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SNAP-21 PROGRAM, PHASE II

DEEP SEA RADIOISOTOPE-FUELED
THERMOELECTRIC GENERATOR
POWER SUPPLY SYSTEM

QUARTERLY REPORT NO. 9

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SNAP-21 PROGRAM, PHASE II

DEEP SEA RADIOISOTOPE-FUELED THERMOELECTRIC GENERATOR POWER SUPPLY SYSTEM

QUARTERLY REPORT NO. 9

OCTOBER 1968

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1.0 SUMMARY

1.0 SUMMARY

The most significant technical accomplishments on the SNAP-21 Program during this period were:

- Completed assembly, processing and acceptance testing of generators A10P2, A10P3 and A10P4 and assembly and processing of A10P5.
- Completed short term performance testing of generator A10P8.
- Completed fabrication and hydrostatic testing of six Berylco 165 pressure vessels.
- Completed fabrication and acceptance testing of power conditioners H10P1 through H10P4.
- Completed fabrication of four system shipping containers and dynamic testing on the first shipping container.
- Completed fabrication of the holding fixture to be used in the shipping containers.
- Completed fabrication of shipping container cooling fin assemblies.
- Completed thermal shipping container tests using system S10D2.
- Components for the electrical receptacle and strain relief plug were received from Vector Cable.
- The four fuel capsules were prepared and encapsulated by ORNL.

- Completed the four NAVSHIPS 10-couple modules and shipped the modules and data package to NAVSHIPS R & D Center, Annapolis, Maryland.
- Assembled system S10D3 using insulation system B10D2.
- Completed electrical performance checks on system S10D3 prior to packaging for shipment to Sandia for dynamic tests.
- Completed insulation system B10D4 failure analysis and recommended a course of action to be followed on future units to RDT for their approval.
- Completed insulation systems B10DL1 and B10DL2 up to the point of closure welding of tension tie rods and started wrapping of insulation system B10DL3.

2.0 TASK I – 10-WATT SYSTEM

2.0 TASK I – 10-WATT SYSTEM

2.1 FUEL CAPSULE

Four fuel pellets were prepared and encapsulated by Oak Ridge National Laboratory during this report period. Strontium titanate in powdered form was measured calorimetrically and a quantity corresponding to 217 ± 1 watts was placed into a platinum (liner) cup residing in the pellet pressing die. The powder was then hot pressed into a cylindrical pellet and the heat output measured. The thermal values obtained were 214, 210, 206, and 204 watts. Two of the pellets were outside of the specified limits of 209 to 219 watts; consequently, it was necessary to prepare two additional pellets. These had thermal outputs of 215 and 216 watts. The difficulty was attributed to a malfunctioning calorimeter.

Relatively fresh strontium-90 was used and a power density of 0.945 watt/cm^3 was achieved. Since the fuel capsule was designed to accommodate a fuel power density of 0.85 watt/cm^3 , stainless steel spacers were required to fill the void and prevent pellet motion in the liner.

Some difficulty was experienced inserting the fueled liner into the capsule. To permit insertion the fueled liner was water cooled and the capsule was heated. After the capsules were closed by electron-beam welding, they were leak checked and ultrasonically inspected. Preliminary examination of the data indicated acceptable weld closures had been achieved. No difficulty was encountered in obtaining a low level of capsule surface contamination.

2.2 BIOLOGICAL SHIELD AND SPIDER

Biological shields Nos. 8 and 9 were received from National Lead during this quarter. An evaluation of the inspection reports received from National Lead indicated that only a minimal amount of dimensional inspection was required at 3M/SDP. Figures 2.2.1 and 2.2.2 show a typical inspection set-up.

The inspection of the inner liner and spider interface dimensions of the shield indicated improper clearance for interfacing the liner and spider with the biological

Figure 2.2.1. Surface Table Measurement of Biological Shield

Figure 2.2.2. Surface Table Measurement of Biological Shield Transferring Measurements to a Cadillac Height Gage

shield. Special instructions were issued and the liner and spider were ground to provide the required clearance.

Quality Assurance personnel reviewed all of the U-8% Mo bolts on hand to insure proper identification and segregation of all bolts that had been exposed to tensile loads.

