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STRONTIUM 90-FUELED THERMOELECTRIC
GENERATOR POWER SOURCE FOR FIVE-WATT
U. S. COAST GUARD LIGHT BUOY

Addendum I

to ~~MND-P-2720~~

~~MND-3043-1~~

April 1964

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Artist's Concept of SNAP 7A Installation in Coast Guard Light Buoy

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FOREWORD

This report has been prepared by the Nuclear Division of the Martin Marietta Corporation. It covers the SNAP 7A power restoration for the period of June 1962 to March 1964. This work was authorized by the AEC and has been performed under Contract AT (30-1)-3043.

For additional information on the SNAP 7A system, refer to the following documents.

- (1) MND-P-2720, February 2, 1962, "Strontium 90-Fueled Thermo-electric Generator Power Source for Five-Watt U. S. Coast Guard Light Buoy--Final Report."
- (2) MND-P-2661, revised January 15, 1962, "Instruction Manual--SNAP 7A Electric Generation System."

This report, an addendum to MND-P-2720, includes data and information related to work performed since issue of the original report.

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SUMMARY

The objectives of Contract AT (30-1)-3043 were to test, evaluate and rework the SNAP 7A system as required to restore the system to operational status.

When the SNAP 7A generator was returned to the Martin Company from Curtis Bay in June 1962, it was thought that a change of the internal gas would correct the power deficiency. This power deficiency was felt to be due to an excess of strontium-89 (which has a shorter half life than strontium-90). Performance of the generator following the gas change was not satisfactory. Further testing of the generator revealed three causes for the power degradation:

- (1) Increase in internal gas pressure.
- (2) Increase in internal resistance.
- (3) Decay of strontium-89 in fuel.

A new statement of work was prepared and presented to the Atomic Energy Commission proposing that the generator be rebuilt and the thermoelectric elements and insulation replaced. By rebuilding the generator, the internal gas pressure increase and internal resistance increase, problems were to be reduced or eliminated.

On June 18, 1963, the SNAP 7A generator was defueled at the Quehanna hot cell facility of the Martin Company. Between this date and November 25, 1963, when the generator was again fueled, it was completely disassembled and rebuilt. The generator refueling was followed by more testing and integration of the generator with the rest of the system early in January 1964. The entire system was delivered and installed in the U. S. Coast Guard buoy at Curtis Bay, Maryland, on January 21, 1964.

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INTRODUCTION

The objectives of the SNAP 7A program were to develop and test a five-watt electric power generation system for a U. S. Coast Guard light buoy.

Under Contract AT (30-3)-217, the SNAP 7A generator was designed, fabricated and tested. The generator was fueled on November 20, 1961 with 40,800 curies of strontium titanate at the Quehanna, Pennsylvania hot cell facility of the Martin Company. After additional testing, the fueled SNAP 7A system was installed in the Coast Guard light buoy at Curtis Bay, Maryland, on December 15, 1961.

In February 1962, the Martin Company was notified by the U. S. Coast Guard of a drop in the output power of the generating system (from 10.5 watts on December 22, 1961 to 9.1 watts on February 16, 1962). After several additional months of observation, generator power output approached eight watts.

The unit was removed from the light buoy in June 1962 and returned to the Martin Company for detailed evaluation. The ensuing engineering evaluation and power restoration program, reported herein, was conducted under Contract AT (30-1)-3043 for the U. S. Atomic Energy Commission.

I. THE RESTORATION PROGRAM

A. HISTORY OF THE SNAP 7A GENERATOR

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. A plot of the results of this test is shown in Appendix A-1. 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 (Appendix A-2) showed that, not only had the pressure increased, but 33.10%, 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 to verify the results shown in Appendix A-3, "SNAP 7A Fuel Inventory Analysis." 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 decreasing 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.

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.

Since an increase in internal resistance with time had been observed in the fueled generator, careful resistance measurements were made at disassembly. A comparison of the resistances of each of the couples and the total resistances of the generator as of June 23, 1963 and as of original assembly on September 7, 1961 is given in Appendix B-1. Module E was removed from the generator, and detailed measurements of resistance and Seebeck voltage were taken. The results of these tests are shown in Appendix B-3. Note that the couple resistance measurements were taken with the module still connected to the cold sink frame with the couples still under the influence of the cold junction compression spring forces.

