NUCLEAR
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MASTER

SNAP Radioisotope Space Programs

Quarterly Progress Report No. 5

Tasks 2, 3 and 7

October 1 through December 31, 1960
MND-P-3013-I

Approved by:

Project Engineer
Auxiliary Power Systems

NUCLEAR MARTIN DIVISION

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FOREWORD

This quarterly report has been prepared to describe SNAP 1A and SNAP 3 thermoelectric generator development and also the radioisotope safety programs conducted by The Martin Company. It covers the work on Tasks 2, 3 and 7 performed from October 1 through December 31, 1960, under Contract AT(30-3)-217 with the U. S. Atomic Energy Commission.

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SUMMARY

I. TASK 2--125-WATT THERMOELECTRIC GENERATOR DEVELOPMENT

Subtask 2.4--Ground handling equipment fabrication. Functional testing was completed on the ground handling equipment to be used for transporting the Cerium-144 heat source container and loading the SNAP 1A generator. Mercury shield fill and drain tests for the generator system and the collar shield were conducted. A total of 4168 pounds of mercury was required to fill the generator and 3185 pounds was needed for the collar shield. Heat transfer tests of the isotope heat source shipping cask were conducted. The maximum cooling fin temperature attained was 163° F at an electrical power input of 4440 watts.

Subtask 2.5--G-2 generator final assembly and test. Simulated rocket-launch environmental tests of vibration, acceleration and shock were completed on the G-2 generator. During the vertical plane vibration test the pressure sensing tubes between the shutter control bellows and the generator housing failed. This failure is attributed to insufficient support of the tubing and will be corrected for the G-3 generator. Analysis of the environmental test data was initiated and will be described in the next quarterly report.

Subtask 2.6--G-3 isotope generator fabrication. Final design studies for the G-3 generator were completed, and a thermoelectric module concept was selected for use in the isotope-fueled generator. Two prebonded thermoelectric couples are installed in each module and may be checked electrically before installation of hermetic-seal closure caps.

Development tests of thermoelectric modules in a module tester were initiated. Initial results indicate average power output per couple of 0.24 watt, which would result in generator output of 73 watts from 304 couples. Development tests will be conducted to reduce internal electrical resistance in order to obtain the desired generator output of 125 watts.

Voltage breakdown tests were conducted on National Bureau of Standards A-418 formulation, a porcelain enamel spray coat. This material was evaluated for application to the G-3 generator inner skin as a possible second discrete barrier against hot junction electrical shorts. Breakdown voltages were 450 to 550 volts at room temperature and 25 to 50 volts at 1055° F for a 2-mil coating.

Subtask 2.7--G-3 generator electrical test. This subtask will commence after the G-3 generator is complete in the second half of Fiscal Year 1961.

Subtask 2.8--Task 2 program direction. During this quarterly reporting period, the manufacturing schedule for the SNAP 1A G-3 generator was reoriented to incorporate a modular concept for thermoelectric couple installation. A revised Statement of Work was prepared to incorporate thermoelectric module development and the rescheduling of G-3 generator assembly completion to April 15, 1961.

B. TASK 3--NUCLEAR THERMOELECTRIC GENERATOR DEVELOPMENT

SNAP 3 generator 3M-1G10 completed 322 days of life test operation on December 13, 1960. Generator power input was terminated on December 19, 1960, after the generator had been operated under a full range of external loads to obtain performance characteristics. Electrical power output after 322 days at steady-state heat source and external load conditions was 1.92 watts, which corresponds to an overall efficiency of 2.9%.

Teardown inspection of the generator confirmed previous indications of increased internal electrical resistance and increased thermal conductivity. These conclusions account for the gradual reduction in generator performance from the start-of-life electrical output of 3.45 watts and 5.2% overall efficiency.

The SNAP 3 3M-1G5 generator was successfully fueled with Po-210 and delivered to the AEC. Maximum electrical power output was 4 watts at an overall efficiency of 5.2%.

C. TASK 7--RADIOLOGICAL SAFETY STUDIES FOR SPACE POWER

This task was initiated late in the reporting period. A program plan defining the scope of work was prepared and submitted to the New York Operations Office of the U. S. Atomic Energy Commission.

Preliminary technical efforts consisted primarily of literature reviews, data assembly and liaison arrangements with the various government agencies and contractors involved.

I. INTRODUCTION

This is the second of regular quarterly progress reports prepared by The Martin Company in accordance with the requirements of Contract AT(30-3)-217 specifically devoted to isotopic power systems for space application. Tasks 2 and 3, which relate to the SNAP 1A and SNAP 3 thermoelectric power conversion generators, respectively, and are continuing programs, and Task 7, which was initiated December 1, 1960, and deals with radioisotope flight safety analyses and tests, are the current programs under contract. As other space applications progress to contract status, they will be included in this series of quarterly reports.

This quarterly progress report was compiled and edited by P. J. Dick, D. J. Knighton and R. J. Wilson. Technical contributions to the report were made by J. H. Vogt, P. H. Hess, J. D. Long and W. Hagis.

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II. TASK 2--125-WATT THERMOELECTRIC GENERATOR

The Task 2 program is directed toward the ground test demonstration of SNAP 1A, a 125-watt isotope-fueled thermoelectric generator for space application. The G-2 generator, the second SNAP 1A ground test unit, was subjected to vibration, acceleration and shock tests. Hardware fabrication of thermoelectric test modules for the third SNAP 1A generator, which is scheduled for fueling, was completed, and performance tests were initiated. Functional checkout of the generator handling equipment was completed. This work included mercury fill and drain tests of the generator system and collar shield, and heat transfer tests of the isotope shipping cask.

A. SUBTASK 2.4--GROUND HANDLING EQUIPMENT FABRICATION

1. Objectives

During this quarterly reporting period, the planned objectives for Subtask 2.4 were:

(1) Marriage tests of the SNAP 1A ground handling equipment.

(2) Mercury fill and drain tests of the generator system and collar shield.

(3) Heat transfer tests of the isotope shipping cask.

2. Scope of Work

a. Ground handling equipment functional tests

During this quarterly report period, functional testing of the ground handling equipment to be used for transporting the Cerium-144 heat source and loading the SNAP 1A generator was completed. The ground handling and test procedures delineated in Ref. 1 were followed in conducting the tests. Marriage of the field loading stand, portable test dolly, generator, collar shield and shipping cask in preparation for simulated generator fueling is shown in Fig. II-1.

b. Mercury fill and drain tests

The mercury fill and drain tests on the generator system and the collar shield were completed during the quarter.

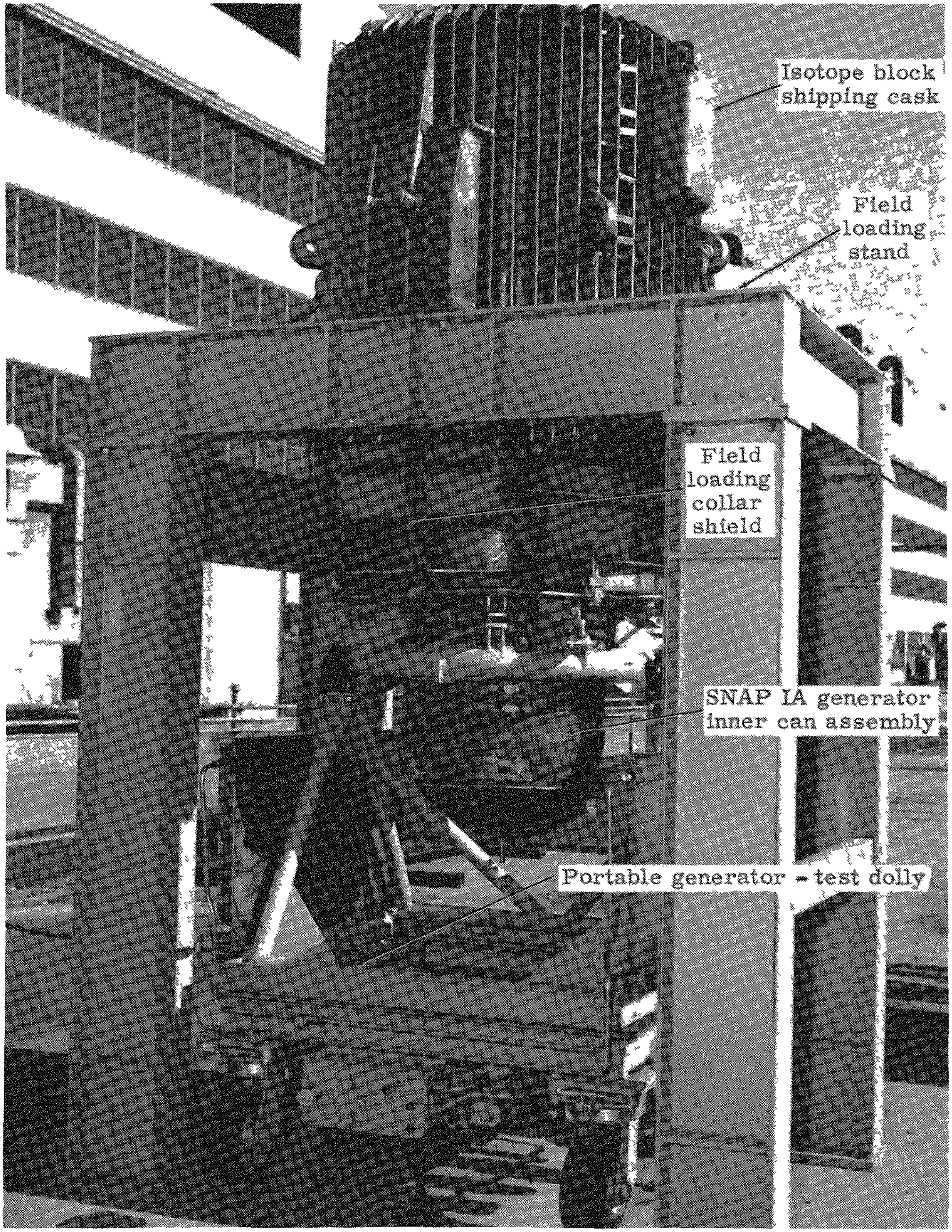

Fig. II-1. SNAP IA Field Fuel Loading System

c. Shipping cask heat transfer tests

Heat transfer tests on the isotope-core shipping cask for the SNAP 1A generator were completed during the quarter.

