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MND-3241

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SPECIAL REVIEW
FINAL
DETERMINATION
Class: U
Reviewer: TR U
Date: 12-23-61

DESIGN SUMMARY
OF
ISOTOPE - THERMOELECTRIC
GENERATORS

~~MASTER~~

MND-3241

Classification cancelled for change to
by authority of DOC
by H.J.C. TIC, date AUG 30 1973

NOVEMBER 1965

Prepared by:

W. Kenneth Nichols Jr.
Design-Analysis Unit

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R-1

November 1965

Revision #1

Revision #1 (R-1) to MND-3241, "Design Summary of Isotope-Thermoelectric Generators," affects the following pages, sections and figures which are to be added or replaced, depending on the (A) or (R) preceding the item.

(R) Title page	(R) 6-0-2, 6-0-3 and 6-0-4
(A) This sheet	(R) Section 9.0, - cover sheet and pages 9-0-1 thru and including 9-0-9
(R) Distribution page, p. A	
(R) Contents, p. B & C	(A) Figures 21-1, 21-2, 21-3, 21-4 and 21-5
(R) SNAP vs Task Nos, p. D	(R) Section 10.0 cover sheet
(R) 1-2-2 and 1-2-3	(A) Section 10.2, pages 10-2-1 thru and including page 10-2-13 and figures 10.2-1 thru and including 10.2-10
(A) Figures 1A-1, 1A-4, 1A-5	
(A) Figures 7A-1, 7A-2	
(A) Figure 7B-2	
(A) Figure 7D-1	
(A) Section 4.6, pages 4-6-1 thru and including 4-6-5 and figures 7F-1, 7F-2 and 7F-3	

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*10.4	Low Cost Generator (LCG 25A)
*10.5	250 Watt Study
*10.6	Apollo

*Not included in Nov., 1965 issue of Design Summary.

Revised Nov., 1965

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D

SNAP vs TASK NUMBERS

Up until the time of SNAP-9A, the programs carried out at the Martin Nuclear Division were identified by Task numbers rather than SNAP numbers. The correlation between the two is as follows:

Task 1	-	SNAP-1
Task 2	-	SNAP-1A
Task 3	-	SNAP-3
Task 4		
Task 5	-	Advanced Technology Program
Task 6	-	Fuel Technology Development
Task 7	-	Safety Studies for Space Power
Task 8	-	SNAP-7
Task 9	-	Transit 4A and 4B Generators
		(Similar, except for fuel, to SNAP-3)

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SECTION 1.0

SNAP-1 GENERATOR

- 1.1 SNAP-1 Turboelectric Space
Generating System
- 1.2 SNAP-1A Thermoelectric Space
Generating System

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Section 1.1

Page 1-1-1

Issue Date: March, 1965

SNAP-1

TURBOELECTRIC SPACE GENERATING SYSTEM

A. Introduction

SNAP-1 was designed as a radioisotope fueled, turboelectric generating system utilizing a mercury vapor rankine cycle. The device was to produce 500 watts of electricity and be suitable for providing power in space.

The Martin Company as prime contractor was responsible for systems integration and for development of the isotope-fueled mercury boiler. Thompson-Ramo-Wooldridge under contract to Martin, was responsible for the development of the turbo-machinery, condenser-radiator and control portions of the program.

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Section 1.2
Page 1-2-1
Issue Date: March, 1965

SNAP-1A

THERMOELECTRIC SPACE GENERATING SYSTEM

A. Introduction

The SNAP-1A program was carried out under Task II of Contract AT(30-3)217. The unit was initially designed as a 125 watt, radioisotope-fueled, thermoelectric generator for space use. The program was later redefined and the generators were designated as ground test units only. A total of three units were designed as part of the SNAP-1A program. The first two, designated G-1 and G-2 were fabricated and tested electrically. The G-2 unit also underwent environmental testing for vibration and shock. The third unit, G-3, was never tested as an assembled unit, but module tests were performed. The electrical tests were carried out using electrical heaters. None of the units were ever fueled. Work was also performed on ground handling systems and on two concepts for a thermal shutter mechanism.

B. Program Status

Work on SNAP-1A has been terminated and no further effort is contemplated.

C. Mission

Originally designated for space applications, later redesignated for ground test only.

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Section 1.2

Page 1-2-2

Issue Date: Nov., 1965

D. Generator Data

1. Net Power, watts (e)	
Design	125
Actual	~85
2. Mission Life	6-months or 1 year
3. Fuel	Cerium 144 (Units were not fueled)
4. Configuration	Cylindrical w/hemispherical heads:
length 34.1 inches,
diameter 24 inches.
5. Generator Weight (lbs)	Operational 200
w/shielding 4200
6. Stress Requirements	Designed to resist launch loads.
7. Shielding	Fuel shielded by mercury during handling.
Mercury drained prior to operation.
8. Thermal Insulation	None. Thermal shutter heat dump mechanism designed.

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Section 1.2
Page 1-2-3
Issue Date: Nov., 1965

E. Design Summary

1. Operating Temperature

Hot Junction Temp.	°F	1000
Cold Junction Temp.	°F	143

2. Power, watts (e)

Design	125
Actual	~85

3. Internal Resistance, ohms

Design	4.45
Actual	11.2-17.70

4. Thermal Loss

Watts	760
Percent	29.6

Note: Results of electrical tests are given in Quarterly Reports referenced in Section I. Considerable degradation was experienced and original design parameters were not met.

F. T/E Design

Thermoelectric elements were purchased from 3M. First two generators (G-1 and G-2) utilized individual couples. Third generator (G-3) utilized modular concept with two couples per module. Module similar to SNAP-9A.

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Section 1.2

Page 1-2-4

Issue Date: March, 1965

1. Material - PbTe - Electrical characteristics for G-3 modules are in MND-P-3013-1; G-2 module is shown in MND-P-1312-1, Figure II-5.
2. Dimensions - Both "N" and "P" elements have circular cross sections.

"N"

"P"

Length

Diameter

3. Bonds - G-1 and G-2 purchased with copper cold junction caps attached
G-3 utilized iron cold shoe
Hot junction utilized GeTe and PbTe on G-1 and G-2;
G-3 utilized different technique

G. Auxiliary Equipment

1. Ground handling equipment- Ground handling equipment for the flight versions of SNAP-1A was designed, constructed and functionally tested.
2. Heat shutter - Heat shutter mechanism was designed and tested for the SNAP-1A.

H. Test Results

See MND-P3011, 3012, 3013 for test results.

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Section 1.2

Page 1-2-5

Issue Date: March, 1965

I. Reports

MND-P-3011

SNAP Programs Quarterly Progress Report No. 3, Tasks 2, 3, 5 and 6 through June 30, 1960.

MND-P-3012-1

SNAP Programs Quarterly Progress Report No. 4, Tasks 2 and 3, July 1 through September 30, 1960.

MND-P-3013-1

SNAP Radioisotope Space Program Quarterly Progress Report No. 5, Tasks 2, 3 and 7, October 7 through December 31, 1960.

MND-P-2184

SNAP-1A Preliminary Operational Hazards Summary Report for Task 2, Thermoelectric Generator, February, 1960

MND-P-2291

Summary Report, Aerodynamic Re-Entry Analysis, Task 2, Thermoelectric Generator, February, 1960.

MND-P-2352

Final Report on SNAP-1A, Hazards, June, 1960.

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Figure 1A-1

SNAP-1A Generator (G-2
Generator Configuration)

SNAP-1A

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SNAP-1A THERMOELECTRIC MODULE G-3 GENERATOR

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Figure 1A-4

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Figure 1A-5

SNAP-21A Thermoelectric Assembly--
G-3 Generator

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SECTION 2.0

SNAP-3 SPACE FEASIBILITY
DEMONSTRATION GENERATOR

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Section 2.0

Page 2-0-1

Issue Date: March, 1965

SNAP-3

SPACE FEASIBILITY DEMONSTRATION GENERATOR

A. Introduction

The Martin Company under contract to the U. S. Atomic Energy Commission developed the SNAP-3 generators in order to demonstrate the feasibility of radioisotope powered thermoelectric generators. Under this program, Minnesota Mining & Manufacturing Company (3M) produced the thermoelectric generators and Martin fueled and tested the units. A total of six generators were produced. A modified version of the SNAP-3 generator was later built, fueled and launched into space. See Section 10.1.

B. Program Status

This program was carried out under Task 3 of Contract AT(30-3)217. No further effort is contemplated.

C. Mission

SNAP-3 generators were produced as "proof-of-principle" devices.

D. Generator Data

1. Net Power (watts)	3-5
2. Design Life	Not specified (Tested 322 days)
3. Fuel	Polonium 210
4. Generator Configuration	Cylindrical with hemi- spherical ends.
Height (inches)	5 21/64
Diameter (inches)	4 53/64

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Section 2.0

Page 2.0.2

Issue Date: March, 1965

5. Stress Requirements	Capable of withstanding launch loads associated with VEGA and WS-117L vehicles.
6. Shielding	Not required
7. Thermal Insulation	Min-K 1301

E. Design Summary

1.	Operating Temperatures	
	Hot Junction	°F 1100
	Cold Junction	°F 230
2.	Power (watts)	4.6
3.	Degradation Allowance	None
4.	Internal Resistance (ohms)	3.13
5.	T/E Efficiency	Unknown
6.	Generator Efficiency	5.9%

F. Thermoelectric Design

Generators were purchased from 3M as complete assemblies.

1. Material - PbTe, "P" sodium doped
 "N" lead iodide doped
2. Dimensions - Both "N" and "P" elements are circular
 in cross section.
 Length (inches) 1.0
 Diameter (inches) 0.255
3. Bonds - Elements are spring-loaded and not bonded.
4. Configuration - Twenty-seven couples arranged
 radically around source. (See figure)
5. Operating Environment - 95% Argon, 5% Hydrogen

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Section 2.0

Page 2.0.3

Issue Date: March, 1965

G. Auxiliary Equipment

H. Test Results

See MND-P-2398

I. Reports

MND-P-2398

SNAP-3 Final Performance Test
Summary, August, 1960.

MND-P-3011

SNAP Programs Quarterly Progress
Report No. 3, Tasks 2, 3, 5 and 6,
April 1 through June 30, 1960.

MND-P-3012-1

SNAP Programs Quarterly Progress
Report No. 4, Tasks 2 and 3,
July 1 through September 30, 1960.

MND-3013-I

SNAP Progress Report No. 5,
Tasks 2, 3 and 7, October 1 through
December 31, 1960.

MND-P-2514

SNAP-3 Thermoelectric Generator
Safe Handling Procedures,
April 1, 1959.

MND-P-2513

SNAP-3 Thermoelectric Generator
Radiological Safety Analysis,
February, 1959.

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SECTION 3.0

SNAP-5 THERMOELECTRIC POWER SUPPLY

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Section 3.0

Page 3-0-1

Issue Date: March, 1965

SNAP-5

THERMOELECTRIC POWER SUPPLY

A. Introduction

The SNAP 5 generator was developed by Martin to be an operational thermoelectric, radioisotope fueled generator. Details of the generator mission are classified. Versions were produced utilizing Polonium-210 and Plutonium-238 as fuel. The unit included the radioisotope heat source, a thermoelectric-generator, a DC to DC Converter, a battery pack and a high voltage output converter.

B. Program Status

Operational units have been delivered and no further work is anticipated.