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.

The results of the above mentioned tests are discussed in Chapter III of this report, entitled, "Generator Performance Since Refueling." The system was then delivered and installed in the U. S. Coast Guard buoy at Curtis Bay, Maryland, on January 21, 1964.

B. CONCLUSIONS AND CORRECTIVE MEASURES

There were two major causes for the loss in power of the SNAP 7A generator:

- (1) Buildup of internal gas pressure resulting in excessive parasitic heat loss.
- (2) Increase in thermoelectric system internal resistance.

1. Buildup of Internal Gas Pressure

Internal gas pressure buildup was first discovered in the SNAP 7A generator. This condition was subsequently found to exist in the SNAP 7B and 7D thermoelectric generators. As a result, a program entitled, "Investigation of Gas Pressure Buildup in Thermoelectric SNAP Generators," was initiated at the Martin Company, Nuclear Division in February 1963 by the Atomic Energy Commission, under Contract AT (30-1)-3143. The reader is referred to MND-3143-1, which is the final report for the Gas Pressure Increase investigation.

In this report, it is stated that the gas pressure increase in the generators that were initially filled with dry inert gas results from:

- (1) Decomposition of the phenolformaldehyde resin that is used as a binder in the Min-K 1301 thermal insulation.
- (2) Desorption of atmospheric gases and water vapor that adsorb on the surface of the insulation.

The degree of gas release in both cases was determined to be temperature and pressure dependent.

The recommended procedure to control gas pressure buildup for all future generators is to:

- (1) Precondition the Min-K by burning off the phenolic resin binder.
- (2) Vacuum outgas the insulation at a temperature above its maximum operating temperature.
- (3) Install a gas getter (zirconium) to absorb any gases that may be released during subsequent generator operation.

The new Min-K 1301 insulation used in the SNAP 7A generator (see Section IIA of this report) was baked in an oven at an elevated temperature for several hours prior to its installation in the generator to burn off the phenolic resin binder. Before reassembling the generator, a 3/4-inch hole was drilled in the center of the heat accumulator fuel block and filled with a getter material (zirconium). After final assembly, the entire generator, while sealed and under evacuation, was exposed to heat lamps to rid the insulation and generator of atmospheric gases and water vapor absorbed primarily in the insulation.

The corrective measures outlined above appear to have solved the internal gas pressure buildup problem, since observation of the generator, over a period of four months since its final assembly and fueling, has not revealed any increase in generator internal pressure.

2. Increase in Generator Internal Resistance

As already noted, careful thermoelectric system resistance measurements were made at disassembly. In addition, Modules E and K were carefully dissected and detailed measurements were made. The results are given in Appendices B-1 through B-3. Examination of the data will show that the sum of module resistances increased from 665.0 milliohms in September 1961 to 842.2 milliohms in July 1963 (an increase of about 27%), and that generator total resistance (across power leads) increased from 669 to 1050 milliohms (57%).

The major increase in internal resistance is concluded to have occurred at the cold junction solder bond. Note, in Tables B-2 and B-4 of Appendix B, that the resistances of the cold bonds were very erratic, ranging from 0.410 milliohms to "cap off." "Cap off" means that the cold junction heat transfer cap of the thermoelectric assembly was not bonded upon removal from the generator.

The thermoelectric assembly procedure has been changed to correct deficiencies previously encountered. The "P" element hot junction bonding material has been changed from germanium-telluride to pure tin, and the bonding operation for both elements is performed by the furnace-bonding technique. On the cold ends of both elements, iron disks have been added to allow a different soldering process to be used. Further changes to the thermoelectric assembly are discussed in Section IIA of this report.

It is interesting to compare the resistance of the "P" and "N" hot bonds in Tables B-2 and B-4 of Appendix B (original SNAP 7A) with those in Table B-5 (SNAP 7A furnace-bonded couples). The bond resistances by the furnace-bonding technique are a factor of four to five lower than those in the original SNAP 7A.