The radiation plugs were sent to National Lead for heat treatment. These plugs had been plasma-sprayed, but had not been finish ground to the required dimensions.

After return to 3M, an examination of the plugs showed that the plasma-sprayed aluminum oxide had separated from the base material. An investigation will be conducted to determine the cause of the separation and to determine the disposition of the plugs.

2.3 INSULATION SYSTEM

2.3.1 B10Q1 Thermal Testing

2.3.1.1 First Thermal/Force Cycle

The purpose of this test was to determine the tension rod load profile and the temperature of the spider in relation to the temperature of the emitter plate while subjecting the unit to a thermal cycle similar to that used on unit B10D4. A secondary purpose of the test was to determine if the biological shield could be cooled at a rapid enough rate to prevent formation of the alpha phase.

The test cycle required a total of 280 hours to complete. The cycle, as used on previous development units, consisted of a heat up to 1550° F with a 32-hour hold at this temperature for insulation material conditioning, followed by cooling to and holding at 1285° F for the determination of thermal performance. This unit was then cooled to 900° F. During this cool down a phase change occurred. The unit was reheated to 1140° F and held at this temperature for 28 hours to convert the formed alpha phase back to gamma phase. The unit was then cooled at a faster rate to ambient temperature, but some alpha phase transformation was again observed.

Figure 2.3.1 shows the temperature and power input plotted against cycle time. Plotted on this figure is the average emitter plate temperature, average spider temperature, and the temperature at the bottom of the heater block. Figure 2.3.2

Figure 2.3.1. Temperature and Power Plotted Against Time for First Thermal Force Cycle

Figure 2.3.2. Tension Rod Load Plotted Against Time for First Thermal Force Cycle

shows the average load measured in each tension rod versus the cycle time. The average rod load was determined by averaging the loads indicated by each of the strain gauges on a given tension rod.

During the first two hours of the test the load in the tension rods increased from an average initial starting point of 300 pounds (preload) to approximately 400 pounds. The tension rod loads then decreased to approximately 350 pounds and remained steady until 400 hours TAT (Total Accumulated Time) when the emitter plate temperature had reached 630° F. From 40 hours TAT to 47 hours TAT the tension rod loads steadily increased to 470 pounds. At 45 hours the strain gauges on tension rods No. 2 and No. 3 became inoperative, however, the strain gauges on tension rod No. 1 remained fully operational throughout the entire test.

From 47 to 52 hours the rod load dropped off sharply to 250 pounds. This is a definite indication that the shield was changing phase from gamma to alpha. The emitter plate temperature went from 870° F to 1023° F during this time period. At 52 hours TAT the tension rod load started to increase sharply until it reached 600 pounds at 59 hours TAT. The emitter plate temperature at this time was 1135° F. This increase in rod load is attributed to the change in the previously produced alpha phase back to the gamma phase and subsequent increase in shield dimensions. From 59 hours to 74 hours TAT the rod loads increased at a lower rate resulting in a rod load of 730 pounds. At 68 hours the emitter plate was at approximately 1285° F. The spider temperature was only 16° F higher. The expected rod load at 1285° F under test conditions, measured at 68 hours TAT would be the sum of the following: Preload equal to 300 pounds, load due to angle tolerance approximately 200 pounds, load due to emitter plate- spider temperature difference approximately 1000 pounds. The total load that should result from test conditions is approximately 1500 pounds. It can be seen that the greatest amount of expected load resulted from the spider temperature being only 16° F higher than the emitter plate temperature, whereas the design considered that the spider would be 145° F higher than the emitter. From the above calculation of the expected load at 68 hours TAT (1285° F emitter), and the actual measured load of approximately 660 pounds, it is apparent that the rods do not experience the loading that would be expected under the test conditions. A discussion is presented in the test conclusion as to why the rod loads deviated from expected.

