SNAP-15A THERMOELECTRIC GENERATOR

SUMMARY REPORT
July 1, 1968 through June 30, 1969

Prepared under
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for the
San Francisco Operations Office
U.S. Atomic Energy Commission

January 22, 1970
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1. **ABSTRACT**

This report summarizes the activities of the SNAP-15A testing program for the period July 1968 through June 1969. During this period twenty five generators were continued on life testing and the data analyzed for performance summary. Also one of the generators with more than 5 years life time was removed from test and examined for compatibility evaluation.

Examination of the interior components of the generator shows that they were in excellent condition even though they had operated in air for over 4 years. The changes in performance of all the generators due to causes other than fuel depletion has been less than 1% per 10,000 hours.

The program is being continued at Gulf General Atomic expense through Fiscal Year 1970 as a life testing program for the remaining twenty-four generators. Several electrically heated generators will have exceeded 5 year lifetime at the end of FY 70.
This report summarizes the past year's progress on a program to develop the SNAP-15A generator, a Pu-238, fueled, metal thermocouple generator capable of producing about 1 milliwatt of output power at greater than 4.5 volts at high reliability under extreme environmental conditions. The specified environmental conditions include an ambient temperature operating range of +165°F to -65°F, with thermal cycling through this range. The dynamic environment included vibration at 10 g from 10 cps to 2000 cps, constant acceleration at 60 g for 5 minutes and mechanical shock of 100 g for 11 milliseconds for all 3 orthogonal axes.

During the first several years of the program, 32 generators were fabricated, and over 1,100,000 total test hours have now been accumulated. During the development phase it was discovered that a more reliable hermetic seal was needed for containment, and that the method of fabrication of thermocouple junctions needed upgrading for reliability. A development program was then conducted which resulted in 1) an all welded and brazed stainless steel hermetically sealed container; 2) two reliable methods of fabrication of thermocouple junctions by dip brazing or electrolytic nickel plating; and 3) a fabrication method for winding of wire thermocouple bundles to achieve complete parallel redundancy of all 1300 thermocouple junctions. During a subsequent phase, 12 generators were fabricated with the upgraded canister design. Several of these generators developed leaks in a solder joint between the electrical output connector and the containment. A method of sealing these leaks and strengthening this joint was developed and proven by mechanical testing. The environmental performance and life testing of these generators was then initiated and is still in progress. The evaluation of long life generators has been initiated. All of the electrically heated prototype generators have operated continuously for more than 5 years. During FY 70 many nuclear heated generators will pass the 5 year lifetime goal.
3. TESTING

3.1 SUMMARY

A total of 24 generators remained on room ambient life testing during the entire report period of July 1, 1968 through June 30, 1969. Of these generators, 19 were fueled with Pu-238 and five were electrically heated. No generators have failed during the report period. A summary of accumulated test hours for all generators is given in Table I. There was no dynamic testing conducted during the report period. All generators were monitored regularly and the performance data was recorded and reported monthly.

3.1.1 Experimental Generators

Three electrically heated experimental generators remained on room ambient life test. Each of these generators has passed five and one-half years operation in air without failure. Accumulated hours for these generators are listed in Table II.

3.1.2 Demonstration Generators

Three prototype demonstration generators were maintained on room ambient life test and monitored regularly. An electrical heater failed in generator number 7 in February. A new heater was installed in the generator and testing was continued on this unit. The heater consists of a 2,000 Ω, 2-watt resistor which operates at ~400°F. This was the first failure of an electrical heater. In July, generator number 8 was removed from test and delivered to the materials evaluation group for disassembly according to an approved plan. At the time of termination, this generator had accumulated 48,833 hours without failure. The two remaining demonstration generators, number 6 and 7 will remain on test and will continue to be reported periodically. The accumulated test times on these generators are presented in Table II.
# TABLE I GENERATOR LIFE TEST SUMMARY