3. Deficiency of Sr-90 in Fuel Inventory

Part of the decrease in power output of the SNAP 7A generator was thought to be due to the presence of strontium-89 in the fuel. It has a shorter half life (51 days) than strontium-90 (27.7 years). During the evaluation of the generator, however, the evidence of excess strontium-89 was insufficient to substantiate this explanation.

II. CHANGES TO THE GENERATOR AND SYSTEM

In this section, changes to the generator and system are discussed. Unless specifically mentioned, components and construction are unchanged.

A. GENERATOR

The thermoelectric assemblies (modules) were removed from the generator and replaced. Prior to use, the Min-K 1301 insulation binder was "burned out" by placing it in an oven. A gas gettering material was inserted (70 grams of zirconium) in a hole drilled in the center of the heat accumulator fuel block. A reworked depleted uranium shield plug was replated and had all of its edges rounded. A sheet of mica insulation has been added between the hot shoes of the thermoelectric elements and each of the four sides of the aluminum oxide coated heat accumulator fuel block to increase electrical resistance between the hot shoes and the fuel block.

Instrumentation has been added which will help to give a more complete picture of the generator's performance. There are now four thermocouples in the generator: one on the fuel block, two on the hot junction, and one on the cold junction side of the thermoelectric assemblies. A new electrical feed-through connector brings the leads from the two additional thermocouples out of the generator. A pressure transducer, installed in the cover of the generator, will indicate the internal gas pressure of the generator.

The generator now contains a gas mixture of 75% helium and 25% argon.

B. BATTERY

The new battery is a nine-ampere-hour, sealed, sintered plate nickel-cadmium, constant-current, charging type (Gulton Industries, No. 10 VO 9P). It has 10 cells, each with a nominal voltage of 1.2 volts, which are connected in series to provide 12 volts.

Sealed construction assures that there will be no spillage or leakage in any operating position. The battery is constructed in such a way as to allow charging at potentials lower than the gassing level, and gassing does not occur during discharge.

C. DC-TO-DC CONVERTER

The original dc-to-dc converter has been replaced by a completely new unit to match the rebuilt generator performance characteristics and charging requirements of the nickel-cadmium battery.

Basically, the converter takes the d-c output voltage of the generator, changes it to an a-c voltage, steps it up by means of a transformer, rectifies the increased voltage back to d-c voltage, and then feeds it to the output terminals of the converter. A special circuit on the input side of the converter shunts off any excess power from the generator and dissipates it internally. The input voltage to the converter is kept constant by a varying converter resistance which shifts to suit the generator output, and the output of the converter is supplied at a constant current. The converter is designed so that the battery cannot discharge through the converter. Figure 1 is a schematic diagram of the converter, and Table 1 lists the parts called out in Fig. 1. Installation of the battery and dc-to-dc converter within the light buoy enclosure is shown in Fig. 2.

TABLE 1
Parts List--SNAP 7A Converter
(P/N S1-631102)

<u>Schematic Part No.</u>	<u>Part Name</u>	<u>Manufacturer's Part No.</u>	<u>Description</u>	<u>Vendor</u>
Q1, Q2	Transistor	2N910	Silicon, NPN	Fairchild
Q3, Q4	Transistor	MHT2305	PNP	Minneapolis- Honeywell
Q5	Transistor	2N574	PNP	Minneapolis- Honeywell
Q6, Q7, Q8	Transistor	2N1647	NPN	Transitron
Q9	Transistor	2N1132	Silicon, PNP	Fairchild
Q10, Q11	Transistor	92K2	Compound, NPN	Fairchild
CR1, CR2, CR3, CR4	Transistor	2N1557	PNP	Motorola
CR5, CR6, CR7, CR8	Diode	USA F1N645	--	Texas Instrument
CR9, CR10	Reference diode	USN1N747A	--	Motorola
C1	Capacitor	90A2-3	0.01 μ fd, 100 volts	Aerovox
C2, C3, C4	Capacitor	CS12AE101M	100 μ fd, 20 volts	Sprague

