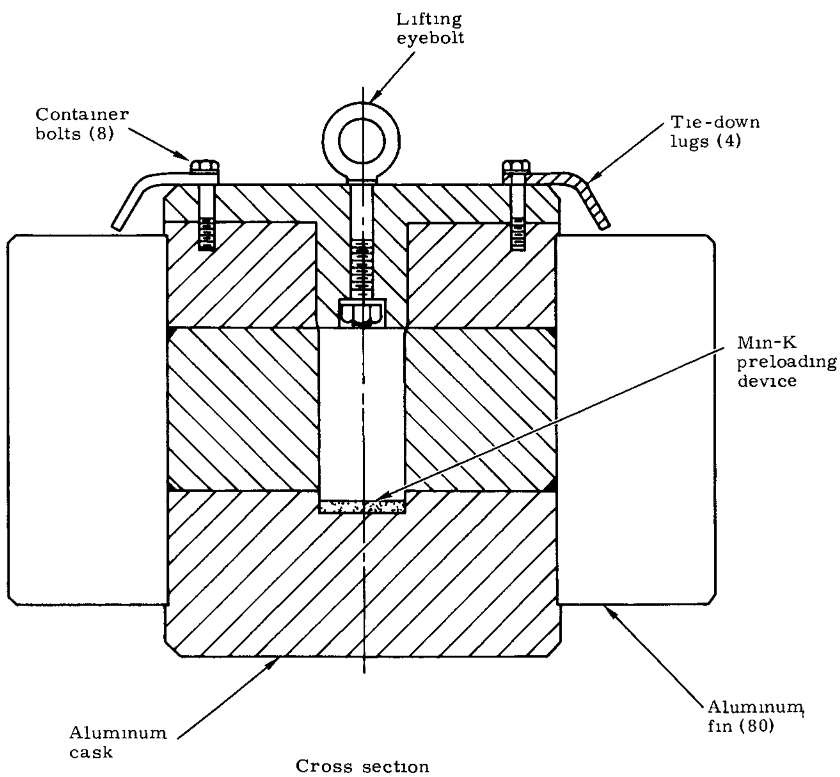


FIG VII-5. FUEL CAPSULE SHIPPING CASK

Thermal analysis performed on the cask indicates that the fin root temperature is 90° F in a 70° F environment and that the fuel capsule surface temperature is 350° F in the same environment.

The fuel capsules shipped during the SNAP 19 program have been transported in a vehicle assigned solely for that purpose.

Four casks were fabricated and all have since been modified to transport the intact re-entry heat source (IRHS).

b. Intact re-entry heat source cask

The IRHS cask meets all the requirements for the dispersal capsule cask, maintains an inert environment around the oxidation-susceptible IRHS and permits sampling of the inert blanket gas.

A cutaway view of the IRHS shipping cask is shown in Fig. VII-6. The aluminum cask was fabricated from the basic SNAP 19 cask (Section B. 1. a.) by enlarging the central cavity and adding the Viton O-ring seal in the cask closure head. A segment of tube welded to the underside of the cask cover takes up the clearance between the installed primary container and the cask cover. A stainless steel jacketed asbestos shim assembly is compressed between the tube segment and the upper surface of the primary container, providing a positive clamping force to support the primary container relative to the aluminum cask.

The primary container is fabricated in two parts from 300 series stainless steel. The closure and body are attached with three bolts, and a silver-plated metal O-ring is in the closure head. Valves, welded into both the head and body of the primary container, are used to draw a test sample of gas before opening the container at the generator fueling facility.

Min-K 2002 pads are installed in the container ends to support the contained IRHS during shipping.

Four IRHS casks were built by modifying the four existing dispersal casks. The IRHS cask can be used for shipping a dispersal capsule by the addition of different pieces of Min-K insulation into the primary steel container.

Table VII-1 presents component storage temperatures for the three IRHS storage conditions:

(1) The complete shipping assembly in air with argon in both the aluminum cask and the primary container

(2) The IRHS in a helium-filled primary container placed in a helium atmosphere

(3) The IRHS in an argon filled primary container placed in an argon atmosphere.

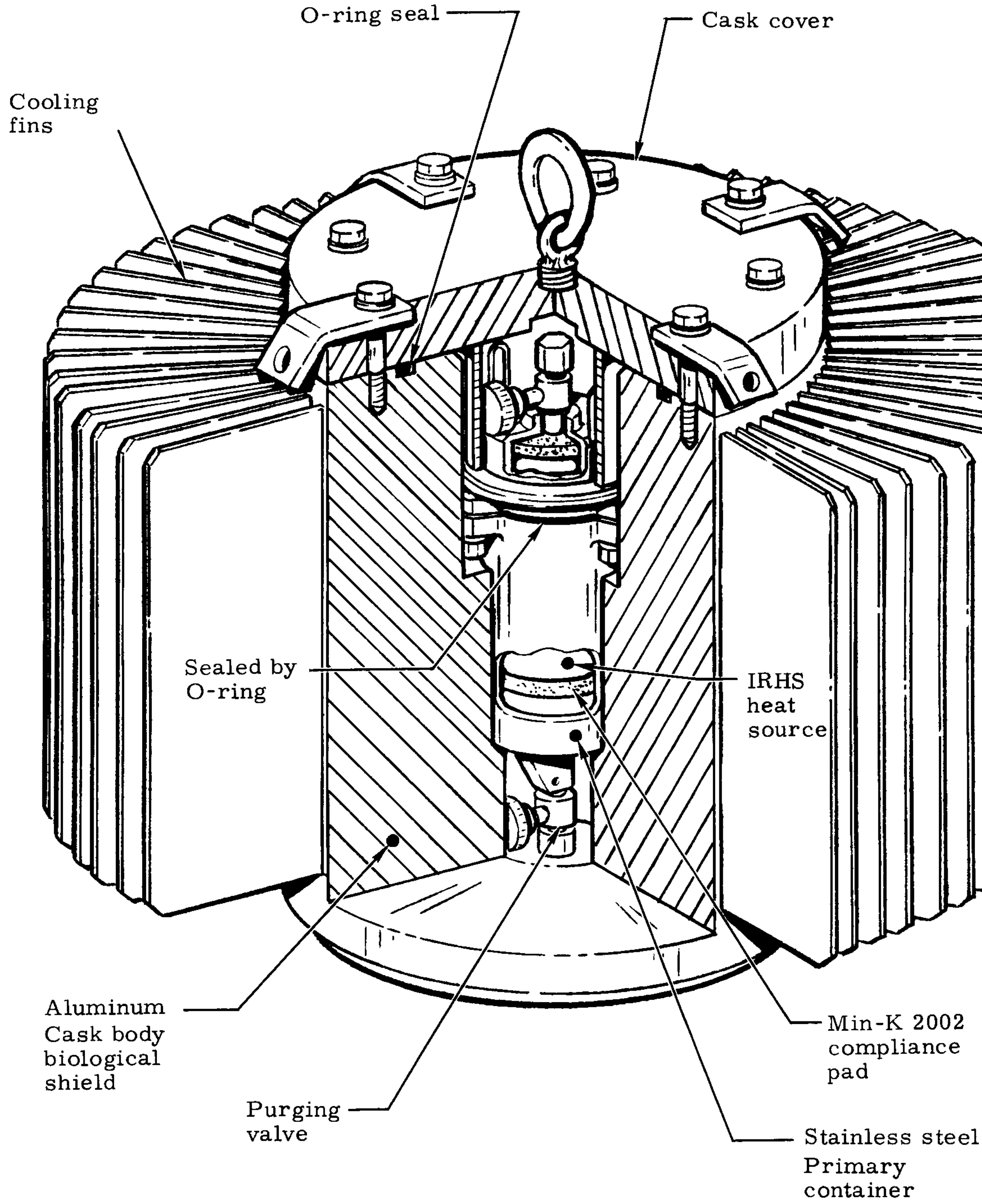


FIG. VII-6. CUTAWAY VIEW OF IRHS SHIPPING CASK

TABLE VII-1

Equilibrium Storage Temperatures of the IRHS
(70° ambient)

Component	Temperature (° F) Argon-Filled Cask in Air	Helium-Filled Primary Container in Helium	Argon-Filled Primary Container In Argon
Cask fin root	90	--	--
Primary container outer wall	194	782	1002
Heat shield	509	824	1252
Tantalum canister	795	873	1446
Haynes capsule	1110	917	1617

2. Generator Subsystem Handling Equipment

a. Generator subsystem handling adapter

The generator subsystem handling adapter (Fig. VII-7) is required for lifting a generator subsystem. The adapter permits lifting the subsystem in either the spacecraft orientation (16° from vertical) or the shipping container mounting orientation (subsystem vertical). (See Fig. VII-8.)

The handling adapter is a small, rectangular plate 8-1/2 x 7-1/2 x 1/2 inches made of 6016-T6 aluminum alloy. Four swivel bosses, one in each corner of the adapter plate, mate over four adapter nuts on top of the generator subsystem. The adapter plate is attached to the subsystem by inserting a quick-release pin through each set of bosses and adapter nuts. The quick-release pins are fastened to the adapter plate with a lanyard assembly, and a pin stowage hole is in the plate for each pin. This stowage feature prevents the pins from swinging and striking the generator emissive-coated surfaces during plate installation. Two angles welded back-to-back with a 7/16-inch gap between them are the attaching points for the offset hoist bar, which can be pinned in either of the two positions.

The handling adapter is proof-loaded to five times generator subsystem weight. Placards indicate the proper orientation for installation and lifting.

Seven handling adapters were built during the SNAP 19 program: five of the type described were delivered. Two retained for in-house use, had eyebolts for lifting instead of the two angles.

b. Offset hoist bar

The offset hoist bar is used with the generator subsystem handling adapter to position the subsystem on the spacecraft. The configuration of the hoist bar enables this operation to be performed without interference with other spacecraft components. Figure VII-9 shows the hoist bar in use for vertical removal

3

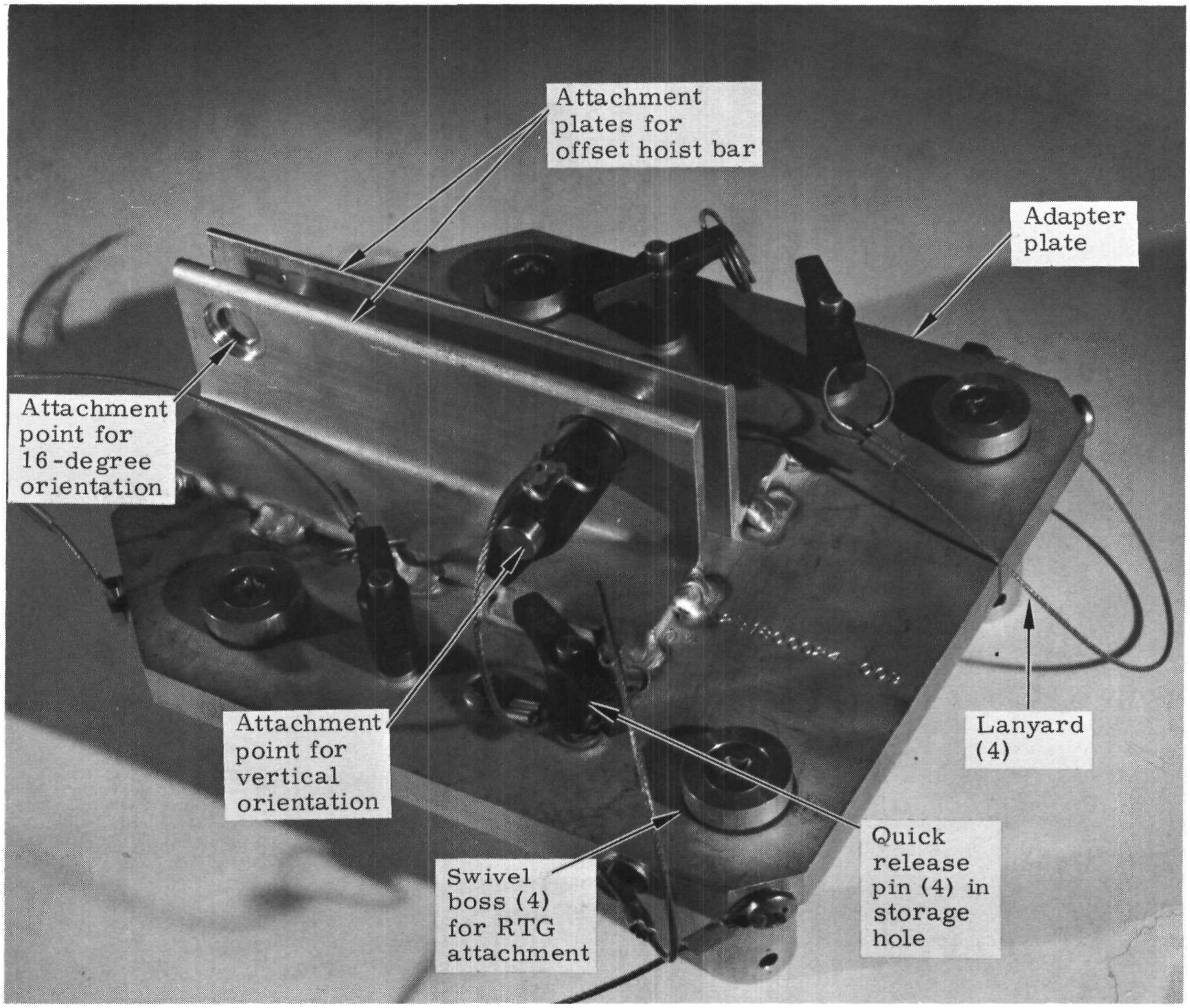


FIG. VII-7. GENERATOR SUBSYSTEM HANDLING ADAPTER

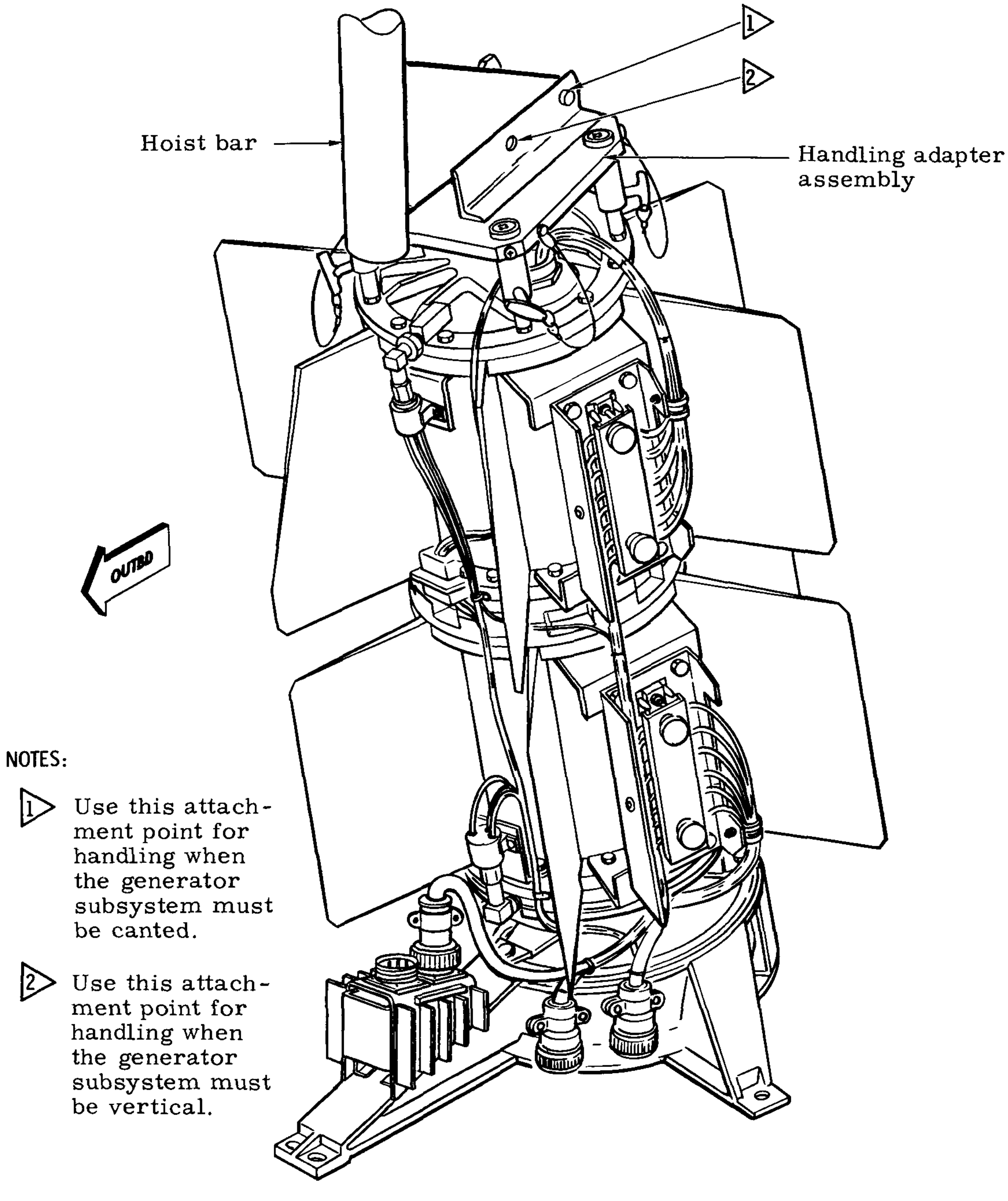


FIG. VII-8. HANDLING ADAPTER AND OFFSET HOIST BAR INSTALLATION

FIG. VII-9. OFFSET HOIST BAR IN USE

of the generator subsystem from the shipping container, and Fig. VII-8 shows the attachment of the hoist bar to the handling adapter. The bar is attached to the generator subsystem handling adapter at a single point; the opposite end of the bar has a single point attachment for an overhead crane. The hoist bar, fabricated from 2-1/2-inch diameter steel pipe and 3/8-inch thick steel plate, is proof-loaded to 650 pounds after assembly.

c. Mobile carriage

The mobile carriage (Fig. VII-10) is a lightweight dolly for transporting both electrically heated and fueled generator subsystems (without stand-off) between working areas and for storage of electrically heated subsystems. It consists of a base on swiveling, rubber-tired casters, carriage upper shelf (subsystem support base), a screen and a heater power control assembly for use with electrically heated generator subsystems. The overall dimensions (24 by 34 by 69 inches high) permit maneuvering on the gantry elevator. The carriage, with the heater power supply, weighs about 160 pounds.

The base assembly is a rectangular angle framework to which a 1/2-inch thick plate is welded. Two of the four 8-inch diameter, rubber-tired, swivel casters on the base are equipped with wheel brakes and with locks that prevent swiveling; the other two casters have swivel locks only. An angle is welded at each of the four corners of the base and extends upward from the base approximately 22 inches. The upper shelf fits inside of these four angles. The series of holes in the angles permit the upper shelf to be raised or lowered. A handle at each end of the carriage, attached to the upright angles, enables manual maneuvering of the carriage. The handles also have tie-in points for the mobile carriage handling sling. The complete base is fabricated from 6061-T6 aluminum alloy.