3. Technical Discussion and Evaluation

a. Ground handling equipment functional tests

In completing the functional tests of the SNAP 1A ground handling equipment, the following checks were accomplished:

(1) Shipping cask preparation for fuel core loading.

(2) System checkout of shipping cask.

(3) Preparation for isotope block loading.

(4) Cask loading of isotope block.

(5) Cask checkout and system disassembly.

(6) Power generator preparation.

(7) Collar shield installation.

(8) System integration.

(9) Shipping cask assembly and installation.

(10) System preparation for fuel block transfer.

(11) Fuel block transfer operation.

(12) Post-transfer operation.

Results of these tests showed that the generator ground handling equipment will be adequate to support the ground test program. Recommended modifications and procedural changes, indicated by the functional tests, which will facilitate the ground test program are as follows:

(1) The isotope shipping cask must be hoisted prior to installation of the protective shipping cage. This procedural change is necessary since the shipping cask hoist beam was not designed to clear the protective cage.

(2) Rotation of the isotope shipping cask from the upright position to the inverted position in preparation for generator fueling requires the use of a 5-ton hoist in addition to a 10-ton cask-lifting hoist. The 5-ton hoist is required to ensure controlled rotation of the cask.

(3) The two-piece generator gimbal ring requires rework to ensure adequate clearance for generator installation.

(4) Two of the four support legs on the field loading stand must be rotated 90° to increase clearance for ease of positioning of the portable generator test dolly.

b. Mercury fill and drain tests

The conclusions drawn from the mercury fill and drain tests were as follows:

(1) The weight of the mercury required to fill the generator was 4168 pounds.

(2) An elongation of 0.001 inch and a decrease in diameter of 0.002 inch in the generator inner skin occurred with 4168 pounds of mercury in the inner skin.

(3) The weight of mercury required to fill the collar shield was 3185 pounds.

The generator was suspended in the gimbal ring of the handling dolly, and a simple drain tube with a valve was attached to the generator. Mercury was poured through the source access hole until the generator was full; a total of 4168 pounds of mercury was poured into the generator skin.

Measurement of the diameter of the inner skin was made at three locations when the generator was full of mercury and when it was empty. These measurements are presented in Table II-1; they indicate that the generator decreases slightly in diameter when full of mercury.

TABLE II-1

Mercury Fill Test: Generator Inner Skin Diameter

Location	Skin Diameter with Full Mercury Load (in.)	Skin Diameter Without Mercury (in.)
Slightly below isotope block loading port	20.885	20.889
Three inches below lift port bellows	20.900	20.900
Slightly above weld joint between cylindrical skin and bottom dome	20.905	20.906

The collar shield was placed near the generator and a connection was made to the inner skin. The mercury from the skin was then passed to the shield by gravity. A total of 3185 pounds of mercury was required to fill the collar shield.

A previous attempt to fill the collar shield through the overflow reservoir failed because vent capacity was not adequate to permit the escape of displaced air. No modification to the existing system is, however, deemed necessary. It will be possible to fill the collar shield with the present system by closing the valves in the fill line and opening the valves in the drain line and associated bypass lines.

c. Shipping cask heat transfer tests

Cask-surface and cask-fin temperature profiles were obtained at electrical power inputs of 4040 and 4440 watts. The maximum recorded temperature at the cask surface was 203° F, and the corresponding fin temperature was 163° F. Table II-2 gives a summary of the results.

TABLE II-2

Summary of Shipping Cask Temperature Profiles

Location	Temperature (°F) 4040 watts	4440 watts
Cask top, left side	146	157
Fin top, left side	113	120
Cask center, left side	Open circuit	194
Fin center, left side	145	155
Cask bottom, left side	103	109
Fin bottom, left side	99	103
Surface of heat source, center	1376	1561
Cask top, right side	156	167
Fin top, right side	112	147
Cask center, right side	191	203
Fin center, right side	154	163
Fin bottom, right side	102	107

Recommended modifications and procedural changes, suggested by the results of the isotope-block shipping cask heat transfer tests, which will facilitate ground handling operations are as follows:

(1) The Wood's metal thermal bond medium should be drained from the cask just prior to rotation of the cask in preparation for installation on the field loading stand. This procedural change will prevent loss of Wood's metal due to possible leakage around the sliding plug.

(2) The cask must be preheated to approximately 170° F at the surface to ensure the passage of the Wood's metal into the isotope core cavity without resolidification. Preheating may be preferentially accomplished by passing steam or hot water through the cask heating coil. The cask may

also be heated by installing the isotope core.

(3) Wood's metal leakage was encountered around the ramrod O-ring seal. It is recommended that this seal be checked for leakage with water, and then with Wood's metal and an electrically heated source block prior to installation of the isotope core.

(4) To ensure the free flow of Wood's metal into the shipping cask, heater wire and insulation should be installed around the lower globe valve and inlet line to the cask.

4. Conclusions

Minor modifications and procedural changes have evolved from functional tests of the SNAP 1A ground handling equipment. Modifications to the field loading stand and generator gimbal ring are required to ensure satisfactory ground handling operations.

B. SUBTASK 2.5--G-2 GENERATOR FINAL ASSEMBLY AND TEST

1. Objectives

During this quarterly reporting period, the planned objectives for Subtask 2.5 were:

(1) Completion of environmental tests of the G-2 generator.

(2) Initiation of analysis of the G-2 generator environmental test data.

2. Scope of Work

a. G-2 generator environmental tests

Environmental tests of the G-2 generator were begun in October and completed in December 1960.

b. G-2 generator environmental test data analyses

Analysis of the G-2 environmental test data was initiated in late December. A complete analysis will be presented in the next quarterly report.

3. Technical Discussion and Evaluation

The setup for vertical plane vibration testing of the G-2 generator is shown in Fig. II-2. During the vibration test (vertical plane, random excitation) the pressure tubes between the shutter control bellows and the generator failed. These failures are attributed to insufficient support of the pressure tubing. The vertical plane acceleration test setup is shown in Fig. II-3. No structural failures were encountered as a result of acceleration tests.

Shock tests were conducted in December 1960. During the final shock test a crack developed in the circumferential weld joint between the cylindrical and lower-dome sections of the outer aluminum skins. It was also observed that the adjacent aluminum shock test fixture bracket supporting the generator had failed completely in the weld joint. In this case it was obviously concluded that the failure of the support bracket transmitted excessive shock loads to the generator. This crack is therefore not considered as a failure due to normally induced shock loads.

4. Conclusions

The SNAP 1A generator structure successfully withstood the simulated environmental conditions of vibration, acceleration and shock associated with rocket launch. The pressure tubing failure which occurred during random excitation vibration will be corrected by additional tubing support.

C. SUBTASK 2.6--G-3 ISOTOPE GENERATOR FABRICATION

1. Objectives

During this quarterly reporting period, the planned objectives for Subtask 2.6 were:

(1) To complete final design of the G-3 generator.

(2) To initiate manufacture and assembly of the G-3 outer can assembly.

(3) To design modularized thermoelectric assemblies for use in the G-3 generator.

(4) To conduct development tests of thermoelectric assembly modules in a module tester.