Fig. 1. SNAP 7A DC-to-DC Converter Schematic Diagram

Fig. 2. Light Buoy Battery-Converter Compartment

TABLE 1 (continued)

<u>Schematic Part No.</u>	<u>Part Name</u>	<u>Manufacturer's Part No.</u>	<u>Description</u>	<u>Vendor</u>
R1	Resistor	RC20GF102J	1000 ohms, 1/2 watt	Ohmite
R2	Resistor	RC20GF222J	2200 ohms, 1/2 watt	Ohmite
R3	Resistor	ARS-5	1 ohm, 5 watts	Dale
R4	Resistor	SR5-W	50 ohms, 5 watts	Sage
R5	Resistor	RC20GF100J	(4) 10 ohms, 1/2 watt (par)	Ohmite
R6, R11	Resistor	RC20GF470J	47 ohms, 1/2 watt	Ohmite
R7	Resistor	RC20GF122J	1200 ohms, 1/2 watt	Ohmite
R8, R9	Resistor	RC20GF822J	8200 ohms, 1/2 watt	Ohmite
R10, R12	Resistor	RC20GF101J	100 ohms, 1/2 watt	Ohmite
R13	Resistor	RC32GF222J	2200 ohms, 1 watt	Ohmite
VR1	Potentiometer	RV6LAYSA102A	1000 ohms, 1/2 watt	Ohmite
VR2	Potentiometer	RV6LAYSA101A	100 ohms, 1/2 watt	Ohmite
T1	Transformer	SLT-631103	Saturating trans- former	ESPD, the Martin Company
T2	Transformer	T-631104	Power trans- former	ESPD, the Martin Company

To protect the unit, it has been potted in a standard military sheet metal container. It is mounted and held to the battery-converter enclosure by means of studs which protrude from the base of the can.

Fig. 3. SNAP 7A System Wiring Diagram

D. ASSEMBLED SYSTEM

Figure 3 is a wiring diagram of the SNAP 7A system as installed in January 1964. Changes in the battery, dc-to-dc converter, and additional instrumentation made it necessary to change the wiring of the assembled system. A schematic diagram of the system is shown in Fig. 4.

Fig. 4. Schematic Diagram--SNAP 7A System

The bench test setup of the system prior to installation in the U. S. Coast Guard light buoy is shown in Fig. 5.

Installation of the battery-converter box into the U. S. Coast Guard light buoy is shown in Fig. 6.

Fig. 5. SNAP 7A Light Buoy System Bench Test

Fig. 6. Installation of Battery-Converter Box in U.S. Coast Guard Buoy

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III. SNAP 7A GENERATOR PERFORMANCE SINCE REFUELING

Figure 7 shows the last parametric performance data taken on the SNAP 7A generator before its delivery on January 21, 1964. Peak power was 10.35 watts.

Table 2 shows SNAP 7A performance data taken by the U. S. Coast Guard since installation of the generator in the light buoy on January 21, 1964.

Fig. 7. SNAP 7A Generator Performance Curve--Last Parametric Curves Taken on SNAP 7A Generator Prior to Its Delivery on 21 January 1964.
Date of Data Curves: 2 January 1964

TABLE 2
 SNAP 7A Performance Data
 (since delivery on January 21, 1964 to the U. S. Coast Guard Yard,
 Curtis Bay, Baltimore, Maryland--data taken by U. S. Coast Guard)