Accumulated Life Test Hours

<table>
<thead>
<tr>
<th>TYPE</th>
<th>TESTS TERMINATED (HOURS)</th>
<th>TESTS CONTINUING (HOURS)</th>
<th>TOTALS FOR ALL TESTS</th>
</tr>
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<tbody>
<tr>
<td>Experimental</td>
<td>5,088</td>
<td>153,240</td>
<td>158,328</td>
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<tr>
<td>Demonstration</td>
<td>48,833</td>
<td>97,459</td>
<td>146,292</td>
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<tr>
<td>Prototype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fueled and Electrical</td>
<td>214,223</td>
<td>602,575</td>
<td>816,798</td>
</tr>
<tr>
<td>TOTALS</td>
<td>268,144</td>
<td>853,274</td>
<td>1,121,418</td>
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## PROTOTYPE GENERATOR LIFE TEST SUMMARY

<table>
<thead>
<tr>
<th>AMBIENT TEMPERATURE °F</th>
<th>ELECTRICALLY HEATED</th>
<th>PLUTONIUM HEATED</th>
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<tr>
<td></td>
<td>ACCUMULATED TEST HOURS</td>
<td>MAXIMUM TEST HOURS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(SINGLE GENERATOR)</td>
</tr>
<tr>
<td>-65</td>
<td>2,564</td>
<td>2,459</td>
</tr>
<tr>
<td>Room</td>
<td>17,700</td>
<td>4,108</td>
</tr>
<tr>
<td>165</td>
<td>4,078</td>
<td>3,627</td>
</tr>
<tr>
<td>Cycling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTALS</td>
<td>24,342</td>
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</table>
### TABLE II LIFE TEST TIMES ON EXPERIMENTAL AND DEMONSTRATION GENERATORS

7/25/69

**Electrically Heated Experimental Generators**

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<thead>
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<th>Serial No.</th>
<th>Test Times (Hours)</th>
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<tr>
<td>3</td>
<td>51,376</td>
</tr>
<tr>
<td>4</td>
<td>51,067</td>
</tr>
<tr>
<td>5</td>
<td>50,797</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>153,240</strong></td>
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</table>

**Electrically Heated Demonstration Generators**

<table>
<thead>
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<th>Serial No.</th>
<th>Test Times (Hours)</th>
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<tbody>
<tr>
<td>6</td>
<td>49,766</td>
</tr>
<tr>
<td>7</td>
<td>47,693</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>97,459</strong></td>
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</table>
3.1.3 Pu-238 Fueled Generators

For the period July 1, 1968 through June 30, 1969, 21 Plutonium fueled generators remained at Gulf General Atomic, Incorporated. Of these, 19 were on room ambient life testing over the entire period. Generators 103 and 104, which were reported in the last annual summary to have failed during vibration testing, remained fueled, but were removed from testing and reporting. The accumulated life test hours of the generators currently on test are listed in Table III, their life performance test plots are presented in Figures 1 through 19.

3.2 EVALUATION OF DATA

The total hours (fueled and electrically heated) and the hours on test under each ambient condition for the generators under test are given in Table IV. The data on those generators removed from test are presented in Table V. Table VI summarizes the hours on test under each ambient condition for all generators which have been electrically heated at least once during the test program.

For evaluation of this data, the generators are separated into two groups for better comparison of performance and for more effective interpretation of changes in operating levels. One group, generators 14, 15, 22, 26, 101 and 111, are known to be operating with air in the body cavity, the Argon having diffused through large leaks in the cannister seal. These generators are listed in Table VII and their life performance data plots are presented referenced to start of life performance with air backfill. The remaining 13 generators are operating with Argon remaining in the cannister but with known leaks. The latest leak rate data on these generators are presented in Table VIII. Life performance data are tabulated in Table IX. The life performance data plots reflect a comparison to initial operation with Argon backfill. Thus, one is able to assess performance changes related to fuel depletion, Argon displacement with time, leak rate, and changes in resistance. Of the factors affecting power output, the displacement of the Argon is the most significant. Complete displacement results in a power loss of approximately 25%. The effect of fuel depletion is a continuing one, but only on the order of approximately 0.6% per 10,000 hours of operation.
<table>
<thead>
<tr>
<th>Gen. No.</th>
<th>Test Hours (1)</th>
<th>( R_i ) (2) KOh</th>
<th>( R_i ) Initial (3) KOh</th>
<th>( R_i ) Now (4) KOh</th>
<th>( V_i ) (5) Volts Initial</th>
<th>( V_i ) (6) Volts Now</th>
<th>( P_i ) (7) Watts Initial</th>
<th>( P_i ) (7) Watts Now</th>
<th>( % P_i ) (8)</th>
<th>( % P_i ) (8)</th>
<th>( % V_i ) (9) Initial</th>
<th>( % V_i ) (9) Now</th>
<th>( % R_i ) (10)</th>
<th>Notes (6)</th>
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Notes: (1) Total accumulated operational hours with PU-238 source.
(2) Internal resistance in ohms of the generator immediately after fabrication. Measured at room temperature.
(3) Internal resistance, open circuit voltage, load voltage, and power output determined at steady-state gradient operation following fueling with PU.
(4) Internal resistance, open circuit voltage, load voltage, and power output determined at the end of the current report period.
(5) Internal resistance, open circuit voltage, load voltage, and power output change from start to fueled life test.
(6) Notes on present status of the generators.
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with air