The upper shelf is a rectangular angle framework to which a 1/2-inch thick plate is welded. Three alignment pins on the plate locate the generator subsystem (minus standoff) and the subsystem is secured by three toggle clamps. The clamps have an over-center locking linkage with a holding capacity of 200 pounds per clamp. The generator subsystem is mounted in its spacecraft orientation. The upper shelf is also fabricated from 6061-T6 aluminum alloy.

For fueled subsystems, the lowest position for the upper shelf is used for maximum stability. For electrically heated units, the shelf is attached at the highest point on the carriage angles to permit installation of the heater power control assembly on the base. Heater power cabling is routed through the upper shelf.

The screen assembly, a framework of aluminum tubing covered with No. 2 mesh aluminum alloy screen, fits over the generator subsystem to protect the subsystem and to prevent personnel contact with the unit. Four quick-release pins attach the screen to the upper shelf. There is a handle at each end of the screen assembly for manual removal and an eyebolt for removal by overhead crane.

The battery-operated heater power supply for electrically heated subsystems can provide 1140 watts of heater power for at least 1/2 hour, but for not more than one hour. The unit also contains controls for monitoring power, hot junction temperature, and usage time. The latter is an aid in determining the state of battery charge. The assembly contains an alarm buzzer and indicator for each generator to warn of a hot junction temperature exceeding 975° F. A buzzer sounds upon overtemperature and activates a red alarm indicator. Heater power is automatically reduced.

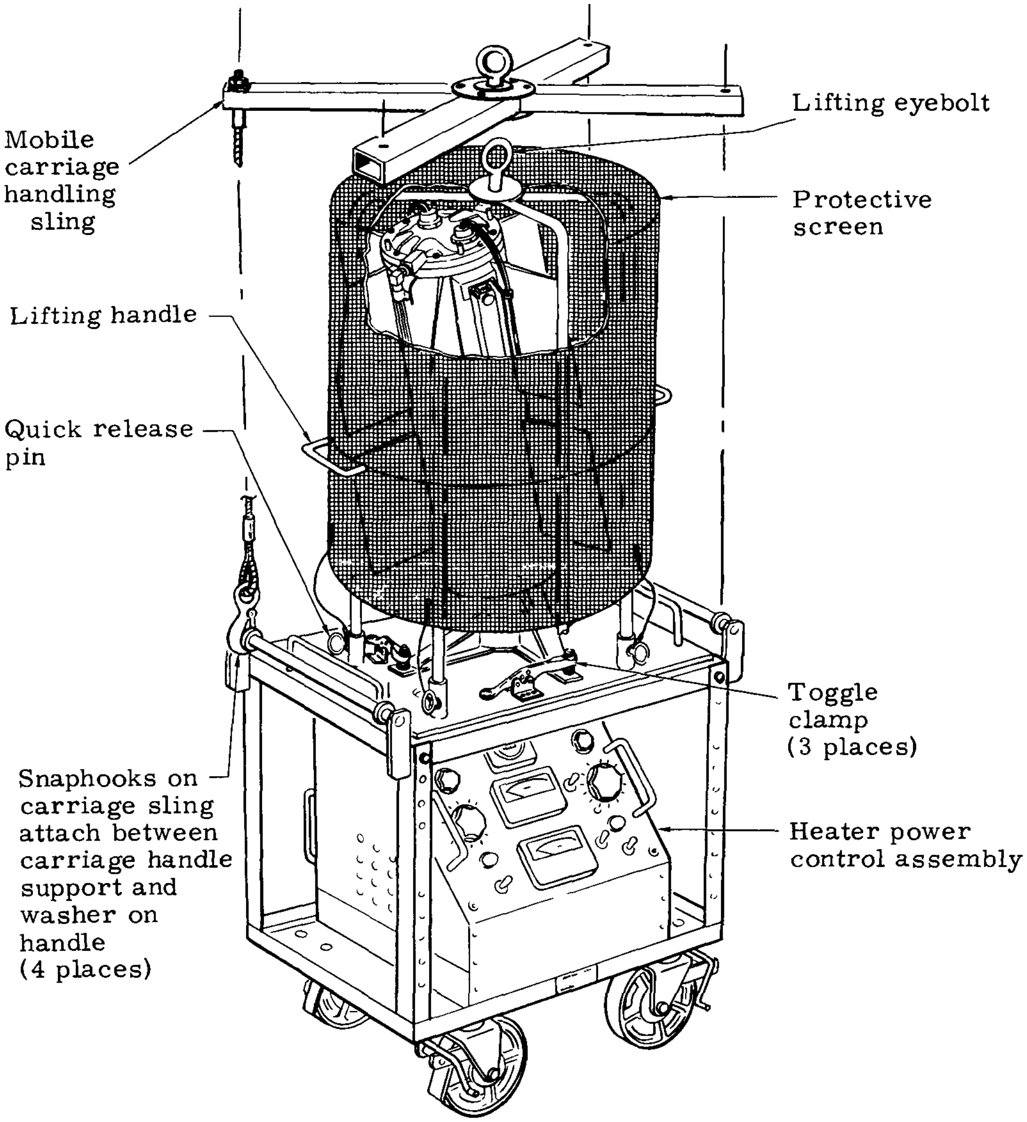


FIG. VII-10. MOBILE CARRIAGE ARRANGEMENT

d. Mobile carriage handling sling

The mobile carriage handling sling (Fig. VII-10) facilitates lifting the carriage with an installed generator subsystem from ground level at the launch site to the gantry elevator entrance level. The sling is attached to the mobile carriage handle at four points and contains a single-point attachment for an overhead crane hook.

The sling is fabricated from 2-inch square, 3/16-inch wall, steel tubing. The sling will handle a 2500-pound load (500 pounds at 5g). (The mobile carriage with a generator subsystem and heater power control assembly weighs about 450 pounds.)

3. Generator Subsystem Shipping and Storage Equipment

a. Fueled generator subsystem shipping container

The generator subsystem shipping container provides the necessary enclosure and biological protection for transporting and storing a subsystem (exclusive of the standoff). The unit meets applicable ICC, BOE and AEC regulations.

The 1900-pound shipping container (Figs. VII-11 and VII-12) is comprised of a storage base and a two-piece shield assembly. These components are paraffin-filled for biological shielding.

The storage base is a sealed assembly 40 inches in diameter and approximately 10 inches high, mounted on four 5-inch diameter, heavy duty casters. Two casters swivel and have brakes; the other two are stationary and have no brakes. The bottom plate is 1/2-inch thick 6061-T6 aluminum alloy. The top edge of the side is crenelated and the top plate is recessed two inches below the upper edge of the side. The top plate is reinforced by channels welded to the underside of the plate; three channel sections welded on top of this plate are mounting pads for the subsystem. The space between the base plate and the top plate is filled with 7 inches of refined paraffin (~150° F melting point) melted and poured through access ports in the top plate to provide biological shielding. When the void is filled, the access port is closed with a welded cover and a relief valve is installed in the cover. This valve permits the paraffin to expand, in case of a fire, without buckling the container.

The generator subsystem is mounted vertically on the base assembly to reduce the shield assembly diameter and weight. Three channel sections that form a 16° plane from the horizontal are used to accomplish vertical mounting. Anchor nuts on the underside of the channel sections secure bolts through the generator subsystem support base. Connectors which mate with the generator power plug, P1, and the two generator instrumentation plugs, P8 and P9, are on a bracket bolted to the base plate. Cables are connected from this bracket assembly to a small connector platform outside the shield assembly. There are three connectors and three electrical standoff posts on this platform. Two connectors, J-14 and J-12, are nine-pin plugs and are identified the same as the connectors on the standoff and support base, respectively, whose function they duplicate. Connector J-14 is used to monitor fin root temperatures (one on each generator) and connector J-12 is used to monitor generator hot junction temperatures (measured by two thermocouples in each generator). The remaining connector, J-13, is a 37-pin connector that duplicates the function of the J-13 connector located on the standoff; it provides the capability to monitor RTG hot junction and fin root temperatures, generator voltage and internal pressure. The generator subsystem, during normal transport and storage, is connected so that all readings can be taken. The cable that runs from the J-17 power plug on the bracket assembly terminates in the three standoff posts, designated GEN 1(+), GEN 2(+) and GEN 1 and 2(-). However, during normal transport and storage, the generator power plug, P1, is not connected to J17, but rather to the short circuit plug, J21, on the auxiliary dummy load box

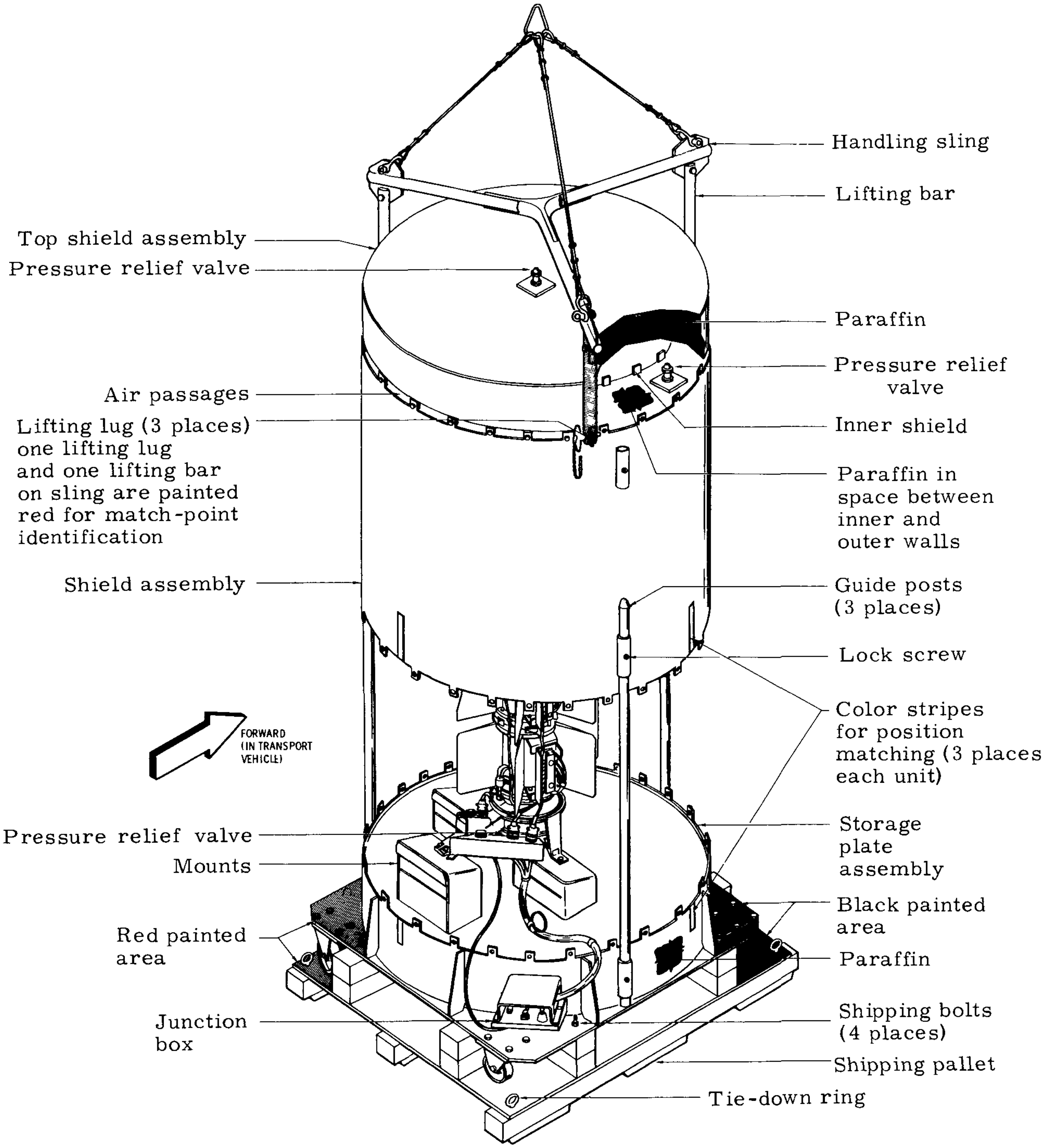


FIG. VII-11. INSTALLATION OF GENERATOR SUBSYSTEM IN SHIPPING CONTAINER

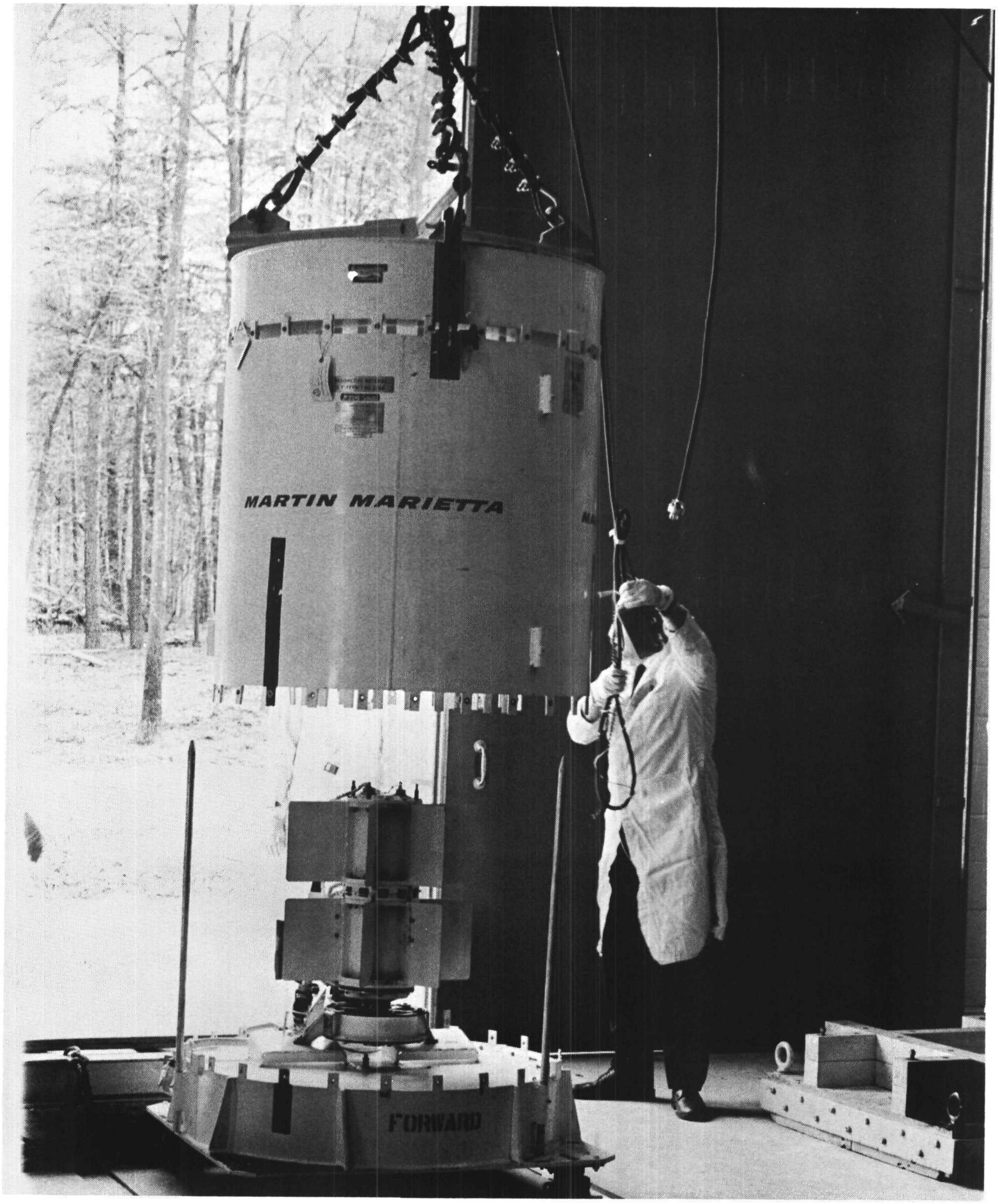


FIG. VII-12. HOISTING SUBSYSTEM SHIPPING CONTAINER SHIELD ASSEMBLY (attachable to support structure leg). For testing purposes, the shield can be raised and the generator power plug, P1, connected into J-17. Another load, or the PCU, can be attached to the external standoff posts. A hat-shaped section snaps over the connector assembly platform for protection.

To facilitate fabrication, the shield assembly is built in two sections, a center section and a cover. The center section is a hollow cylinder 40 inches in diameter, 40 inches high and 8 inches thick. The inner and outer walls are 1/4-inch thick aluminum alloy, with the top and bottom of each tube crenelated around the complete circumference. The annular top and bottom plates are 1/2-inch thick aluminum alloy plate. The inner tube inside diameter is 24 inches, which allows a nominal radial clearance of 1.4 inches at the generator fin tips. Seven 1/4-inch thick ribs are welded between the inner and outer tubes. Both top and bottom welded plates are recessed two inches from the ends of the cylinder. The space between the two tubes is filled with paraffin for radiological shielding. Shield thickness between the inner and outer tubes is 7-1/2 inches. The upper lid assembly is similar to the base, with a 7-inch thick section of paraffin. Both sections of the shield assembly are equipped with relief valves.

The completed assembly is bolted through the crenelations as shown in Fig. VII-11. Three lugs located on the shield assembly are used to lift the complete loaded assembly or to remove the shield assembly from the base plate (for generator subsystem installation or removal). For handling operations, the shield assembly is visually and physically keyed to the base plate. Three guide tubes are used to mate the shield to the base and to prevent the shield from contacting the generator subsystem.

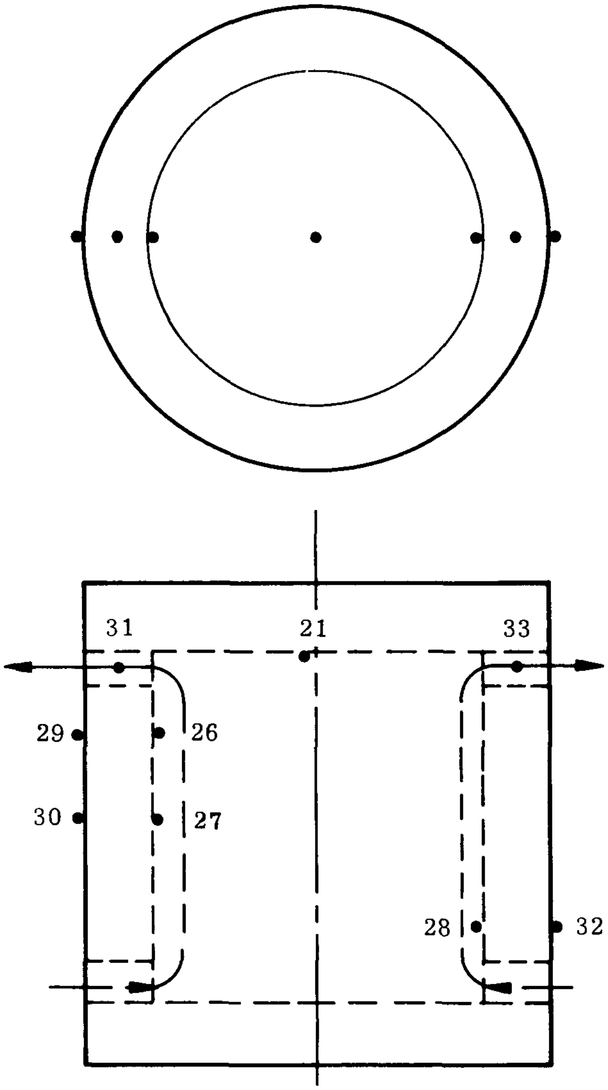
The container assembly can be handled either by fork-lift truck or by a specially designed handling sling. For shipping, a wooden skid is also used. The complete container assembly is coated with Dow-Corning 92-007 paint.