(5) To test electrical insulation coatings for application to the

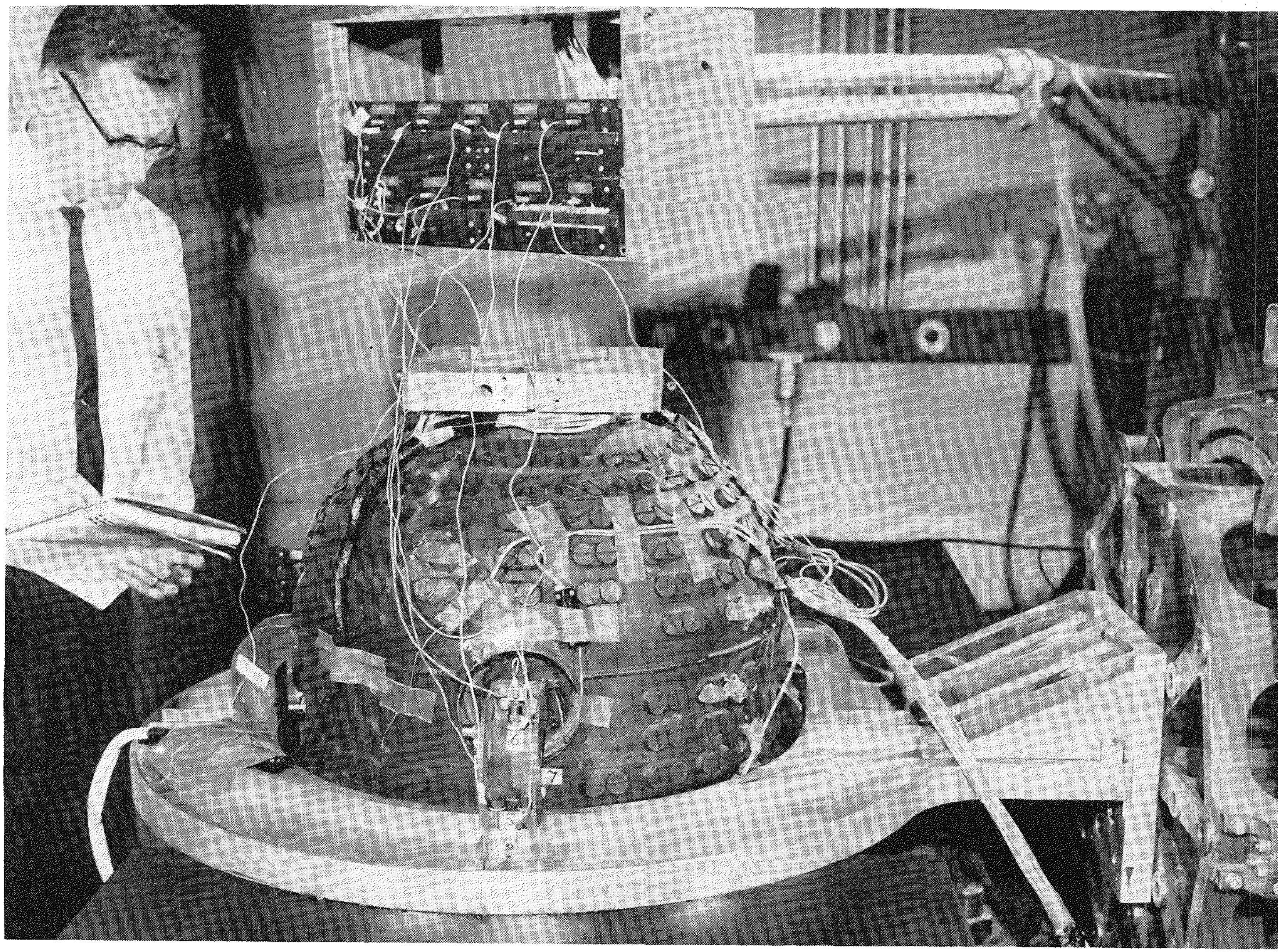

Fig. II-2. SNAP IA G-2 Generator--Vertical Plane Vibration Test Arrangement

Fig. II-3. SNAP IA G-2 Generator--Vertical Acceleration Test Arrangement stainless steel inner hot skin of the G-3 generator.

2. Scope of Work

a. Final design of G-3 generator

Final design of the G-3 generator was completed. The generator will incorporate a thermoelectric module concept which was also designed, developed and tested during this reporting period. A cutaway view of this module design is shown in Fig. II-4.

b. Manufacture and assembly of G-3 generator

Assembly of the G-3 generator inner skin was resumed late in December. The inner can assembly is scheduled for completion by the end of January 1961. Fabrication and assembly of the complete generator, with the exception of the thermoelectric module installation, is scheduled for the end of February 1961. The installation of the modularized thermoelectric system will be completed by April 15, 1961.

c. Thermoelectric module design and development

Studies for the thermoelectric assembly module design were completed during this reporting period. Various module configurations were evaluated in terms of thermal characteristics and fabrication problems.

d. Development tests of thermoelectric assembly modules

Development tests of prebonded thermoelectric modules for the G-3 generator were initiated in mid-December 1960. Isothermal room temperature checkout of the modules as installed in the module tester is shown in Fig. II-5.

3. Technical Discussion and Evaluation

a. Thermoelectric module design and development

The configuration of the thermoelectric assembly module was chosen as a result of design studies completed during this reporting period. The chosen arrangement, one of about ten considered, is based upon two couples per module. This arrangement is shown in Fig. II-4. Prebonded hot and cold junctions of high purity iron will be used on both P and N elements. The complete module assembly is designed for ease of installation and removal and may be checked electrically before installation of the hermetic-seal closure caps.

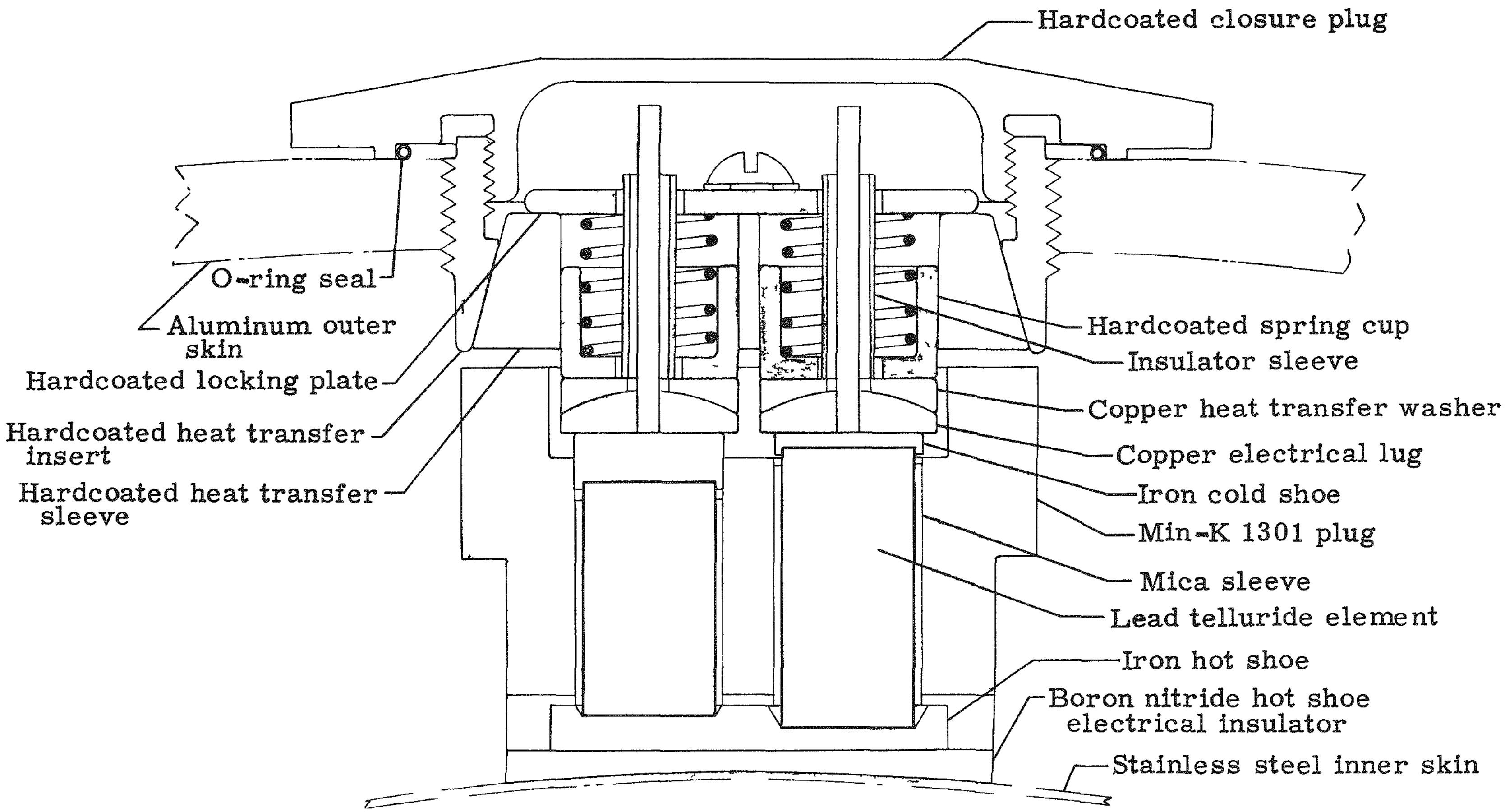

Fig. II-4. SNAP IA Thermoelectric Module--G-3 Generator

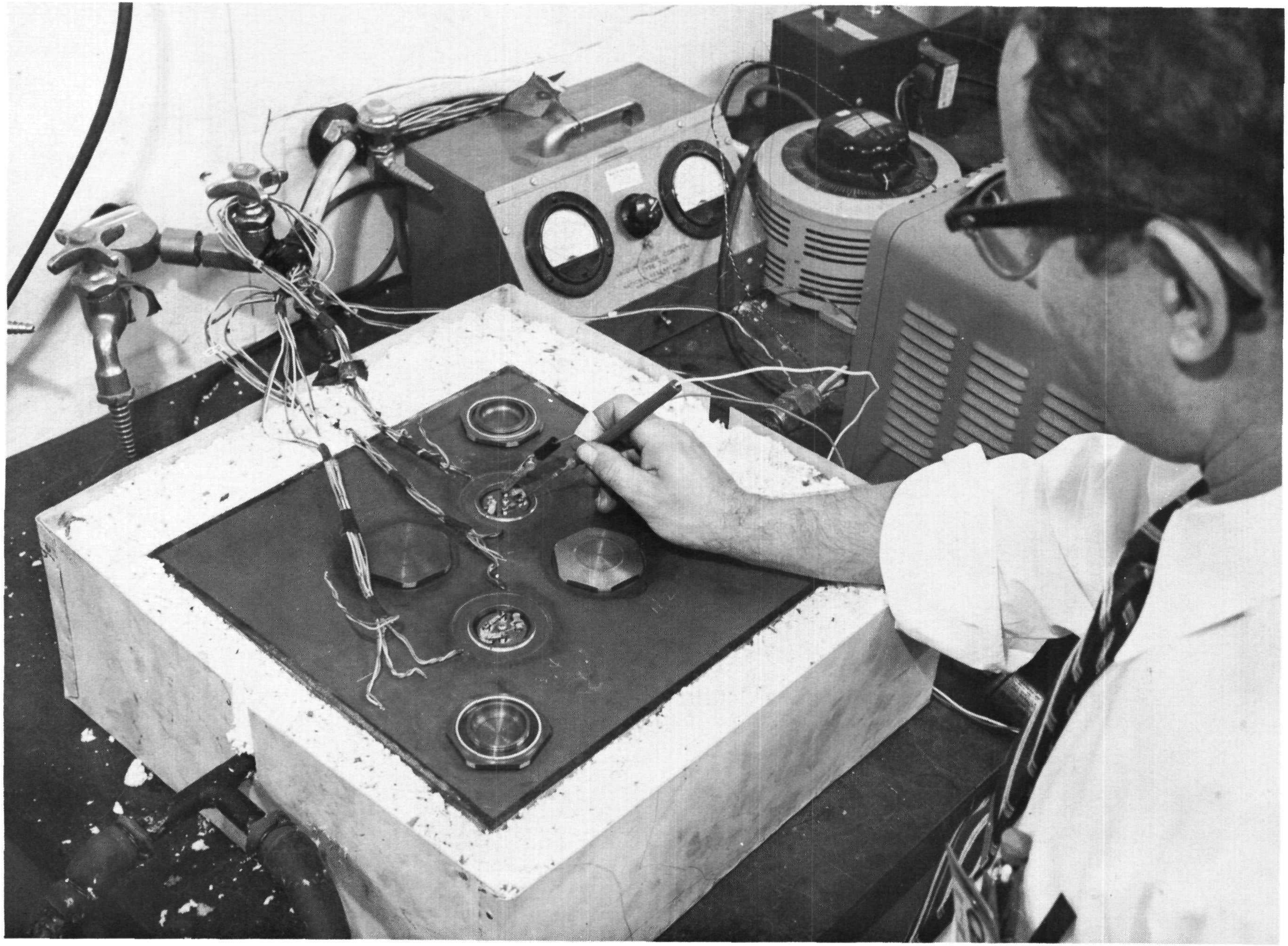

Fig. II-5. SNAP IA G-3 Generator--Module Test Arrangement

Detail parts for the module assembly are shown in Fig. II-6. The assembled thermoelectric module is shown in Fig. II-7.