C. Mission

Classified

D. Generator Data

1. Net Power, watts (e)	.325
2. Mission Life	one year
3. Fuel	Polonium-210
Plutonium-238
4. Envelope Dimensions	
Generator (alone)	7 inch diameter
Complete Power Package	see drawings
5. Generator Weight	
Generator (alone), pounds	4.3
Complete Power Package, pounds	38.1

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Section 3.0

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Issue Date: March, 1965

6. Stress

Designed to resist shock and vibration encountered in normal transportation and handling

7. Shielding

None required

8. Thermal Insulation

Diatomaceous Earth and Min-K

E. Design Summary

1. Operating Temperatures

Hot Junction Temp., °F	835
Cold Junction Temp., °F	112

2. Power, Watts	0.320
-----------------	-------

3. Degradation Allowance	—
--------------------------	---

4. Internal Resistance, Ohms	12.5
------------------------------	------

5. Thermal Loss

Watts	—
Percent	—

6. Stress

Designed to resist shock and Vibration encountered in transportation and handling

7. Efficiencies

Thermal	—
Thermoelectric	—
Generator	2.22

F. Thermoelectric Design

Design & Fabrication of the thermoelectric generators were subcontracted to Minnesota Mining & Manufacturing Company.

1. Material - PbTe

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Section 3.0

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Issue Date: March, 1965

2. Dimensions - (See Dwg. 3M-2B2)

"N" Diameter, inches	0.103
"P" Diameter, inches	0.129

3. Bonds

4. Configuration - (See Dwg. 3M-2B2)

5. Operating Environment (external) ambient air

G. Auxiliary Equipment

1. DC to DC converter - Basic circuitry breadboarded and tested by Martin prior to issuance of procurement spec. Three companies submitted models for test. A Bendix-Redbank unit was chosen, based on life test performance. Converter characteristics of an operational unit are given below

Input Voltage	1.75 Volts
---------------	------------

Converter Outputs	
+ 14 terminal	17.03 Volts
+ 7 terminal	9.28 Volts
- 7 terminal	9.18 Volts
- 14 terminal	17.00 Volts

Converter Efficiency %	80.2
------------------------	------

2. Battery Pack - An extensive battery testing program was carried out to evaluate various brands of batteries. (See MND-P-2307 & MND-W-2371.
3. High Voltage Converter - This unit was designed & provided by others. Martin had no responsibility for its performance.

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Section 3.0

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Issue Date: March, 1965

H. Test Results

See MND-W-2371

I. Reports

MND-W-2371

SNAP 5, Final Summary Report
Task 4.0 Thermoelectric Generator

MND-P-2307

SNAP 5, Battery Evaluation Test
Program, March, 1960

J. Drawings

SNAP 5 is covered by Martin 356-XXX XXXX series drawings

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SECTION 4.0

SNAP-7 TERRESTRIAL GENERATORS

4.1	SNAP-7A	Floating Navigational
Buoy Power Supply
4.2	SNAP-7B	Navigational Aid Power
Supply - Light House
4.3	SNAP-7C	Weather Station Power
Supply - Near McMurdo
Base (Antarctica)
4.4	SNAP-7D	Floating Weather Station
Power Supply
4.5	SNAP-7E	Acoustic Beacon Power
Supply (Undersea)
4.6	SNAP-7F	Navigational Aid Power
Supply Gulf of Mexico
Gas Well Platform

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Section 4.1

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Issue Date: March, 1965

SNAP-7A

FLOATING NAVIGATIONAL BUOY POWER SUPPLY

A. Mission

Provide electrical power for the operation of a U. S. Coast Guard floating light buoy.

B. Introduction and Operational History

Approximately two months after delivery of the SNAP-7A system to Curtis Bay, Maryland, on December 15, 1961, a drop in the generator power output and hot junction temperature was noted. This drop continued until, on June 20, 1962, the generator was removed from service and returned to the Martin Company for laboratory evaluation.

Following its return from Curtis Bay, the SNAP-7A generator was subjected to several tests. The first, a parametric test, verified the reduction in power reported by the U. S. Coast Guard. At the optimum performance point, the generator output power was 8.1 watts.

After the parametric test was completed, a check was made on the internal gas of the generator. Its pressure at this time was found to be 16.9 inches of mercury (gauge), an increase of 10.9 inches of mercury over the original charging pressure. The discovery of this increased pressure was the first indication of a gas pressure buildup. Several gas samples were taken from the generator at this time for analysis. The results of this analysis showed that, not only had the pressure increased,

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Section 4.1

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but, 12.11%, by volume, of contaminants were found in the gas.

Reduction of the generator internal gas pressure (without changing the generator gas fill) to 0.2 inch of mercury (gauge) was sufficient to increase the hot junction temperature 41°F and restore the generator output power from 8.1 to 8.80 watts. Complete change of the generator gas to 100% helium at a pressure of 0.2 inch of mercury (gauge) resulted in a 4°F increase in hot junction temperature and increased the power to 8.95 watts.

On August 14, a second parametric performance test was initiated. After completion of the parametric test, the generator gas was changed to 60% helium and 40% argon in an effort to further increase the hot junction temperature and generator power by increasing the thermal conductivity of the gas fill. This gas change produced a hot junction temperature of 931°F. A second gas change, this time to 30% helium and 70% argon, resulted in a hot junction temperature of 965°F. The parametric test which followed (starting September 4) indicated a maximum output power of 10.27 watts. However, by September 9, the hot junction temperature had decreased to 955°F.

Prior to a test of the complete system, the battery was checked. It was found that two cells had excessive loss of water. Three of the battery cells were replaced with spares. The original dc-to-dc converter was used in the system test.

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Section 4.1

Page 4-1-3

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At the beginning of the system test, the output power from the generator was 10.08 watts, and the hot junction temperature was 948°F. After 10 days, the power output was 9.83 watts at a hot junction temperature of 943°F.

On December 19, 1962, the power output of the generator was measured at 9.27 watts, and at this time, the internal gas was changed to 100% argon. The power increased to 9.40 watts, while the hot junction temperature rose to 955°F. On June 18, the Sr-90 fuel capsules were removed from the generator at Quehanna in preparation for generator rework.

During September and October 1963, the SNAP-7A thermoelectric assembly was rebuilt. The assembly was completed during the first week in November, and the generator placed into its shield housing. After outgassing at a surface temperature of 200° to 250°F for several days, the generator was shipped to Quehanna, Pennsylvania for refueling. Generator fueling was completed on November 25, 1963. SNAP-7A was returned to Baltimore on November 27 and readied for parametric and system tests.

C. Program Status

The SNAP-7A generator was put back into service in January, 1964, and since that time has degraded rapidly. The company is preparing a proposal to rebuild the SNAP-7A generator a second time.

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Section 4.1

Page 4-1-4

Issue Date: March, 1965

D. Generator Physical and Design Characteristics

1. Power, watts - electrical output
Design - begin of life 10
Actual - after rebuild of 1963 9.55*
2. Mission Life, years 10
3. Fuel - 40,800 curies of Strontium
90 Titanate (SrTiO_3)
contained in four hastalloy
"C" capsules
Thermal Inventory 256 watts
Generator Fueling Date
(Original fueling) - November 20, 1961
4. Envelope Dimensions
Diameter, inches 19-1/4
Length, (height), inches 21
5. Generator Weight, pounds 1840
6. Shielding - Depleted Uranium
(Min. thickness 2.625 in.)
7. Thermal Insulation - Min-K 1301
8. Operating Temperatures (Actual
after rebuild 1963)
Hot Junction, °F 910-930*
Cold Junction, °F 70-80 *
9. Design Degradation Allowance None
10. Internal Resistance 3.40Ω
(January 2, 1964)
11. Stress Levels Generator Design
Tested to:
Vibration, g's 3
Shock, g's 6

*Data recorded by U.S.C.G. January 22, 1964

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Section 4.1

Page 4-1-5

Issue Date: March, 1965

12. Efficiencies - design (end of life)

Thermal	75%
Thermoelectric	6.23%
Generator	4.65%

E. T/E Design

Entire thermoelectric assemblies in the SNAP-7A generator were built by Martin Company.

1. Element Material

"P" Element - cast lead telluride containing 0.81 atomic percent free telluride and doped with .06 weight percent sodium.

"N" Element - cast lead telluride containing 0.71 atomic percent free lead and doped with 0.05 percent lead iodide.

2. Element Dimensions (nominal)

"N" Element

Length, inches	1.000
Diameter, inches	0.235

"P" Element

Length, inches	1.000
Diameter, inches	0.277

3. Bonds: The SNAP-7A modules were replaced in the rebuild of 1963 with ones using different bonding techniques. "Before" and "after" bonds are listed below.

a. Before rebuild of 1963 (see Figures)

"P" Element

Hot Junction - Germanium Telluride
Cold Junction - Tin

"N" Element

Hot Junction - Nickel
Cold Junction - Tin

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Section 4.1

Page 4-1-6

Issue Date: March, 1965

- b. After rebuild of 1963. Ferro-Vac-E iron disk (diffusion barrier) has been added between elements and cold (copper) caps. "N" element disk is nickel plated. Hot shoes are slightly different, and cold cap assembly is now gold plated.

Bonds are: (see Figures)

"N" Element

Element, hot shoe bond, nickel
Element, diffusion disk bond, nickel
Diffusion disk, cold cap bond, tin

"P" Element

Element, hot shoe bond, tin
Element, diffusion disk bond, tin
Diffusion disk, cold caps bond, tin

4. T/E Arrangement

5 Couples/module }
12 Modules/generator } -Series wiring
Pressure maintained on T/E elements by
spring-piston arrangement
Spring designation C 300-038-0500
Spring compression 0.070 inches (cold)
Spring rate 38.6 #/inch
Spring pressure (nominal-cold)
"N" Element 63 psi
"P" Element 45 psi

Wiring is "series" only.

5. Operating Environment

- a. Before rebuild of 1963: 100% Helium up, until its return to the Martin Company
- b. Presently (since rebuild of 1963):
75% Helium, 25% Argon

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Section 4.1

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Issue Date: March, 1965

F. Auxiliary Equipment

1. DC-DC Converter - Replaced at time of generator rebuild with a new one built by Martin. (New Converter SI-631102).

Input 7.6 to 14 watts at 5.0 V.D.C.

Output 0 to 14 or 0-14 V.D.C. (depending on battery charge state) at constant current.

2. Battery - Nine-ampere-hour, sealed, sintered plate nickel-cadmium. Goulton Industries 10V09P. Ten cells at nominal 1.2 volts/cell for 12 volts.

G. Test Results

Last parametric curve before generator placed back in operation (January, 1964) appears as Figure 7 of Addendum I to final report. Monthly report is received from the U. S. Coast Guard on generator performance.

H. Reports

MND-P-2720

SNAP-7A Final Report

MND-P-2720
(Addendum I)

Addendum to final report
covers rebuild of 1963.

MND-P-2661

Instruction Manual. (Manual
is not up to date.)

I. Engineering Drawings

1. Generator Drawings - combination of 398-30210XX and 398-30213XX drawings. Generator Assembly is 398-3021310 and 398-3021000.
2. System Drawings are 398A-1080000, 398A-1080050 through 053, 398A-1080055 and 398A-1080058.