Fig. 1 SNAP-15A Generator No. 14
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with air

Fig. 2 SNAP-15A Generator No. 15
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 3 SNAP-15A Generator No. 19
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 4 SNAP-15A Generator No. 20
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with air

Fig. 5 SNAP-15A Generator No. 22
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with air

Fig. 6 SNAP-15A Generator No. 26
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 7 SNAP-15A Generator No. 29
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 8 SNAP-15A Generator No. 30
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 9 SNAP-15A Generator No. 31
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 10 SNAP-15A Generator No. 32
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with air

Fig. 11 SNAP-15A Generator No. 101
NOTE: 1. Ambient temperature 76°F  
2. Generator backfilled with argon

Fig. 12  SNAP-15A Generator No. 105
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 13 SNAP-15A Generator No. 106
NOTE:
1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 14 SNAP-15A Generator No. 107
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 15 SNAP-15A Generator No. 108
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 16 SNAP-15A Generator No. 109
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 17 SNAP-15A Generator No. 110
NOTE: 1. Ambient temperature 76°C
2. Generator backfilled with air

Fig. 18 SNAP-15A Generator No. 111
NOTE: 1. Ambient temperature 76°F
2. Generator backfilled with argon

Fig. 19 SNAP-15A Generator No. 112
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<th>Thermal Cycling</th>
<th>Total Fueled Test Time Hours</th>
<th>Total Electrical Test Hours</th>
<th>Cumulative Total</th>
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<td>45256</td>
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TABLE V TIME AND TEMPERATURE DISTRIBUTION OF SNAP-15A
FUELED GENERATORS REMOVED FROM TEST

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<th>Generator Number</th>
<th>-65°F</th>
<th>Room Temp.</th>
<th>165°F</th>
<th>Thermal Cycling</th>
<th>Total Fueled Test Time Hours</th>
<th>Electrically Heated Test Hours</th>
<th>Cumulative Total Test Time</th>
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* Electrically heated generator No. 16 is currently operating at the Gulf General Atomic office in Washington, D.C.
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<th>Generator Number</th>
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<th>Total Hours</th>
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<td>17</td>
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<td>16</td>
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<td>18</td>
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<td>16</td>
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Generators Currently on Fueled Life Test

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<td>331</td>
<td>339</td>
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<td>32</td>
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Total Electrical Life Test Hours 122,368
TABLE VII FUELED GENERATORS REFERENCED TO INITIAL AIR OPERATION

<table>
<thead>
<tr>
<th>Generator Number</th>
<th>Test Hours</th>
<th>Due to Fuel Depletion (%)</th>
<th>Other Causes (%)</th>
<th>Total Power Output Change (%)</th>
<th>Non-Fuel Causes per 10,000 hrs (%)</th>
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### TABLE VIII MEASURED LEAK RATES ON FUELED GENERATORS REFERENCED TO ARGON

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<th>Generator Number</th>
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<th>Test Time</th>
<th>Remarks</th>
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<td>Argon depletion not completed</td>
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<td>$&lt; 1 \times 10^{-9}$</td>
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<td>Argon depletion not completed</td>
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<td>$&lt; 1 \times 10^{-9}$</td>
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<td>105</td>
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<td>109</td>
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<td>112</td>
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### TABLE IX FUELED GENERATORS REFERENCED TO INITIAL ARGON OPERATION