The generator subsystem is cooled by free convection air flow in at the lower crenelations and out at the upper crenelations. Container test data with an installed subsystem (570 watts per generator) are given in Fig. VII-13. The corresponding generator fin root temperature is ~270° F.

The thermal response of the shipping container was also analytically determined for adverse conditions of shipment in an AEC transportation van, assuming an air conditioning failure, an ambient temperature of 120° F and maximum solar input. The following temperatures were determined:

Van outside surface	146° F
Van inside surface	153° F
Van inside air	164° F
Shipping container exit air	208° F
Shipping container top (inner surface)	~200° F
Generator fin root	380° F

Although the paraffin would be molten during the worst-case situation, the low vapor pressure of the paraffin (~0.01 mm Hg at 200° F) would prevent its escape from the pressure relief valves (set at ~1 psig). Since the generators are allowed to be heated to 385° F on the fin root, the 380° F temperature is acceptable.



	Thermocouple	T_{avg} (°F)
Container Interior	26	92
	27	86
	28	82
Container Exterior	29	87
	30	82
	32	79
Exit Air	31	115
	33	117
Top	21	105

FIG. VII-13. SHIPPING CONTAINER TEMPERATURE DISTRIBUTION IN 70°F AIR

Paraffin (a hydrogenous low density material) was selected for the shipping container biological shield, because the unshielded neutron dose rate from the subsystem is about 10 times the unshielded gamma dose rate. Paraffin was selected over water because the latter is more vulnerable to loss. It was also chosen over polyethylene because of temperature considerations. Higher density shields (lead, iron, etc.), although more effective for the gammas, are not as effective for neutrons.

Analyses of both an unshielded and a paraffin-shielded generator subsystem were performed (both for 625-watt-per-generator fuel loadings) and are presented in Ref. VII-2. Corresponding measured dose rates taken on flight subsystem S/N 8A (570 watts per generator) are presented in Section IV-F.

b. Wooden skid

The wooden skid (Fig. VII-11) supports the generator subsystem shipping container without permitting the casters to rest on the skid. The base of the container bolts directly to the skid by one bolt in each corner. Eyebolts in each corner are tie-down points for shipment. The skid is designed for fork-lift handling and it color coded for matching with the shipping container base. It is constructed from 4 by 4-inch hardwood with a 1-inch thick plywood base, assembled with 1/2-inch diameter bolts.

The skid is designed to minimum g-levels of 1.2, 1.0 and 4.0 in the forward, lateral and vertical directions, respectively. To transfer the vertical loads to the four tie-down eyebolts, a 1/4-inch thick steel plate is bolted to both the inside and outside of the two skid outboard runners.

c. Generator subsystem shipping container handling sling

The generator subsystem shipping container handling sling is used to lift the shipping container shield body from the base for installation or removal of a generator subsystem (Fig. VII-11), and to lift the complete shipping container assembly (with generator subsystem installed).

The sling, fabricated from carbon steel pipe, plate and bar has a three-point attachment to the shipping container and a single-point attachment to the hoisting mechanism. The sling can lift the loaded container under inertial loads produced by acceleration of 5 g acting in a vertical direction through the combined container/subsystem cg. Use of the sling requires an overhead crane hook height of 12 feet minimum.

d. Shipping container for electrically heated generator subsystem

The shipping container for the electrically heated subsystem (cold) is a rectangular wooden box approximately 33 inches square at the base by 4 feet high. Attached to the bottom of the container are heavy wooden skids that permit handling by fork-lift truck.

The subsystem is mounted on an aluminum plate which, in turn, is shock-mounted to the wooden base. The subsystem is positioned in a polyethelene protective bag fastened (with a large gasket) to the mounting base. Through a small hole, the bag is evacuated and purged with argon. The bag is finally closed by heat sealing. The sides of the container and their attachments to the base and top are fastened with wood screws. The container and protective bag are both reusable items.

A similar but smaller wooden crate is used to ship single electrically heated generators.

C. TECHNICAL MANUAL

The technical manual (Ref. VII-3), written and produced in general accord with Ref. VII-4, furnishes operating and maintenance instructions on electrically heated and fueled generators, the power conditioner unit, the telemetry signal conditioner unit and the aerospace ground equipment associated with the SNAP 19 power supply system.

The manual describes the system, each of its components and the aerospace ground equipment. Illustrations are included where necessary to aid in description. Operating and maintenance instructions are given in detailed, step-by-step form. Interconnecting cable diagrams are furnished with the operating instructions, and maintenance instructions are supported by diagrams and schematics.

The manual was produced in preliminary unverified, preliminary verified and formal verified phases. The preliminary unverified version contained data available in the early stages of the program. Its content was updated as the design progressed, and accuracy was verified by use with the equipment at the Martin Marietta Corporation plant, in simulated exercises at General Electric, Valley Forge, and in simulated exercises at Vandenberg Air Force Base. After verification, changes were issued against the preliminary manual to remove the unverified status. The formal manual was then prepared and was issued in October, 1967. A change to the formal manual was issued incorporating changes through January 15, 1968.

The October 1967 basic issue and the January 15, 1968 change form the final version of the manual.

D. GENERATOR SUBSYSTEM TRANSPORTATION

A loading, transporting and unloading procedure for generator subsystems and associated equipment was developed, (Ref. VII-5). The procedure was based on use of either of two AEC courier vans (Trojan E-27195 or E-26935). In addition to the shipping skid and shipping container assembly which houses the generator subsystem, the other items to be carried by the van includes:

(1) Portable monitor package and associated interconnecting cables

(2) Generator shipping container sling

(3) Offset hoist bar

(4) Handling adapter assembly

(5) Mobile carriage assembly.

Items (1) and (2) are used for monitoring generator temperatures and pressures and handling of the shipping container, respectively; therefore, their inclusion on any generator subsystem shipment is essential. Incorporation of the remaining three items is determined by the purpose of shipment and hardware availability.

Existing applicable Martin Marietta, Sandia, AEC and GE procedures, ICC shipping regulations and military specifications were reviewed. Planned work included placement of packages in the AEC van, a stress analysis of the tie-down arrangement, a thermal analysis of van heater/refrigeration failure and the preparation and release of a procedure for loading and unloading of an AEC van. Further, a procedure was produced for monitoring the generators during the transport phase (Ref. VII-5). AEC is responsible for radiation monitoring equipment and procedures during this in-transit period.

A worst-case thermal analysis of an AEC van refrigeration failure determined that the van inside temperature will not exceed 170° F. The conditions established for the analysis were: van disabled and motionless with doors closed in 120° F ambient temperature, steady-state sunlight at a 45° angle of incidence. Therefore, a refrigeration failure cannot constitute an emergency, i. e., these worst-case conditions will not produce a fin root temperature above the 385° F limit. However, refrigeration in the van is desirable to keep the inside van temperature under 80° F to limit generator thermoelectric hot junction temperatures, thus minimizing thermoelectric degradation. Similarly, a heater failure in cold weather does not constitute an emergency. The generator subsystem is not affected by cold ambient temperatures, but a lower limit of 40° F inside van temperature was established to ensure proper operation of the portable monitor package.

The generator shipping container was positioned in the van so that, when not utilizing a loading dock, it could be loaded and unloaded by a fork-lift truck without sliding the container skid on the van bed. Stress analyses were conducted on several shock load guidelines. Finalized loading criteria specified that the tie-down arrangement withstand zero-to-peak loads of 1. 2 g fore and aft, 1. 0 g lateral and 4. 0 g vertical. The resultant stress analysis revealed that, while the tie-down arrangement was adequate, the shipping container skid required minor modifications (adding shear plates to the main skid runners and replacement of existing eye bolts with a stronger version).

A rough draft of the loading, transporting and unloading procedure (Ref. VII-5) was prepared. This procedure was utilized in a practice loading and unloading of an AEC van held at Martin Marietta on January 11, 1968. Fig. VII-14 is a view of the van with all equipment installed. Improvements resulting from the loading and unloading demonstration were incorporated in the final issue of the procedure.

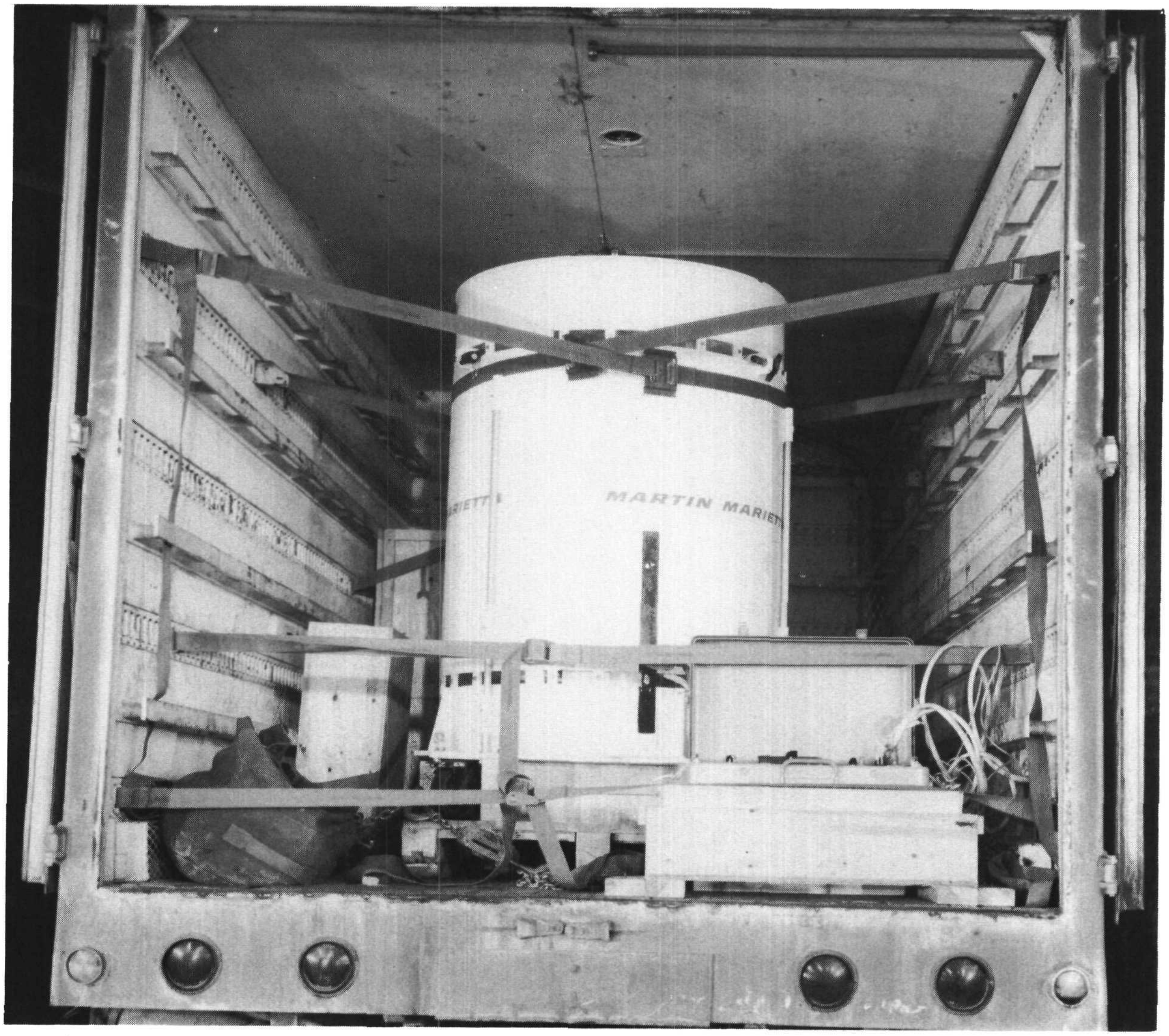


FIG. VII-14. EQUIPMENT SECURED IN VAN FOR SHIPMENT

VIII. SPACECRAFT INTEGRATION

A. SNAP 19 POWER SUPPLY TESTS

1. Generator Subsystem Transmissibility

The environment specified for the SNAP 19 generator subsystem when installed on the Nimbus B spacecraft necessitated design of the subsystem support structure as a triaxial, vibration-damped isolation mount of well-defined dynamic response characteristics. These facets of the design were necessary to provide practicable design criteria for the radioisotopic thermoelectric generators and the support structure itself.

Three principal considerations influencing design of the generator support were:

(1) Cantilevered configuration required by satellite spatial constraints

(2) Lowest resonant frequency (in each of three mutually perpendicular axes) between 30 and 60 Hz to be compatible with spacecraft input load spectrum

(3) An 80 g equivalent static load requirement based on compliance with (2), above.

After consideration of a series of design concepts, it was decided to incorporate the required elasticity and damping into the support structure itself. The complex nature of the structure precluded use of manual calculations; therefore, a Martin Marietta-developed digital computer program for analysis of dynamic and static response of three-dimensional elastic structures was used. Analysis concurrent with design (Ref. VIII-1), coupled with comprehensive design evaluation tests (Ref. VIII-2), resulted in a design-qualified support structure which exhibited the essential transmissibility characteristics desired. The configuration of the support structure is illustrated in Fig. II-20.

2. Thermal Conductance from Generator Subsystem to Spacecraft

A key integration factor was heat flow to the spacecraft sensory ring. Although the spacecraft has a thermal radiation view of the generator subsystem, the mode of primary concern was thermal conductance through the subsystem support structure. Nimbus had a well-developed thermal control system which would not accommodate large thermal inputs from the generators; it was, therefore, essential to limit the heat flow. Although the radiator (housing and fins) was designed to dissipate all of the waste heat, some heat flow to the spacecraft was unavoidable in view of the large thermal inventory of the generator subsystem--about 1.2 kw.

Other support structure design constraints decreased its thermal conductance. These were vibration isolation and the then-existing requirement for ejection (Ref. VIII-3). Both factors necessarily led to mechanical interfaces, and thus thermal contact resistances, which otherwise would not have been present in a hard mounted, no-ejection installation.

Estimates based on analysis and on support structure temperature data obtained in the Phase II thermal vacuum testing of RTG subsystem S/N 2 (Ref. VIII-4) indicated that the heat conducted to the spacecraft could be less than 50 watts. In conjunction with NASA and the General Electric Company, an experiment was designed to ensure the heat input to the spacecraft, using an electrically heated generator (S/N 1). The experiment, performed by General Electric, showed that the heat flow to the sensory ring was about 12 watts (Refs. VIII-5 and VIII-6). Changes to the spacecraft thermal control system were therefore not necessary.

3. Magnetic Moments Measurements

Any Nimbus B subsystem which exhibits a magnetic field can affect the in-orbit control of the spacecraft through development of a magnetic moment, i.e., interaction of the magnetic fields of the earth and the subsystem. The spacecraft is maintained in its proper orbital orientation by its control system, using gas jets. Therefore, excessive use of the spacecraft control system due to magnetic moments could shorten the Nimbus B mission life. Since a significant amount of the SNAP 19 power supply system is made of iron and other magnetically permeable material and since the system does contain circuits which carry direct currents, the power supply system was tested at NASA-GSFC to determine its magnetic moments characteristics.

A nonmagnetic test fixture was designed and fabricated. Mounted to the test fixture was generator subsystem S/N 7, power conditioning unit S/N 8, a dummy load and interconnecting harnessing. The setup in the GSFC facility is shown in Fig. VIII-1.

The magnetic moments test was conducted in three phases. The magnetic state of the system (without TSCU), as received, was evaluated in three axes. Then a 15-gauss (dc) field was applied in one axis and the system was evaluated for magnetic susceptibility. The system was then demagnetized (depermed) and a third system evaluation performed. The field application was repeated in the other two axes with subsequent demagnetization and evaluation. The generator subsystem was then placed on short circuit and removed from the test facility. Finally, the load box was evaluated to determine a magnetic moment correction factor.

Based on the results of test on subsystem S/N 7, it was decided to conduct a similar test on the flight subsystem, S/N 8A. The results of this test are presented in Table VIII-1. The high initial magnetic moments may have resulted from magnetization induced while the subsystem was being vibrated on the MB C-210 vibration machine; the vibration tests were a part of the subsystem flight acceptance test program. The final values of magnetic moment after demagnetization were considered acceptable for flight. The subsystem values were again measured after 17 hours in the shorted mode and 2 hours in the dummy load mode, with no apparent increase in magnetic moment.