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Figure 7A-2

Artist's Concept of
SNAP-7A and 7C Generators

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FIGURE 7A-3

SNAP-7A, 7C AND 7E
T/E COUPLE ASSEMBLY

(THIS T/E COUPLE USED IN SNAP-7A)
(BEFORE RE-BUILD OF 1963-64 ONLY)

FERRO-VAC-E IRON HOT SHOE WITH
AL₂O₃ SPRAY COAT ALL OVER EXCEPT
IN AREA OF COUNTER-BORES. "N"
ELEMENT COUNTER-BORE AREA IS
NICKEL PLATED

REFERENCE DWG'S:
398-3021010
398-3021011

SCALE: 2/1

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SNAP-7A, 7C AND 7E
T/E MODULE ASSEMBLY

(THIS T/E MODULE ASS'Y USED IN
SNAP-7A UP UNTIL REBUILD OF '63-64')

SCALE: 1/1

REFERENCE DWG'S
398-3021009
398-3021045
398-3021046
398-3021047

FIGURE 7A-4

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FIGURE 7A-5

SNAP-7A
T/E COUPLE ASSEMBLY
(FOR RE-BUILT SNAP-7A GENERATOR)

REFERENCE DWG'S.

398-3021010

398-3021302

398-3021303

398-3021306

SCALE: 2/1

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SNAP-7A
T/E MODULE ASSEMBLY
(USED IN REBUILT SNAP-7A GENERATOR)

SCALE: 1/1

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REFERENCE DWG'S:
398-3021301
398-3021303
398-3021304
398-3021305

FIGURE 7A-6

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Section 4.2

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Issue Date: March, 1965

SNAP-7B

NAVIGATIONAL AID POWER SUPPLY LIGHT HOUSE

A. Mission

At present the SNAP-7B generator is the power supply for the Baltimore Light House. Some time in the future it will be placed in a more remote location by the U. S. Coast Guard.

B. Program Status

Generator fueled in January, 1963, and installed at Curtis Bay (U. S. Coast Guard Yard) in November, 1963. Generator was moved to Baltimore Light in the fall of 1964 by U. S. Coast Guard. No further company effort is foreseen.

C. Generator Physical and Design Characteristics

1. Net Power, nominal, watts (e) 60

2. Mission Life, years 10

3. Fuel - 224,000 curies of Strontium 90
Titanate (SrTiO_3) contained in
in 14 hastalloy "C" capsules.

Thermal Inventory 1410 watts

Generator Fueling date
January, 1963

4. Envelope Dimensions

Diameter, inches 21-3/4
Length, inches 34-1/2

5. Generator Weight, pounds ~4600

6. Shielding - Depleted Uranium

7. Thermal Insulation - Min-K 1301

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Section 4.2

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8. Operating Temperatures
(in operating environment)

Hot Junction, °F 935
(Peak power beginning of life)

Cold Junction, °F 150
(Peak power beginning of life)

9. Degradation Allowance None

10. Internal Resistance, ohms ~ 1.7

11. Stress Levels Generator
Tested to:

Vibration, g's 3
Shock, g's 3

12. Efficiencies (end of life)

Thermal 87.9%
Thermoelectric 5.35%
Generator 4.72%

D. T/E Design

Elements and T/E assemblies built by Martin Company.

1. Material

"P" Element - cast lead telluride containing
0.81 atomic percent free tellurium and 0.060
weight percent sodium.

"N" Element - cast lead telluride containing
0.71 atomic percent free lead and 0.050
weight percent lead iodide.

2. Element Dimensions (nominal)

"P" Element

Length, inches 1.0
Diameter, inches 0.567

"N" Element

Length, inches 1.0
Diameter, inches 0.431

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Section 4.2

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3. Bonds (See Figure)

"P" Element

Hot Junction - Germanium Telluride
Cold Junction - Tin

"N" Element

Hot Junction - Nickel
Cold Junction - Tin

4. Bonding Technique for Hot Junction Bonds. Clamped in a spring loaded fixture and heated by induction method in a 15% hydrogen, 85% argon atmosphere.

5. T/E Arrangement

4 Couples/module } Series wiring
30 Modules/generator }
Pressure maintained on T/E elements
by spring-piston arrangement
Spring designation C480-063-0625
Spring compression 0.27 inches (cold)
Spring rate 79.1 #/inch
Spring force (nominal-cold) 21.4#
Spring pressure (nominal-cold)
"N" Element 148 #/inches²
"P" Element 85 #/inches²

5. Operating Environment

- a. First four years of operation (after fueling), 100% helium gas.
b. Next six years of operation, 100% argon

E. Auxiliary Equipment

1. DC-DC converter - maintains constant input voltage

Input Voltage (nominal)	12.25 VDC
Input Current (nominal - beginning to end of life)	5.85 to 3.85 Amps.DC
Output Voltage (nominal),	34 VDC
and Regulated (nominal)	12.25 VDC

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Section 4.2

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2. Batteries

- a. 12-Volt, 9-Series connected cells. Cells are sintered plate nickel, cadmium type with 10-ampere-hour capacity.
- b. 32-Volt, 4-Series connected batteries. Each battery consists of six-nickel cadmium sealed cells. Total capacity 30-ampere-hours.

3. Container - The entire system (generator, batteries, converter, etc.) is enclosed in a finned aluminum tank.

F. Test Results

The parametric curve obtained after the generator was fueled is shown in Figure 7B-5. Data on the generator's performance is periodically received from the U. S. Coast Guard.

Degradation Tests

A 20-couple module test was conducted over a 10.5 month period. The data obtained is based on the average value of these couples. The total internal resistance decreased from 0.273 ohms to 0.230 ohms during the test period. Most of the decrease occurred in the first 500-hours of operation. The Seebeck coefficient decreased during the test from .200 μ volts/ $^{\circ}$ C to .186 μ volts/ $^{\circ}$ C, or approximately 7%. The output power shows an average increase of 0.65% per 1000 hours which can be attributed to the decrease in internal resistance and a slight increase in temperature differential.

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Section 4.2

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Issue Date: March, 1965

G. Reports

MND-P-2762A	Final Safety Evaluation of SNAP-7B System.
MND-P-2762A (Addendum I)	Final Safety Evaluation of SNAP-7B System.
MND-P-2795	Fueling Instructions SNAP-7B and 7D Generators.
MND-P-2834	Instruction Manual SNAP-7B System.
MND-P-2836	Final Report on SNAP-7B System.

H. Engineering Drawings

1. Generator Drawings - 398-30211XX series.
2. System Drawings - 398B-108005X series.

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Figure 7B-2

Artist's Concept of 60 Watt
Thermoelectric Generator
Applicable to SNAP-7B, 7D
and 7F

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FIGURE 7B-3

SNAP-7B, 7D AND 7F
T/E COUPLE ASSEMBLY

REFERENCE DWG'S

398-3021110

398-3021111

398-3021145

SCALE: 2/1

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FIGURE 7B-4

SNAP-7B, 7D AND 7F
T/E MODULE ASSEMBLY

SCALE: 1/1

REFERENCE DWG'S
398-3021145
398-3021146
398-3021147

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SNAP 7B Generator (Fueled)--Parametric Data (internal gas: pure helium)

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Figure 7B-5

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Section 4.3

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Issue Date: March, 1965

SNAP-7C

WEATHER STATION POWER SUPPLY (ANTARCTICA)

A. Introduction and Operational History

After its installation as a power supply for a remote automatic weather station in the Antarctic (January, 1962), the performance of the SNAP-7C generator degraded to the point where it was unable to supply sufficient power to the station. The generator was placed on short circuit and its electronics equipment package removed in the fall of 1963. In November, 1964, the generator internal gas was changed to one with a lower thermal conductivity after an outgassing process, and a new DC to DC converter installed to more closely match the increased internal resistance of the generator. The generator internals, except for the gas fill, remain as originally built and are the same as the SNAP-7A before it was rebuilt.

B. Program Status

Complete. No further effort is anticipated.

C. Mission

Provide 5 watts of DC power to operate a U. S. Navy Automatic Weather Station in the Antarctic.

D. Generator Physical Characteristics

Same as SNAP-7A except for item 3, fuel. See SNAP-7A Section D.

Fuel - 40,000 curies Strontium 90
266 Thermal Watts

Fueling date; September, 1961

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Section 4.3

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Issue Date: March, 1965

E. Operating Characteristics Summary

1. Operating Temperatures (Nominal)

Hot Junction, °F	850-950
Cold Junction, °F	50-100

2. Power (Nominal - beginning of life) 10 watts

3. Degradation Allowance None

4. Internal Resistance, ohms 2.5
(Shortly after fueling)

F. T/E Design

Same as SNAP-7A before SNAP-7A was rebuilt except for operating environment. See SNAP-7A Sections F1, F2 and F3a. Also see Figures 7A-1 and 7A-2

Operating Environment for SNAP-7C

1. Before November, 1964 - 100% Helium

2. After November, 1964 - 100% Argon

G. Auxiliary Equipment

1. DC-DC Converter - Replaced in reactivation of system in November, 1964. See Drawing 398C-1080061 for schematic of new power conditioner.

Converter Input Voltage	4.37-4.25 V.DC
Converter Input Current	1.1-2.0 Amps.
Converter Output Voltage	24-30 V. DC
Converter Output Current	110-150 Milliamps

2. Battery - The battery is a 10-ampere hour, sintered plate, nickel cadmium type (Sonotone 24-10H120) and is made up of 22 cells connected in series and tapped to provide -12 and -28 volts.

H. Test Results

The latest parametric curve, obtained by Navy personnel in the Antarctic after the internal gas change of November, 1964, appears as Figure 7C-1. The Martin Company was not notified as to exact operating temperatures after the gas change, and so ranges have been indicated under Section E of this Summary.

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Section 4.3

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I. Reports and Instruction Manuals

MND-P-2614

Final Safety Analysis SNAP-7C

MND-P-2640

(Second Revision
November 20, 1964)

Instruction Manual SNAP-7C
Electric Generator System

MND-3296-1

Instructions for Revision and
Internal Gas Change of SNAP-7C
Electric Generator System.

J. Engineering Drawings

1. Generator Drawings 398-30210XX Series

2. System Drawings 398C108005X Series
398C108006X Series

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FIGURE 7C-1

SNAP-7C Electric Generation System Installation

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FIGURE 7C-2

SNAP-7C

GENERATOR PERFORMANCE CURVES

SEPTEMBER 1961

INTERNAL GAS: 100% HELIUM

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FIGURE 7C-3

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Section 4.4

Page 4-4-1

Issue Date: March, 1965

SNAP-7D

FLOATING WEATHER STATION POWER SUPPLY

A. Mission

Provide all electrical power required for a U. S. Navy Floating Weather Station (NOMAD) located in the Gulf of Mexico.

B. Program Status

Complete.

C. Generator Information

Same as SNAP-7B except for fuel loading (See Section C of SNAP-7B , page 4-2-1).

Fuel - 224,000 curies (1411.3 thermal watts)
of Strontium 90 (SrTiO_3).
Generator fueled on June 12, 1962.

Fuel is contained in 13 capsules installed in outer fuel block holes and bottom of center hole. Fourteenth capsule was placed empty in top of center fuel block hole.

D. Design and Actual Characteristics

1. Operating Temperatures (Beginning of Life)

Hot Junction, °F	960
Cold Junction, °F	150

2. Power (Peak power point - beginning of life)	67 watts
--	----------

3. Degradation Allowance	None
--------------------------	------

4. Internal Resistance, ohms (Beginning life)	~ 1.75
--	--------

5. Stress Levels to which the Generator was tested:

Vibration, g's	3
Shock, g's	3

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Section 4.4

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6. Efficiencies (End of Life)

Thermal	85.7%
Thermoelectric	5.22%
Generator	4.47%

E. T/E Design

Same as SNAP-7B. See Section E of SNAP-7B and Figures 7B-1 and 7B-2.