From 74 hours until 90 hours TAT when the emitter plate reached 1550° F, the load in the rods continued to decrease at a steady rate resulting in a load of approximately 525 pounds at 90 hours TAT. While holding the emitter temperature of

1550° F the load continued to decrease until it reached approximately 250 pounds at 110 hours TAT. The rod load held fairly steady in approximately 250 pounds until the power was turned off at 122 hours TAT to allow the emitter plate to cool to 1285° F. At 1550° F the spider was only 65° F higher in temperature than the emitter plate. For the design it was expected that the temperature of the spider would be 180° F higher than the emitter plate.

While cooling from 1550° F to 1285° F the load in the rods dropped off to an indicated average of approximately 50 pounds. It is somewhat questionable at this low indicated load as to whether or not the rods were loose. The accuracy of the strain gauges is judged to be not better than ± 50 pounds at this temperature.

The emitter plate temperature reached 1285° F at 140 hours TAT. It was maintained at this temperature for 27 hours (167 TAT) when the power was turned off to start the cool down. When the unit had cooled to 942° F emitter plate temperature (196.5 TAT) the slope of the cool down curve decreased indicating a phase change was starting to occur. At 203 hours the emitter plate temperature leveled off at 915° F and remained at this temperature until approximately 208 hours when the temperature began to decrease.

In an attempt to provide an all gamma phase shield after cool down, the unit was heated to 1150° F, which is above the transformation temperature, and held for approximately 27 hours to assure that the previously produced alpha phase would be transformed back to gamma phase. The unit was then allowed to cool normally to 1050° F. At this point the insulation space (vacuum) was backfilled with argon to increase the unit heat loss and consequently provide a faster cool down rate. Even with an argon backfill the cool down rate was not sufficient to allow the shield to cool without some alpha transformation.

Conclusions Drawn from the First Thermal Force Cycle

The conclusions drawn from the first cycle on unit B10Q1 can be summarized as follows:

- The temperature of the spider in relation to the emitter plate was considerably less than that assumed in the design.
- The measured loads in the tension rods did not correlate with the loads expected at the test operating temperatures.
- The biological shield was not cooled fast enough to prevent a partial gamma to alpha transformation.

The less than design temperature difference between the spider and emitter plate has the effect of increasing the load in the tension rods. As the temperature of the emitter plate increases it is apparent that the difference between the spider and emitter plate temperature must become greater to result in a neutral rod condition. During this test, it was observed that the spider was 65° F hotter than the emitter plate with the emitter plate at 1550° F as well as at 1285° F under steady state conditions.

After the tension rods reached a maximum loading of 740 pounds the indicated loads began to decrease. The events that could possibly account for the load loss are as follows: relaxation of the Clark load washers at high load, creep of the tension rods at high load, and creep of the biological shield.

The Clark load washers are made from two metallic washers separated by a substance which changes resistance with loading. It is possible that this conducting substance relaxed when exposed to the loads in the tension rods. The relaxation of the load washers would, of course, cause the rod loads to decrease.

Creep in the tension rods while loaded to 740 pounds at operating temperature, and higher, is a distinct possibility. Investigation of the primary creep data for the rod materials will be made to determine how much creep should be expected. The design of the unit considered that the rod loads would be a minimum of about 400 pounds at operating temperature. It was found that at these loads secondary creep was not a problem during the 5-year life of the unit.

2.3.1.2 Second Thermal/Force Cycle

Prior to conducting the second thermal/force cycle the Clark washers were removed to eliminate any problems they may have presented during the first cycle by causing the rod loads to decrease. The strain gauges that had become inoperative during the first cycle were repaired.

The second cycle was conducted to simulate a fueled unit with an installed thermoelectric generator. The generator heat loss was simulated by a copper rod installed in the neck tube area of the unit. The unit was electrically heated to simulate the heat input of a 215-watt fuel capsule installed in the unit. The rod loads and

relative temperatures between the spider and emitter plate were also determined. After a period of time at the 1285° F operating temperature, the unit was heated to 1550° F to determine the effect of this conditioning temperature on the rod loads and spider-emitter plate temperature relationship. Finally, an attempt was made to cool the unit at a rate fast enough to eliminate any phase change during cool down.

The test cycle required a total of 217 hours to complete. The cycle consisted of a heat-up to 1285° F to simulate the heat-up of a fueled unit. The unit then was held at operating temperature for 44 hours and then heated to 1550° F. It was held at this temperature for 37 hours to determine the effects of this conditioning temperature on the rod loads. After conditioning the unit was cooled to and held at operating temperature for 7 hours, then cooled to ambient temperature.