TABLE VIII-1

Magnetic Moment--Subsystem S/N 8A
(dyne-cm/oersted)

	M_X	M_Y	M_{XY}	M_Z	M_T
Initial (shorted)	2800	24	2800	3660	4600
(dummy)	2620	171	2620	3420	3890
Post 15-g X-axis	3720	215	3720	3420	4700
Post 1st deperm	730	100	730	245	735
Post 15-g Y-axis	630	1400	1535	245	1540
Post 2nd deperm	755	159	795	245	800
Post 15-g Z-axis	860	86	915	1320	1600
Post 3rd deperm	790	120	835	245	870
	Roll	Pitch		Yaw	

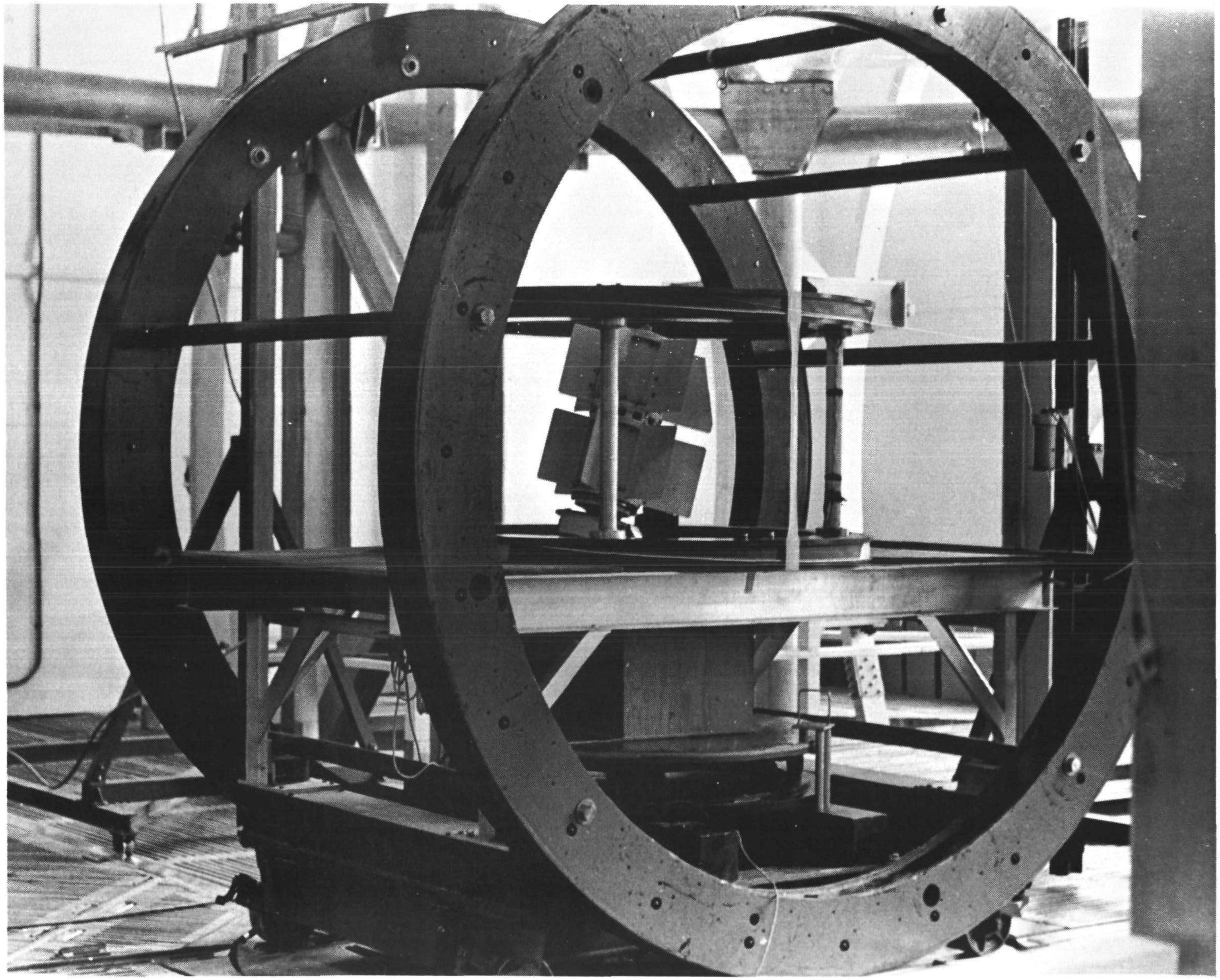


FIG. VIII-1. MAGNETIC MOMENTS TEST SETUP AT GODDARD SPACE FLIGHT CENTER

4. Shroud Cooling Tests

To determine the air conditioning requirements of the enshrouded Nimbus B spacecraft with a fueled RTG installed on the sensory ring, a shroud cooling test was conducted at General Electric, Valley Forge. For this test, the Nimbus C prototype spacecraft and SNAP 19 generator subsystem No. 1 were used.

Cooling air at a temperature of 57° F was introduced into the shroud at 45 lb/min while the heating cycle was initiated on the generators. Various operating modes of the spacecraft were evaluated during the test. Tests at flow rates of 30 and 60 lb/min and a simulated air conditioner failure test were also performed. During the simulated failure, the cooling air was off for 1 hour and 40 minutes, during which time no over-temperature problems were observed on the spacecraft.

The results of the tests indicated that the average spacecraft temperature is more responsive to air temperature than to air flow rate and that, to maintain the sensory ring temperatures below the required 20° C level, the cooling air temperature must be maintained below 53° F and the flow rate must be 45 lb/min or more. The generator fin root temperature for the recommended air inlet temperature and flow rate will be 50° F to 60° F below the levels which would be obtained for free-air ambient operation. This is more than adequate to meet the launch constraint of a maximum fin root temperature of 250° F.

B. SPACECRAFT LEVEL TESTING

1. Vibration Model Spacecraft

Prototype level qualification vibration tests were performed on the Nimbus B structural dynamics model spacecraft at GEVF. Generator subsystem S/N 1 was mounted on the sensory ring during these tests.

The tests included the following three phases:

(1) Sinusoidal vibration sweep tests at 0.3g level, flight and prototype levels along each of the three major axes

(2) Random vibration tests at the prototype level along each of the three major axes

(3) Modal survey conducted at 0.3g level.

The data acquired during these tests were used to evaluate and define primary resonant frequencies, structural amplifications, spacecraft displacements and spacecraft loads.

Examination of the results of these tests provided the basis for modifying the sinusoidal vibration flight and prototype test levels for the SNAP 19 RTG subsystems. Some of the changes were significant in that the inputs were reduced in those frequency ranges where the subsystem exhibited a critical response when mounted on the shaker but not when integrated with the spacecraft structure. Other modifications included smoothing the input spectrum for better test control. The spacecraft structure was adequate to sustain the stresses and strains induced by the RTG subsystem.

2. Electrical Systems Model Spacecraft Model Spacecraft

The SNAP 19 engineering model power supply system (system No. 2) consists of generator subsystem S/N 2, PCU S/N 3 and TSCU S/N 2. These units and ground support test console (GSTC) S/N 1 were used with the electrical systems model (ESM) spacecraft for extended system performance tests at General Electric Co., Valley Forge. The system output power for each test utilizing heated generators is illustrated in Fig. VIII-2.

Bench compatibility tests, conducted using PCU S/N 3 and the pulse width modulator regulator, revealed no problems. The GSTC S/N 1 was used to simulate the generators during these compatibility tests.

The TSCU S/N 2 and PCU S/N 3 were installed in the ESM sensory ring and these modules were electrically integrated with the spacecraft. The GSTC S/N 1 was used to simulate the generators for the integration test and for all spacecraft testing from that time until the generators were integrated with the spacecraft.

The first installation of the generators on the spacecraft showed that there was mechanical interference between the spacecraft and both the dummy load and heater connector brackets. These mechanical problems were resolved by relocating (to the outboard leg of the tripod) both brackets on subsequent generator subsystems.

After all subsystems had been integrated into the ESM spacecraft, a series of RF, electrical compatibility and electrical systems tests was performed. Several minor problems were identified and corrected during this series of tests.

Two vacuum-thermal (V/T) tests were performed on the ESM during May 1967. These were the last major tests with the ESM spacecraft; no problems were encountered with the SNAP 19 system during these tests.

3. Flight Spacecraft

Most of the testing on the flight spacecraft prior to delivery to the Air Force Western Test Range (AFWTR) was accomplished using the electrically heated prototype generator subsystem S/N 5 rather than the fueled flight generators. System No. 5, consisting of generator subsystem S/N 5, PCU S/N 4 and TSCU S/N 4, were received at GE with standoff S/N 5 and GSTC S/N 3 on June 30, 1967. Bench acceptance and bench integration tests were performed using system No. 5. The average system output power for each test in which the system No. 5 generators were heated is illustrated in Fig. VIII-3.

The only anomalies observed during the first electrical compatibility test on the flight spacecraft and the first RF systems test were occasionally erratic TM indications on both converter temperatures and on some of the hot junction temperatures. At the conclusion of the RF systems test, the noise was measured on all of the outputs from the TSCU to the PCM multicoder. The noise (using TSCU S/N 4) was greater than one volt, peak-to-peak, on both converter temperature channels while the noise level on all other channels was below 100 mv. Resolution of this problem is discussed under TSCU circuit modification in Section II. E.

After completion of TSCU modifications and subsequent vibration and vacuum thermal testing, TSCU S/N 7 (a flight unit) was integrated into the flight spacecraft with no problems. From that time on, all testing of the flight spacecraft involved the use of PCU S/N 7 and TSCU S/N 7.

The second electrical systems and RF systems tests were performed, with no problems observed on SNAP 19 equipment during these tests.

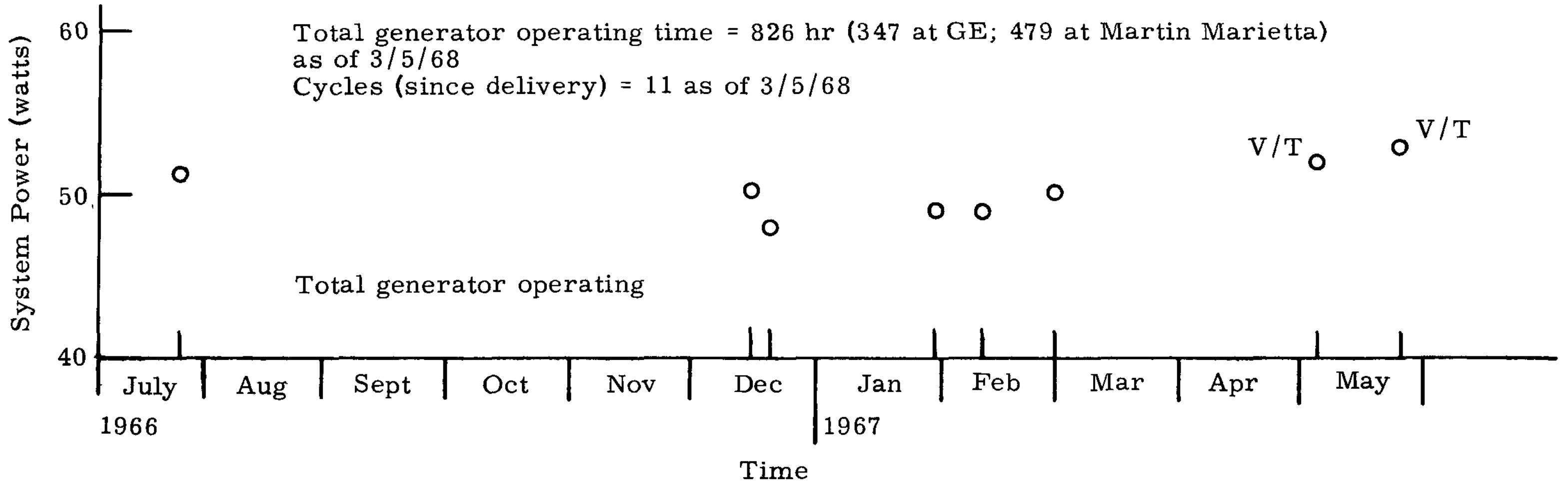


FIG. VIII-2. SYSTEM NO. 2 PERFORMANCE SUBSEQUENT TO DELIVERY (DATA FROM T/M)

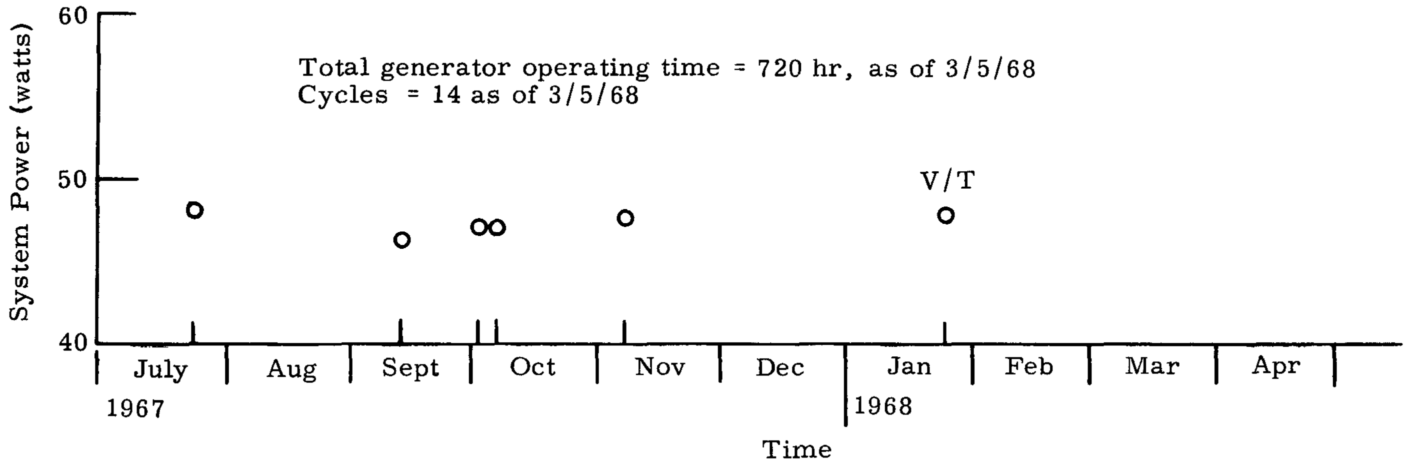


FIG. VIII-3. SYSTEM No. 5 GENERATOR PERFORMANCE AT GE (DATA FROM T/M)

During the first vacuum thermal test on the flight spacecraft, using generator subsystem S/N 5, there were some power input fluctuations on the heater of the lower generator and an intermittent open on the associated heater alarm circuit. This problem was probably due to leakage in the heater circuit (which subsequently became excessive during the third vacuum thermal test and resulted in a short circuit between the heater leads near the point where they enter the generator). A second vacuum thermal test was conducted to troubleshoot a problem with the spacecraft controls subsystem. The generators were heated and cooled during the test, but no problems were observed with the SNAP 19 equipment during the test. A third vacuum thermal test was conducted with the flight spacecraft. During the generator heating cycle, a short developed in the heater circuit of the lower generator; therefore, only the upper generator was heated for this entire test. At the conclusion of the mass properties tests which followed the vacuum thermal test, the heater wires on the lower generator were replaced. The problem was caused by insulation breakdown from either abrasion or overheating. During the repairs, fiberglas sleeving was added to these wires to give added protection.

Additional tests to be conducted prior to delivery of the flight spacecraft to AFWTR and which involve SNAP 19, are:

(1) An additional RF system test

(2) Vibration test

(3) Center-of-gravity determination, using fueled generators

(4) Electrical integration of the fueled generator subsystem S/N 8A.

C. LAUNCH SITE OPERATIONS

1. Installation Sequence

The activities at AFWTR with respect to the Nimbus B spacecraft and the SNAP 19 (RTG) experiment will be conducted in two basic phases. These are: (1) mate, checkout, and mock countdown using the electrical systems model (ESM) spacecraft and the electrically heated prototype RTG (ERTG); (2) mate, checkout, countdown and launch of the flight spacecraft and flight RTG.

The schedule at AFWTR is set as a sequence of "R-days." This schedule begins with checkout of the ESM spacecraft in the spacecraft assembly building (SAB) on R minus 13 and R minus 12 days. On R minus 11 through R minus 8, checkouts and installations are made to simulate R minus 4 through R minus 1. R minus 7 is mock countdown.

The flight generators will arrive at AFWTR on approximately R minus 9 day. They will be stored in the SAB until R minus 2, at which time they will be transported to the Pad Agena shelter, unloaded, transferred to the gantry fourth level and installed on the flight spacecraft. All of these operations, removal of the fueled generators from the flight spacecraft, and handling of the electrically heated RTG are covered in Ref. VIII-7.

The installation of the flight RTG on R minus 2 day will be rehearsed using the cold ERTG on R minus 9 day. After installation, the ERTG will be heated and the mock exercises will continue as stated above.

2. Procedural Verification

In order to verify the handling and installation procedures for the RTG, simulated exercises were conducted at GE on May 8, 1967 and at AFWTR on May 13 and 14, 1967. In addition, mock countdown exercises were performed at GE on December 4 through 7, 1967.

The simulated exercises covered a rehearsal of receiving and subsequent shipping of fueled generators at GE, receiving at AFWTR, transport from SAB to the Pad Agena shelter and transport to and from the gantry fourth level. A generator handling dummy was used for these exercises.

The mock countdown consisted of a simulated transfer of fueled generators from the Pad Agena shelter to the gantry fourth level and rehearsal of the installation and removal procedure on the spacecraft. The ERTG in a cold condition was used for these exercises.

To better simulate thermally hot generators, the installation and removal rehearsals were repeated using the engineering model generators (system No. 2) in a heated condition.

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APPENDIX A

SYSTEM CHRONOLOGIES

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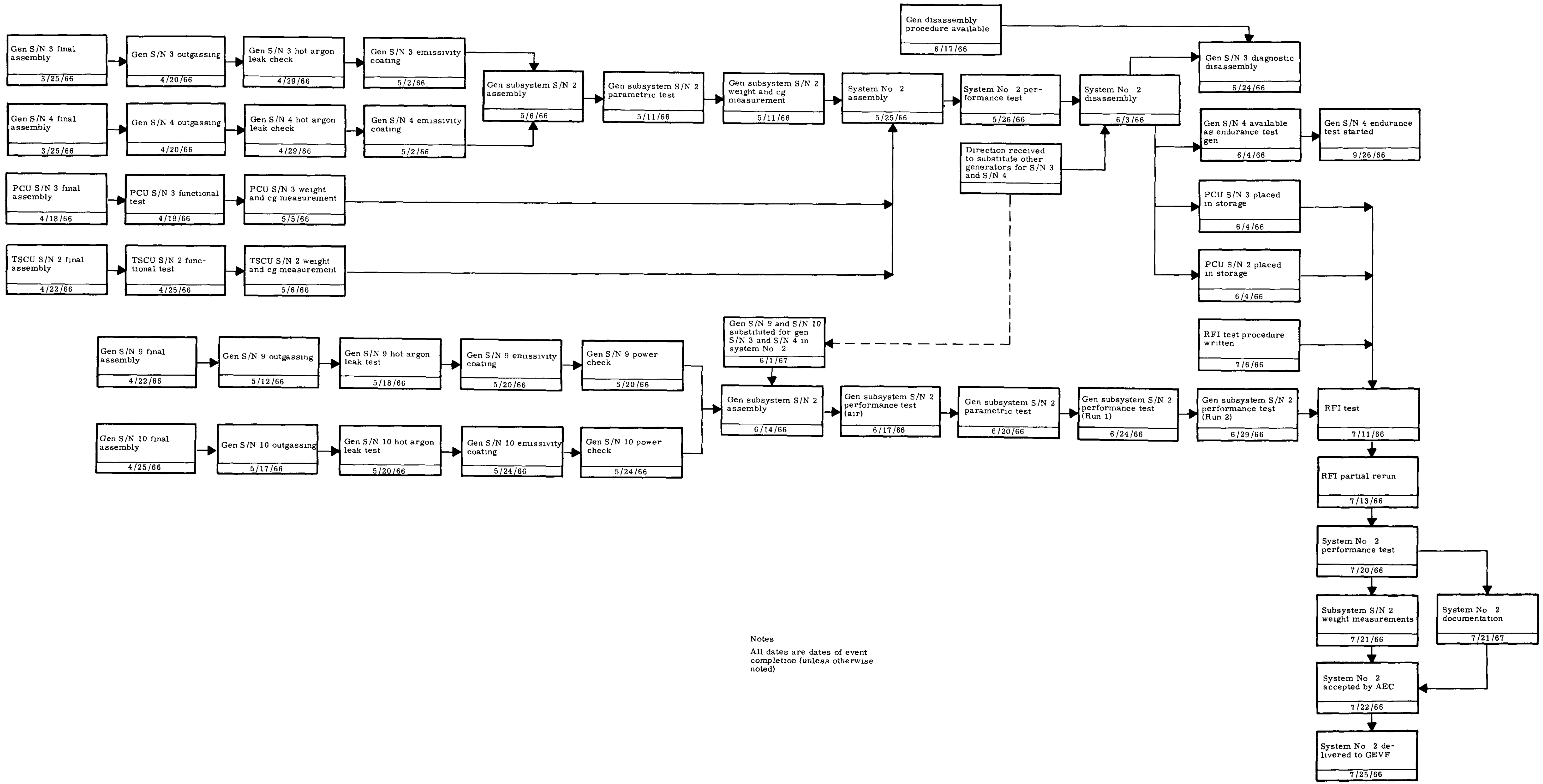