F. Auxiliary Equipment

1. Batteries - Three 3VO 170P (Gulton) batteries in series. Nickel cadmium sealed cells, with nominal voltage of 3.6 volts (each battery) and capacity of 170 AH at 2 hour rates.
2. Current sensing mechanism adjusted to automatically switch weather station to auxiliary battery supply if generator current drops below 3 amps.

G. Test Results

See final report for details. Figure 7D-2 of this Summary shows the parametric curve obtained after the generator was fueled.

H. Reports

MND-2664	Safety Evaluation of SNAP-7D System.
MND-P-2786	"Instruction Manual SNAP-7D Electric Generator System."
MND-P-2835	Final Report "Generator Power Source, Thirty Watt U.S. Navy Floating Weather Station."

I. Engineering Drawings

1. Generator Drawings 398-30211XX Series
2. System Drawings 398D-1080050 and 398D-1080051

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Figure 7D-1

SNAP-7D Generator Installation, --
Floating Weather Station Power
Supply

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SNAP 7D Generator (Fueled) Parametric Data (Internal Gas: Pure Helium; Water Temperature: 75° F)

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FIGURE 7D-2

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Section 4.5

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Issue Date: March, 1965

SNAP-7E

ACOUSTIC BEACON POWER SUPPLY (UNDERSEA)

A. Mission

Provide a nominal 6 watts at 28 volts to power an undersea acoustic beacon.

B. Introduction and Operational History

The SNAP-7E generator was originally constructed and electrically heated for SNAP-7A and 7C operational tests. After these tests were completed the generator was de-rated to ~8 watts (e) by reducing the fuel loading, and was then used as SNAP-7E. The system leaked on the first emplantment effort and was returned to the Martin Company where redesign and rebuild of the system pressure containment vessel was carried out.

The SNAP-7E Undersea Generator System was successfully emplaced in 15,600 feet of water approximately 100 miles southwest of Bermuda on July 13, 1964. The system has been operating satisfactorily since that date. The generator provides power for an underwater acoustic beacon which emits an acoustic signal every 60 seconds.

C. Program Status

Complete. No further company effort is anticipated.

D. Generator Physical Characteristics and Performance Summary

1. Power, watts

Design (Beginning of life)	8
Actual (at emplantment)	6.45
End of Life Requirement	~4.5

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Section 4.5

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2. Mission Life
(After Emplantment), years 2
3. Fuel - 31,000 curies of Strontium 90
Titanate (SrTiO_3) contained
in four hastalloy "C" capsules.

Thermal Inventory 195 watts

Fueling date; June 25, 1962
4. Envelope Dimensions
(Lower half of forged pressure
vessel) See Figure 7E-1

Diameter, inches 30
Length, inches 30
5. Generator Weights, pounds

Generator (alone) 235*
Biological Shield/Pressure Vessel 6000**
6. Shielding - consists of depleted
uranium shield plug, cast iron and
4340 forged steel pressure vessel.
7. Thermal Insulation Min-K 1301
8. Operating Temperatures, °F (Actual)

Hot Junction
(In air, Argon gas fill 3/64) 810-820
Cold Junction
(In air 3/64) 90-95
9. Internal Resistance (3/64) ohms 2.8
10. Open Circuit Voltage (3/64), 8.6 V DC

E. T/E Design

Same as SNAP-7A before SNAP-7A was rebuilt except for module atmosphere. See SNAP-7A Sections F1, F2 and F3a, and Figures 7A-1 and 7A-2.

Module Atmosphere (Internal gas) 100% Argon gas

*Including 114# depleted uranium shield plug.

**Is not entire system weight.

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Section 4.5

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F. Auxiliary Equipment

1. DC-DC Converter - New converter built prior to second and final emplantment effort.

DC-DC Converter Design Operating Points:

Beginning of life (3/64)

Input voltage, volts DC	4.0
Input current, amps	1.58
Output voltage	28.0

End of life (6/68)

Input voltage, volts DC	4.0
Input current, amps	1.36
Output voltage	28.0

2. Capacitor Bank - 42 (12,000 mfd) capacitors connected in parallel to give approximately 0.5 farads.
3. Electronics Package (G.F.E.) - provides 20 milli-second, 3.4 ampere electrical pulse at a peak of 500 volts to transducer once every 60 seconds.
4. Transducer (G.F.E.)

G. Test Results

The last parametric curve generated before the successful emplantment is shown in Figure 7E-2. The empty SNAP-7E pressure vessel was successfully tested to 8000 psi at the Naval Research Laboratory hydrostatic test facility near Washington, D.C. The pressure vessel and installed generator were successfully pressure tested to 6000 psi at the same facility at a later date.

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Section 4.5

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H. References

MND-P-2706

Safety Analysis of a Ten-Watt
Sr-90 Fueled Generator for
Deep Sea Application (Feb., 1962).

MND-2821

Instruction Manual - SNAP-7E
Electric Generator System, 2nd
Revision (June 25, 1964).

MND-P-3058

Safety Evaluation of Proposed
SNAP-7E Modification Procedure
in Support of Application for
Amendment to License No. 19-1398-21.

MND-3241-2

Nuclear Safety Evaluation of the
Modified SNAP-7E Undersea Acoustic
Beacon.

I. Engineering Drawings

1. Generator Drawings 398-30210XX Series
2. System Drawings 398E-30212XX Series

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FIGURE 7E-1

SNAP-7E - PRESSURE VESSEL -
SNOW SHOE ASSEMBLY

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FIGURE 7E-2

GENERATOR PERFORMANCE CURVES - SNAP 7E

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Section 4.6

Page 4-6-1

Issue Date: Nov., 1965

SNAP-7F

NAVIGATIONAL AID POWER SUPPLY

A. Introduction

The SNAP-7F generator was originally built as a test unit and was therefore installed in a test container and operated with electrical heaters. It was used in the gas build-up study program aimed at determining the cause of the internal gas pressure buildup in various SNAP generators (Final Report, MND-3143-1,--"Investigation of Gas Pressure Buildup in Thermo-electric SNAP Generators"). During these tests the unit was identified only as an "Operating Model". Following the gas build-up program the electrical heaters were removed and the generator installed in a biological shield in preparation for fueling. The generator was re-designated as SNAP-7F.

Immediately after fueling, the SNAP-7F generator was sent to Geneva, Switzerland for a United Nations exhibit. Following its return from Geneva, the SNAP-7F generator was stored at the Martin Company to await a decision by the A.E.C. on its final disposition. The installation of the SNAP-7F generator in an off shore petroleum production platform (Fulf of Mexico) was slowed by the fact that the first choice in installation sites, a Tenneco oil production platform, was destroyed by hurricane "Hilda" in the fall of 1964. After some delay, a second installation site, Phillips Petroleum Company's Rollover A-No. 1",

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was selected and the generator installed in s support leg of the platform on June 21, 1965.

On August 6, 1965 the Martin Company wad advised of non-normal performance of the system. In the next twenty days the problem was determined to be a generator internal short from the generator thermoelectrics to the generator case and through the water to the platform leg, which was compensated for by re-wiring two internally grounded flashing lights and the monitoring light to isolate them from platform ground.

Again on October 2, 1965, the Martin Company was advised of a SNAP-7F system malfunction. Examination of the generator system at its installation site led to the conclusion that the problem was within the generator, and the generator was therefore removed from the platform and returned to the Martin Company on October 27, 1965.

B. Mission

1. As Operating Model (Electrically Heated) - Provide data on performance of SNAP-generators and on the gas pressure buildup associated with them.
2. Geneva Display (Generator Fueled) - Provide electrical power required by a floating weather station (similar to that powered by SNAP-7D) for demonstration purposes at United Nations exhibit.
3. Petroleum Production Platform (Generator Fueled) - Provide electrical power required by two flashing

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Section 4.6

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navigational warning lights and an electronic fog horn on a Phillips Petroleum Company production platform in the Gulf of Mexico (see Figure 7F-1).

C. Program Status

Generator has been returned from petroleum production platform for repair of problem, the nature of which is not known at present. Corrective action awaits contract agreement and funding by A.E.C.

D. Generator Design Characteristics

Unless listed below, the generator design characteristics are the same as those contained in Section 4.2 under Item C.

1. Fuel - 212,000 curies (1334 thermal watts) of fuel Strontium 90--less than 0.15 percent Strontium 89 at loading). Generator fueled on July 13, 1964.

2. Operating Characteristics

	Output Power*, Watts(e)	Operating Temperatures* H/J** C/J		Internal Resistance* Ohms
Nominal beg. of life	60	850-900	150-155	1.75
July 1964	See Figure 7F-3			
May 1965	See Figure 7F-4			

**Uneven fuel distribution causes ΔT along H/J surface. H/J temperature depends on operating load and T/C read on H/J surface.

* Vary according to load at which generator is operated.

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Section 4.6
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E. Thermoelectric Design

Same as SNAP-7B--see Section 4.2, Item D and Figures 7B-3 and 7B-4.

F. System Components (Besides Generator)

For the petroleum production platform, the following equipment was furnished by the Martin Company:

1. "Battery Box", which houses;
 - a. Current Sensing Relay - which automatically switches system load to auxiliary batteries if the generator output current drops below a preset value.
 - b. Readout Meters - for generator charging current and system battery voltage.
 - c. System Batteries - Ni Cad batteries 9 cells (@1.30 volts/cell) in series for approximately 12.0 V.D.C. at 10 amp drain rate. Capacity, -170 ampere hours. (Gulton Industries 3VO-170P)
2. Cable and Water Tight Feedthrough Connector - Neoprene sheath cable with two #2 AWG copper conductors. Cable moulded to feedthrough connector. Cable connects generator to "Battery Box".

G. Test Results

See Figures 7F-3, 7F-f and Item H of this section.

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Section 4.6

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H. Reports and Instruction Manuals

MND-3143-1	Final Report, "Investigation of Gas Pressure Buildup in Thermo-electric SNAP-Generators".
MND-3366-1	Fueling Instructions - SNAP-7F Sr-90 T/E Generator
MND-3366-2	SNAP-7F - Safety, System Installation and Operation Instructions for Geneva, Switzerland Display (August 17, 1964 - Rev. I)
MND-3366-3	Gas Production Platform Site Safety Analysis for SNAP-7F (April 23, 1965)
MND-3366-4	Instruction Manual - SNAP-7F Electric Generator System, Gas Production Platform Site.
MND-3296-5	Trip Report - SNAP-7F Production Platform Installation (June 25, 1965)
MND-3296-6	Trip Report - SNAP-7F Power Supply Inspection (August 31, 1965)
MND-3296-8	Trip Report - SNAP-7F Power Supply Inspection (Oct. 25, 1965)

I. Engineering Drawings

1. Generator Drawings - 398-30211XX series.
2. System Drawing - 398F-3021001 - Modifies SNAP-7B Container Tank shown in Dwg. 398B-1080050, Sht's. 1 and 2 for Geneva Exhibition.

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Figure 7F-1
SNAP-7F Navigational Aid
Power Supply System

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Figure 7F-2

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SNAP-7F 60 Watt Generator -
Locations of Capsules in
Generator

TOTAL THERMAL POWER - SNAP 7F GENERATOR 1334 WATTS
AT DATE OF FUELING, JULY 13, 1964.

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Figure 7B-3

SNAP7F Fueled Generator
Parametric Curves

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MND-3241

JULY 18 THRU JULY 21
1964

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SECTION 5.0

SNAP-9A TRANSIT SPACE GENERATOR

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Section 5.0

Page 5-0-1

Issue Date: March, 1965

SNAP-9A

TRANSIT SPACE GENERATOR

A. Mission

Space power system capable of furnishing the power required by a Department of Defense Satellite.