A test fixture was also designed to duplicate, dimensionally, the G-3 generator thermoelectric installation. This fixture, containing four complete thermoelectric modules, will be used to test installation and operation characteristics of the thermoelectric system. The module tester components are shown in Fig. II-8.

The module configuration finally selected represented a compromise between thermal and fabrication considerations. Particularly critical in the selected design, from thermal considerations, are the temperature drop in the cold closure cap and the maximum temperature variation of the hot skin. These areas have been investigated, and the results of the investigations are presented in this report.

Analyses of the temperature drop from the iron cold shoe to the outer skin and the maximum temperature variation in the stainless hot skin were made with the diagram of Fig. II-9 used to identify interface locations.

Temperature drop in cold end. The heat flowing through every element is, approximately, the total heat flow (2550 watts) divided by the total number of elements (564).

$$\frac{2500}{564} = 3.42 \text{ watts per element, or } 15.15 \text{ Btu per hour per element}$$

The temperature drop in the metal components will be small compared with the temperature drop at each interface.

Temperature drop at interface No. 1. This is a spherical copper-to-copper pressure contact with highly finished, well fitting parts. The contact conductivity was estimated for this interface, from Ref. 1, as 1025 Btu per hour-foot^2-°F. The area of the interface is 0.0013 square foot. The temperature drop may then be calculated as follows:

$$\Delta T_1 = \frac{15.15}{(1025)(0.0013)} = 11.3° \text{ F.}$$

Temperature drop at interface No. 2. This is a flat copper-to-hardcoated aluminum pressure contact with highly finished, well fitting parts. The contact conductivity was estimated, from Ref. 1, to be 1000 Btu per hour-foot^2-°F. The area of this interface is 0.0013 square foot. The temperature drop is

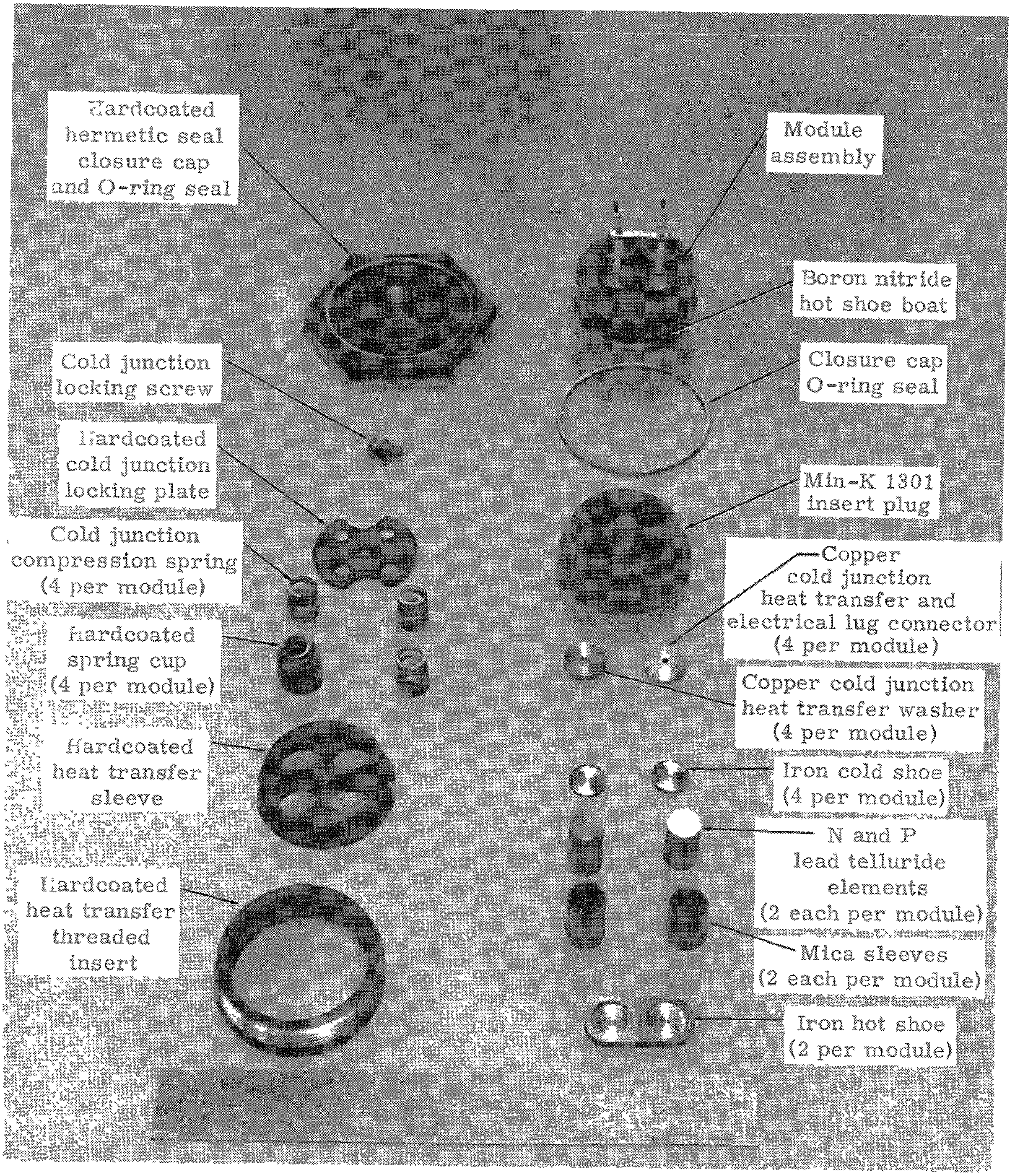

Fig. II-6. SNAP IA G-3 Generator--Thermoelectric Module Details

Fig. II-7. SNAP IA G-3 Generator--Thermoelectric Module Insert and Hermetic Seal Closure Cap