Figure 2.3.3 shows the temperature and power input plotted against cycle time. The average emitter plate temperature, average spider temperature and the temperature at the bottom of the heater block are plotted in Figure 2.3.3.

During the first two hours of test 75 watts of power were supplied to the unit. Power was then increased to 150 watts for two additional hours before setting to the required power level of 215 watts at 4 hours total accumulated time (TAT). The power was continued at 215 watts until 44.5 hours TAT when power was increased to 250 watts so as to reach operating temperatures more quickly. At 44.5 hours the emitter temperature had reached 1041° F. At 69.75 hours the unit had reached an operating temperature of 1295° F and the power was reduced to 215 watts. The emitter plate was maintained at operating temperature (1285° F to 1295° F) by adjusting copper rod as required until 113.7 hours TAT. The power was then increased to 300 watts to bring the emitter plate to a conditioning temperature of 1550° F. This temperature was reached at 139.45 hours TAT and power was then set to 275 watts. The unit was maintained at the conditioning temperature until 176 hours TAT when the power was turned off to allow the unit to cool to operating temperature (1285° F to 1295° F). Operating temperature was reached at 181.63 hours and the power was resumed at 225 watts again maintaining the unit at operating temperature by copper rod adjustment. At 187.54 hours TAT the power was turned off to cool the unit to ambient temperature.

Figure 2.3.3. Temperature and Power Plotted Against Time for Second Thermal Force Cycle

At 192.5 hours the insulation system vacuum was broken back with argon to atmospheric pressure to increase the cooling rate. As shown by Figure 2.3.3, no phase change of the biological shield occurred. A phase change would cause a change in cooling rate in the region of from 1000° F to 900° F. It is felt that the shield at ambient temperature is in the all-gamma state and therefore useful for subsequent testing.

Figure 2.3.4 shows the average load in each tension rod versus the test cycle time. Prior to applying power to the unit the average rod loads were: rod No. 1, 225 pounds; rod No. 2, 207 pounds; rod No. 3, 250 pounds. During the first six hours of the test the rod loads increased to an average of approximately 380 pounds. This increase in rod load was caused by the emitter plate temperature being higher than the spider temperature. From 6 hours TAT to 18 hours (TAT) rod loads slowly decreased to an average of about 340 pounds. At 20 hours (TAT) there was an increase in rod loads followed by a decrease to approximately the same loads as were recorded at 18 hours TAT. At 35 hours TAT with the emitter plate temperature at 950° F the rod loads started to increase sharply. At 49 hours TAT the following maximum average loads were recorded; rod No. 1, 990 pounds; rod No. 2, 925 pounds; rod No. 3, 1040 pounds. The increase in load was caused by transformation of the alpha phase which was present in the shield during tension rod assembly to the gamma phase. This alpha phase was formed in the unit during the cool down after the first cycle. The alpha phase is transformed to gamma phase with a corresponding dimensional increase which would cause rod tightness.

When the emitter plate was stabilized at operating temperature, the average rod loads had decreased to: rod No. 1, 915 pounds; rod No. 2, 885 pounds; rod No. 3, 960 pounds. While at operating temperature the rod loads continued to decrease until they reached an apparent leveling off at 107 hours TAT. The rod loads at 107 hours TAT were: rod No. 1, 690 pounds; rod No. 2, 750 pounds; rod No. 3, 750 pounds. It is expected that some of the tension rod load loss was caused by the spider-emitter temperature difference becoming greater and that some of the load loss was a result of primary creep.

When the power was increased to 300 watts at 113 hours (TAT) to bring the unit to 1550° F conditioning temperature, the tension rod loads increased slightly at first, then steadily declined until approximately 165 hours (TAT) when the tension rod

Figure 2.3.4. Tension Rod Load Plotted Against Time for Second Thermal Force Cycle

loads leveled off to: rod No. 1, 150 pounds; rod No. 2, 100 pounds; rod No. 3, 225 pounds. It is expected that this decrease in tension rod load was caused by primary creep while at 1550° F.