<u>Date</u> <u>(1964)</u>	<u>Battery Voltage</u> <u>(volts, d-c)</u>	<u>Generator Voltage</u> <u>(volts, d-c)</u>	<u>Generator Current</u> <u>(amp)</u>	<u>Generator Power</u> <u>(watts)</u>	<u>Generator Pressure</u> <u>(psia)</u>	<u>Fuel Block</u> <u>Temperature</u> <u>(°F)</u>	<u>Hot Junction</u> <u>Temperature</u> <u>(°F)</u>	<u>Cold Junction</u> <u>Temperature</u> <u>(°F)</u>	<u>Water</u> <u>Temperature</u> <u>(°F)</u>	<u>Air</u> <u>Temperature</u> <u>(°F)</u>
January 22	14.00	5.49	1.74	9.55	15.8	919	914	69	36	40
January 23	14.15	5.54	1.72	9.55	15.9	915	907	58	37	44
January 27	14.14	5.40	1.71	9.22	15.9	927	922	76	38	52
February 4	14.19	5.50	1.66	9.15	15.9	928	924	74	37	39
February 10	14.14	5.46	1.64	8.95	15.9	929	923	76	39	38
February 17	14.21	5.48	1.62	8.87	15.9	930	923	75	38	48
February 24	14.28	5.54	1.58	8.77	16.1	929	924	77	39	43
March 2	14.22	5.50	1.58	8.70	15.8	932	926	74	39	62
March 9	13.96	5.38	1.59	8.54	15.9	940	935	84	46	58
March 16	14.05	5.40	1.57	8.48	15.9	940	931	84	45	50
March 23	14.05	5.42	1.55	8.40	15.9	938	934	79	46	52

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APPENDIX A

A. GENERATOR GAS ANALYSIS

The performance of the SNAP 7A generator was tested after receipt from the U. S. Coast Guard, and the data is shown in Fig. A-1.

Prior to changing the gas in the SNAP 7A generator, two gas samples were obtained. The gas bottles were evacuated and attached to the manifold, which in turn was evacuated. The valves were then opened to allow the gas to flow from the generator into the manifold and sample bottles. The bottles were then valved off and sent to the laboratory for analysis.

The gas analyses were performed with gas chromatograph equipment. Two independent checks were made on equipment located in the Space Flight Laboratory and in the Nuclear Laboratory. The results agreed within the accuracy expected of the equipment.

Since the gas chromatograph 'carrier gas' masks out the existence of hydrogen, the percent by volume of hydrogen has been calculated by using the initial temperature and pressure of the generator internal gas and the temperature and pressure of the gas at the time of its removal from the generator. The following data show the results of the gas analysis:

<u>Constituent</u>	<u>Percent by Volume</u>
N ₂	7.27
O ₂	1.00
CO	0.08
CO ₂	1.40
CH ₄	1.07
H ₂	20.99
Unidentified*	<u>1.29</u>
Contaminants	33.10

* It is now believed that the unidentified contaminants were propane and ethane. This belief is based on the results of other SNAP 7 series generator gas analyses made by the Institute of Gas Technology in Chicago, Illinois.

The original gas, according to the manufacturer's specification, was 99.995% pure helium. The contamination, therefore, has apparently been picked up from within the generator. The prime suspect is the outgassing or organic binder decomposition of the Min-K insulation. The proof of this is beyond the scope of this report.

Fig. A-1. SNAP 7A Generator Performance Data Upon Return from Curtis Bay--
Water Temperature at $77 \pm 1^{\circ}$ F

B. SNAP 7A FUEL INVENTORY ANALYSIS

Generator conditions--July 10, 1962

Hot junction temperature (F)	885
Water temperature (F)	77
Gas pressure (helium) (in. Hg gauge)	+ 0.2
Voltage (volts)	5.912
Current (amp)	1.514
Power (watts)	8.95
Power adjusted to +3 in. Hg gauge to match electrical tests on generator (watts)	8.63
Internal resistance of generator (7/10/62) (ohms)	3.10
Internal resistance of generator (electrical tests) (ohms)	2.57
Power loss due to ΔR_i (watts)	1.46
Power loss due to off-optimum load (watts)	0.04
Maximum power output (8.63 + 0.92 + 0.04) ($R_i = 2.57$, optimum load, +3 in. Hg gauge) (watts)	10.13
Power required during electrical tests to give 10.13-watt output (watts, thermal)	260
Assuming lead losses of 12 watts, estimated thermal power of generator (7/10/62) (watts)	248
Assuming 298 thermal watts encapsulated 10/1/62	
Sr-90 content at encapsulation (watts)	252
Sr-89 content at encapsulation (watts)	46.10
At present (8/10/62)	
Sr-90 (watts)	247
Sr-89 (watts)	<u>1.0</u>
	248 watts