B. Introduction

The external and cross-sectional appearances of the SNAP-9A generator are as shown in Figures 9A-1 and 9A-2 respectively. During the program a total of six generators were constructed and tested. The present status of each of these generators is as follows (generators identified by serial numbers, - S/N):

S/N 1 - Destroyed in safety test

S/N 2 - Presently exists as an electrically
heated test generator

S/N 3 - Was disassembled for diagnosis as reported in
Appendix B of Final Report - Now exists in
disassembled state

S/N 4 - Space mission

S/N 5 - Failed to achieve space orbit after launch

S/N 6 - Space mission

C. Program Status

Complete, - No further company effort anticipated.

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Section 5.0

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Issue Date: March, 1965

D. Generator Characteristics and Performance Summary

1. Power, watts (nominal - end of life)*	25
2. Mission Life, years	6
3. Fuel* - Curies of Plutonium-238 500-520 thermal watts Fueling dates - vary	
4. Envelope Dimensions, inches	
Diameter (without fins)	9
Diameter (with fins)	20
Length	26
5. Generator Weight, pounds	
6. Shielding - None besides Haynes 25 Fuel Capsule	
7. Thermal Insulation - Min-K 1301	
8. Operating Temperature (Design) °F*	
Hot Junction (end life)	920
Cold Junction (end life)	340
9. Degradation Allowance	10%
10. Internal Resistance*	
11. Stress levels generator design tested to	
Sustained Acceleration	
Thrust axis	36 g's for 3 minutes
Lateral axis	3 g's for 1 minutes
Shock	
Thrust axis	30 ± 3 g for 11 ± 1 milliseconds

* These values vary from one 3/N generator to another and from one time to another. The reader should see Appendix C of Volume II of the Final Report for more information.

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Section 5.0

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Vibration - sinusoidal

Thrust axis - frequency sweep from 5 to

2000 cps at 2 octaves/min.

5-10 cps at 0.5 inch DA
10-50 cps at ± 2.3 g
50-500 cps at ± 10.7 g
500-2000 cps at ± 21 g

Lateral axis - frequency sweep from 5 to

2000 cps at 2 octaves/min.

5-50 cps at ± 0.9 g
50-500 cps at ± 2.1 g
500-5000 cps at ± 4.2 g

Vibration - random

Lateral axis - spectral density of $0.07 \text{ g}^2/\text{cps}$
from 20-2000 cps for 4.4 minutes

Thrust axis - same except for duration of
4.0 minutes

12. Efficiencies - design efficiencies not available.

E. T/E Design

1. General Configuration

2 couples/module, 35 modules/generator,
spring-piston arrangement maintains press on bonds

2. Element Material - Elements were manufactured by the
Minnesota Mining and Manufacturing Company.

"P" Element - lead telluride, - pressed and
sintered. Manufacturers type, 3M-2P

"N" Element - lead telluride, - cast. Manu-
facturers type, 3M-2N

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Section 5.0

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Issue Date: March, 1965

3. Element Dimensions, inches

"P" Element

Length 0.595 $\begin{matrix} +.000 \\ -.010 \end{matrix}$

Diameter 0.410 $\begin{matrix} +.002 \\ -.003 \end{matrix}$

"N" Element

Length 0.625 $\begin{matrix} +.000 \\ -.010 \end{matrix}$

Diameter 0.375 $\pm .002$

4. Bonds - The bonds on the SNAP-9A generators are all the same with the exception of S/N 2 generator. Bond materials are identified accordingly.

a. For all but S/N 2 generator

"P" Element Bonds

Hot junction - Tin

Cold junction (between element and disk diffusion barrier) - Tin

Cold junction (between disk diffusion barrier and copper electrical connections) - Tin

"N" Element Bonds

Hot junction - Nickel

Cold junction (between element and disk diffusion barrier) - Nickel

Cold junction (between disk diffusion barrier and copper electrical connections) - Tin

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Section 5.0

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Issue Date: March, 1965

b. For S/N 2 Generator

"P" Element Bonds

Hot junction - Germanium Telluride (GeTe)

Cold junction (between element and
disk diffusion barrier) - Germanium
Telluride (GeTe)

Cold junction (between disk diffusion
barrier and copper electrical
corrections) - Tin

"N" Element Bonds - Same as all other generators

5. Spring-piston pressure

Spring designation C 300-038-0560

Spring compression, inches	Max.	Min.
----------------------------	------	------

Cold (room temp)	.297	.194
------------------	------	------

Hot (operating temp)	.291	.188
----------------------	------	------

Spring Rate, #/in.		32.3
--------------------	--	------

Spring pressure	Max.	Min.
-----------------	------	------

Cold	87.18	47.16
------	-------	-------

Hot	85.20	46.0
-----	-------	------

Note: Maximum case is associated with the "N" element,
while minimum case corresponds to the "P" element.

6. Operating environment - Various gases, such as argon, krypton and helium (and combinations there of) used during generator tests. Argon gas used in all generators launched into space.

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Issue Date: March, 1965

F. Auxiliary Equipment

A DC-DC converter was designed to be furnished with the generator. Because the Applied Physics Laboratory (Johns Hopkins) was able to design a more efficient converter, the Martin built unit was not used with the system. See the Final Report (Volume II) for the details concerning the DC-DC converter built by Martin.

G. Test Results

1. Operation Tests - All generators have been individually tested with varying results. The results which follow are for one generator, but are typical of all [495 watts (e) heater input, argon gas fill].
 - a. Temperatures, °F

Hot junction	940°
Cold junction	320°
 - b. Power, Watts (e) 27
 - c. Internal Resistance, ohms 1.35
 - d. Open circuit voltage, volts 11.3
2. Dynamic Tests - Passed all dynamic and safety tests without revision.
3. Module Test - No reliable data gathered from module test due to leaks in fixture.
4. Thermal Test - Thermal tests indicated that the actual parasitic thermal losses were approximately 45 watts.

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5. Space Environment Test - Placed generator in vacuum chamber and simulated orbital conditions. Power remained stable except for the approximately 0.5 watt variation from dark to light condition.

H. Reports

MND-P-2700-1
-2
-3

SNAP-9A - Quarterly Progress Reports

MND-P-2775

SNAP-9A Preliminary Safety Analysis

MND-P-2775-1
and -2

SNAP-9A Final Safety Analysis Reports

MND-P-2804

SNAP-9A Safety Test Report

MND-P-3098-1
and -2

SNAP-9A Final Report
Volumes I and II

I. Engineering Drawings

For the SNAP-9A generator are of the 417-3021XXX series with 417-3021000 as the top assembly drawing.

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FIGURE 9A-1

SNAP-9A

EXTERNAL VIEW

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FIGURE 9A-2

SNAP-9A

CROSS-SECTIONAL VIEW

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FIGURE 9A-3

SNAP-9A T/E COUPLE ASSEMBLY

REF. DWG'S:

417-3021005

417-3021006

417-3021008

417-3021009

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FIGURE 9A-4

SNAP-9A
T/E MODULE ASSEMBLY

REF. DWG's:

417 - 3021006

417 - 3021007

417 - 3021048

SCALE 2/1

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SECTION 6.0

SNAP-11 RADIOISOTOPE POWER SYSTEM
FOR THE
SURVEYOR SPACECRAFT

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Section 6.0

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Issue Date: March, 1965

SNAP-11

RADIOISOTOPE POWER SYSTEM FOR THE
SURVEYOR SPACECRAFT

A. Introduction

SNAP-11 is being developed for NASA to supply power for the instruments of an unmanned laboratory which may be "soft-landed" on the surface of the moon. The radioisotope package can also supply heat to the electronic package during the lunar night. The unit will be capable of supplying 25 watts of electricity for 120 days and will be fueled with Curium-242. SNAP-11 is sometimes internally referred to as the "431 Project."

B. Program Status

S/N's 1, 2, 3 & 4 were built & tested. S/N 4 was reworked to include modifications. S/N 5 is being built incorporating improvements developed in the test program.

C. Mission

Supply power to Surveyor Spacecraft. Surveyors mission is to study the moon's terrain and gravitational field over a 90 day period and transmit data and television pictures back to earth.

D. Generator Design Summary

1. Net Power, watts (e)	21.25
2. Mission Life, days	120
3. Fuel	Curium-242

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Section 6.0

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4. Envelope Dimensions

Diameter (including fins), inches	18.00
Length	12.38

5. Generator Weight, lbs 35

6. Shielding None required

7. Thermal Insulation Min-K-1301

8. Operating Temperatures, °F

Hot Junction	925
Cold Junction	350

9. Degradation Allowance

10. Internal Resistance, ohms ~ .35

11. Thermal Loss

Watts	~ 95
Percent	~ 20

12. Shock & Vibration Environment

Shock, g's	25
Vibration, g's	22.5
Acceleration, g's	10

13. Efficiencies

Thermal, %
T/E, %
Generator, %

E. T/E Design (See Figures 11-2 and 11-3)

1. General Arrangement

6 Couples/module, 12 modules/generator

Bonds on T/E couples are supplemented by a spring-piston arrangement.

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Section 6.0

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Issue Date: Nov., 1965

For generators S/N 1, S/N 2, S/N 3 and S/N 4:

Spring Designation C300-038-0560
Spring Rate, #/in. 32.3 $\pm$ 10%

Spring Compression, inches	Nominal	Max.	Min.
Cold (Room Temp.)	0.180	0.233	0.132
Hot (Operating Temp.)	0.202	0.255	0.154

Spring Pressure, psi	Nominal	Max.	Min.
Cold (Room Temp.)	62	88	41
Hot (Operating Temp.)	70	96	48

For generators S/N 5 and up:

Spring Designation C300-045-05605
Spring Rate, #/in. 65.2 $\pm$ 10%

Spring Compression, inches	Nominal	Max.	Min.
Cold (Room Temp.)	0.180	0.233	0.132
Hot (Operating Temp.)	0.202	0.255	0.154

Spring Pressure, psi	Nominal	Max.	Min.
Cold (Room Temp.)	125	178	83
Hot (Operating Temp.)	141	194	96

Note: N and P elements are same size. Therefore, spring pressures are the same for both elements. Numbers above are from generator tolerance studies

2. Material - PbTe purchased from 3M

3. Bonding - Furnace brazed

"P" bonds are tin at both ends

"N" bonds are nickel at hot end, tin at cold end.

4. Dimensions - Circular elements, both N and P have identical dimensions.

Diameter, inches	0.346
Length, inches	0.500

5. Internal Atmosphere Argon

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F. Auxiliary Equipment

1. DC-DC Converter

Input, VDC	3.3
Output, VDC	28
Efficiency, percent	85

2. Thermal Shutter - Because of the relatively short half life of Curium-242, excess fuel is required at the beginning of life in order to meet end of life power requirements. A NaK actuated thermal shutter is incorporated in the design to dump the excess heat.

G. Reports

MND-P-2811

SNAP-11, Surveyor Program
Quarterly Progress Reports

MND-P-2952

SNAP-11, Surveyor Program
Quarterly Progress Reports

H. Drawings

Drawings may be found under the following numbers.

431A-XXXX XXX	S/N's 1, 2 and 3 generators Proto-type generators; for test purposes only.
431B-XXXX XXX	S/N 5 generator and up are now being built. Electrically heated test generators with modified thermal controlled shutter system.
431C-XXXX XXX	S/N 4 generator only - Hybrid test unit.
431D-XXXX XXX	Flight or fueled configuration - 431B generators will probably be converted to 431D units by removing electrical heater block and fuel.