Upon cooling the unit to 1285° F operating temperature, the tension rod loads decreased further, resulting in what was considered a no-load situation within the accuracy of measuring the tension rod loads.

After the unit was cooled to ambient temperature the receptacle extensions were removed to allow access to the tension rods. The anti-rotation pins were removed and the female portion of the tension rod was threaded off the male portion of the rod. During rod removal it was discovered that tension rods Nos. 1 and 2 were forced against the top edge of the spherical washer (unit in vertical upright position). To remove these two rods it was necessary to first remove the pins that locate the spherical washer in the receptacle to allow the washer to move and relieve the binding. While removing the rods the strain gauges were damaged. With the female rods removed it was observed that the male rods Nos. 1 and 2 could not be moved through an arc or in the direction of the rod axis as was possible to do with rod No. 3.

The insulation covering the spider and male rods was removed to completely expose the rods. The ball joint between the male tension rod and the spider was seized on rod No. 1 and No. 2. The rods were loosened by tapping them on the side with a copper mallet, allowing them to be removed from the spider.

After disassembling the tie rods, the lubricant used at the tie rod hot end was investigated. Before the original selection of the lubricant, a literature search had been conducted and Alpha Molykote Corporation was consulted. The two materials recommended by Alpha Molykote Corporation were Molykote Type Z and Molykote X-15. Molykote Type Z is a powder and Molykote X-15 contains a sodium silicate binder. It was stated that both are excellent in a vacuum at elevated temperatures. Molykote Type Z is the lubricant which is used to lubricate the tie rod spherical surfaces. After it was found that the tension tie rods would not rotate, a further investigation of the lubricant was made. NASA - Lewis Research Center was contacted and they confirmed that molybdenum di-sulfide disassociated between 1500° F and 1550° F but that there was measurable disassociation at

1400° F. During the second thermal force cycle, the maximum temperature at the spider was 1625° F, or above the temperature at which the lubricant would disassociate. For the third thermal force cycle on unit B10Q1 and for the remaining units to be built, it is expected that the spider temperature will not exceed 1400° F and the lubricant should perform satisfactorily.

The male tension rods were inspected to determine the overall length and degree of bending. It appears that all the bending occurred in one plane which was common to the axis of the lock pin hole which is the axis of rod rotation when the unit is heated. On two of the rods, Nos. 1 and 2, all bending appeared to have occurred in the shaft directly adjacent to the spherical ball. Rod No. 3 also appeared to be bent slightly along the entire rod length. The amount of bending recorded was as follows: rod No. 1, 2° 16' to 2° 22'; rod No. 2, 1° 23'; rod No. 2, 1° 47' to 2° 18'.

The overall length of the male rods was measured, recording both the maximum and minimum lengths (length not equal due to bending). The results of the measurements were as follows:

	<u>Rod No. 1</u>	<u>Rod No. 2</u>	<u>Rod No. 3</u>
Before test	1.9950 in.	1.9945 in.	1.9950 in.
After test	2.0038 - 2.0067 in.	2.0023 - 2.0106 in.	1.9997 - 2.0021 in.
Average elongation	0.0102 in.	0.0119 in.	0.0059 in.

This average elongation shows that primary creep occurred during the test because the rod loads as measured were not great enough to cause stresses greater than the proportional limit of the Inconel 625 rod material.

The Inconel 718 female tension rods were also measured after the test with the following measurements being recorded:

	<u>Rod No. 1</u>	<u>Rod No. 2</u>	<u>Rod No. 3</u>
Before test	1.5046 in.	1.5050 in.	1.5059 in.
After test	1.5048 - 1.5055 in.	1.5041 - 1.5049 in.	1.5045 - 1.5049 in.

These measurements of the female tension rods show that the female rods did not increase in length during the test. The small differences in the before and after measurements are attributed to measurement inaccuracy.

Conclusions Drawn from the Second Thermal/Force Cycle

The spider-emitter plate temperature relationship measured during the test was not the same as the temperature relationship used in the calculations to determine the tension rod angle. Calculations show that the spider-emitter temperature relationship measured will cause higher tension rod loads at operating temperature than the temperature relationship used in the unit design. A new tension rod set angle was calculated based on the measured temperature relationship.