<table>
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<tr>
<th>Generator Number</th>
<th>Test Hours</th>
<th>Due to Fuel Depletion (%)</th>
<th>Other Causes (%)</th>
<th>Total Change (%)</th>
<th>Non-Fuel Causes per 10,000 hrs. (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
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<td>-2.8</td>
<td>Leaking - 1% Resistance Decrease</td>
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<td>41071</td>
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<td>-8.9</td>
<td>-11.5</td>
<td>-2.2</td>
<td>Leaking - 2% Resistance Decrease</td>
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<td>-9.4</td>
<td>-1.7</td>
<td>Leaking - 1% Resistance Decrease</td>
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<tr>
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<td>41093</td>
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<tr>
<td>32</td>
<td>41067</td>
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<td>-7.2</td>
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<td>-1.8</td>
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<td>105</td>
<td>18548</td>
<td>-1.2</td>
<td>-10.3</td>
<td>-11.5</td>
<td>-5.0</td>
<td>Leaking - 6% Resistance Decrease</td>
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<tr>
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<td>Thermopile shorts</td>
</tr>
<tr>
<td>106</td>
<td>18515</td>
<td>-1.2</td>
<td>-17.3</td>
<td>-18.5</td>
<td>8.5</td>
<td>Leaking - 6% Resistance Decrease</td>
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<td>Thermopile shorts</td>
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<tr>
<td>107</td>
<td>18491</td>
<td>-1.2</td>
<td>-0.7</td>
<td>-1.9</td>
<td>0.3</td>
<td>Leaking - No Resistance Change</td>
</tr>
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<td>108</td>
<td>18395</td>
<td>-1.2</td>
<td>+0.1</td>
<td>-1.1</td>
<td>0.05</td>
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<tr>
<td>109</td>
<td>17760</td>
<td>-1.1</td>
<td>-3.9</td>
<td>-5.0</td>
<td>-1.9</td>
<td>Leaking - No Resistance Change</td>
</tr>
<tr>
<td>110</td>
<td>17736</td>
<td>-1.1</td>
<td>-2.2</td>
<td>-3.3</td>
<td>-1.1</td>
<td>Leaking - No Resistance Change</td>
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<tr>
<td>112</td>
<td>17688</td>
<td>-1.1</td>
<td>-2.5</td>
<td>-3.6</td>
<td>-1.2</td>
<td>Leaking - No Resistance Change</td>
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</table>
For those generators with air backfill, changes in power output as a result of causes other than fuel depletion is less than 1% per 10,000 hours. Generator 101 shows a slightly higher rate of degradation, but shows a greater change in resistance indicating that there are possibly electrical problems within the thermopile. Although generator 111 does not show a significant change in internal resistance, the change in power output is about the same as for generator 101. This can be explained since the circuitry is series-parallel where combinations of opens and shorts can produce no net change in internal resistance.

Generators 105 and 106 have experienced the greatest change in power output due to possible thermopile damage during vibration testing conducted during the previous report period. The Argon backfilled generators all show a considerably higher total change in power output as a result of gradual air diffusion into the cannister.
4. GENERATOR EVALUATION

4.1 SUMMARY

A SNAP-15A thermoelectric generator which had operated satisfactorily for a period of six years was examined for signs of deterioration and no signs of adverse behavior were observed. This particular generator used an internal electrical heater, powered by an external source, for maintaining the hot junction at 390°F. This generator contained 26 thermobundles with 25 thermocouples in series in each thermobundle, resulting in 650 thermocouples in series. There are two series circuits of thermocouples connected in parallel at each thermobundle junction for a total of 1300 thermocouples in a thermopile.

The examination of the unit consisted of removing the outer aluminum can and the thermal insulation thereby exposing the thermopile for closer examination. After removing several thermobundles, the thermopile was mounted and sectioned at discreet places for microscopic examination. In particular, the following features were examined.

4.1.1 Individual Thermobundles

The condition of the RTV insulation on the removed thermobundles was visually examined and voltage breakdown tests were conducted of the wires through the ML varnish and RTV insulation.

4.1.2 Individual Wires

A sample of RTV was removed from a thermobundle and the thermocouple wires were examined to observe any surface discoloration of the ML varnish insulation. Voltage breakdown tests of the individual wires and the ML varnish were performed.