APPENDIX B

TABLE B-1
SNAP 7A Couple Resistance Installed in Generator

<u>Module</u>	<u>Couple</u>	<u>September 1961 Resistance (milliohms)</u>	<u>July 1963 Resistance* (milliohms)</u>
A	1	9.5	9.4
	2	11.2	10.6
	3	8.2	10.4
	4	9.8	12.6
	5	10.9	13.1
B	1	9.8	17.9
	2	10.5	12.0
	3	12.3	11.4
	4	12.6	16.2
	5	11.7	15.4
C	1	12.0	17.5
	2	12.9	15.1
	3	10.9	12.4
	4	11.1	12.6
	5	13.3	16.4
D	1	10.7	11.4
	2	9.5	12.1
	3	10.3	9.6
	4	9.6	9.3
	5	13.9	11.0
E**	1	11.1	9.6
	2	12.5	9.5
	3	10.3	9.9
	4	13.1	14.2
	5	13.1	21.5
F	1	11.1	15.0
	2	9.9	10.0
	3	9.1	10.5
	4	9.0	10.9
	5	10.6	13.4

*July 1963, date of disassembly--prior to rebuild.

**See Table B-2 for detailed resistance readings of Module E.

TABLE B-1 (continued)

<u>Module</u>	<u>Couple</u>	<u>September 1961 Resistance (milliohms)</u>	<u>July 1963 Resistance* (milliohms)</u>
G	1	10.9	13.2
	2	11.3	13.1
	3	10.4	13.6
	4	10.6	10.4
	5	11.5	13.5
H	1	11.6	14.2
	2	11.8	15.1
	3	11.7	10.1
	4	12.5	18.6
	5	11.4	11.5
J	1	11.2	10.0
	2	10.1	11.0
	3	11.1	10.5
	4	9.9	11.8
	5	8.9	10.4
K	1	10.1	10.6
	2	13.5	47.2
	3	10.6	14.4
	4	10.0	10.4
	5	11.5	11.4
L	1	12.2	11.9
	2	9.5	11.9
	3	10.5	10.1
	4	10.8	19.1
	5	10.8	13.2
M	1	11.4	15.6
	2	11.3	16.4
	3	11.4	11.5
	4	10.6	12.6
	5	9.6	10.6
Σ modules		665.0	842.2
Generator**		669	1050

*July 1963, date of disassembly--prior to rebuild.

**Measured across power leads.

TABLE B-2
Detailed Resistances--Module E* at Disassembly
(milliohms)

<u>Couple No.</u>	<u>"N"</u>			<u>"P"</u>		
	<u>Cold Bond</u>	<u>Element</u>	<u>Hot Bond</u>	<u>Cold Bond</u>	<u>Element</u>	<u>Hot Bond</u>
1	0.47	2.91	1.02	Cap off	3.40	1.00
2	0.68	2.99	1.00	0.63	2.93	1.24
3	0.52	2.50	1.10	0.72	3.59	2.55
4	0.47	3.80	0.95	0.94	8.80	1.18
5	0.46	3.40	0.97	12.0	2.36	0.89

*See Table B-1, couple resistances--all modules.

TABLE B-3
Seebeck Voltages from Module E

<u>Couple No.</u>	<u>"N" Seebeck (mv)</u>		<u>"P" Seebeck (mv)</u>	
	<u>September 1961</u>	<u>July 1963</u>	<u>September 1961</u>	<u>July 1963</u>
1	74.9	76.0	68.6	88.5
2	75.3	73.1	70.3	72.9
3	70.8	69.6	79.5	72.4
4	81.7	82.1	69.8	73.4
5	76.9	77.9	68.1	77.3

TABLE B-4
Detailed Resistances--Module K at Disassembly
(milliohms)