The male tension rods experienced creep during the test, however, it was demonstrated that the rods were able to maintain loads of approximately 750 pounds at 1285° F and approximately 150 pounds at 1550° F. To reduce the rod creep to a minimum, the insulation conditioning temperature should be reduced to a temperature less than 1550° F.

The unit was cooled fast enough to prevent alpha transformation during the cool down by using a copper heat transfer rod in the neck tube area and by backfilling the unit with argon.

The decision was made to run a third thermal/force cycle with the tension rods set at an angle appropriate to the measured spider-emitter temperature relationship while starting with a biological shield in the all-gamma condition. During the course of the third cycle the effects on the tension loads with reduced insulation material conditioning temperature were investigated.

2.3.2.3 Third Thermal/Force Cycle

Unit Closure

The elongated male tension rods removed from the unit after the second thermal force cycle were replaced with new male tension rods. The spherical ball on each of the new male rods was lapped to the respective spider seat with the spider still

mounted on the biological shield. Following lapping, Molykote Type Z lubricant was applied to the mating surfaces of the rod and spider and the male rods were installed in the spider and secured with the anti-rotation pins.

The multi-layer insulation which had been removed to allow tension rod access was re-installed over the spider end of the unit.

The bottom enclosure head was installed and tack welded to the top enclosure head and the joint was vacuum sealed with epoxy. The female tension rods were installed at an angle of $27^{\circ} 11'$ to determine the required washer thickness needed to provide an overall rod length of 2.939 ± 0.005 in. The washer was fabricated and the female tension rod was re-installed at $27^{\circ} 11'$ using the spacer washer. The tension rods were torqued in 5 in.-lb increments to 23 in.-lb to provide the required tension rod preload. The spherical washers were anchored to the receptacle by installing the required size pins between the spherical washer and the receptacle. These pins were epoxied to the receptacle to prevent movement. A chromel-alumel thermocouple was installed in the bore of each female rod to measure the temperature at the end of the male rod (rod junction temperature). With the thermocouple installed, the bore of each female rod was filled with quartz paper to reduce the heat loss and to hold the thermocouple in place. The anti-rotation pin was installed in the slot of each female rod and epoxied to the spherical washer. A chromel-alumel thermocouple was attached to the cold end of each female rod to measure this cold end temperature during unit operation.

Receptacle extensions were epoxied to the enclosure head and all the instrumentation wiring was brought out of the unit through commercial vacuum feed-throughs. The unit was evacuated and leak-checked with a helium leak detector. The leak rate was found acceptable.

Test Set-Up

Following the third thermal force cycle the unit was to be fast cooled using a water cooled chill block which was installed in the inner liner and bolted to the emitter plate bolt circle. To become familiar with the use of this chill block and to establish a procedure for this operation, the block was installed in the unit to simulate the actual installation. The procedure established for installing the chill block was as follows:

1. Turn power off.
2. Loosen copper rod in cover plate (do not remove).
3. Disconnect heater wires and thermocouple wires from terminal strip (straighten and clip off at cover plate).
4. Cut silicone rubber seals around wires and seal around outer edge of cover plate.
5. Remove cover plate.
6. Remove bulk Min-K insulation with special tool (Caution - Do not touch neck tube with tools).
7. Loosen packed Min-K insulation around emitter plate and emitter plate bolts.
8. Vacuum clean loose Min-K insulation to expose emitter plate bolts.
9. Loosen emitter plate bolts with long handle allen wrench and remove with long tweezers.
10. Thread lifting eye bolt in heater block.
11. Insert 3/4-inch diameter bar through eye of lifting bolt and lift heating block out of unit. (Set hot heater block on concrete floor.)
12. Vacuum clean inner liner.
13. Install copper chill block with water circulating through chill block.
14. Install and tighten special long bolts to secure chill block to inner liner.