4.1.3 Cross Sections of Thermopile

The cross sections of the thermopile were examined microscopically for evidence of microcracks or spalling of the RTV insulation and possible
reactions between the braze and the RTV in the hot junction area.

4.2 METHODS AND PROCEDURES

A jeweler's saw was used to cut open the outer aluminum can and expose the thermal insulation (Fig. 20). The electrical heater was bonded to the hot junction of the thermopile and couldn't be removed at this initial stage. The insulation between the heater wires and the top of the outer can was removed carefully to avoid damaging the hot junctions. After removing the thermal insulation, the thermopile was exposed for examination (Fig. 21).

Six thermobundles from the thermopile were removed for observations and voltage breakdown studies. Using the technique shown in Fig. 22, the voltage breakdown of the thermobundle through the ML and RTV insulation was determined. Individual thermocouple wires were removed from the thermobundle for visual observations and the voltage breakdown through the ML insulation was determined.

For microscopic examination, the rest of the thermopile was mounted and sectioned at three locations. The sections are near the hot junction, in the center of the thermopile and near the cold junction (Fig. 23). A jeweler's saw was used for initial cuts through the mounted thermopile, but it was necessary to remount these individual sections prior to a final polishing due to the elasticity of the RTV insulation.

4.3 RESULTS

4.3.1 Thermobundles

The RTV insulation around each thermobundle that was checked showed no detectable signs of having degraded elastically. These checks consisted of probing the material with a pair of fine tweezers and comparing it to new material. Table X shows the results of the voltage breakdown of the wires through the ML varnish of the wires and the RTV insulation of the thermobundle. The value for the voltage breakdown is an average for approximately six times. Sometimes the first or first few breakdowns were higher in value than the successive ones, and this value is given together with the steady state value.
Fig. 20 SNAP-15A generator after removal of container from thermopile - insulation assembly
Fig. 21 SNAP-15A generator components after disassembly (operating time > 48,000 hours)
Fig. 22 Method for determining voltage breakdown of thermobundle or individual thermocouple wire
Fig. 23 Sections of thermopile examined
<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>V BREAKDOWN (kv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.0</td>
</tr>
<tr>
<td>2</td>
<td>2.3</td>
</tr>
<tr>
<td>3</td>
<td>3.0 - 2.6</td>
</tr>
<tr>
<td>4</td>
<td>2.5</td>
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<tr>
<td>5</td>
<td>4.0 - 3.5</td>
</tr>
<tr>
<td>6</td>
<td>3.5</td>
</tr>
</tbody>
</table>

NOTE: When two (2) values are given, first no. represents initial value, second no. represents steady state average for approximately six (6) voltage breakdown cycles.
4.3.2 Individual Wires

Examination of the individual wires revealed little, if any at all, change in the color of the ML varnish. Table XI shows the results of the voltage breakdown obtained from five wire specimens. As with the previous results in Table X, if the first or first few values for breakdown were higher than the steady state value, both values are given. As seen from Table XI, several wires had rather high initial breakdown values.

4.3.3 Cross Sections of Thermopile

The thermopile was mounted and polished and examined metallographically. In all cases, the braze between the wire showed no degradation nor did it exhibit any attack beyond the initial braze on the cupron or tophel special wires. Figures 24 and 25 show typical hot junction braze joints in the thermopile. The RTV-60 surrounding each couple also showed no degradation and Fig. 25 shows several of these couples in the RTV-60 matrix.
### TABLE XI  VOLTAGE BREAKDOWN OF INDIVIDUAL WIRES WITH ML VARNISH

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>V BREAKDOWN (kv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>2</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
</tr>
<tr>
<td>4</td>
<td>4.0 - 0.4</td>
</tr>
<tr>
<td>5</td>
<td>2.0 - 0.6</td>
</tr>
</tbody>
</table>

**NOTE:** When two (2) values are given, first no. represents initial value, second no. represents steady state average for approximately six (6) voltage breakdown cycles.
Fig. 24  Brazed hot junctions of SNAP 15A generator after operation > 48,000 hours
Fig. 25 Several brazed hot junctions of SNAP 15A generator separated by RTV-60 after operation > 48,000 hours
REFERENCES