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FIGURE 11-1

SNAP II
EXTERNAL APPEARANCE

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FIGURE 11-2

SNAP 11
T/E COUPLE ASSEMBLY

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FIGURE 11-3

SNAP-11

T/E MODULE ASSEMBLY

REF. DWG'S.

431-1110006

431-1110007

431-1110034

431-1110040

431-1110045

TIN BOND BETWEEN
ELEMENT DISK AND
GOLD PLATED CONNECT-
ING AND TERMINAL
LUGS.

SCALE: 1/1

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SECTION 7.0

SNAP-17A COMSAT (SPACE GENERATOR)

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Section 7.0

Page 7-0-1

Issue Date: March, 1965

SNAP-17A

COMSAT - SPACE GENERATOR

A. Introduction

A major objective of the SNAP-17 Program is to demonstrate the feasibility and practicality of Strontium-Yttrium 90 as a fuel for reliable, long lived space power supplies. The power supply is supported by a ground handling system for fueling the generator. This equipment is being developed concurrently with the generator system.

B. Program Status

The SNAP-17A Program has been divided into three contract phases:

- I. Design and development
- II. Build and test
- III. Production

Phase I has been completed by the Martin Company in competition with General Electric. Presently, the Phase I efforts are being evaluated in preparation for award of Phase II of the SNAP-17A contract. Phase I competition has resulted in two different generators; thus the Martin Company's generator is designated SNAP-17A, while G.E.'s is SNAP-17B.

C. Mission

Space, - specifically, the U.S.A.F. Medium Altitude Communications Satellite System.

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Section 7.0

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Issue Date: March, 1965

D. Generator

1. Net Power, watts (e)	Nominal 29
2. Mission Life, years	5
3. Fuel	Strontium-Yttrium 90
4. Envelope Dimensions:	
Diameter	17.76"
Length	12.5"
5. Generator Weight, pounds	24.5
6. Stress	
Shock, g's	50
7. Shielding - fuel shielded during ground handling only	
8. Thermal Insulation - combinations of flexible Thermo-flex batting, Min-K 2000 and Min-K 1301.	

E. Design Summary

1. Operating Temperatures	
Hot Junction Temp, °F	1415
Cold Junction Temp, °F	430°
Radiator Temp, °F	425
2. Power, watts (nominal)	29.0
3. Degradation Allowance	10%
4. Internal Resistance, ohms	1.12
5. Thermal Loss	
Watts	30.5
Percent	20.4%

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6. Stress - shock and vibration for launch

Shock, g's	50
Vibration, g's	16
Sustained Acceleration, g's	15

7. Efficiencies

Thermal	79.6%
T/E	6.46%
Generator	5.15%

F. T/E Design

Thermoelectric modules will be purchased from RCA as complete module assemblies.

1. Material - SiGe - For electrical properties, see Appendix L of MND-3307-33-1.

2. Dimensions - both "N" and "P" elements are semi-circular in cross-section.

Diameter, inches	0.23"
Length, inches	0.75"

3. Bonds - numerous, - see discussion of in MND-3307-33-1

4. Appearance - see Figures 17-1 and 17-2

5. Operation Environment - air or hard vacuum

G. Auxiliary Equipment

A DC to DC converter will be supplied with the following characteristics.

	At launch	After 5 years
1. Input voltage, volts	7.18	6.34
2. Output voltage, volts	30.8	25.2

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At launch After
 5 years

3. Efficiency 90%

4. Weight, pounds

H. Test Results

Not completed under Phase I. Preliminary results indicate modules will satisfy electrical and mechanical requirements.

I. Reports

MND-3307-33-1 Part 1	SNAP-17A System Phase I Final Summary Report
MND-3307-33-1 Part 2	SNAP-17A System, Safety -- Phase I Final Summary Report
MND-3307-33-2	SNAP-17A System, Phases II and III Development Plan
MND-3307-33-3	SNAP-17A System, Specifications
MND-3307-33-4	SNAP-17A System, Costs -- Phases II and III
MND-3307-33-5	SNAP-17A System, Summary
MND-3307-33-6	SNAP-17A System, "Topical T/E . Test and Development

J. Engineering Drawings

For Drawing System Breakdown, see drawing 451A0100000

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FIGURE 17A-1

SNAP 17A GENERATOR
25 WATT (e) SYSTEM

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FIGURE 17A-2

SNAP 17A
DETAILS OF "AIR-VAC" THERMOCOUPLE
CONSTRUCTION AND ASSEMBLY
(TO BE BUILT BY R.C.A.)

SCALE: ~ 2/1
SKETCH DATE 22 DEC '64

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FIGURE 17A-3

SNAP 17A
T/E MODULE ASSEMBLY
(TO BE BUILT BY R.C.A.)

SCALE: < 1/1
SKETCH DATE 22 DEC. '64

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SECTION 8.0

SNAP-19 NIMBUS (SPACE GENERATOR)

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Section 8.0

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Issue Date: March, 1965

SNAP-19

NIMBUS - SPACE GENERATOR

A. Mission

Space power supply, - specifically Nimbus B for which two SNAP-19 generators will be required.

B. Program Status

Effort continuing, - hardware as follows has been built:

S/N 1* Generator - Electrically heated test model,
interconnections between T/E modules are made with
one #8 wire connected to terminal lugs by
soldering.

S/N 2 Generator - Electrically heated test model,
interconnections between T/E modules made with
two #12 wires which are soldered to terminal lugs.

S/N 3 and 4 Generators - Electrically heated test models,
interconnections between T/E modules are made with
one enlarged stranded wire which is crimped to
terminal lug.

S/N 5 and 6 Generators - Flight or fueled models now under
construction (Dec., 1964), T/E module inter-
connections same as S/N 3 and 4.

* S/N = Serial Number

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Section 8.0

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C. Generator Characteristics

1. Power, watts (end-of-life)	30
2. Mission Life, years	
Shelf	1
Space	1
3. Fuel - Curies of Plutonium-238 (635 thermal watts)
contained in six fuel capsules.	
4. Envelope Dimensions, inches	
Diameter (excluding fins)	
Diameter (including fins)	22-1/2
Length	10
5. Generator Weight (Flight Gen), pounds	
6. Shielding - Fuel capsule material is all required	
7. Thermal Insulation - Min-K 1301	
8. Operating Temperatures, °F	
Hot Junction	940
Cold Junction	400
9. Design Degration Allowance	10%
10. Internal Resistance, ohms	0.132
11. Design Stress Levels	
12. Efficiencies (design - end-of-life)	
Thermal	91.5%
Thermo-electric	6.05%
Generator	5.54%

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Section 8.0

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Issue Date: March, 1965

D. T/E Design

1. General Configuration (see Figures 19-2 and 19-3)

15 Couples/module, 6 modules/generator

Series - parallel wiring arrangement

3 Couples/parallel grouping

Spring-piston arrangement supplement bonds

Spring Designation

Spring Rate, #/in

Spring Compression, inches

Max. Min.

Cold (room temp)

Hot (operating temp)

Spring Pressure, psi

Max. Min.

Cold

Hot

2. T/E Material - Lead telluride, elements manufactured by the Minnesota Mining and Manufacturing Company.

"N" Element

3M-TEGS-2NB, pressed and sintered

"P" Element

3M-TEGS-2PB, pressed and sintered

3. T/E Element Dimensions

"N" and "P" elements are same size. Size is:

Diameter, inches 0.377 $\pm$.002

Length, inches 0.500 $\begin{smallmatrix} +.000 \\ -.010 \end{smallmatrix}$

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4. Bonds (see Figure 19-2 and 19-3)

"P" Element Bonds

Hot junction - Tin

Cold junction (between element and
and disk diffusion barrier) - Tin

Cold junction (between disk diffusion
barrier and copper electrical
connections) - Tin

"N" Element Bonds

Hot junction - Nickel

Cold junction (between element and
disk diffusion barrier) - Nickel

Cold junction (between disk diffusion
barrier and copper electrical
connections) - Tin

5. Module Operating Environment - Argon

E. Auxiliary Equipment

DC to DC converters (2) will be supplied as part of the SNAP-19 system. A parallel arrangement of the converters will allow one converter to handle both generators should one converter fail.

Converter Characteristics (end-of-life)

Input voltage, volts

Input power, watts

Output voltage, volts

Output power, watts

F. Test Results

See reports as listed in the following section.

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Section 8.0

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G. Reports

MND-3169

All SNAP-19 Reports - Different reports are identified by dash numbers.

H. Engineering Drawings

SNAP-19 drawings are identified by the following numbers:

452A-XXXX XXX Electrically heated test generators

452B-XXXX XXX Fueled or "flight" generators

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FIGURE 19-1

SNAP 19 GENERATOR
30 WATT (e) SYSTEM

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FIGURE 19-2

SNAP 19

T/E COUPLE ASSEMBLY

REFERENCE DWG'S:

452A 130000 1

452A 130000 3

452A 130000 4

PN 7400000

SCALE : 2/1

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SNAP 19 T/E MODULE ASSEMBLY

FIGURE 19-3

MIN-k 1301
INSULATION

TIN BOND BETWEEN
GOLD PLATED CONNECTOR
AND IRON DISC (DIFFUSION
BARRIER)

REFERENCE DWG'S.

452A1300000
452A1300001
452A1300005
452A1300006
452A1300007

HOT SHOE ELEMENT ASS'Y
(T/E COUPLE ASS'Y)

SCALE: 1/1

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SECTION 9.0

SNAP-21A UNDERSEA GENERATOR

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Section 9.0

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Issue Date: Nov., 1965

SNAP-21A

UNDERSEA GENERATOR

A. Introduction

The SNAP-21 program plan calls for three phases of design and fabrication as follows:

Phase I - Design and development of generators with a nominal 10 watt(e) output power.

Phase II - Fabrication of prototype 10 watt(e) generators and design of 20 and 60 watt(e) output power units.

Phase III - Fabrication of prototype 20 and 60 watt(e) generators.

The Atomic Energy Commission awarded parallel Phase I contracts to the Martin Company (under Contract AT(30-1)-3322) and the Minnesota Mining and Manufacturing Company, the best performance during the Phase I program to determine the winner of Phase II. The Phase I generator designed and developed by the Martin Company was designated as SNAP-21A, while that designed and developed by 3M designated as SNAP-21B.

Design and development efforts on SNAP-21A resulted in significant improvement and change in thermoelectric couple design and fabrication, and in the design of the entire generator during the Phase I period over that originally proposed. Many thermoelectric couples were produced and tested, and the design changed frequently. An electrically heated operating

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model of the SNAP-21A generator was built and tested. The results of these development efforts led the Martin Company to recommend for Phase II a thermoelectric couple assembly which had been tested in parts but not as a complete assembly. The generator design recommended also differed from the one built and tested. The data and figures which follow are a summary of the generator design characteristics recommended by the Martin Company to the A.E.C. for Phase II of the SNAP-21A program, and for that reason the details will be different from those to be seen by casually glancing through various reports, etc.

SNAP-21A includes several previously unused desirable concepts for isotope thermoelectric generator design. First, the thermoelectric module is independently sealed and may be removed and installed without concern for the radiation produced by the radioactive fuel, due to shielding between the fuel and module. These features would permit "in field" installation and replacement of the module if necessary. Secondly, the concept of "split" shielding, i.e., some of the biological shielding is external to the thermal insulation and some internal to it, results in a smaller size for the generator than would otherwise be required.