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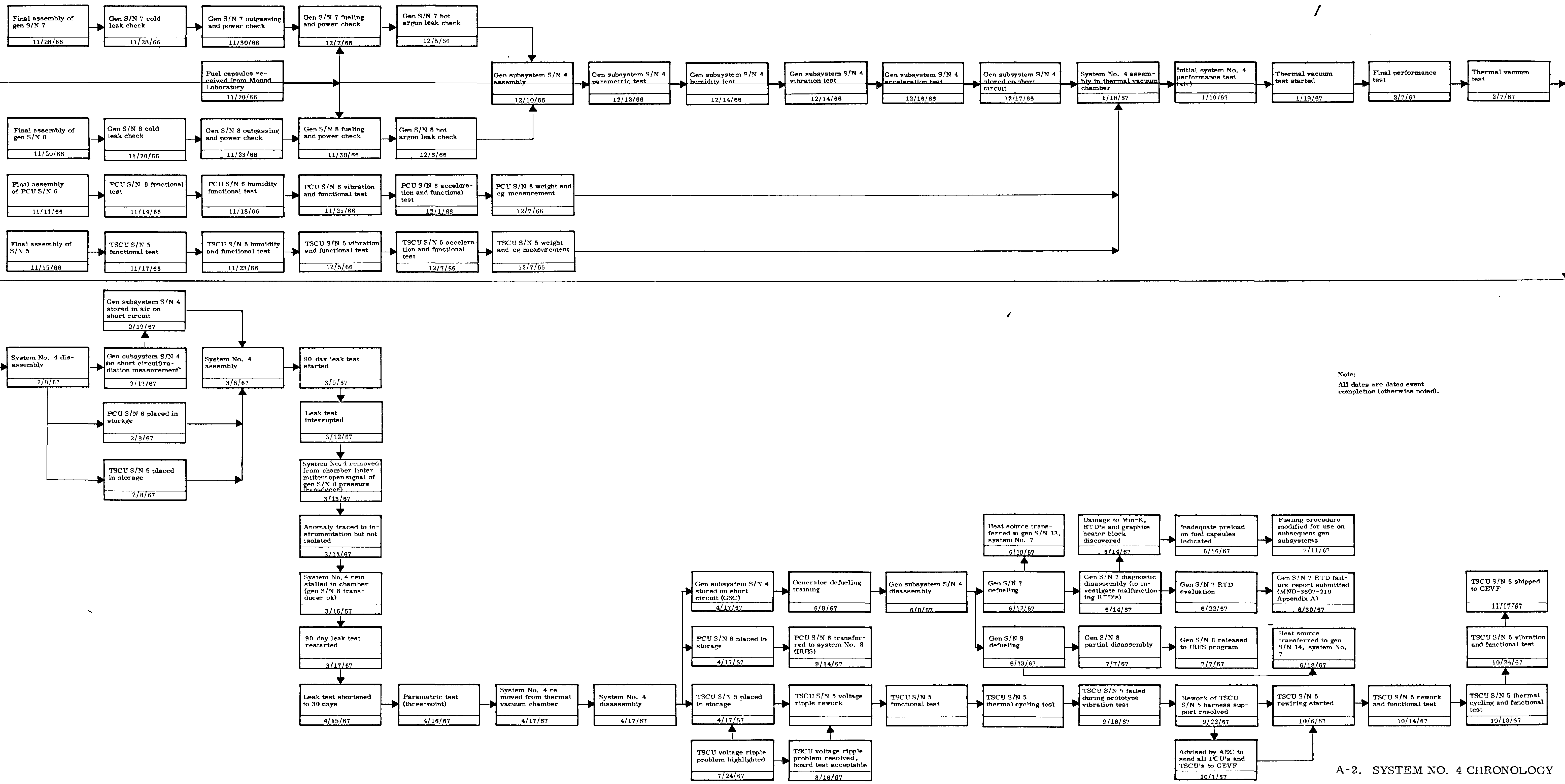

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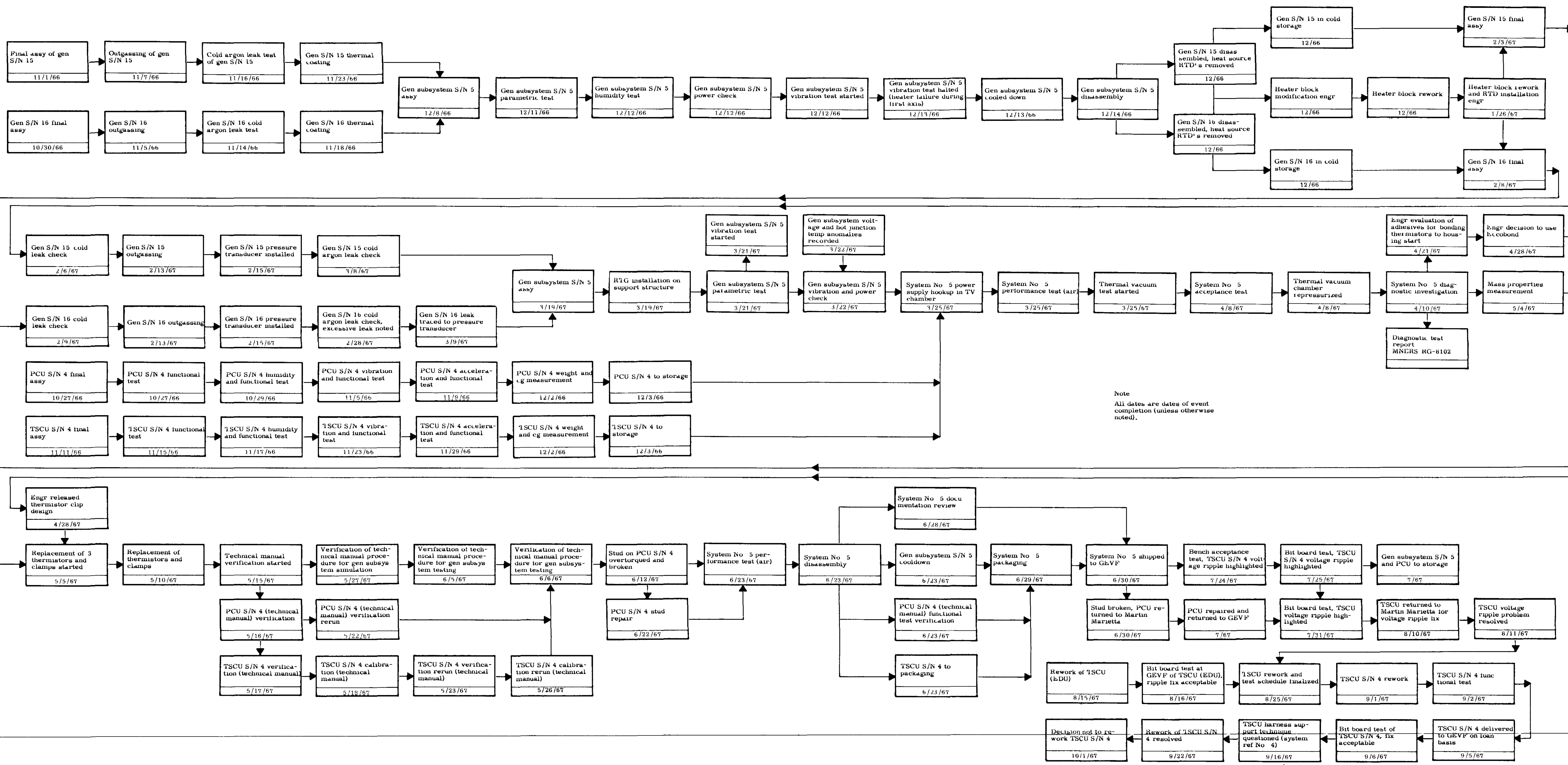

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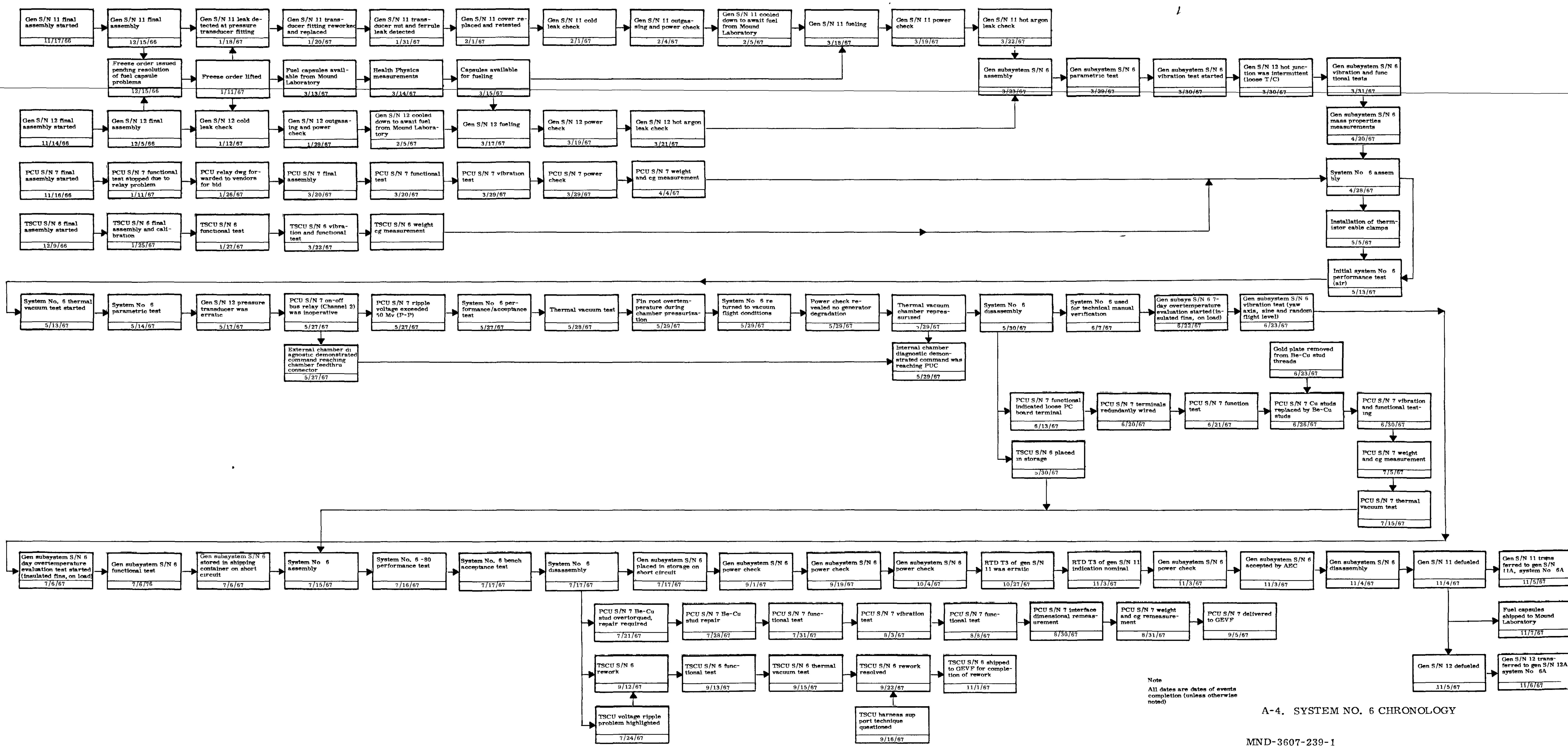

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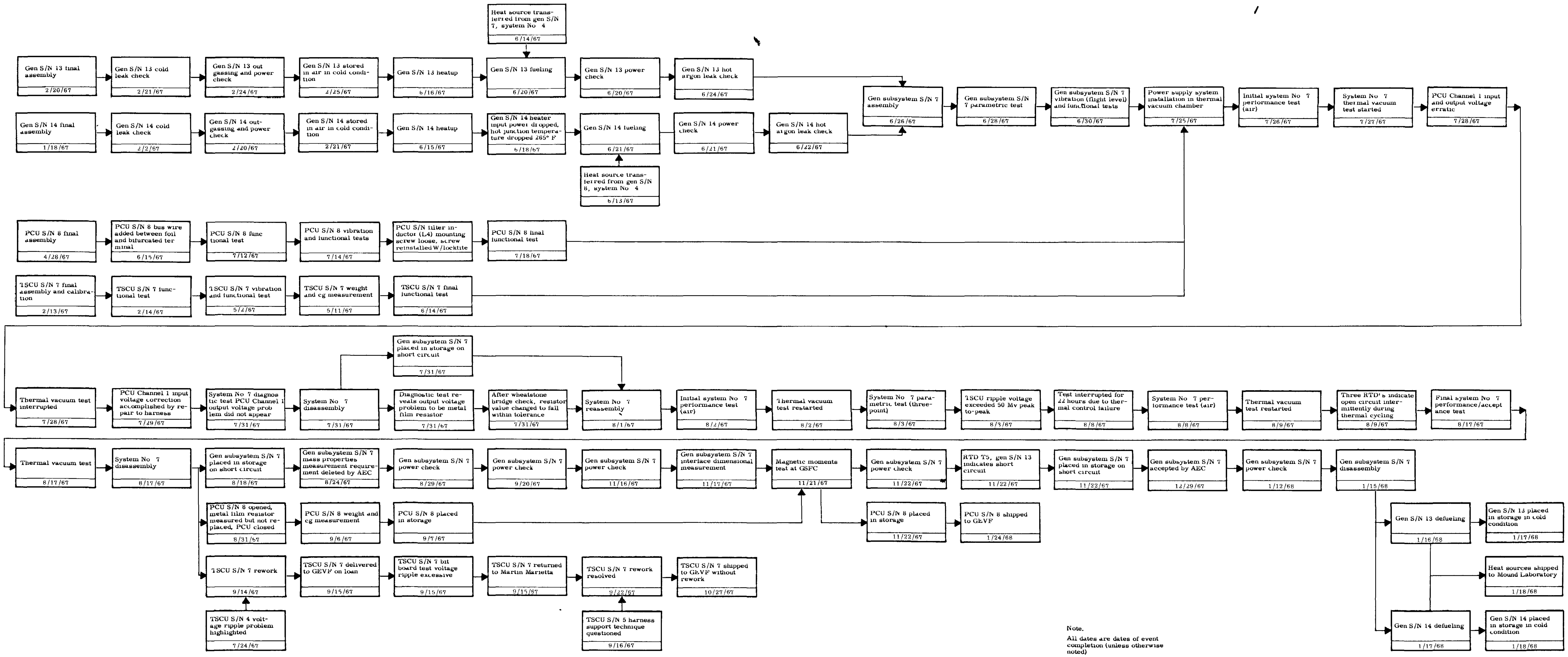

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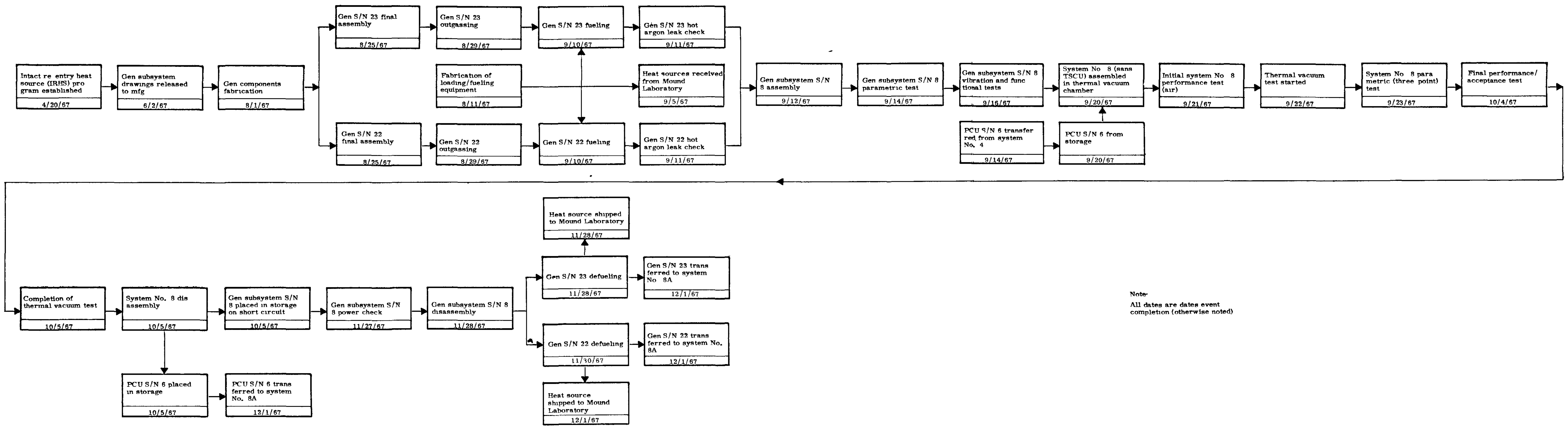

Note:
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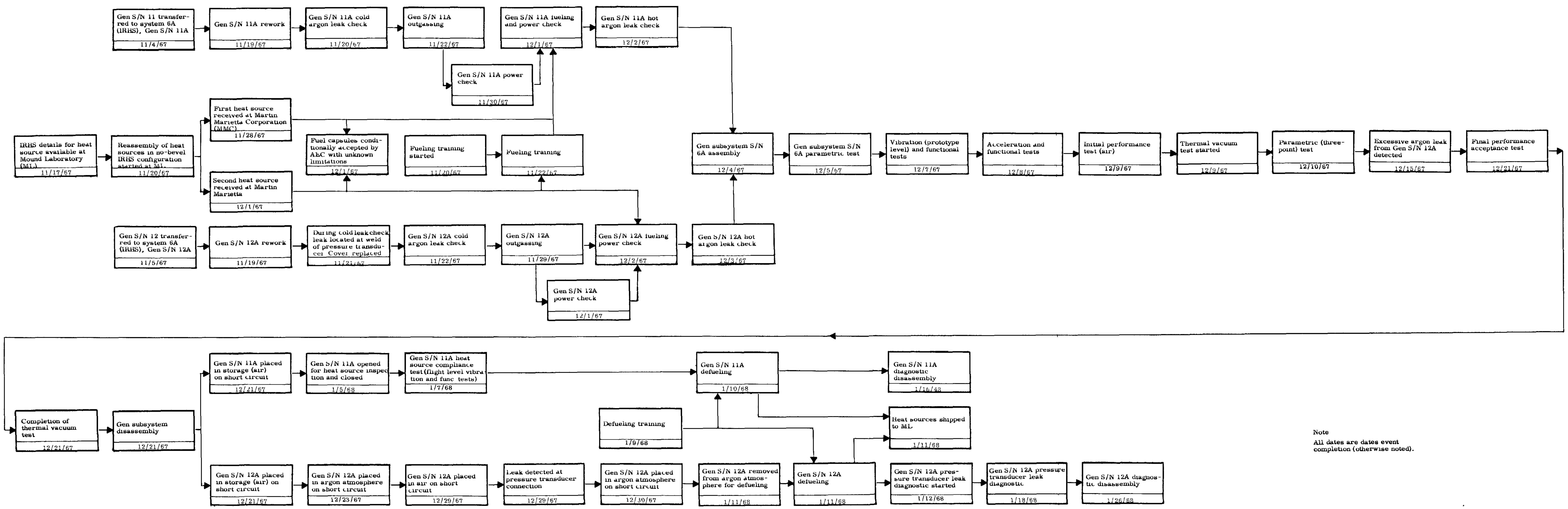