Following the establishment of the above procedure the heater block was installed in the unit and the emitter plate was bolted to the inner liner. An anti-seize compound was used on the bolt threads. The inner liner was insulated with Min-K insulation in the same manner as was performed for unit B10D4 (copper disk and stainless steel ring used). A thermocouple was installed on the bottom of the heater block to determine the temperature at this location during heat-up. Thermocouples were installed on the unit enclosure in the same locations as on unit B10D4 and, in addition, a thermocouple was installed on the outer enclosure as close as possible to each receptacle extension. To complete the preparation of the unit for the third thermal force cycle all the instrumentation was connected to the respective readout equipment.

Conclusions from Third Thermal/Force Cycle

The conclusions drawn from this test are as follows:

1. The tension rods maintained loading while the unit was at operating temperature and at ambient temperature at the conclusion of the run.
2. Conditioning at 1400° F emitter plate temperature for 65 hours resulted in a average tension rod load loss of 85 pounds due to primary creep. There is adequate pre-load so that the loss of 85 pounds load during conditioning is not critical and will not affect the performance of the unit.
3. The biological shield can be cooled rapidly with the water cooled copper chill block thereby preventing the formation of alpha phase.

Since this test was completed late in the report period, the details will be reported on the next report after the test data has been analyzed in detail.

2.3.2 B10D2 Dynamic Test to Specification

Unit B10D2 successfully passed the vibration test (3 g at 50 cps) and the shock test (6 g at 6 ms) during this reporting period. This test followed by approximately

four months the ambient temperature vibration test that had been previously performed on this unit. The insulation system remained at Ogden Laboratories between the tests and was not transported.

The inner liner was insulated with Min-K insulation using the same configuration as was used on unit B10D4. The unit was electrically heated to 1285° F at which time the 1/2-in. diameter copper rod was installed to simulate heat loss from the thermoelectric generator. The testing was conducted with the unit at 1285° F while supplying approximately 220 watts of power to the unit.

The dynamic vibration test was conducted according to the development test plan (three sweeps at 3 g maximum for 15 minutes on each axis). The unit pressure remained below 0.2 micron during and after the vibration tests.

The dynamic shock test was conducted according to the development test plan (three shocks each direction each axis, 6 g peak sawtooth at 6 ms). As for the vibration test, the unit pressure was below 0.2 microns at the conclusion of the testing, making it apparent that a failure did not occur during the shock test. At the completion of the test the unit was removed from the test fixture, installed in the shipping container and shipped to 3M Company.

2.3.3 Quality Assurance

Quality Assurance personnel performed surveillance at Linde on the following activities:

- Completion of the instrumentation of development insulation system B10Q1. No problems or discrepancies were noted.
- Upper closure/inner liner weld operation on insulation system 10DL1. Weld parameters were developed during the early development states and are now called out on the drawing. The weld is a semi-automatic operation in that the system rotates but is hand welded. The weld was accomplished in accordance with drawing and specification requirements.

- Final insulation wrapping stages of insulation system 10DL2. No discrepancies were noted.

A sample check was made on Linde's traceability system. The log book for B10Q1 was checked to verify that Linde could trace parts supplied by 3M after installation, into the system. The system appears adequate since all parts checked were traceable.

Linde's inspection results of the alignment and handling fixture were reviewed. A complete set of inspection reports of all components is on file in their Quality Department. No discrepancies were noted during the review.

A 3M/SDP Quality Assurance representative was at Linde's facility during the week of 16 September through 20 September 1968 to observe the following:

- The dimensional inspection and the fit-up of the spider and shield subassembly for system 10DL3.
- Preliminary torque setting on the tie rods including rod angle setting. Each rod is set using a dial indicator and calculations furnished by engineering and checked by a Quality Control engineer.
- Shrink fit of spider to shield. The 3M Quality Assurance representative witnessing torqueing operation of spider bolt, after return of spider/shield to ambient temperature, noted a Linde technician break a thermometer depositing mercury globules over shield and spider. The shield and spider were immediately cleaned with alcohol. The spider was sprayed with liquid nitrogen to shrink it for removal from the shield. A small globule of mercury was found on the inside surface of the surface of the spider. It was removed and careful inspection of the shield (tapped hole) showed no further mercury deposits.