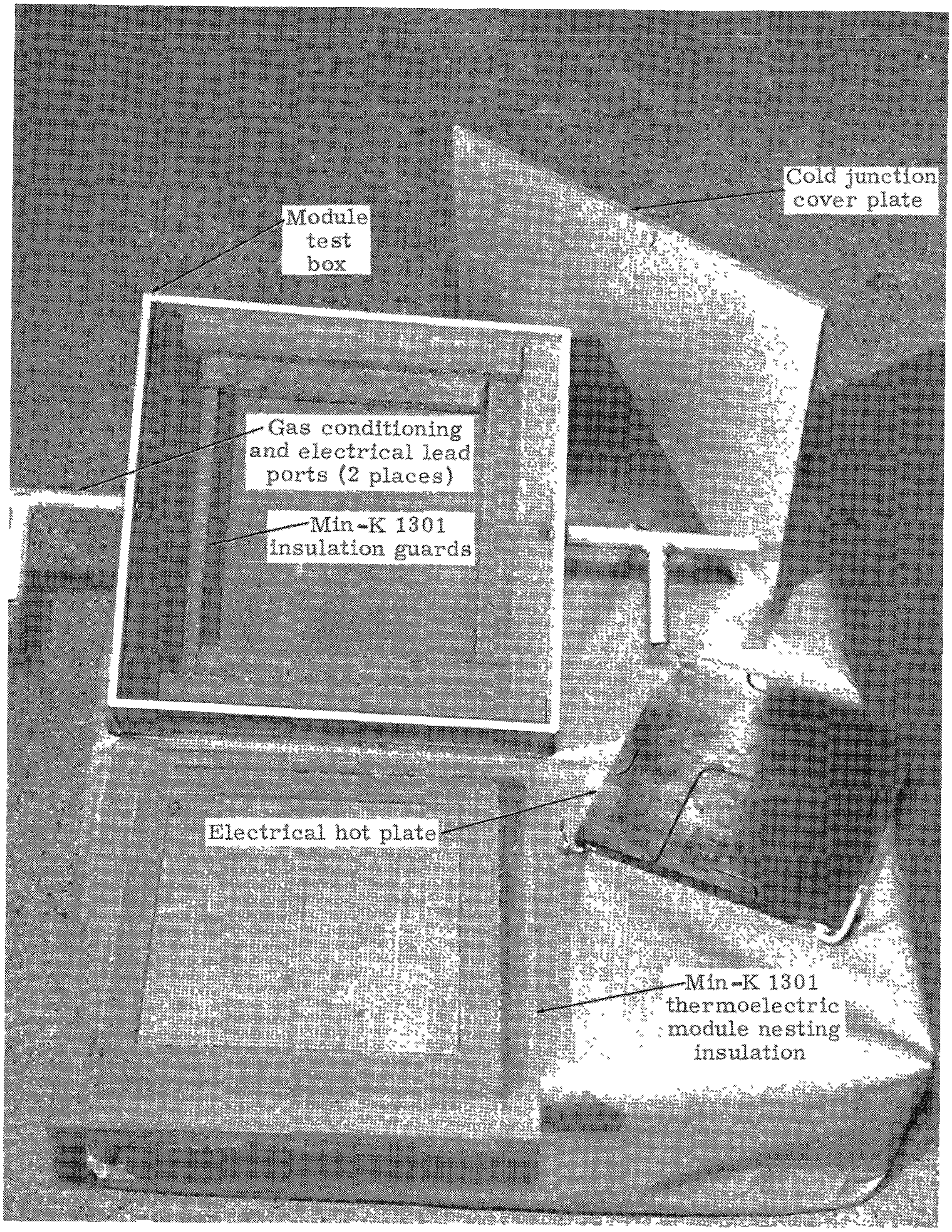

Fig. II-8. SNAP IA G-3 Generator--Module Tester Components

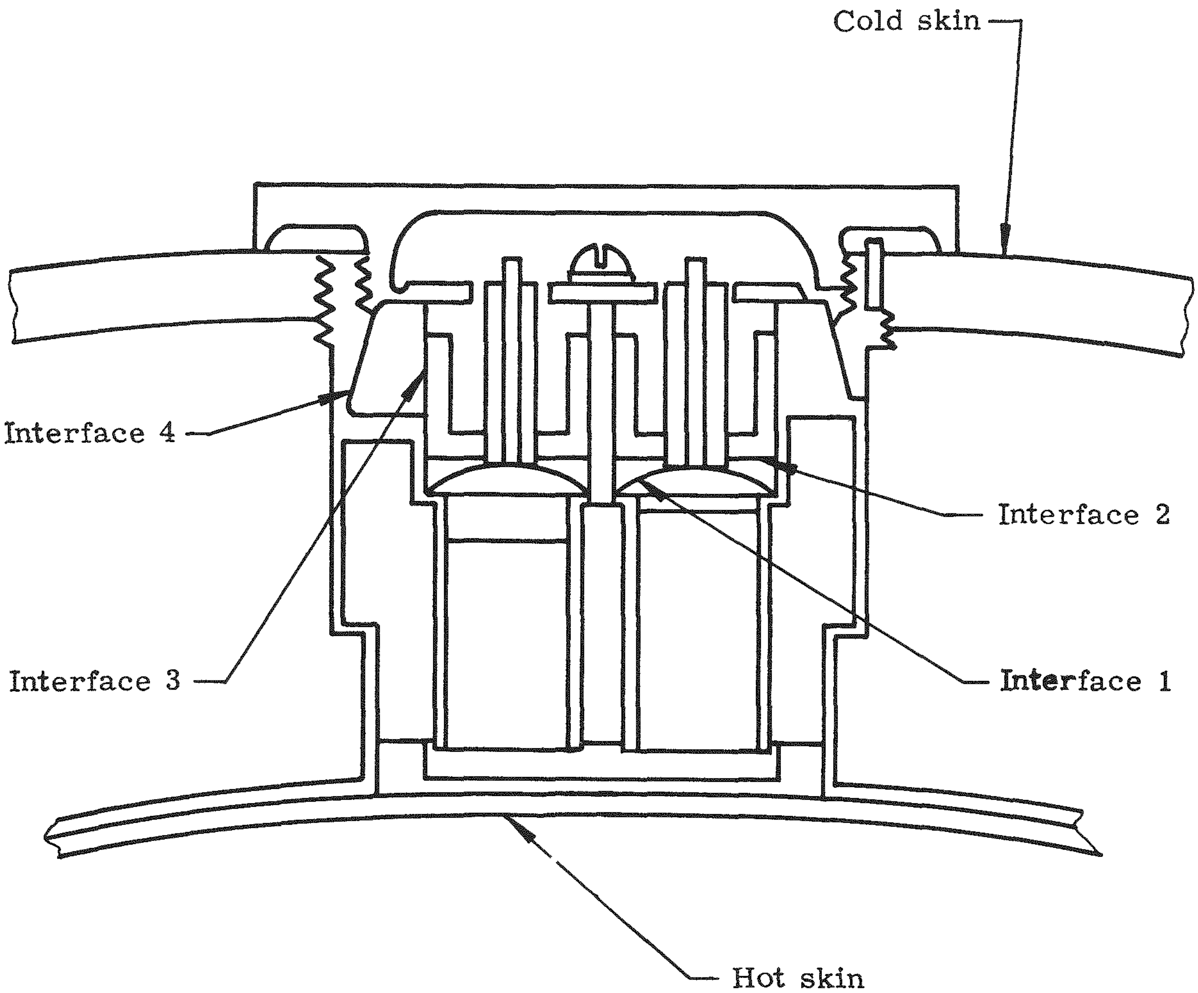

Fig. II-9. SNAP IA G-3 Generator--Thermoelectric Module Cutaway

$$\Delta T_2 = \frac{15.15}{(1000)(0.0013)} = 11.6° \text{ F.}$$

Temperature drop at interface No. 3. This is a hardcoated aluminum-to-hardcoated aluminum sliding contact with highly finished parts. The average radial clearance between the mating piston and cylinder is 0.001 inch. If heat is assumed to be transferred from piston to cylinder wall by conduction through the gas in the gap, the interface conductivity may be calculated to be approximately 120 Btu per hour-foot^2-°F. The area of the interface is 0.0041 square foot and the temperature drop may be calculated to be

$$\Delta T_3 = \frac{15.15}{(120)(0.0041)} = 30.8° \text{ F.}$$

Temperature drop at interface No. 4. This is a hardcoated aluminum-to-hardcoated aluminum pressure contact with highly finished, well fitting parts. The contact conductivity was estimated to be 500 Btu per hour-foot^2-°F. The area of the interface is 0.0082 square foot. All of the heat flowing through the four elements passes through this interface. The temperature drop through this interface may be calculated as follows:

$$\Delta T_4 = \frac{60.6}{(500)(0.0082)} = 14.75° \text{ F.}$$

The total temperature drop from the element cold end to the skin is then

$$\Delta T = \Delta T_1 + \Delta T_2 + \Delta T_3 + \Delta T_4 = 68.45° \text{ F.}$$

This value neglects temperature drop through the aluminum and copper components; however, considerable conservatism has been built into the estimates for contact temperature drops. The total temperature drop should not exceed 70° F if all of the parts fit as designed. A significant reduction in this number should take place due to the use of lubricants in the interfaces. A wet lubricant is more desirable than a dry lubricant.

b. Development tests of thermoelectric assembly modules

Specific objectives of this module development and test program were as follows:

(1) To duplicate applicable components and dimensions of the G-3 generator to assure representative performance and installation characteristics.

(2) To incorporate thermoelectric elements that have been prebonded to the hot shoe.

(3) To permit complete removal and replacement of modules in the generator.

(4) To determine by a 30-day life test that contamination of the thermoelectric elements would not occur.

(5) To determine heat loss characteristics of the module tester before and after installation of the module assemblies.

(6) To conduct shock and vibration tests of the thermoelectric assemblies in the module tester to determine simulated rocket launch capability.

At the end of this quarterly reporting period the objectives listed in Items (1) through (4) had been completed. The remaining objectives are scheduled for completion by the end of February 1961. All prototype components of the thermoelectric module assembly were fabricated, as planned, for the generator. Prebonding of the P and N thermoelectric elements to the hot shoe was accomplished successfully, and the prebonded assembly was installed in the module tester without difficulty. Results of room temperature internal resistance measurements for the eight couples after installation in the module tester are shown in Table II-3.

TABLE II-3

Couple Resistance at Room Temperature After Installation in Module Tester

Initial Installation		After Replacing Modules 3 and 4		
Couple Number	Couple Internal Resistance (milliohms)	Element Assembly Number	Element Internal Resistance (milliohms)	Couple Internal Resistance (milliohms)
1-1	8.9	1-1N 1-1P	1.93 9.90	11.2
1-2	8.3	1-2N 1-2P	1.70 6.90	8.8

TABLE II-3 (continued)

Initial Installation		After Replacing Modules 3 and 4		
Couple Number	Couple Internal Resistance (milliohms)	Element Assembly Number	Element Internal Resistance (milliohms)	Couple Internal Resistance (milliohms)
2-1	8.0	2-1N 2-1P	1.87 7.80	9.9
2-2	6.8	2-2N 2-2P	1.89 6.65	8.5
3-1	12.0	3-1N 3-1P	1.59 28.20	29.0
3-2	21.0	3-2N 3-2P	1.59 5.95	7.6
4-1	9.2	4-1N 4-1P	1.89 8.20	10.0
4-2	8.7	4-2N 4-2P	1.90 10.00	11.8

Typical couple performance characteristics for prebonded pairs are shown in Table II-4. From these data G-3 generator performance is estimated to be approximately 73 watts for 304 couples. Since power output of the order of 0.4 watt per couple is needed to attain a total power output of 125 watts, couple internal resistance should be reduced from the average value of 43 milliohms, as shown in Table II-4, to about 30 milliohms per couple. Additional tests will be conducted to determine the exact source of high internal resistance and effort will be aimed at improving this condition.

Heat loss characteristics were obtained for the module tester before drilling of the Min-K 1301 insulation and after drilling for acceptance of the thermoelectric modules. A summary of these results is shown in Table II-5.

TABLE II-4

Module Tester Thermoelectric Couple Performance Summary

Date	Thermoelectric Couple Number	Hot Junction Temperature* (° F)	Cold Junction Temperature** (° F)	Open Circuit Voltage (mv/ couple)	Load Voltage (mv/ couple)	Electrical Power Output (watts/ couple)	Load Current (amperes)	Internal Resistance (mΩ/ couple)
12/ 21/ 60	2-1	1020	231	214.3	67.5	0.264	3.91	37.5
1/ 10/ 61	2-1	1010	220	212.3	144.4	0.249	1.72	39.4
1/ 11/ 61	2-1	1020	225	216.3	145.5	0.254	1.74	40.6
12/ 21/ 60	2-2	1020	231	212.6	57.0	0.223	3.92	39.8
1/ 10/ 61	2-2	1010	220	208.8	131.1	0.226	1.72	45.0
1/ 11/ 61	2-2	1020	225	212.3	132.0	0.230	1.74	46.0
1/ 10/ 61	3-1	1010	220	211.5	122.0	0.212	1.73	51.7
1/ 11/ 61	3-1	1020	225	217.0	129.5	0.226	1.74	50.2
1/ 10/ 61	3-2	1010	220	210.8	147.2	0.255	1.73	42.0
1/ 11/ 61	3-2	1020	225	212.7	154.0	0.269	1.74	33.6

Average electrical power output per couple--0.241 watt.