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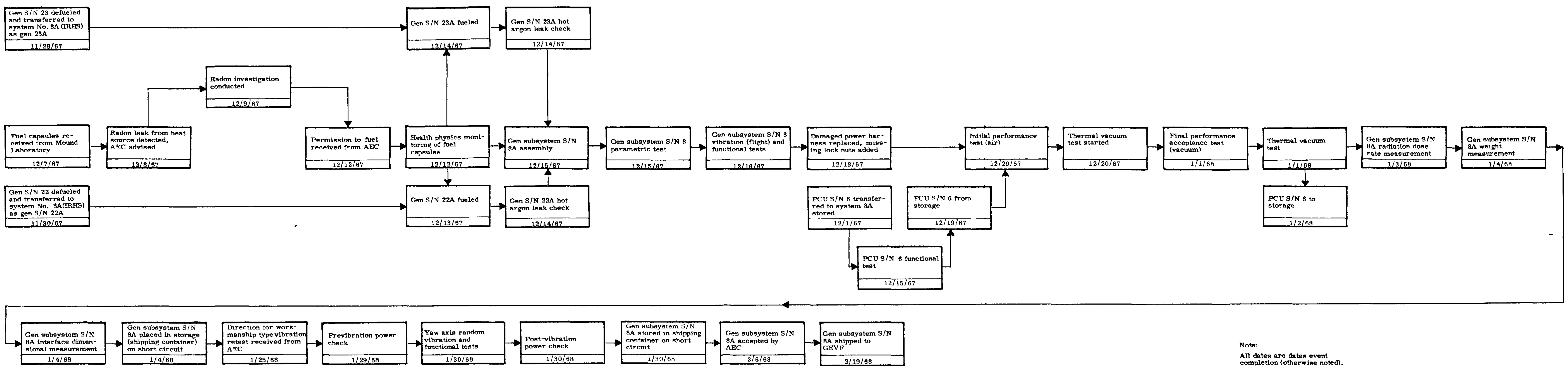

Note:
All dates are dates event completion (otherwise noted).

A-8. SYSTEM NO. 8A CHRONOLOGY

040101825

APPENDIX B

GENERATOR SUBSYSTEM TEST DATA SUMMARY

TABLE B-1

Generator Subsystem S/N 4 Test Data Summary

<table>
<tr><th>Test and Date</th><th>Martin Marietta Test Procedure</th><th>Martin Marietta Test Report No.</th><th>Test Result Summary</th></tr>
<tr><td>Fueling
S/N 7--12/2/66
S/N 8--11/30/66</td><td>452B1900009
(Fueling)
452B1900051
(Handling and functional tests)</td><td>MND-3607-189
(Fueling)
MND-3607-198
(Functional)</td><td>Fueling of both generators successful. During disassembly (electrically heated configuration) of S/N 8, considerable arcing detected around internal heater leads. Information was programmed into total heater investigation (Ref. IV-6). Prefueling and post-fueling functional power checks data follow:
<table>
<tr><th></th><th>Generator S/N 7</th><th></th><th>Generator S/N 8</th><th></th></tr>
<tr><th></th><th>Prefueling</th><th>Post-fueling</th><th>Prefueling</th><th>Post-fueling</th></tr>
<tr><td>Avg hot junction (°F)</td><td>747</td><td>767</td><td>819</td><td>846</td></tr>
<tr><td>Avg fin root (°F)</td><td>227</td><td>229</td><td>297</td><td>280</td></tr>
<tr><td>Load voltage (v)</td><td>2.583</td><td>2.588</td><td>2.605</td><td>2.606</td></tr>
<tr><td>Power output (w)</td><td>27.12</td><td>27.9</td><td>28.26</td><td>30.99</td></tr>
</table></td></tr>
<tr><td>Hot argon leak
S/N 7--12/5/66
S/N 8--12/3/66</td><td>452B1900064</td><td></td><td>Facility problems during testing of S/N 7 prevented assignment of credible numerical value to leak rate Test demonstrated that leak rate was below maximum limit of 1 x 10^{-4} scc/sec. S/N 8 leaked 4.5 x 10^{-5} scc/sec, well within allowable.</td></tr>
<tr><td>Parametric
S/N 4--12/12/66</td><td>452B1900016</td><td>MND-3607-198</td><td>Graphic representation of parametric data presented for flight generators S/N 22A and 23A only (Fig B-1 and B-2) Data are typical and is available for subject subsystem in ref test report.</td></tr>
<tr><td>Humidity and power check</td><td>452B1900022
(Humidity)
452B1900023
(Power check)</td><td>MND-3607-194</td><td>No visible damage observed after humidity exposure. Post-humidity power check data follow:
<table>
<tr><th></th><th>Generator S/N 7</th><th>Generator S/N 8</th></tr>
<tr><td>Avg hot junction (°F)</td><td>781</td><td>793</td></tr>
<tr><td>Avg fin root (°F)</td><td>254</td><td>254</td></tr>
<tr><td>Load voltage (v)</td><td>2.597</td><td>2.598</td></tr>
<tr><td>Power output (w)</td><td>30.51</td><td>30.60</td></tr>
</table></td></tr>
<tr><td>Prototype vibration
12/14/66</td><td>452B1900024
(Vibration)
452B1900023
(Power check)</td><td>MND-3607-194</td><td>No external damage observed. Changes noted in generator S/N 7 load voltage and hot junction temperature instrumentation. Power check data follow:
<table>
<tr><th></th><th>Generator S/N 7</th><th></th><th></th><th>Generator S/N 8</th><th></th><th></th></tr>
<tr><th></th><th>Yaw</th><th>Roll</th><th>Pitch</th><th>Yaw</th><th>Roll</th><th>Pitch</th></tr>
<tr><td>Avg hot junction (°F)</td><td>723</td><td>777</td><td>763</td><td>783</td><td>790</td><td>797</td></tr>
<tr><td>Avg fin root (°F)</td><td>229</td><td>252</td><td>251</td><td>252</td><td>252</td><td>251</td></tr>
<tr><td>Load voltage (v)</td><td>2.581</td><td>2.653</td><td>2.598</td><td>2.585</td><td>2.595</td><td>2.598</td></tr>
<tr><td>Power output (w)</td><td>29.71</td><td>28.16</td><td>28.58</td><td>30.70</td><td>30.37</td><td>30.68</td></tr>
</table></td></tr>
<tr><td>Acceleration
12/16/66</td><td>452B1900025
(Acceleration)
452B1900023
(Power check)</td><td>MND-3607-194</td><td>No external damage observed. No instrumentation changes noted. Power check data follow:
<table>
<tr><th></th><th>Generator S/N 7</th><th>Generator S/N 8</th></tr>
<tr><td>Avg hot junction (°F)</td><td>722</td><td>785</td></tr>
<tr><td>Avg fin root (°F)</td><td>236</td><td>244</td></tr>
<tr><td>Load voltage (v)</td><td>2.628</td><td>2.635</td></tr>
<tr><td>Power output (w)</td><td>28.25</td><td>30.24</td></tr>
</table></td></tr>
<tr><td>Defueling
6/12/67
6/13/67</td><td>452B1900074
(Defueling)
452B1900051
(Handling and power check)</td><td>MND-3607-187</td><td>S/N 7 heat source difficult to extract as powdered Min-K had filled clearance gap around heat source. Load distribution disk in S/N 7 loosened with preload loss and damaged RTD's. Generator S/N 8 easily defueled without any of problems of S/N 7. Power check data before defueling follow:
<table>
<tr><th></th><th>Generator S/N 7</th><th>Generator S/N 8</th></tr>
<tr><td>Avg hot junction (°F)</td><td>646</td><td>744</td></tr>
<tr><td>Avg fin root (°F)</td><td>242</td><td>248</td></tr>
<tr><td>Load voltage (v)</td><td>2.605</td><td>2.619</td></tr>
<tr><td>Power output (w)</td><td>25.21</td><td>26.21</td></tr>
</table></td></tr>
</table>

TABLE B-2

Generator Subsystem S/N 5 Test Data Summary

<table>
<tr><th>Test and Date</th><th>Martin Marietta Test Procedure</th><th>Martin Marietta Test Report No.</th><th>Test Result Summary</th></tr>
<tr><td>Cold argon leak
S/N 15--3/8/67
S/N 16--3/9/67</td><td>452B1900044</td><td>MND-3607-158</td><td>Indicated leak rate of generator S/N 15, measured by three-scan average, was 8 7 x 10^{-7} cm^3/sec, well within limit of 4 x 10^{-6} scc/sec First run on generator S/N 16 indicated excessive leak rate, leak was traced to pressure transducer fitting, which was retightened to nominal torque value. Second run indicated still excessive leak rate, fitting was replaced. Third run indicated average leak of 2 3 x 10^{-6} cm^3/sec of argon.</td></tr>
<tr><td>Parametric
3/21/67</td><td>452B1900055</td><td>MND-3607-164</td><td>See Table A-1 for graphical representations of parametric data</td></tr>
<tr><td>Flight acceptance vibration
3/22/67</td><td>452B1900045</td><td>MND-3607-174</td><td>No external damage observed. Transient response noted in generator S/N 15 output voltage and current and one hot junction T/C. Performance of subsystem immediately after vibration test demonstrated no permanent effects of vibration environment. Power check data were as follows
<table>
<tr><th></th><th>Generator S/N 15</th><th></th><th></th><th>Generator S/N 16</th><th></th><th></th></tr>
<tr><th></th><th>Yaw</th><th>Pitch</th><th>Roll</th><th>Yaw</th><th>Pitch</th><th>Roll</th></tr>
<tr><td>Avg hot junction (°F)</td><td>771</td><td>771</td><td>776</td><td>749</td><td>746</td><td>758</td></tr>
<tr><td>Avg fin root (°F)</td><td>236</td><td>241</td><td>238</td><td>226</td><td>222</td><td>230</td></tr>
<tr><td>Load voltage (v)</td><td>2.616</td><td>2.615</td><td>2.615</td><td>2.608</td><td>2.569</td><td>2 596</td></tr>
<tr><td>Power output (w)</td><td>27.72</td><td>27.72</td><td>27.38</td><td>27.64</td><td>27.23</td><td>27.59</td></tr>
</table></td></tr>
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TABLE B-3

Generator Subsystem S/N 6 Test Data Summary

<table>
<tr><th>Test and Date</th><th>Martin Marietta Test Procedure</th><th>Martin Marietta Test Report No.</th><th>Test Result Summary</th></tr>
<tr><td>Fueling
S/N 11--3/18/67
S/N 12--3/15/67</td><td>452B1900009 (Fueling)
452B1900051 (Handling and functional tests)</td><td>MND-3607-159</td><td>The fueling of both generators successful. An adjustment made in flight Min-K insulation on generator S/N 11. Round recess in Min-K block halves enlarged to allow block halves to seat properly atop module block and around module block fastening post. Pre- and post-fueling functional power checks produced following data.
<table>
<tr><th></th><th>Generator S/N 11</th><th></th><th>Generator S/N 12</th><th></th></tr>
<tr><th></th><th>Prefueling</th><th>Post-fueling</th><th>Prefueling</th><th>Post-fueling</th></tr>
<tr><td>Avg hot junction (°F)</td><td>788</td><td>812</td><td>755</td><td>770</td></tr>
<tr><td>Avg fin root (°F)</td><td>233</td><td>234</td><td>256</td><td>224</td></tr>
<tr><td>Load voltage (v)</td><td>2.641</td><td>2.634</td><td>2.634</td><td>2.608</td></tr>
<tr><td>Power output (w)</td><td>28.04</td><td>30.21</td><td>27.71</td><td>30.98</td></tr>
</table></td></tr>
<tr><td>Hot argon leak
S/N 11--3/22/67
S/N 12--3/21/67</td><td>452B1900064</td><td>MND-3607-162</td><td>Indicated leak rates of generators S/N 11 and12, measured by three-scan average, were 3.6 x 10^{-5} cm^3/sec and 4.3 x 10^{-5} cm^3/sec, respectively. rates were well within 1 x 10^{-4} scc/sec limit.</td></tr>
<tr><td>Parametric
3/29/67</td><td>452B1900016</td><td>MND-3607-163</td><td>See Table A-1</td></tr>
<tr><td>Flight acceptance vibration
3/31/67</td><td>452B1900045</td><td>MND-3607-175</td><td>No external damage observed. Electrical discontinuities observed on pressure transducers on generators S/N 11 and 12 subsequently attributed to deterioration of interior transducer coating. Power check data were as follows
<table>
<tr><th></th><th>Generator S/N 11</th><th></th><th></th><th>Generator S/N 12</th><th></th><th></th></tr>
<tr><th></th><th>Yaw</th><th>Pitch</th><th>Roll</th><th>Yaw</th><th>Pitch</th><th>Roll</th></tr>
<tr><td>Avg hot junction (°F)</td><td>825</td><td>831</td><td>826</td><td>802</td><td>810</td><td>804</td></tr>
<tr><td>Avg fin root (°F)</td><td>251</td><td>259</td><td>253</td><td>250</td><td>258</td><td>257</td></tr>
<tr><td>Load voltage (v)</td><td>2.611</td><td>2.608</td><td>2.607</td><td>2.605</td><td>2.590</td><td>2.596</td></tr>
<tr><td>Output power (w)</td><td>30.94</td><td>31.00</td><td>30.95</td><td>32.19</td><td>32.19</td><td>32.15</td></tr>
</table></td></tr>
<tr><td>Defueling
S/N 11--11/4/67
S/N 12--11/5/67</td><td>452B1900074 (Defueling)
452B1900051 (Handling and power check)</td><td>N/A</td><td>Power check data before defueling were as follows
<table>
<tr><th></th><th>S/N 11</th><th>S/N 12</th></tr>
<tr><td>Avg hot junction (°F)</td><td>785</td><td>784</td></tr>
<tr><td>Avg fin root (°F)</td><td>232</td><td>227</td></tr>
<tr><td>Load voltage (v)</td><td>2.589</td><td>2.609</td></tr>
<tr><td>Power output (w)</td><td>26.64</td><td>27.78</td></tr>
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TABLE B-4

Generator Subsystem S/N 7 Test Data Summary

<table>
<tr><th>Test and Date</th><th>Martin Marietta Test Procedure</th><th>Martin Marietta Test Report No.</th><th>Test Result Summary</th></tr>
<tr><td>Fueling
S/N 13--6/20/67
S/N 14--6/21/67</td><td>452B1900009
(Fueling)
452B1900051
(Handling and functional tests)</td><td>MND-3607-191</td><td>Fueling of both generators successful. During fueling of S/N 13 and 14, bottom Min-K load disc was off center. Load disc was quickly recentered and fueling continued. Pre- and post-fueling power checks produced following data
<table>
<tr><th></th><th>Generator S/N 13</th><th></th><th>Generator S/N 14</th><th></th></tr>
<tr><th></th><th>Prefueling</th><th>Post-fueling</th><th>Prefueling</th><th>Post-fueling</th></tr>
<tr><td>Avg hot junction (°F)</td><td>748</td><td>777</td><td>742</td><td>772</td></tr>
<tr><td>Avg fin root (°F)</td><td>221</td><td>228</td><td>222</td><td>226</td></tr>
<tr><td>Load voltage (v)</td><td>2.629</td><td>2.606</td><td>2.630</td><td>2.621</td></tr>
<tr><td>Power output (w)</td><td>26.55</td><td>28.8</td><td>25.72</td><td>28.7</td></tr>
</table></td></tr>
<tr><td>Hot argon leak
S/N 13--6/24/67
S/N 14--6/22/67</td><td>452B1900064</td><td></td><td>Indicated leak rates of generators S/N 13 and 14, measured by three-scan average, were 3.8×10^{-5} cm^3/sec and 2.1×10^{-5} cm^3/sec, respectively. Leak rates were well within 1×10^{-4} scc/sec limit.</td></tr>
<tr><td>Parametric
6/28/67</td><td>452B1900016</td><td></td><td>See Table A-1.</td></tr>
<tr><td>Flight acceptance vibration
6/30/67</td><td>452B1900045</td><td>MND-3607-213</td><td>No external damage observed. Subsystem S/N 7 completed vibration without any apparent power output degradation. Power check data were as follows
<table>
<tr><th></th><th>Generator S/N 13</th><th></th><th></th><th>Generator S/N 14</th><th></th><th></th></tr>
<tr><th></th><th>Yaw</th><th>Pitch</th><th>Roll</th><th>Yaw</th><th>Pitch</th><th>Roll</th></tr>
<tr><td>Avg hot junction (°F)</td><td>814</td><td>817</td><td>819</td><td>813</td><td>816</td><td>817</td></tr>
<tr><td>Avg Fin root (°F)</td><td>260</td><td>265</td><td>264</td><td>259</td><td>263</td><td>262</td></tr>
<tr><td>Load voltage (v)</td><td>2.602</td><td>2.601</td><td>2.641</td><td>2.642</td><td>2.619</td><td>2.637</td></tr>
<tr><td>Power output (w)</td><td>29.45</td><td>29.57</td><td>29.55</td><td>29.43</td><td>29.46</td><td>29.45</td></tr>
</table></td></tr>
<tr><td>Magnetic moments
11/21/67</td><td></td><td>MND-3607-199</td><td>Generator subsystem S/N 7 successfully completed magnetic moments test at Goddard Space Flight Center, Greenbelt, Md. Results of test will be published by NASA. During Post-test power check, RTD on S/N 12 was mal-
<table>
<tr><th></th><th>Generator S/N 13</th><th></th><th>Generator S/N 14</th><th></th></tr>
<tr><th></th><th>Pretest</th><th>Post-test</th><th>Pretest</th><th>Post-test</th></tr>
<tr><td>Avg hot junction (°F)</td><td>785</td><td>797</td><td>784</td><td>789</td></tr>
<tr><td>Avg fin root (°F)</td><td>232</td><td>233</td><td>229</td><td>229</td></tr>
<tr><td>Load voltage (v)</td><td>2.628</td><td>2.581</td><td>2.589</td><td>2.589</td></tr>
<tr><td>Power output (w)</td><td>27.09</td><td>27.44</td><td>26.51</td><td>26.77</td></tr>
</table></td></tr>
<tr><td>Defueling
S/N 13--1/16/68
S/N 14--1/17/68</td><td>452B1900074
(Defueling)
452B1900023
(Power check)</td><td></td><td>Both defueling operations successful and without incident. Power check data before defueling were as follows
<table>
<tr><th></th><th>Generator S/N 13</th><th>Generator S/N 14</th></tr>
<tr><td>Avg hot junction (°F)</td><td>806</td><td>797</td></tr>
<tr><td>Avg fin root (°F)</td><td>239</td><td>237</td></tr>
<tr><td>Load voltage (v)</td><td>2.612</td><td>2.595</td></tr>
<tr><td>Power output (w)</td><td>26.8</td><td>26.0</td></tr>
</table></td></tr>
</table>