<u>Couple No.</u>	<u>"N"</u>			<u>"P"</u>		
	<u>Cold Bond</u>	<u>Element</u>	<u>Hot Bond</u>	<u>Cold Bond</u>	<u>Element</u>	<u>Hot Bond</u>
1	Cap off	2.90	1.04	0.760	2.65	1.66
2	0.696	2.90	4.69	Cap off	2.17	1.26
3	5.22	2.57	2.30	0.920	2.16	1.10
4	0.410	2.85	1.76	Cap off	2.49	8.80
5	0.438	3.30	1.55	1.35	2.61	1.35

TABLE B-5
SNAP 7A Test Run Module (rebuilt)

Resistance (milliohms)														
Couple No.	"N"						"P"						Total Couple	
	Cold Bond		Element		Hot Bond		Cold Bond		Element		Hot Bond			
	Before*	After**	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
27	0.110	0.270	3.60	3.45	0.185	0.225	0.110	0.230	2.95	2.75	0.190	0.150	7.00	7.35
22	0.232	0.252	3.30	3.21	0.345	0.389	0.050	0.500	3.90	3.02	0.130	0.080	7.85	--
28	0.180	0.215	3.20	3.20	0.230	0.265	0.080	0.125	3.00	2.59	0.210	0.160	6.82	2.00
26	0.290	0.300	3.70	3.32	0.255	0.320	0.100	0.190	3.39	4.85	0.160	0.060	7.80	9.70
29	0.109	0.210	3.20	3.20	0.160	0.251	0.100	0.190	2.69	2.70	0.190	0.120	6.62	6.80

*Before module assembly.

**After module assembly.

Pure tin solder, pre-tin caps, 530° F in vacuum.

All solder joints 100% bonded.

APPENDIX C

SNAP 7A ENGINEERING DRAWINGS REVISED
DURING RESTORATION OF POWER

<u>Title</u>	<u>Number</u>
Installation--SNAP 7A Electric Generation System	398A-108000
Modifications--USCG Electric Lighted Buoy	398A-1080050
Details--Buoy Modification	398A-1080051
Battery--Converter Enclosure	398A-1080052
Thermoelectric Generator	398A-1080053
Cable Clamp Assembly	398A-1080055
Wiring and Schematic Diagrams	398A-1080058
Generator--Biological Shield Assembly	398-3021000
Cylinder--Fuel Capsule	398-3021001
End Plate--Fuel Capsule	398-3021002
Fuel Capsule Assembly	398-3021003
Fuel Block	398-3021004
Details--Fuel Block	398-3021005
Shield--Strontium-90 Generator	398-3021006
Insulation Strip	398-3021008
Thermoelectric Elements	398-3021010
Details--Cold Junction	398-3021012
Piston	398-3021013
Washer	398-3021014
Frame--Heat Sink	398-3021015

<u>Title</u>	<u>Number</u>
Bars--Heat Sink	398-3021016
Insulation--Corner Strip	398-3021017
Insulation--Spacer	398-3021018
Insulation--Plate	398-3021019
Plug--Flange Screw Holes	398-3021021
Electrical Connector	398-3021022
Connector Mount	398-3021023
Connecting Bar	398-3021025
Shipping Pallet	398-3021026
Nameplate	398-3021027*
Cover--Generator Test	398-3021028*
Cap Screw	398-3021029
Fuel Capsule Shipping Cask	398-3021040*
Biological Shield Container	398-3021041
Generator Cover Assembly	398-3021043
Details and Assembly--Fuel Shipping Cask	398-3021044*
Heat Sink Assembly	398-3021048
Generator Shell Assembly	398-3021049
Generator Pallet--Shipping Assembly	398-3021050
Electrical Connector	398-3021300
Insulation Block	398-3021301
Disk Details	398-3021302
Hot Shoe Element Assembly	398-3021303

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*Indicates nondeliverable items

<u>Title</u>	<u>Number</u>
Cold Shoe Assembly	398-3021304
Thermoelectric Module Assembly	398-3021305
Shoe--Hot Junction	398-3021306
Shield Block	398-3021307
Wire Guide	398-3021308
Generator Assembly	398-3021310