Average internal resistance per couple--42.6 milliohms.

*As corrected for 30° F temperature drop from heater plate to hot junction.

**As corrected for 70° F temperature drop from cold junction to cold skin.

TABLE II-5

Thermoelectric Module Tester Heat Loss Data

Condition of Tester	Power Input (watts)	Hot Skin Temperature (°F)	Cold Skin Temperature (°F)
Before drilling Min-K-1301	75.8	1047	281
After drilling Min-K-1301 (boron nitride boats and Min-K-1301 drilled plug installed)	86.4	1046	315
After installing 4 module assemblies	128.3	1049	185

c. High temperature electrical insulation coating tests

The National Bureau of Standards A-418 formulation, a porcelain enamel spray coat, was tested for voltage breakdown characteristics. This material has been evaluated for application to the G-3 generator inner skin as a possible second discrete barrier against hot junction electrical shorts. Spray coating to a thickness of 2 mils and heat treatment at 1850° F has given satisfactory results on several stainless steel samples, including a SNAP 1A generator inner skin.

Electrical resistance test data were obtained for room temperature and hot junction operating temperature conditions using 1.5- to 2- mil coatings on stainless steel. Results for A-418 were as follows:

Temperature (°F)	Resistance (ohms)	Breakdown Voltage (volts)
70	2×10^6	450 to 550
1055	50×10^3	25 to 50

Since A-418 coating offers only moderate resistance to voltage breakdowns at the hot skin operating temperature, 1050° F, a second discrete electrical insulation barrier will not be used in the G-3 generator.

4. Conclusions

A satisfactory mechanical design for the SNAP 1A G-3 generator has been evolved. The thermoelectric module concept has been successfully demonstrated in module development tests.

Internal electrical resistance measurements which were obtained by thermoelectric module tests late in this quarter require further improvement to assure the desired electrical power output of 125 watts. Additional development tests will be conducted in the next quarter to correct this condition.

D. SUBTASK 2.7--G-3 GENERATOR ELECTRICAL TEST

This subtask will start after the G-3 generator is completed in the fourth quarter of Fiscal Year 1961. The planned objectives for Subtask 2.7 are the following:

(1) Preoperational tests to condition the thermoelectric assembly hot junctions and to check for hermetic seal leakage.

(2) Power output tests to determine initial rated power and efficiency of the G-3 generator with thermal heat dissipation shutters closed.

(3) Performance tests to correlate efficiency with internal and external loads at various constant hot junction temperatures.

(4) Shutter response tests to determine the ability of the generator to dump excess heat and maintain constant hot junction temperature.

(5) Transient heatup tests to establish the lag time before operational temperatures are reached.

E. SUBTASK 2.8--TASK 2 PROGRAM DIRECTION

1. Objectives

During this quarterly reporting period, the planned objectives for Subtask 2.8 were:

(1) Initiation of a revised Task 2 Program Plan to incorporate thermoelectric module design, development and test for ultimate use in the isotope-fueled G-3 generator.

(2) Technical direction and administration of the Task 2 program to fulfill the technical objectives and the schedule.

(3) Preparation of regular monthly progress letters and contributions to the SNAP Radioisotope Space Programs Quarterly Report.

2. Scope of Work

a. Thermoelectric module development program

As a result of the decision to conduct additional thermoelectric module development for the G-3 generator design, final assembly of the generator has been rescheduled from mid-November 1960 to mid-April 1961. Module design, development and tests, including simulated rocket vibration and shock environmental inputs, will be conducted in the period from October 1960 through February 1961.

b. Task 2 program technical direction

During this quarter Amendment No. 1 to the Statement of Work for Task 2, Ref. 2, was prepared and submitted to the AEC. This amendment reflects the Task 2 program reorientation to include thermoelectric assembly module development for the G-3 generator. This Statement of Work is the current controlling document for Contract AT(30-3)-217 in performing the Task 2 effort for Fiscal Year 1961. The Task 2 Program Plan, Ref. 3, was also prepared and submitted to the AEC. This document reflects similar changes and indicates how the additional objectives for Fiscal Year 1961 will be accomplished.

c. Report preparation

During this quarter the reports listed as Refs. 4, 5, 6, 7 and 8 were distributed.

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III. TASK 3--SNAP 3 THERMOELECTRIC GENERATOR

A. OBJECTIVES

During this reporting period, the planned objectives for Task 3 were:

(1) To complete the life test and obtain performance characteristics for the 3M-1G10 generator.

(2) To conduct a post life-test internal inspection of the 3M-1G10 generator.

(3) To fuel the 3M-1G5 generator with Po-210 and deliver it to the AEC.

(4) To contribute to the quarterly progress report and prepare regular monthly progress letters.

B. SCOPE AND EVALUATION OF WORK

1. Life Testing

Life testing of the 3M-1G10 generator was terminated for teardown inspection on December 13, 1960, after continuous operation for 322 days. The conditions of power input (approximately 66.5 watts) and external environment (room temperature, air and 4.5 ohms external load) were maintained essentially constant.

The generator output at the end of 322 days of operation was 1.92 watts(e), and the corresponding end-of-life test efficiency was 2.9%. At the start of life the power output was 3.45 watts(e) and the overall efficiency, 5.2%. The reduction in generator performance was caused primarily by an increase in internal resistance. The resistance reached 4.92 ohms in 322 days of operation, compared to 3.0 ohms at life test initiation. Performance data obtained during life testing is summarized in Fig. III-1.

After completion of the life test on December 13, 1960, the generator was operated under various external loads to obtain a performance characteristic curve. These results are shown in Fig. III-2 and can be compared with a similar curve, Fig. III-3, obtained on January 25, 1960, at the initiation of the life test program. Thermal power input to the generator was terminated on December 19, 1960, in preparation for teardown inspection.