B. Mission

Under-sea applications in water pressures up to 10,000 psi.

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C. Program Status

The Phase I effort was completed by the Martin Company in June, 1965. After evaluation of the competing firms' reports, Phase II of the SNAP-21 program was awarded to the Minnesota Mining and Manufacturing Company. No further Martin Company effort is anticipated on this project.

D. Generator Design and Performance Summary

1. General - The SNAP-21A Power System is composed three major subassemblies as follows (see Figure 21-2).

- a. The upper titanium pressure vessel contains a thermoelectric module employing 16 segmented couples, a dc-to-dc power conditioner with a 24-volt dc output, and a electrical quick attach-detach feedthrough connector.
- b. A Hastelloy C Fuel Capsule containing 28 kilocuries of Strontium-90 and a mechanically attached Uranium-8% molybdenum biological top shield.
- c. The lower titanium pressure vessel contains a Uranium-8% molybdenum biological shield and a evacuated foil-type thermal insulation canister assembly.

2. Specific

- a. Power (Generator - End of Life),
watts

11.1

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Section 9.0

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- b. Mission Life (years) 5.0
- c. Fuel - Strontium-90 Titanate
- Thermal input, start of life
(watts(t)) 178.0
- Fuel loading (curies) 28,000.0
- d. Envelope Dimensions
- Diameter (inches) 14.25
- Length (inches) 19.60
- e. System Weight (pounds) 580
- f. Thermal Insulation
- Capsule - High efficiency vacuum insulation
by Linde Company - super-insulation
- Module - Min-K 1301
- g. Biological Shielding - Uranium, 8% Molybdenum
- h. Operating Temperatures
- Hot Junction (End of Life) 950°F
- Cold Junction (End of Life) 120°F
- i. Internal Resistance (at
operating temperature, ohms)
- Couple 0.014
- Module 0.224
- j. System Design Environment
- Ambient Water Operating
Temp (°F) 34.5 ± 6.5
- Pressure (PSI) Sea Level to 10,000
- Humidity--External (Percent) 0-100
- Shock (g's) 6 Peak
- Vibration 5-32 CPS with excursion of
0.54 to 0.066 in. or 3g,
whichever is less.

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k. Efficiencies (percent)

Thermal	70.0
Thermoelectric	10.1
Generator (excluding converter, end of life)	7.07
dc-to-dc Power Conditioner	90.0

l. Pressure Vessel Material Titanium

D. Thermoelectric Design (See Figures 21-3, 21-4 and 31-5)

Pancake module configuration, wherein, 32 alignment buttons, pistons and compression springs are used to preload the sixteen thermoelectric couples and to provide alignment features and compensate for variations in the length of individual elements. The module heat sink is made from copper for its high thermal conductivity and is designed to mate with the upper pressure vessel. A block of Min-K is machined to accept the 32 thermoelectric elements and fill the surrounding volume with this highly efficient insulating material. A two-mil wafer of zirconium getter material is placed on the inner surface of the bellows diaphragm and then a 10-mil sheet of aluminum oxide is installed to provide electrical insulation between the thermocouple hot shoes and steel diaphragm. When the module is completely assembled, the interior is evacuated and back-filled with an inert gas to eliminate oxidation and minimize thermal losses. When the interior environment is established, the module gas conditioning tube is pinched off and sealed by soldering.

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1. Module Spring Configuration

Spring Designation C300-045-0560 Associated
Spring Corp.

Spring Compression (cold) inches-"P" leg-0.187,
"N" leg-0.167

Spring Material Music Wire

Spring Constant, #/in. 78.3

Spring Force (Nominal goal-hot
conditions) 150.0

Spring Force on Bellows
(pounds) 443.0

2. Module Atmosphere - slightly in excess of one
atmosphere pressure of
argon gas.

3. Couple Configuration (See Figure 21-2)

a. "N" Element - Two cast PbSnTe segments joined
by hot pressing with tin, tin bond at hot
junction, and between the cold end of the
element and the stainless steel cold shoe.
The two cast PbSn segments are different in
doping level.

b. "P" Element - The hot segment material is
3P (3 M Co.) and the cold segment material
is BiSbTe. The two segments are joined with
bismuth solder. The nickel flashed iron cold
shoe is soldered to the cold segment with
bismuth solder. Tin telluride is used to hot
press bond the hot segment to the hot shoe.

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c. Summary of Thermoelectric Element Characteristics

	P _{Hot} Segment	P _{Cold} Segment	N _{Hot} Segment	N _{Cold} Segment
Material	3P (3M Co.)	BiSbTe	Pb _{0.85} Sm _{0.85} Te	Pb _{0.85} Sn _{0.15} Te
Fab. Med.	Cold Pressed & Sintered	Cast, Single Crystal	Cast	Cast
Length	0.306	0.244	0.289	0.236
Diameter	0.354	0.354	0.319	0.319

d. Hot Shoe - Ferro-Vac-e iron material with
0.080 deep counterbore for the P-element and
.045 deep counterbore for the N-element.

E. Auxiliary Equipment

DC-to DC Converter

Input

2.0 VDC

12.0 Watts

Output

24.0 VDC

10.0 Watts

F. Test Results

See Quarterly and Summary Reports.

G. Reports

MND-3322-7

First Quarterly Progress Report
SNAP-21 Ten Watt Deep Sea Isotopic
Power Source

MND-3322-13

Second Quarterly Progress Report
SNAP-21 Ten Watt Deep Sea Isotopic
Power Source

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MND-3322-19

Third Quarterly Progress Report
SNAP 21 Ten Watt Deep Sea Iso-
topic Power Source.

MND-3322-25
Volume I

Summary Report--Phase I SNAP-21
Ten Watt Deep Sea Isotopic Power
Supply

MND-3322-25

Summary Report--Phase I SNAP-21
Ten Watt Deep Sea Isotopic Power
Supply

H. Engineering Drawings

<u>No.</u>	<u>Title</u>	<u>Class.</u>
453A0200005	Heater Block-Opr. Model	-
007	Insul. Eff. Test Tool	-
* 011	16 Couple Module Assy-- Spring Loaded	Conf.
* 012	Heat Sink-16 Couple Test Mod. Spring & Piston	-
013	Wiring Diag.,-16 Couple Module Development	-
014	Seal Ring	-
015	Alignment Components,- T/E Module	-
* 016	T/E Couple Assy-Spring Contact	-
017	Terminal Strip	-
018	Test Canister	-
019	Plate Bellows Clamp	-
453A0300000	Pressure Vessel Assy.- Hydro. Test	-
453A1000000	Generator Assy. Operating Model	Conf.
001	Generator Sub Assy.- Lower Sect.	-
453A1000002	Generator Sub Assy.- Upper Sect.	Conf.
453A1100010	Housing-Generator-Lower Sect.	-
011	Spacer & Hold-down com- ponents	-
012	Housing-Generator-Upper Sect.	-

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453A1100013	Insulation Ring	-
014	Spacer-Insulation Support	-
453A1200000	Heat Source Assy. (not drawn)	-
011	Fuel Canister (not released)	Conf.
012	Fuel Capsule	Conf.
*453A1300002	Module Assy.-Spring Loaded Oper. Model	Conf.
014	Insulation Block	-
016	Index Pin	-
* 017	Heat Sink-Spring & Piston Oper. Model	Conf.
018	Insulation Block-Oper. Model	Conf.
019	Insulation Disk	-
453A1500000	DC/DC Converter (not drawn)	-
001	Wiring Diagram - Generator Assy.	Conf.

Procurement Items

PN 1000000	Biological Shield	-
2000005	Forging-Gen. Housing-Upper Sect.	-
2000006	Forging-Gen. Housing-Lower Sect.	-
4400004	Bellows Assy.	-
5500000	Insulation Assy.	-

*These drawings are designated "development" and will remain in the development status.

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Figure 21-1
Artist's Concept of SNAP-21A
Generator External Appearance

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Figure 21-2
SNAP-21A Ten Watt Undersea
Generator

LEGEND

A Electrical feedthrough connector	H Hold-down ring
B Cooling fin	I T/E module assembly
C Instrumentation space	J Vacuum insulation assembly
D Dc/dc converter	K Biological shielding
E Pressure vessel	L Fuel capsule
F Flange bolt	M Fuel canister
G Viton O-ring seals	N Cold junction heat sink

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Fig. II-11. SNAP 21A Thermoelectric Couple Configuration

Figure 21-3
SNAP-21A Thermoelectric Couple Configuration

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Figure 21-4
SNAP-21A Thermoelectric
Module Components

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Figure 21-5
SNAP-21A Thermoelectric Module--
Assembled and Wired for Test

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SECTION 10.0

UNDESIGNATED ISOTOPE - THERMOELECTRIC GENERATORS

- 10.1 Space Generators Used with Transit 4A & 4B. (Similar to SNAP-3)
- 10.2 Axel Heiberg Weather Station Power Supply
- 10.3 IMP - Space Power Supply for Inter-Planetary Monitoring Probe
- 10.4 Product Line Generator
- 10.5 250 Watt Study
- 10.6 Apollo

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AXEL HEIBERG

WEATHER STATION POWER SUPPLY

A. Introduction

An entire automatic, nuclear powered, meteorological data transmitting radio station was designed and fabricated by the Martin Company for the Division of Isotopes Development, U. S. Atomic Energy Commission, and the U. S. Weather Bureau, for unattended service on Axel Heiberg Island in the Arctic Region. The purpose of the weather station was the transmission of weather data, barometric pressure, wind direction and speed, and air tempeature, to a manned weather station at Resolute Bay, Cornwallis Island, approximately 225 miles away.

The weather station obtained electrical power for its operation from an integral generator fueled by Strontium-90. This generator is generally referred to as the "Axel Heiberg Generator", and was the fore-runner of the SNAP-7 series of generators. Though of lower electrical power output, the thermoelectric assembly of the "Axel Heiberg Generator" was very similar to that of the SNAP-7A, 7C and 7E generators.

After its installation on August 17, 1961 in its Axel Heiberg Island operating site, the generator and weather station system operated as expected for approximately two years. Then problems developed within the electronics of the weather

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station. As a result, the weather station portion of the system was removed from the site in the summer of 1963 so that it could be repaired. The generator, which continued to operate normally, was left on short circuit at the site while the weather station was removed for repair. In the summer of 1964 the generator internal gas was changed, and the weather station electronics replaced. The station electronics operated intermittently for eight months until it was finally removed in the spring of 1965 for good. On August 20-21 of the same year the power system (generator and batteries) was also removed for shipment back to the Martin Company to await relocation.

B. Program Status

As of the first of November of 1965 the "Axel Heiberg" generator was located at the Martin Company's Baltimore plant awaiting a decision from the A.E.C. as to its new disposition, and a contract to perform any work that may be necessary to relocate the generator.

C. Mission

Power supply for remote weather station in the Arctic Region (see Fig. 10.2-10).