<u>TABLE B-5</u>

Generator Subsystem S/N 8 Test Data Summary

<table>
<tr><th>Test and Date</th><th>Martin Marietta Test Procedure</th><th>Martin Marietta Test Report No.</th><th>Test Result Summary</th></tr>
<tr><td>Fueling
S/N 23--9/10/67
S/N 22--9/10/67</td><td>452B1900100</td><td></td><td>Fueling of both generators successful. Pre- and post-fueling power checks produced following data:
<table>
<tr><th></th><th colspan="2">Generator S/N 23</th><th colspan="2">Generator S/N 22</th></tr>
<tr><th></th><th>Prefueling</th><th>Post-fueling</th><th>Prefueling</th><th>Post-fueling</th></tr>
<tr><td>Avg hot junction (°F)</td><td>777</td><td>751</td><td>722</td><td>737</td></tr>
<tr><td>Avg fin root (°F)</td><td>266</td><td>229</td><td>222</td><td>227</td></tr>
<tr><td>Load voltage (v)</td><td>2.602</td><td>2.607</td><td>2.615</td><td>2 604</td></tr>
<tr><td>Power output (w)</td><td>27.61</td><td>28.08</td><td>26.33</td><td>28.93</td></tr>
</table></td></tr>
<tr><td>Hot argon leak
S/N 23--9/11/67
S/N 22--9/11/67</td><td>452B1900064</td><td>MND-3607A-016</td><td>Indicated leak rates of generators S/N 23 and 22, determined from three-scan average, were 2 3 x 10^{-5} cm^3/sec and 4.2 x 10^{5} cm^3/sec, respectively. Leak rates were well within permissible limit of 1 x 10^{-4} scc/sec argon</td></tr>
<tr><td>Parametric</td><td>452B1900016</td><td>MND-3607A-016</td><td>See Table A-1.</td></tr>
<tr><td>Flight acceptance vibration
9/16/67</td><td>452B1900045</td><td></td><td>No external damage observed. Subsystem S/N 8 completed vibration without apparent power output degradation Power check data were as follows:
<table>
<tr><th></th><th colspan="3">Generator S/N 23</th><th colspan="3">Generator S/N 22</th></tr>
<tr><th></th><th>Yaw</th><th>Pitch</th><th>Roll</th><th>Yaw</th><th>Pitch</th><th>Roll</th></tr>
<tr><td>Avg hot junction (°F)</td><td>807</td><td>810</td><td>816</td><td>787</td><td>792</td><td>796</td></tr>
<tr><td>Avg fin root (°F)</td><td>268</td><td>272</td><td>277</td><td>262</td><td>268</td><td>271</td></tr>
<tr><td>Load voltage (v)</td><td>2.605</td><td>2 605</td><td>2.608</td><td>2.601</td><td>2.605</td><td>2 595</td></tr>
<tr><td>Power output (w)</td><td>29.96</td><td>29 96</td><td>30.02</td><td>30.22</td><td>30.19</td><td>30.28</td></tr>
</table></td></tr>
<tr><td>Defueling
S/N 23--11/28/67
S/N 22--11/30/67</td><td>452B1900107</td><td></td><td>Both defueling operations were successful and without incident. Power check data before defueling were as follows:
<table>
<tr><th></th><th>Generator S/N 23</th><th>Generator S/N 22</th></tr>
<tr><td>Avg hot junction (°F)</td><td>784</td><td>766</td></tr>
<tr><td>Avg fin root (°F)</td><td>241</td><td>237</td></tr>
<tr><td>Load voltage (v)</td><td>2.600</td><td>2.604</td></tr>
<tr><td>Output power (w)</td><td>28.24</td><td>28 41</td></tr>
</table></td></tr>
</table>

TABLE B-6

Generator Subsystem S/N 6A Test Data Summary

<table>
<tr><th>Test and Date</th><th>Martin Marietta Test Procedure</th><th>Martin Marietta Test Report No.</th><th>Test Result Summary</th></tr>
<tr><td>Fueling
S/N 11A--12/1/67
S/N 12A--12/2/67</td><td>452B1900100</td><td></td><td>Fueling of both generators successful Pre- and post-fueling power checks produced following data:
<table>
<tr><th></th><th colspan="2">Generator S/N 11A</th><th colspan="2">Generator S/N 12A</th></tr>
<tr><th></th><th>Prefueling</th><th>Post-fueling</th><th>Prefueling</th><th>Post-fueling</th></tr>
<tr><td>Avg hot junction (°F)</td><td>766</td><td>815</td><td>759</td><td>777</td></tr>
<tr><td>Avg fin root (°F)</td><td>231</td><td>231</td><td>217</td><td>230</td></tr>
<tr><td>Load voltage (v)</td><td>2.629</td><td>2.607</td><td>2.593</td><td>2.601</td></tr>
<tr><td>Power output (w)</td><td>22.32</td><td>25.23</td><td>23.73</td><td>25.70</td></tr>
</table></td></tr>
<tr><td>Hot argon leak
S/N 11A--12/2/67
S/N 12A--12/3/67</td><td>452B1900064</td><td></td><td>Indicated leak rates of generators S/N 11A and 12A, determined from three-scan average, were 3.3×10^{-5} scc/sec and 2.6×10^{-5} scc/sec, respectively. Leak rates well within permissible limit of 1×10^{-4} scc/sec</td></tr>
<tr><td>Parametric
12/5/67</td><td>452B1900016</td><td></td><td>See Table A-1.</td></tr>
<tr><td>Prototype vibration
12/7/67</td><td>452B1900101</td><td></td><td>No external damage noted. Subsystem S/N 6A completed prototype vibration without apparent power output degradation. Power check data are as follows:
<table>
<tr><th></th><th colspan="3">Generator S/N 11A</th><th colspan="3">Generator S/N 12A</th></tr>
<tr><th></th><th>Yaw</th><th>Roll</th><th>Pitch</th><th>Yaw</th><th>Roll</th><th>Pitch</th></tr>
<tr><td>Avg hot junction (°F)</td><td>839</td><td>833</td><td>834</td><td>805</td><td>806</td><td>804</td></tr>
<tr><td>Avg fin root (°F)</td><td>255</td><td>251</td><td>251</td><td>248</td><td>246</td><td>245</td></tr>
<tr><td>Load voltage (v)</td><td>2.591</td><td>2.603</td><td>2.606</td><td>2.590</td><td>2.594</td><td>2.607</td></tr>
<tr><td>Power output (w)</td><td>25.88</td><td>25.82</td><td>25.72</td><td>26.31</td><td>26.20</td><td>26.22</td></tr>
</table></td></tr>
<tr><td>Acceleration
12/8/67</td><td>452B1900102</td><td></td><td>No external damage observed, no instrumentation changes noted. Power check data are as follows:
<table>
<tr><th></th><th>Generator S/N 11A</th><th>Generator S/N 12A</th></tr>
<tr><td>Avg hot junction (°F)</td><td>836</td><td>808</td></tr>
<tr><td>Avg fin root (°F)</td><td>254</td><td>247</td></tr>
<tr><td>Load voltage (v)</td><td>2.611</td><td>2.608</td></tr>
<tr><td>Power output (w)</td><td>25.69</td><td>26.11</td></tr>
</table></td></tr>
<tr><td>Defueling
S/N 11A--1/10/68
S/N 12A--1/11/68</td><td>452B1900107</td><td></td><td>Both defueling operations successful and without incident. Power check before defueling not performed.</td></tr>
</table>

TABLE B-7

Generator Subsystem S/N 8A Test Data Summary

<table>
<tr><th>Test and Date</th><th>Martin Marietta Test Procedure</th><th>Martin Marietta Test Report No.</th><th>Test Result Summary</th></tr>
<tr><td>Fueling
S/N 23A--12/14/67
S/N 22A--12/13/67</td><td>452B1900100</td><td></td><td>Fueling of both generators successful. Pre- and post-fueling power check data are as follows
<table>
<tr><th></th><th colspan="2">Generator S/N 23A</th><th colspan="2">Generator S/N 22A</th></tr>
<tr><th></th><th>Prefueling</th><th>Post-fueling</th><th>Prefueling</th><th>Post-fueling</th></tr>
<tr><td>Avg hot junction (°F)</td><td>784</td><td>785</td><td>766</td><td>761</td></tr>
<tr><td>Avg fin root (°F)</td><td>241</td><td>233</td><td>237</td><td>230</td></tr>
<tr><td>Load voltage (v)</td><td>2.600</td><td>2.600</td><td>2.604</td><td>2.602</td></tr>
<tr><td>Power output (w)</td><td>28.24</td><td>28.60</td><td>28.41</td><td>27.87</td></tr>
</table></td></tr>
<tr><td>Hot argon leak
S/N 23A--12/14/67
S/N 22A--12/14/67</td><td>452B1900064</td><td></td><td>Indicated leak rates of generators S/N 23A and 22A, determined from averaging three scans, were 1.8×10^{-5} scc/sec and 2.8×10^{-5} scc/sec, respectively. Leak rates will within the 1×10^{-4} scc/sec limit.</td></tr>
<tr><td>Parametric
12/15/67</td><td>452B1900016</td><td></td><td>See Figs B-1 and B-2 for graphical representations of parametric data.</td></tr>
<tr><td>Flight acceptance vibration
12/16/67</td><td>452B1900045</td><td></td><td>Chafing of power harness observed. Damage caused by harness striking generator fin in area of connector J17. Teflon sleeving added to susceptible portions of power harness to prevent future chafing. Subsystem S/N 8A completed vibration without apparent power output degradation. Power check data were as follows
<table>
<tr><th></th><th colspan="3">Generator S/N 23A</th><th colspan="3">Generator S/N 22A</th></tr>
<tr><th></th><th>Yaw</th><th>Roll</th><th>Pitch</th><th>Yaw</th><th>Roll</th><th>Pitch</th></tr>
<tr><td>Avg hot junction (°F)</td><td>800</td><td>797</td><td>798</td><td>780</td><td>780</td><td>772</td></tr>
<tr><td>Avg fin root (°F)</td><td>252</td><td>252</td><td>252</td><td>248</td><td>249</td><td>243</td></tr>
<tr><td>Load voltage (v)</td><td>2.602</td><td>2.609</td><td>2.625</td><td>2.605</td><td>2.595</td><td>2.615</td></tr>
<tr><td>Power output (w)</td><td>28.75</td><td>28.73</td><td>28.72</td><td>28.08</td><td>28.16</td><td>27.93</td></tr>
</table></td></tr>
<tr><td>Flight acceptance vibration
(Modified-workmanship verification)
1/30/68</td><td>452B1900045</td><td></td><td>No external damage noted. Subsystem S/N 8A completed yaw axis random vibration without any apparent power output degradation. Power check data were as follows
<table>
<tr><th></th><th colspan="2">Previbration</th><th colspan="2">Post-vibration</th></tr>
<tr><th></th><th>S/N 23A</th><th>S/N 22A</th><th>S/N 23A</th><th>S/N 22A</th></tr>
<tr><td>Avg hot junction (°F)</td><td>806</td><td>789</td><td>806</td><td>781</td></tr>
<tr><td>Avg fin root (°F)</td><td>261</td><td>251</td><td>261</td><td>249</td></tr>
<tr><td>Load voltage (v)</td><td>2.607</td><td>2.604</td><td>2.608</td><td>2.603</td></tr>
<tr><td>Power output (w)</td><td>28.08</td><td>27.37</td><td>28.01</td><td>27.15</td></tr>
</table></td></tr>
</table>

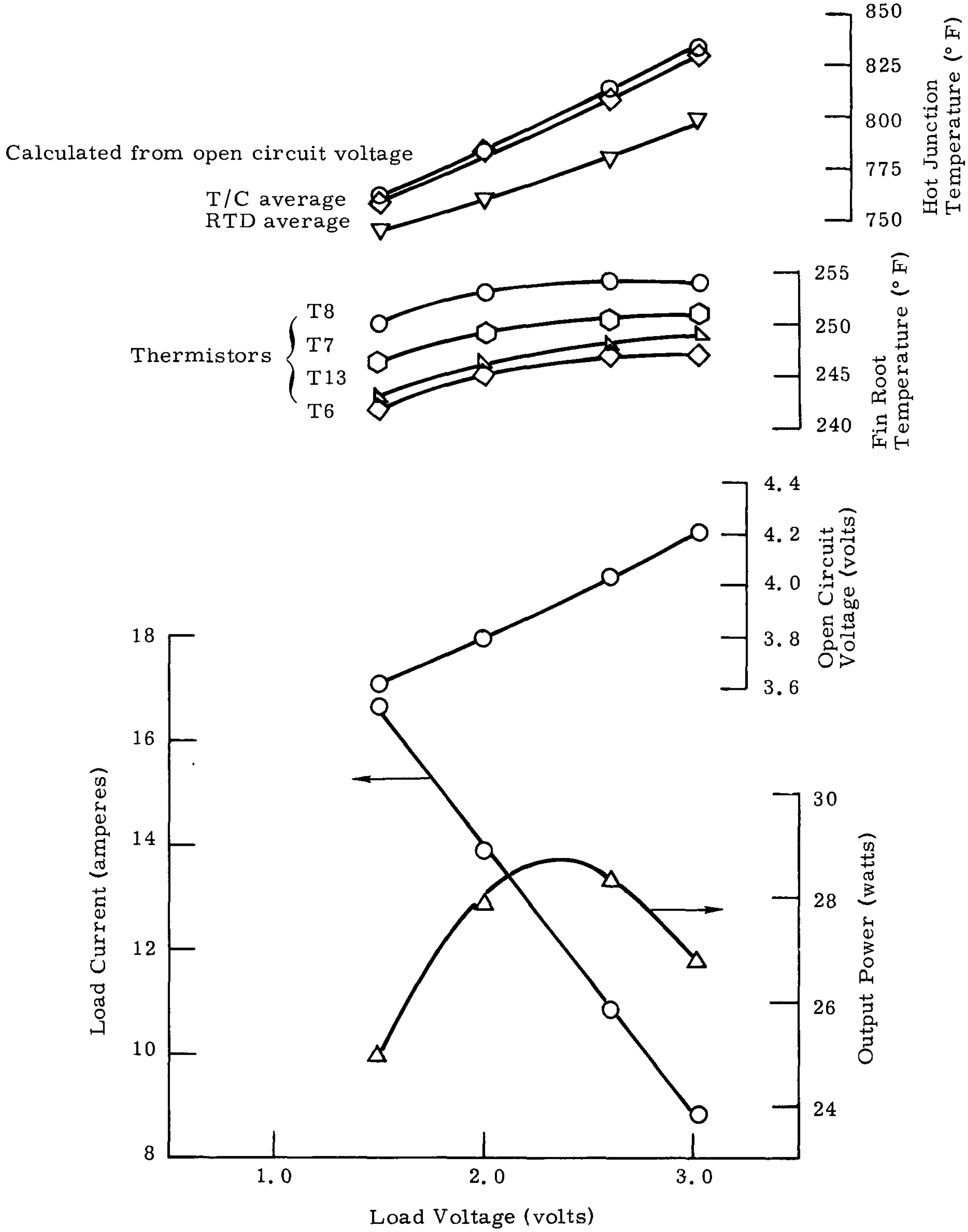

FIG. B-1. GENERATOR S/N 22A PARAMETRIC TEST DATA (FLIGHT GENERATOR)

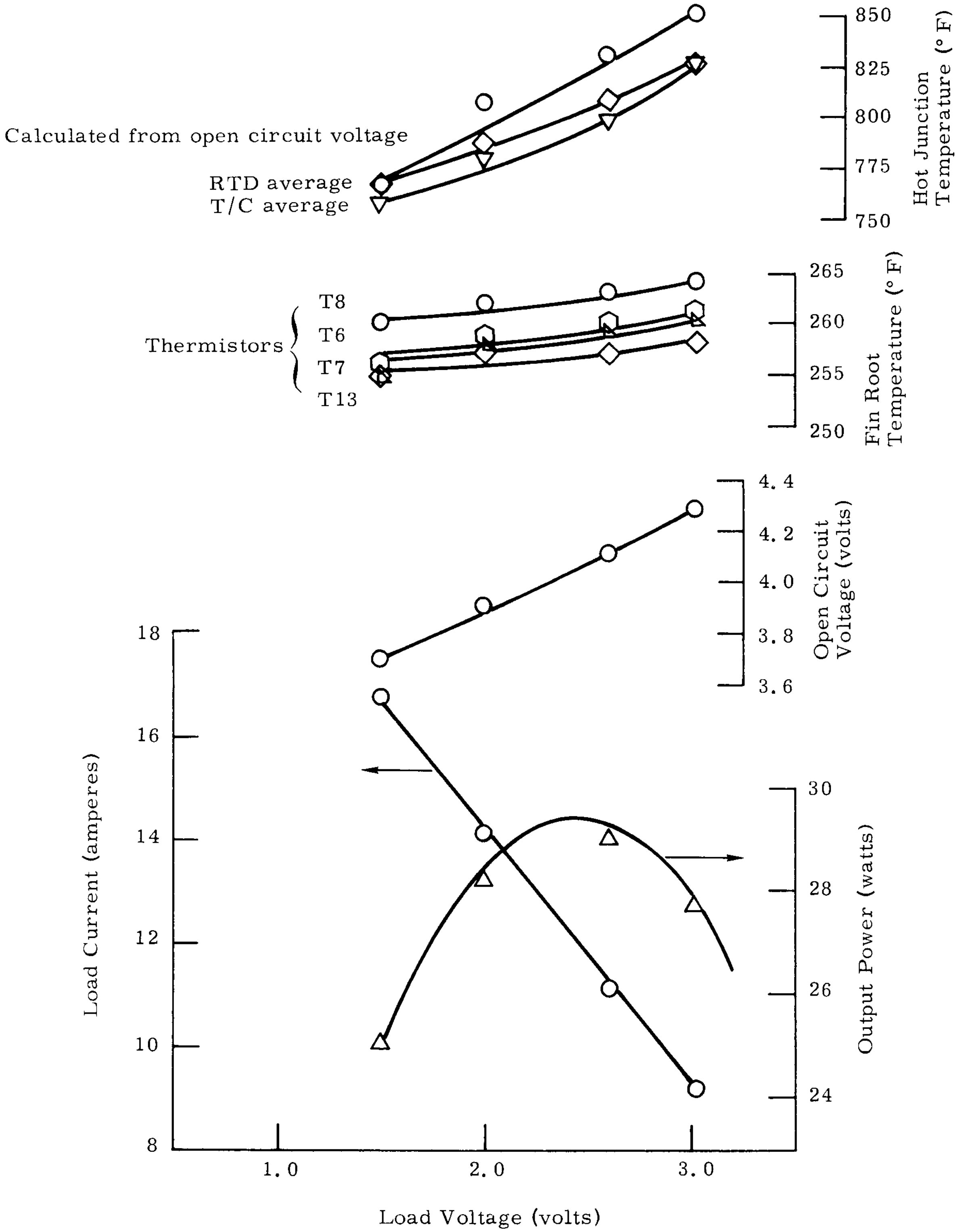

FIG. B-2. GENERATOR S/N 23A PARAMETRIC TEST DATA (FLIGHT GENERATOR

APPENDIX C

POWER SUPPLY SYSTEM TEST DATA AND TEST PROCEDURE LIST

TABLE C-1

System No. 4 Test Data

Test and Date	Martin Marietta Test Procedure	Martin Marietta Test Report No	Test Result Summary
Thermal vacuum and system performance 1/19/67 to 2/7/67	452B1900036	MND 3607 139 MND 3607 140	