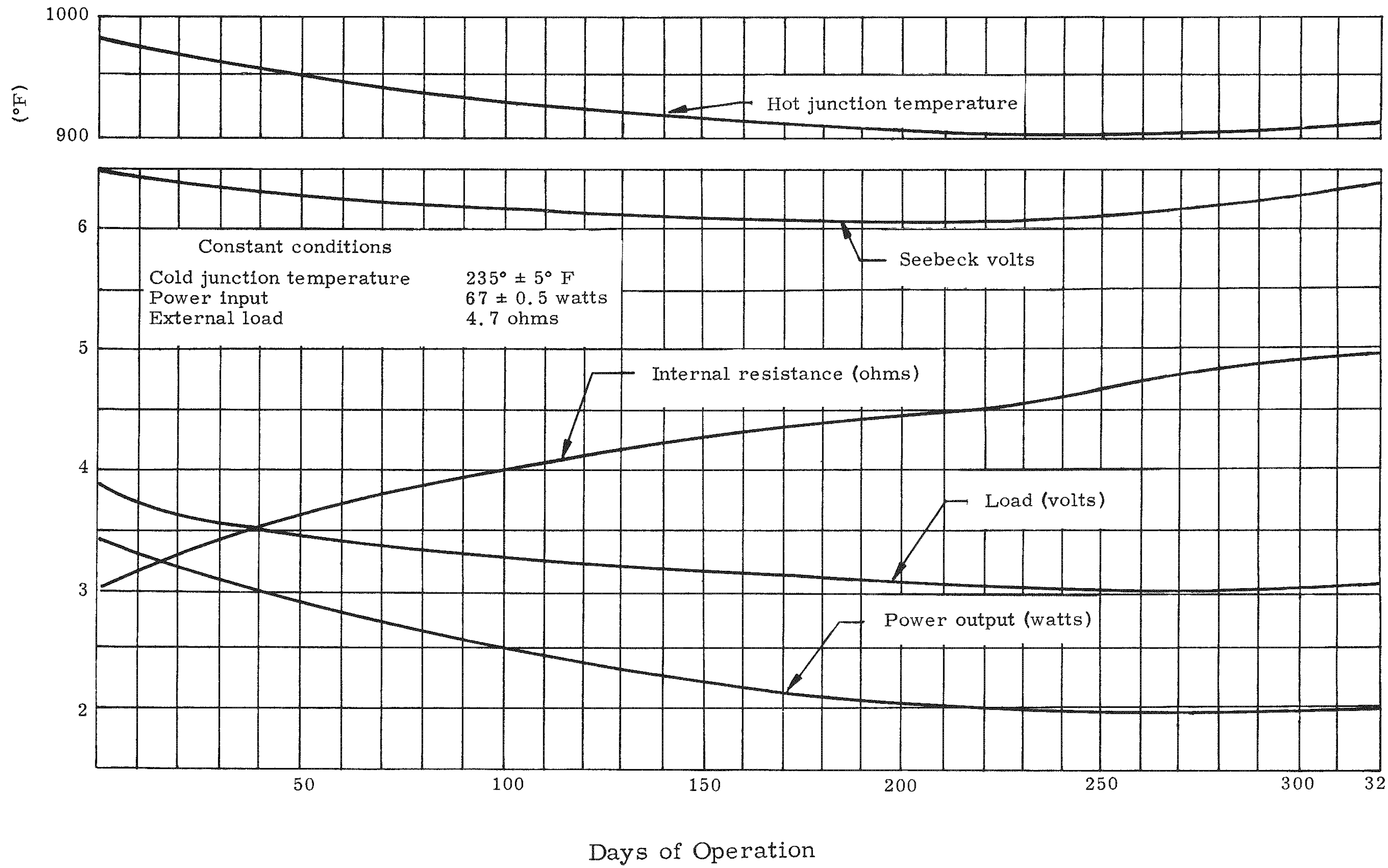

Fig. III-1. 3M-1G10 Generator Life Test

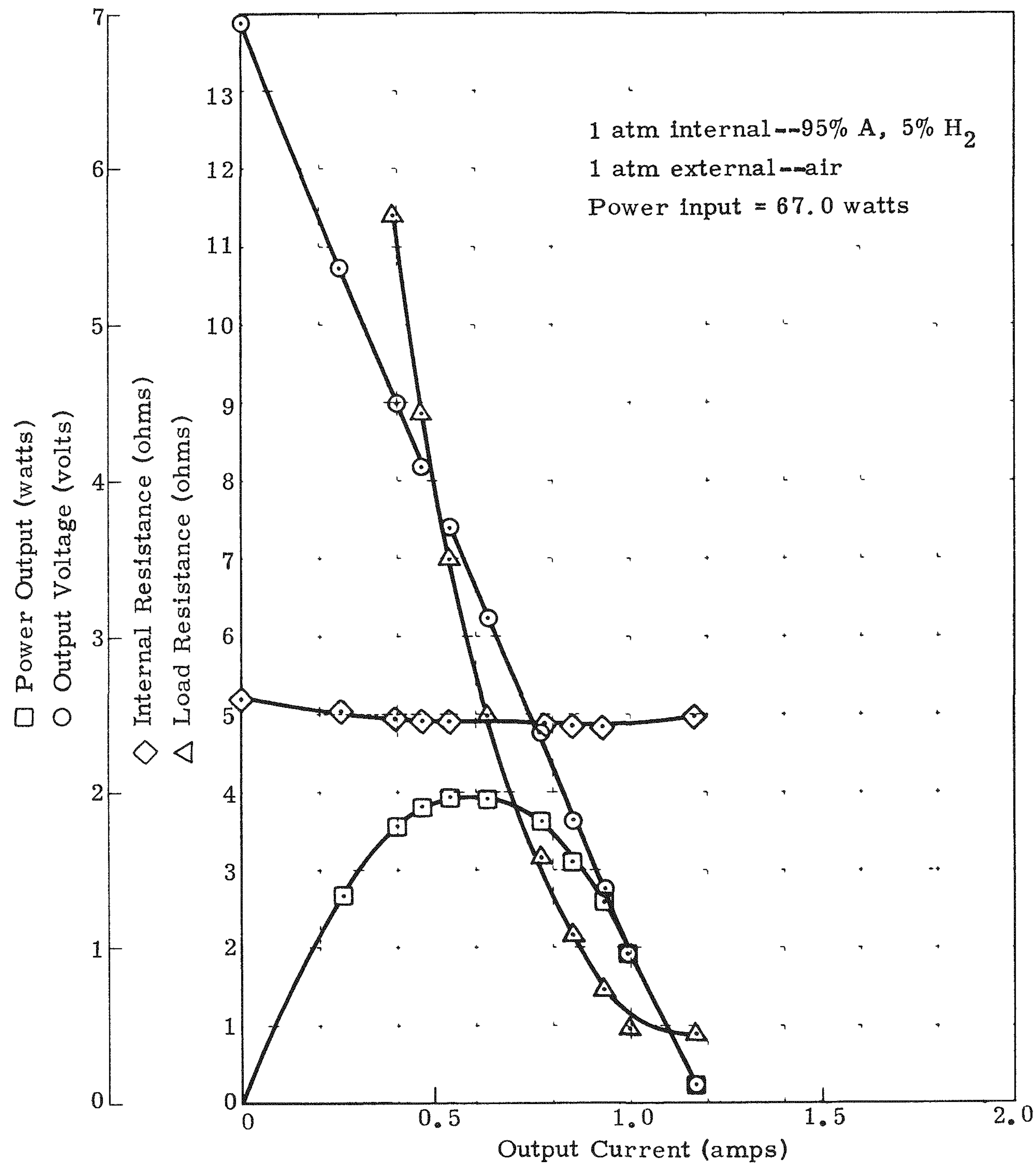

Fig. III-2. SNAP III 3M-1G10 Generator--Post Life Test Performance Data (After 320 Days Operation)

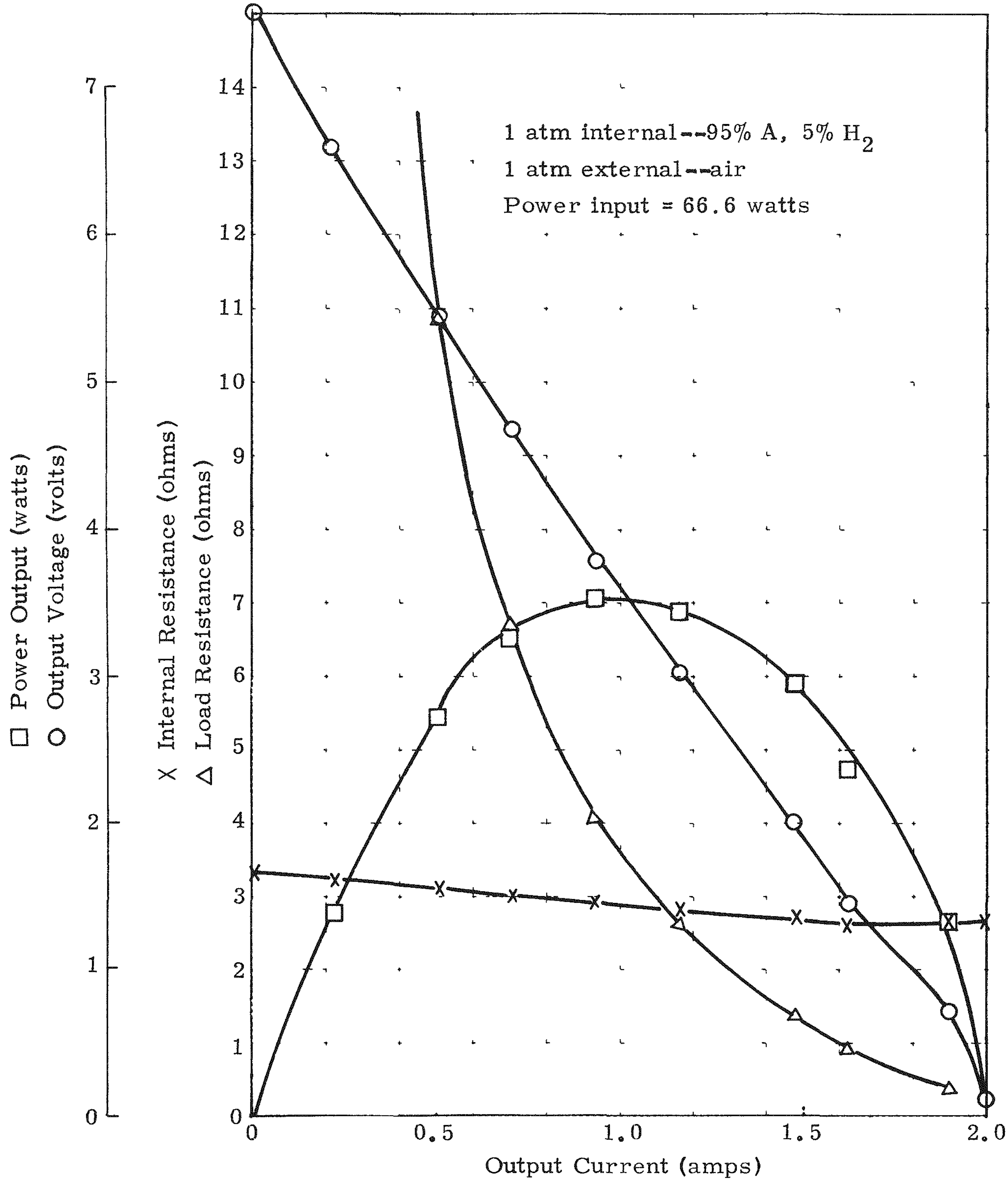

Fig. III-3. SNAP III 3M-1G10 Generator--Prelife Test Performance Data

2. Post-Test Inspection

A post life-test inspection of the 3M-1G10 generator was completed in late December 1960. The generator was in very good mechanical condition, with minor deposits of lead and tellurium in evidence on the thermal insulation near the element hot junctions.

Thermoelectric internal resistances were found primarily in the P elements and their hot junctions and varied between 0.012 and 0.210 ohm. N element and hot junction contact resistance averaged 0.0072 ohm, with two exceptions at 0.0155 and 0.012 ohm. The total internal resistance of the generator at isothermal room temperature conditions was 3.15 ohm.

Prior to disassembly the generator was operated at 79 watts power input to attain a hot shoe temperature of 1098° F under open-circuit conditions. At the start of the life-test program 66.4 watts power input was required to attain the corresponding hot shoe temperature. Table III-1 summarizes this comparison and shows that thermal conductivity of the generator did increase with no degradation in Seebeck voltage.

Additional detail of the teardown inspection will be presented in an addendum to Ref. 9 which will be distributed in March 1961.

3. Isotope Fueling of SNAP 3 Generator 3M-1G5

The SNAP 3 generator 3M-1G5 was fueled with 2420 curies of Po-210 as of October 13, 1960, and delivered to the AEC on October 25, 1960. The generator, which had a maximum output of 4 watts at an efficiency of 5.2% on October 20, 1960, was scheduled for demonstration at the "Atoms at Work" exhibition opening in November at Buenos Aires, Argentina. Measured and predicted generator performance is given in Fig. III-4.