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D. Generator Data

1. Power, watts (e)
Designed 5.00
Actual (Beginning of Life) 4.85
2. Mission Life, years 2.0
3. Fuel - Strontium-Titanate
(SrTiO_3) in one fuel
capsule (~17.5 Kilo curies)
100 Watts - Sr-90) Fuel thermal inventory
7 Watts - Sr-89) at May 12, 1961 fueling
date.
4. Envelope Dimensions
(Biological Shield)
Diameter, inches 17.875
Length, inches 19.0
5. Generator Enclosure
Assembly
Diameter, inches 8.0
Length 10.125
6. Thermal Insulation Min-K, Type 1301
7. Biological Shielding
Material Lead
Thickness, Average, inches 4.4
8. Operating Temperatures
Hot Junction, °F
(Actual-Beg. Life) 900.0
Cold Junction, °F
(Actual-Beg. Life) 140.0
9. Internal Resistance, ohms 3.45

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10. Stress Requirements -
USAF Bulletin Spec. 106A

Shock, g's	30
Vibration, g's	15

11. Efficiencies

Thermal, percent (design)	84.5
Thermoelectric, percent (design)	7.45
Generator, percent (Actual-Beg.Life)	4.14

E. Thermoelectric Design

1. Thermoelectric Material

"P" Element - Martin Cast Lead Telluride
"N" Element - Martin Cast Lead Telluride

2. Thermoelectric Arrangement

5 couples/module, 12 modules/generator for a total of 60 couples/generator. Electrical interconnections are series. (See Figs. 10.2-2, 10.2-5 and 10.2-9.)

3. Thermoelectric Element Dimensions, inches

	Length	Diameter
"P" Element	1.250 $\pm$.010	0.235 $\pm$ 0.002
"N" Element	1.250 $\pm$.010	0.190 $\pm$ 0.002

4. Hot Shoe Material--Ferro-Vac-E, spray coated with aluminum oxide .010 thick on H/J surface and nickel plated in the counterbore for element bonding.

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5. Bonds and Bonding Process

"P" Element

Hot Junction - Germanium Telluride

Cold Junction - Indium-Lead-Tin Solder

"N" Element

Hot Junction - Nickel

Cold Junction - Indium-Lead-Tin Solder

The bonding process is shown by pictures in Figs. 10.2-1 through 10.2-9. Briefly, first "N" and "P" elements were ultrasonically tinned, as shown in Fig. 10.2-1, with indium-lead-tin solder on what was to become the "cold" end. Then the hot shoe, with the "N" element counterbore nickel plated, was placed in the assembly fixture, shown in Figs. 10.2-3 and 10.2-4, along with a thin germanium-telluride disk in the "P" element counterbore and the "N" and "P" thermoelectric elements. The couple bond was then made in a hydrogen-argon atmosphere by induction heating the surface on which the hot shoe rested while subjecting the elements to a compressive spring load. To complete a module assembly, five couples were placed in the module insulation piece and then in a positioning tool adjacent to the previously ultrasonically tuned cold cap assemblies. The "cold" end bond was made by heating the assembly in air. The

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module assembly sequence is shown in Figs. 10.2-6, 10.2-7, and 10.2-8. A completed module is shown in Fig. 10.2-9.

6. Thermoelectric Compressive Loading

Spring Designation	C-300-032-0440
Spring Material	Music Wire
Spring Constant, #/in	27.3
Element Loading	Presently Unknown

7. Generator Internal Atmosphere--1 atmosphere (mixture 95% argon and 5% hydrogen)

F. Auxiliary Equipment

1. dc-dc Converter with charge limiting regulation

Input	Output
4.2 Volts	28.0 volts (approximately)
4.5 watts	2.4 watts

G. Test Results

See Quarterly Progress and Final Progress Reports as listed under Item H, Reports.

H. Reports

1. MND-Sr-1672 - Strontium-90 Power Project Quarterly Report No. 1.
2. MND-SR-1673 - Strontium-90 Power Project Quarterly Progress Report No. 2.
3. MND-SR-1674 - Strontium-90 Power Project Quarterly Progress Report No. 3.
4. MND-SR-1675 - Strontium-90 Power Project Quarterly Progress Report No. 4.
5. MND-SR-1676 - Strontium-90 Power Project Final Summary Report.

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6. MND-SR-2259 - Hazards Summary Report - Five-Watt Radiostrontium Gen. for an Unattended Meteorological Station.
7. MND-SR-2308 - Hazards Summary Report, 100-Watt Radiostrontium Gen. for Land.
8. MND-SR-2586 - Final Safety Analysis - Five-Watt Radiostrontium Fueled Gen. for Unattended Meteorological Station.
9. MND-SR-2428 - Data Telemetry Package, Powered by a Strontium-90 Generator, Interim Report.
10. MND-SR-2606 - Instruction Manual - Data Telemetry Package Powered by a Strontium-90 Generator.
11. MND-SR-2615 - Data Telemetry Package Powered by a Strontium-90 Fueled Generator Final Report.

I. Engineering Drawings

1. Generator Drawings

<u>Drawing Number</u>	<u>Title</u>
383-3021000	Generator and Shield Assembly
383-3021001	Thermoelectric Elements
383-3021002	Details - Stron.-90 Gen.
383-3021003	Container Assembly
383-3021004	Heat Sink--Stron.-90 Gen.
383-3021005	Heater Housing
383-3021006	Thermoelectric Element Assembly
383-3021007	Details Fuel Housing
383-3021008	Generator Housing Assembly

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383-3021009	Electrical Connector--Stron.-9 Gen.
383-3021010	Min-K Insulation
383-3021011	Biological Shield Container
383-3021012	Fuel Capsule Assembly
383-3021013	Generator Housing Cap
383-3021014	Spacer
383-3021015	Fuel Capsule
383-3021016	End Plate
383-3021017	Electrical Connector
383-3021018	Insulation--Inner Generator
383-3021019	Electrical Test Container
383-3021125	Key
383-3021126	Shipping Pallet
383-3021127	Name Plates
383-3021128	Container Weather Station
383-0099001	Thermoelectric Elements
383-0099002	Thermoelectric Elements
383-0099003	Base Plate
383-0099004	Details
383-0099005	Details
383-0099006	Thermoelectric Element Ass'y.

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2. Weather Station Drawings

383-3021025	Data Telemetry Package Assembly
383-3021026	Welded Assembly Electronic Device
383-3021027	Details Electronic Deck
383-3021028	Wiring Diagram, Sta. Programming Sub-System
383-3021029	Assembly, Data Processing
383-3021030	Assembly, Data Processing
383-3021031	Details, Data Processing
383-3021032	Wiring Diagram, Data Processing Sub-System
383-3021033	Card Nos. 1 and 2 Assemblies, Data Processing
383-3021034	Schematic, Diagram Cards 1 and 2 Wind Speed Counter Shift Register
383-3021035	Card No. 2 Trigger Multiplexer
383-3021036	Schematic, Card No. 2 Trigger Multiplexer
383-3021037	Card No. 4, Data Processing Assembly
383-3021038	Schematic, Card No. 4 Data Multiplexer
383-3021039	D.C. Motor Master Timer, Automatic Weather Station
383-3021040	Assembly, Master Timer
383-3021041	Details, Master Timer
383-3021042	Schematic, Master Timer

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383-3021043	Master Timer Test Spec. 383-3021040
383-3021044	Chronometer Watch Master Timer-- Automatic Weather Station
383-3021045	Assembly, Converter Battery Charger
383-3021046	Details, Converter Battery Charger
383-3021047	Schematic, Converter Battery Charger
383-3021048	Converter Battery Charger Test Spec. 383-3021045
383-3021049	Top Assembly Drawing, Auto. Weather Sta.
383-3021050	Oscillator-Driver Assy.--Trans- mitter
383-3021051	Schematic Diagram, Oscillator Driver
383-3021053	Details, Oscillator Driver
383-3021055	Bias Power Supply Assembly, Details and Schematics
383-3021056	Test Spec., Transmitter Bias Supply Assembly 383-3021055
383-3021058	Schematic, Bat. Reg., Isotopic Gen.
383-3021059	Component Board Bat. Reg., Isotopic Gen.
383-3021060	Transmitter Assembly
383-3021061	Details, Transmitter

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383-3021062	Schematic, Final Amplifier Transmitter
383-3021063	Test Spec.--Transmitter Assembly 383-3021050 and 060
383-3021065	Assembly, Power Supply
383-3021066	Details, Power Supply
383-3021067	Schematic, Power Supply
383-3021068	Test Spec., High Voltage Supply Assy. 383-3021065
383-3021069	Battery Regulator Detail and Assy.
383-3021070	Barometer Assembly
383-3021071	Digital Barometer Assy.--Outline Drawing
383-3021072	Barometer Amplifier Printed Card Assy.
383-3021073	Schematic, Barometer Amplifier
383-3021074	Test Spec., Altimeter Setting Indicator Assembly 383-3021070
383-3021084	Wind Direction Indicator, Wiring Diagram
383-3021085	Assembly, Anemometer
383-3021086	Details, Anemometer
383-3021087	Installation Anemometer
383-3021088	Schematic, Anemometer Assy.
383-3021089	Wind Speed Indicator Test Spec., Martin Part No. 383-3021085
383-3021090	Wind Direction Indicator Assy.
383-3021091	Details Wind Direction Indicator Assy.

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383-3021092	End Coder Assy., Wind Direction Indicator
383-3021093	Installation Wind Direction Indicator
383-3021094	Wind Direction Indicator Test Spec., Martin Part No. 393-3021090
383-3021095	Thermometer Assembly
383-3021096	Therm. Element Assy., Digital Therm.
383-3021097	Encoder Assy., Thermometer
383-3021098	Radiation Shield and Therm. Assy.
383-3021099	Thermometer Wiring Diagram
383-3021100	Sequencer (Repeat Cycle Timer) Assy.
383-3021101	Test Spec., Sequencer and Power Switching
383-3021102	Test Spec., Data Processing Sub-system #383-3021030
383-3021103	Test Spec., Thermometer Assembly #383-3021095
383-3021105	Card No. 5 Data Processing
383-3021106	Card No. 5 Gray Shift Register
383-3021107	Card No. 6 Data Processing
383-3021108	Schematic, Card No. 6, Gray to Binary Converter and IRPG Nos. 1 and 2
383-3021114	Junction Box Wiring Diagram

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383-3021116	Junction Box Assy. (Modified)
383-3021117	Install Junction Box
383-3021118	FSK Converter Assembly
383-3021119	Schematic, FSK Converter
383-3021120	Thermometer Assembly Installation
383-3021121	Test Spec., Communication System Assembly 383-3021050 055 060 065 113 115 118
383-3021122	Interval Timer Details, Assembly and Schematic
383-3021123	Test Spec., Interval Timer 383-3021122-9
383-3021124	Weather Station System Test Spec.

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FIGURE 10.2-1

B-42x03

ULTRA-SONIC TINNING OF ELEMENT

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FIGURE 10.2.2

COUPLE DETAILS AND ASSEMBLY

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FIGURE 10.2-3

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FIGURE 10.2.4

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COUPLE FABRICATION AND ALIGNMENT TOOL

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FIGURE 10.2-8

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*APPROXIMATE DIMENSIONS

COLD CAP

7.600"

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AXEL HEIBURG GENERATOR
ASSEMBLED T/E MODULE

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FIGURE 10.2-9

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FIGURE 10.2-10

AXEL HEIBERG WEATHER STATION

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Section 10.3

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Issue Date: March, 1965

IMP (NO SNAP DESIGNATION)

A. Mission

Space power supply, specifically for the Inter-planetary Monitoring Probe.

B. Program Status

Program terminated due to magnetic effects created by the generator. A complete set of engineering drawings were made and module tests were run. The modules used in the module tests were run. The modules used in the module tests were found to produce an intolerable magnetic effect (satellite very sensitive to magnetic effects) which resulted in termination of the program.

C. Generator Characteristics and Other Data

Not included in this summary at this time IMP generator similar in many respects to the SNAP-19 generator.

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