	Initial Performance Test (on bus)		100% Bus Voltage		Parametric Test 50% Bus Voltage		75% Bus Voltage		Final Performance/Acceptance (on bus)	
Generator	S/N 7	S/N 8	S/N 7	S/N 8	S/N 7	S/N 8	S/N 7	S/N 8	S/N 7	S/N 8
Avg hot junction (°F)	901	912	900	911	862	878	884	893	--	912
Avg fin root (°F)	332	337	332	337	333	339	332	338	333	338
Gen pressure (psia)	17 93	14 73	17 93	14 73	17 93	14 73	17 93	14 73	16 16	12 68
Gen load voltage (v)	2 60	2 62	2 62	2 63	1 50	1 51	2 10	2 10	2 60	2 62
Gen power output (w)	27 04	29 21	27 25	29 19	22 80	24 01	26 25	27 93	26 52	28 82
PCU output voltage (v)	24 51	24 58	24 50	24 57	12 13	12 18	18 81	18 87	24 46	24 52
PCU output current (a)	0 9883	1 058	0 9856	1 057	1 472	1 520	1 206	1 264	0 9717	1 036
PCU power output (w)	24 22	26 01	24 15	25 97	17 86	18 51	22 68	23 85	23 77	25 40
System power output (w)	50 23		50 12		36 37		46 53		49 17	

Test and Date	Martin Marietta Test Procedure	Martin Marietta Test Report No	Test Result Summary
Thirty-day leak 3/17/67 to 4/15/67	452B1900045	MND-3607-169 MND 3607 170	

	Performance Tests			
	(On bus) Initial		(100% parametric point) Final	
Generator	S/N 7	S/N 8	S/N 7	S/N 8
Avg hot junction (°F)	934	921	--	931
Avg fin root (°F)	327	341	330	345
Gen pressure (psia)	14 85	11 82	11 8	9 02
Gen load voltage (v)	2 58	2 62	2 57	2 60
Gen power output (w)	26 06	27 77	25 4	26 9
PCU output voltage (v)	24 47	24 54	24 47	24 54
PCU output current (a)	0 9534	1 024	0 93	0 99
PCU output power (w)	23 34	25 13	22 7	24 3
System power output (w)	48 47		47 0	

TABLE C-2

System No. 5 Test Data

Test and Date	Martin Marietta Test Procedure	Martin Marietta Test Report No	Test Result Summary										
Thermal vacuum and system performance 3/25/67 to 4/8/67	452B1900043	MND 3607 166		Initial Per formance Test (on bus)		100% Bus Voltage		Parametric Test 50% Bus Voltage		75% Bus Voltage		Final Perform-ance/Acceptance (on bus)	
			Generator	S/N 15	S/N 16	S/N 15	S/N 16	S/N 15	S/N 16	S/N 15	S/N 16	S/N 15	S/N16
			Avg hot junction (°F)	876	852	879	866	843	829	859	846	869	855
			Avg fin root (°F)	336	335	337	338	337	338	337	337	337	337
			Gen pressure (psia)	29 1	28 7	29 0	28 7	28 8	28 7	28 5	28 7	28 1	27 9
			Gen load voltage (v)	2 49	2 50	2 49	2 51	1 42	1 46	1 96	1 98	2 48	2 50
			Gen power output (w)	27 39	27 25	27 39	28 11	22 01	23 07	25 87	26 73	26 29	26 50
			PCU output voltage (v)	24 50	24 46	24 53	24 53	12 17	12 21	18 46	18 48	24 51	24 50
			PCU output current (a)	0 9937	0 9785	1 000	1 016	1 425	1 454	1 202	1 228	0 9594	0 9639
			PCU power output (w)	24 35	23 93	24 53	24 92	17 34	17 75	23 19	22 69	23 52	23 62
			System power output (w)	48 28		49 45		35 09		44 88		47 14	

TABLE C-3

System No. 6 Test Data

Test and Date	Martin Marietta Test Procedure	Martin Marietta Test Report No	Test Result Summary										
Thermal vacuum and system performance 5/16/67 to 5/28/67	452B1900036	MND 3607-208		Initial Per formance Test (on bus)		100% Bus Voltage		Parametric Test 50% Bus Voltage		75% Bus Voltage		Final Perform ance/Acceptance (on bus)	
			Generator	S/N 11	S/N 12	S/N 11	S/N 12	S/N 11	S/N 12	S/N 11	S/N 12	S/N 11	S/N 12
			Avg hot junction (°F)	908	904	908	904	867	864	887	884	908	903
			Avg fin root (°F)	336	340	336	340	336	340	336	340	336	340
			Gen pressure (psia)	15 7	14 5	15 7	15 0	15 3	14 5	15 3	14 75	15 0	13 7
			Gen load voltage (v)	2 62	2 64	2 62	2 64	1 43	1 46	2 025	2 058	2 62	2 65
			Gen power output (w)	29 61	31 15	29 61	31 15	24 30	25 56	28 36	29 75	29 34	30 74
			PCU output voltage (v)	24 8	24 8	24 9	24 8	12 5	12 5	18 9	18 8	24 9	24 8
			PCU output current (a)	1 09	1 13	1 09	1 13	1 58	1 60	1 32	1 36	1 08	1 11
			PCU power output (w)	26 77	27 69	26 76	27 68	19 38	19 91	24 58	25 31	26 31	27 29
			System power output (w)	54 46		54 44		39 29		49 89		53 60	

TABLE C-4

System No. 7 Test Data

Test and Date	Martin Marietta Test Procedure	Martin Marietta Test Report No.	Test Result Summary										
Thermal vacuum and system performance 8/2/67 to 8/17/67	452B1900036	MND-3607-205		Initial Performance Test (on bus)		100% Bus Voltage		Parametric Test 50% Bus Voltage		75% Bus Voltage		Final Performance/Acceptance (on bus)	
			Generator	S/N 13	S/N 14	S/N 13	S/N 14	S/N 13	S/N 14	S/N 13	S/N 14	S/N 13	S/N 14
			Avg hot junction (°F)	884	908	888	911	847	867	864	886	887	914
			Avg fin root (°F)	335	339	338	341	337	340	335	338	335	342
			Gen pressure (psia)	14.9	16.0	14.7	16.3	14.7	16.3	14.7	16.3	14.1	15.8
			Gen load voltage (v)	2.650	2.640	2.645	2.630	1.51	1.52	2.09	2.10	2.645	2.625
			Gen power output (w)	29.46	29.94	29.49	29.85	24.16	24.78	28.11	28.88	28 96	29.32
			PCU output voltage (v)	24.60	24.82	24.41	24.78	12.4	12.6	18.60	18.80	24.45	24.82
			PCU output current (a)	1.086	1.056	1.088	1.058	1.58	1.58	1.32	1 29	1.073	1.043
			PCU power output (w)	25.67	25.91	25.75	25.97	18.82	19.28	23.64	24.00	25.45	25.66
			System power output (w)	51.58		51.72		38.10		47.64		51.11	

TABLE C-5

System No. 8 Test Data

Test and Date	Martin Marietta Test Procedure	Martin Marietta Test Report No.	Test Result Summary										
Thermal vacuum and system performance 9/22/67 to 10/5/67	452B1900104	MND-3607A-015		Initial Performance Test (on bus)		100% Bus Voltage		Parametric Test 50% Bus Voltage		75% Bus Voltage		Final Performance/Acceptance (on bus)	
			Generator	S/N 23	S/N 22	S/N 23	S/N 22	S/N 23	S/N 22	S/N 23	S/N 22	S/N 23	S/N 22
			Avg hot junction (°F)	879	869	877	870	834	826	850	844	877	873
			Avg fin root (°F)	337	341	335	339	339	346	337	341	336	341
			Gen pressure (psia)	15.06	15.40	15.08	15 42	14.93	15.43	14.82	--	14.35	14.55
			Gen load voltage (v)	2.697	2.709	2.694	2.708	1.584	1.596	2.145	2.154	2.688	2.700
			Gen power output (w)	29.69	29.39	29.83	29.38	26.37	26.21	29.39	29.08	29.41	29.16
			PCU output voltage (v)	24.52	24.54	24.49	24.51	12.21	12.22	18.47	18.48	24.47	24.49
			PCU output current (a)	1.072	1.081	1.074	1.084	1.594	1.596	1.310	1.311	1.068	1.077
			PCU power output (w)	26.28	26.52	26.30	26.59	19.46	19.50	24.19	24.22	26.13	26.37
			System power output (w)	52.80		52 89		38.96		48.41		52.50	

TABLE C-6

System No. 6A Test Data

Test and Date	Martin Marietta Test Procedure	Martin Marietta Test Report No.	Test Result Summary										
Thermal vacuum and system performance 12/9/67 to 12/21/67	452B1900109			Initial Performance Test (on bus) (in air)		100% Bus Voltage*		Parametric Test 50% Bus Voltage		75% Bus Voltage		Final Performance/Acceptance (on bus)	
			Generator	S/N 11A	S/N 12A	S/N 11A	S/N 12A	S/N 11A	S/N 12A	S/N 11A	S/N 12A	S/N 11A	S/N 12A
			Avg hot junction (°F)	825	805	919	905	877	862	894	879	900	916
			Avg fin root (°F)	240	240	336	342	335	336	337	338	334	337
			Gen pressure (psia)	15.6	14.0	16.6	14.7	16 5	14.3	16.5	14.3	15.4	10.4
			Gen load voltage (v)	2.721	2.629	2.697	2.698	1 493	1.503	2.003	2.012	2.703	2.699
			Gen power output (w)	25.0	25.0	26.5	26.8	21.8	22.1	25.2	25.4	26.4	27.1
			PCU output voltage (v)	--	--	--	--	--	--	--	--	--	--
			PCU output current (a)	--	--	--	--	--	--	--	--	--	--
			PCU power output (w)	--	--	--	--	--	--	--	--		--
			Total power output (w)	50.0		53.3		43.9		50.6		53.5	

*The initial performance test (vacuum) and the 100% bus voltage parametric were both taken at the same data point.

TABLE C-7

System No. 8A Test Data

Test and Date	Martin Marietta Test Procedure	Martin Marietta Test Report No.	Test Result Summary										
Thermal vacuum and system performance	452B1900104			Initial Performance Test (on bus)		100% Bus Voltage		Parametric Test 50% Bus Voltage		75% Bus Voltage		Final Performance/Acceptance (on bus)	
			Generator	S/N 23A	S/N 22A	S/N 23A	S/N 22A	S/N 23A	S/N 22A	S/N 23A	S/N 22A	S/N 23A	S/N 22A
			Avg hot junction (°F)	880	874	880	871	832	823	855	844	876	870
			Avg fin root (°F)	336	337	337	340	337	340	337	340	335	338
			Gen pressure (psia)	15.50	15 45	15.48	15 45	15.35	15 45	15.35	15.43	15.20	--
			Gen load voltage (v)	2.70	2 70	2 70	2.70	1.35	1 37	1.95	1 96	2 69	2.70
			Gen power output (w)	29.3	28 9	29 3	28.9	22 8	22 7	27 1	27 0	29.1	28.8
			Total power output (w)	58 2		58 2		45 5		54 1		57 9	

TABLE C-8

Test Procedure Listing

Procedure No.*	Title
452B1900003	SNAP 19 Program Controlled Parts List
452B1900004	Generator Assembly Procedure
452B1900006	Fueled Generator Subsystem Assembly Procedure
452B1900008	Installation Procedure Fueled Generator into Shipping Container
452B1900009	Generator Fueling Procedure
452B1900010	Test Procedure for Endurance Testing of Generator S/N 4
452B1900012	Emissive Coating Procedure
452B1900013	Hot Argon Leak Test Procedure
452B1900014	Monitoring Procedure for Unattended Fueled Generators
452B1900015	Capsule Radiation Measurements Test Procedure
452B1900016	Generator Subsystem Parametric
452B1900018	SNAP 19/Nimbus B Power Supply System Functional Test Procedure
452B1900019	Subsystem Radiation Measurements Test Procedure
452B1900021	Power Conditioner Functional Acceptance Test Procedure
452B1900022	SNAP 19/Nimbus B Generator Subsystem Humidity Test Procedure
452B1900023	SNAP 19/Nimbus B Generator Subsystem Power Check Procedure
452B1900024	SNAP 19/Nimbus B Generator Subsystem Prototype Level Vibration Test for Electrically Heated and Fueled Generators
452B1900025	SNAP 19/Nimbus B Generator Subsystem Acceleration Test Program
452B1900026	Telemetry Signal Conditioning Unit Functional Acceptance Test Procedure
452B1900027	SNAP 19/Nimbus B Power Conditioner Humidity Test Procedure
452B1900028	SNAP 19/Nimbus B Power Conditioner Vibration Test Procedure
452B1900029	SNAP 19/Nimbus B Power Conditioner Acceleration Test Procedure
452B1900030	SNAP 19/Nimbus B Telemetry Conditioner Humidity Test Procedure
452B1900031	SNAP 19/Nimbus B Telemetry Signal Conditioner Vibration Test Procedure
452B1900032	SNAP 19/Nimbus B Telemetry Conditioner Acceleration Test Procedure
452B1900036	Radioisotope Fueled Thermoelectric Generator System Thermal Vacuum Test/Performance Test Procedures
452B1900038	Procedure for Mass Spectrometer Gas Analysis of Thermoelectric Generators
452B1900039	SNAP 19 Power Conditioner Reliability Demonstration Unit Vibration and Electrical Performance Test Procedure

TABLE C-8 (continued)

Procedure No.*	Title
452B1900040	Power Conditioner Endurance Test Procedure
452B1900041	SNAP 19 Fueled Shipping Cask and Fuel Capsule Radiological Monitoring
452B1900042	SNAP 19/Nimbus B Telemetry Signal Conditioning Unit Calibration Procedure
452B1900043	Thermal Vacuum Test Electrically Heated System
452B1900044	Cold Argon Leak Check Test Procedure
452B1900045	SNAP 19/Nimbus B Generator Subsystem Vibration Flight Acceptance Test Procedure for Electrically Heated and Fueled Generators
452B1900046	90 Day Leak Test (Fueled) Test Procedure
452B1900048	Cold Leak and Outgassing Procedure
452B1900049	SNAP 19 Power Check Procedure
452B1900050	Cooldown and Backfill Procedure
452B1900051	Transporting and Power Checking RTG's for Fueling
452B1900052	Transportation Procedure for SNAP 19/Nimbus B Generator (Cold) from One Location to Another Within the Martin Marietta
452B1900054	SNAP 19 Fuel Capsule Requirements
452B1900055	Parametric Test for Electrically Heated RTG's and Subsystems
452B1900056	Power Check and Endurance Check for Electrically Heated RTG's and Subsystems
452B1900058	SNAP 19/Nimbus B Transfer Procedure for Electrically Heated Generators--Including Heatup and Cooldown
452B1900059	Submarine Operating Procedure
452B1900060	SNAP 19/Nimbus B Power Check Procedure for Electrically Heated RTG's
452B1900061	SNAP 19/Nimbus B Power Conditioner Test Procedure for the Determination of Weight and Center of Gravity
452B1900062	SNAP 19B Fuel Capsule Thermal Shock Test Procedure
452B1900063	SNAP 19 Fuel Capsule Internal Pressure Test Procedure
452B1900064	Hot Argon Leak Test Procedure for Electrically Heated or Fueled Generators
452B1900065	SNAP 19 Capsule-in-Generator Burst Test Procedure
452B1900067	Transfer Procedure for the SNAP 19/Nimbus B Electrically Heated RTG Subsystem
452B1900068	Transporting the SNAP 19 Fueled RTG Subsystem to and from the ETL and Installing for Test
452B1900069	SNAP 19/Nimbus B Telemetry Conditioner Test Procedure for the Determination of Weight and Center of Gravity

TABLE C-8 (continued)

Procedure No.	Title
452B1900070	Monitoring Procedure During Humidity Testing of the SNAP 19/ Nimbus B Electrically Heated Subsystem
452B1900072	Disassembly Procedure Generator Subsystem Assembly System 4
452B1900073	SNAP 19/Nimbus B Power Supply System Performance/Acceptance Criteria
452B1900074	Generator Defueling Procedure
452B1900075	Transporting the SNAP 19 Fueled RTG Subsystem to and from the KC Building and Monitoring During Test
452B1900076	SNAP 19/Nimbus B Generator Subsystem Mass Properties Determination Test Procedure for Electrically Heated or Fueled Generators
452B1900077	RTG and Subsystem Resistance Check Procedure for Thermistors
452B1900100	Generator Fueling Procedure SNAP 19 IRHS
452B1900101	Prototype Level Vibration Test Procedure for SNAP 19 IRHS
452B1900102	Acceleration Test Procedure for SNAP IRHS
452B1900103	SNAP 19 IRHS Radiological Checkout
452B1900104	Radioisotope Fueled Thermoelectric Generator Thermal Vacuum Test/Performance Test Procedures
452B1900105	Disassembly Procedure for Generators 11 and 12
452B1900106	Assembly Procedure to Convert Generators 11 and 12 to IRHS Generators
452B1900107	Generator Defueling Procedure SNAP 19 IRHS
452B1900108	Diagnostic Disassembly Procedure for Subsystem 6A
452B1900109	RTG Fueled Subsystem Thermal Vacuum Test Procedure Utilizing Laboratory Instrumentation
452B1900110	Loading, Transporting and Unloading Procedure of SNAP 19 RTG Subsystems and Associated Ground Equipment
452B1900111	Portable Monitor Package Connection and Operation Procedure
452B1900112	Installation Procedure, Fueled Generator into Shipping Container

All procedures listed are Martin Marietta documents.