TABLE III-1

Comparison of 3M-1G10 Generator Temperature and Seebeck Voltage
Before and After Life Test

Date	Power Input (watts)	Hot Junction Temperature (°F)	Cold Junction Temperature (°F)	ΔT (°F)	Open Circuit Voltage (volts)	Open Circuit Volts /ΔT (mv/°F)
1/25/60	66.4	1098	235	863	7.55	8.75
12/19/60	79.0	1098	263	835	7.60	9.10

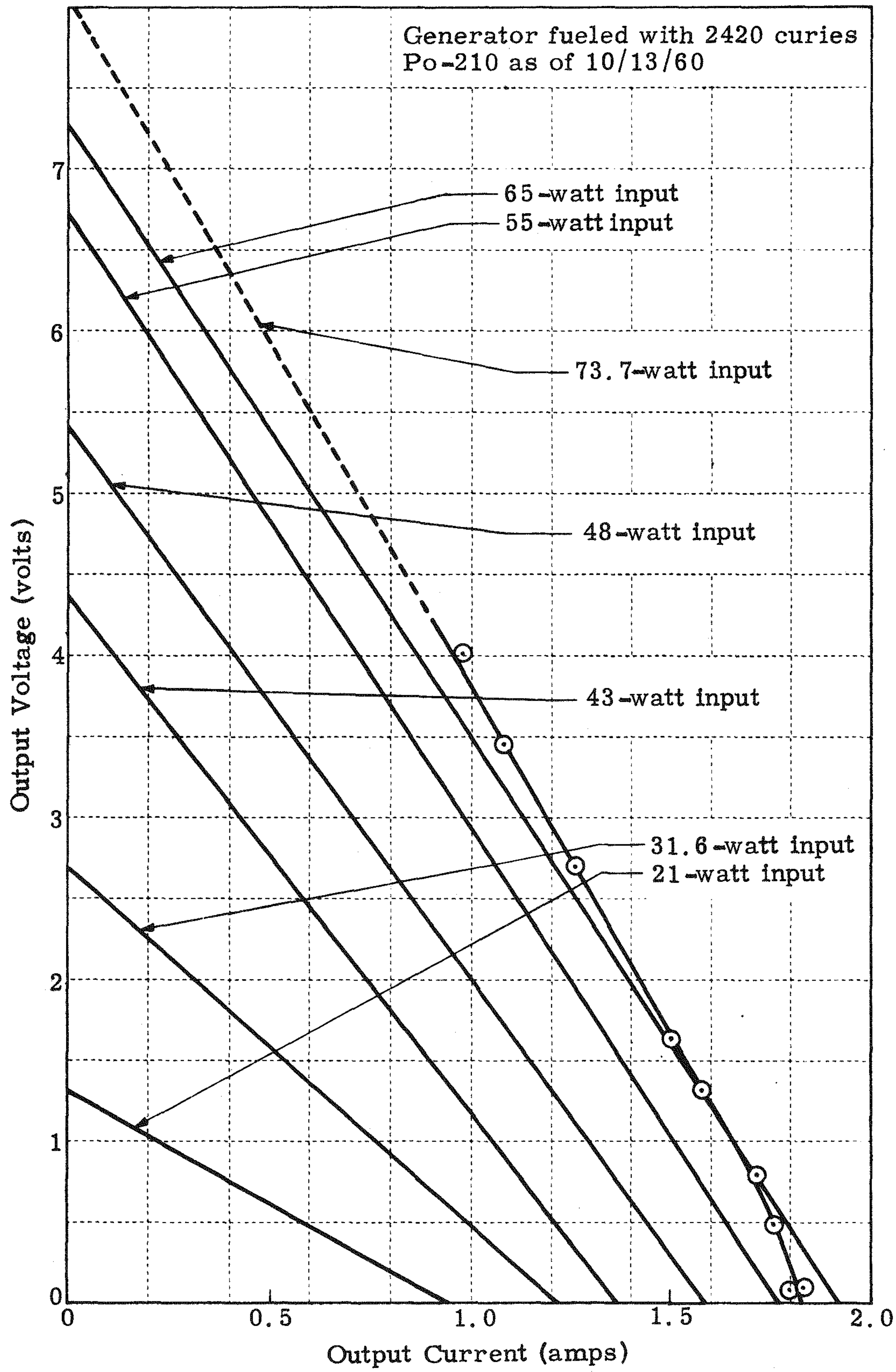

Fig. III-4. E Versus I for SNAP III, 3M-1G5 Generator with Power Input Parameter and Steady State Load

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IV. TASK 7--RADIOLOGICAL SAFETY STUDIES FOR SPACE POWER

This task was initiated as a modification to Contract AT(30-3)-217. effective November 28, 1960. A program plan (Ref. 13) defining the scope of work for Fiscal Year 1961 was prepared and submitted to the New York Operations Office of the U. S. Atomic Energy Commission. This plan also established the breakdown of the overall effort into subtasks and sub-subtasks with objectives as follows.

A. SUBTASK 7.1--SAFETY STUDY OF A TYPICAL CAPE CANAVERAL LAUNCH

Objectives:

(1) To analyze the launch of three SNAP-type units on the Atlantic Missile Range as to launch-pad, ascent and intermediate- or final-stage failures.

(2) To define the following for each kind of failure for each system type:

(a) Altitude, velocity and range.

(b) Forces imposed on the generator as a result of the conditions determined under (a).

(c) Final deposition of the isotope fuel as a result of the forces determined under (b).

B. SUBTASK 7.2--STUDY OF A LUNAR IMPACT OF A RADIOISOTOPE-FUELED THERMOELECTRIC GENERATOR

Objectives:

(1) To define the lunar surface and environment through a literature search.

(2) To define a typical or composite lunar landing trajectory.

(3) To determine the results of impact at 500 and 9000 feet per second with a generator similar to that proposed for the Surveyor Program. The primary fuel will be curium;

however, an equivalent thermal load of polonium will also be considered. These results will be correlated with the trajectory defined under (2).

(4) To define a test program and the facilities required to verify the analytical results determined under (3).

C. SUBTASK 7.3--UPPER ATMOSPHERE EXPERIMENTAL RE-ENTRY STUDY

Objective; To verify the analytical calculations used in establishing radioisotope fuel core and SNAP generator burnup on re-entry.

This program has been divided into five sub-subtasks as follows:

(1) Sub-subtask 7.3.1--Fuel Core Heating

Objective: To determine the heating phenomena experienced by generator cores during re-entry into the earth's atmosphere following an ICBM ballistic trajectory.

(2) Sub-subtask 7.3.2--Fuel Core Ablation Studies

Objective: To establish the rate of ablation of bodies re-entering the earth's atmosphere on an ICBM trajectory.

(3) Sub-subtask 7.3.3--Generator Burnup

Objective: To determine the susceptibility of an auxiliary power unit's heterogeneous exterior construction to burnup during re-entry.

(4) Sub-subtask 7.3.4--High Altitude Sampling

Objective: To investigate the feasibility of establishing particle size distribution, dispersion and rate of fallout of simulated fuel materials during re-entry by high altitude sampling.

(5) Sub-subtask 7.3.5--Project Direction and Reporting

Objective: To maintain technical liaison with the many government agencies and contractors involved and to direct and report on the overall task progress.

D. SUBTASK 7.4--RADIOISOTOPE SHIELDING CODE

Objectives:

(1) To determine a machine calculation code to accomplish the following, using the Monte Carlo Technique:

(a) To determine optimum shielding characteristics, including evaluation of such factors as cost, weight, material and heat transfer.

(b) To determine the shielding necessary to reduce radiation dosage to any selected value or, conversely, determine gamma radiation for a given shield configuration.

(2) To utilize the code developed to calculate the dose rate from one fueled generator for comparison with actual measurements.

E. PROGRAM REVIEW

During a review of the program plan and the individual statements of work at the New York Operations Office, several minor revisions and corrections were requested. These will be incorporated and reported next period.

F. PROGRAM PROGRESS

Preliminary technical efforts were initiated in all phases of the program except Sub-subtask 7.3.4. Since the other phases of Subtask 7.3 culminate at specific vehicle launch dates, a high priority was assigned to their initiation.

These preliminary efforts consisted primarily of literature reviews, data assembly and liaison arrangements with the various government agencies and contractors involved. A bibliography pertaining to the lunar surface and environment was assembled and reviewed. Vehicle trajectory and performance data on hand were reviewed. Additional data were requested through the Aircraft Reactors Branch of the AEC and discussed informally during a meeting with G. Sweetnam of Jet

Propulsion Laboratory and A. Von Doenhoff of NASA Headquarters.

Arrangements for a coordination meeting of the AEC, AFSWC, AMR, Convair and The Martin Company are under way. Preliminary information on the ballistic missile trajectory and pod configuration was received and is being used to determine the anticipated re-entry conditions. Materials to be used for simulation of both the container and radioactive fuel are being reviewed.

Radioisotope shielding calculation methods were verified, and some changes to the original technique were incorporated. These involved the method of obtaining the Compton scattering of photons. A method allowing a saving in machine calculation time was substituted (Ref. 14).

V. REFERENCES

1. "Preliminary Technical Manual--Loading, Shipping and Testing Procedures," MND-P-2316, March 24, 1960.

2. Task 2--Statement of Work, Amendment No. 1, MND-P-2181, October 20, 1960.

3. Task 2--Program Plan, Revision 4, MND-P-2172, November 14, 1960.

4. "Final Safety Analysis Report, Task 2 Radioisotope-Powered Thermoelectric Generator," MND-P-2352.

5. "SNAP Radioisotope Space Programs Quarterly Progress Report No. 4," Tasks 2 and 3, MND-P-3012-I, July 1 through September 30, 1960.

6. Task 2--Monthly Progress Letter, MND-P-2222-12, covering period ending September 30, 1960.

7. Task 2--Monthly Progress Letter, MND-P-2222-13, covering period ending October 31, 1960.

8. Task 2--Monthly Progress Letter, MND-P-2222-14, covering period ending November 30, 1960.

9. "SNAP 3 Final Performance Test Summary," MND-P-2398, August 1960.

10. Task 3--Monthly Progress Letter, MND-P-2187-12, covering period ending September 30, 1960.

11. Task 3--Monthly Progress Letter, MND-P-2187-13, covering period ending October 31, 1960.

12. Task 3-- Monthly Progress Letter, MND-P-2187-14, covering period ending November 30, 1960.

13. Task 7--Program Plan, MND-P-2467, December 22, 1960.

14. Kahn, H., "Application of Monte Carlo," AECU-3259.