The surfaces of the shield and spider were again cleaned with alcohol and the parts re-assembled. Record of this accident was entered in the unit log book. Linde personnel are investigating safer procedures for the temperature measurement operation.

2.4 THERMOELECTRIC GENERATORS

2.4.1 Phase I

Data collection and analysis of the Phase I 6-couple modules and prototype generators continued this part quarter. Performance data for 6-couple modules A1, A3, and A4 is given in Table 2.4.1 and Figures 2.4.1 through 2.4.3. Data from prototypes P5, P6, and P7 is given in Tables 2.4.2 through 2.4.4 and Figures 2.4.4 through 2.4.6. This data indicates no significant change in 6-couple or prototype generator performance.

The water passages in the cooling block for 6-couple module A3 became blocked with corrosion. As this prevented the proper cooling of the cold end, the power was shut off and the cooling block was replaced. This condition was discovered on September 5, 1968. The unit operated at a maximum of 135° F for less than 24 hours, 20° F over the normal operating temperature of 115° F. No harmful effects to the unit were apparent.

2.4.2 Phase 2

There are five Phase II thermoelectric generators on long-term test. The generators and the accumulated test hours for each are:

<u>Generator</u>	<u>Test Hours *</u>
A10D1	7392
A10D2	9230
A10D6	6212
A10D7	5949
A10P1	821

*As of 24 September 1968.

All Phase II generators have been connected to the data acquisition system.

Table 2.4.1. Performance Data of SNAP-21 6-Couple Modules

Module	Date	T _h (° F, est)	T _c (° F)	E _o (volts)	E _L (volts)	I _L (amps)	P _o (watts)	R (milliohms)	P _I (watts)	Hours
A1	7-10-68	1040	113	1.26	0.63	1.72	1.09	365	32.0	34,727
	7-29-68	1040	116	1.26	0.63	1.72	1.09	365	32.0	35,183
	8-13-68	1040	115	1.29	0.64	1.75	1.12	371	32.0	35,543
	8-27-68	1040	114	1.28	0.63	1.73	1.10	373	32.0	35,879
	9- 6-68	1040	115	1.28	0.63	1.73	1.10	373	32.0	36,119
	9-16-68	1040	116	1.27	0.63	1.73	1.09	369	32.0	36,359
A3	7-10-68	1040	119	1.29	0.64	1.77	1.14	365	46.5	33,395
	7-29-68	1040	119	1.29	0.65	1.76	1.14	366	46.5	33,851
	8-13-68	1040	117	1.30	0.65	1.76	1.14	372	46.5	34,211
	8-27-68	1040	119	1.30	0.64	1.77	1.14	371	46.5	34,547
	9- 6-68	1040	119	1.30	0.64	1.76	1.13	374	46.5	34,787
	9-16-68	1040	119	1.29	0.64	1.76	1.13	367	46.5	35,027
A4	7-10-68	1040	116	1.24	0.62	2.28	1.41	273	39.5	32,555
	7-29-68	1040	118	1.24	0.61	2.29	1.40	274	39.5	33,011
	8-13-68	1040	117	1.24	0.62	2.28	1.42	271	39.5	33,571
	8-27-68	1040	118	1.23	0.61	2.28	1.39	272	39.5	33,707
	9- 6-68	1040	119	1.24	0.61	2.28	1.39	276	39.5	33,947
	9-16-68	1040	118	1.24	0.61	2.28	1.40	275	39.5	34,187

Figure 2.4.1. Performance of SNAP-21B 6-Couple Module A1

Figure 2.4.2. Performance of SNAP-21B 6-Couple Module A3

Figure 2.4.3. Performance of SNAP-21B 6-Couple Module A4

Table 2.4.2. Typical Performance Data SNAP-21B Prototype P5*

Date	T _h ¹ (°F)	T _c ² (°F)	E _o (volts)	E _L (volts)	I _L (amp)	P _o (watts)	R (ohms)	P _I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
4-19-65	1112	117	11.20	5.60	2.04	11.42	2.74	--	0.99	1.26	0.78	24
5-12-65	1115	127	10.92	5.46	2.00	10.92	2.73	--	0.97	1.24	0.77	576
6-30-65	1097	135	10.65	5.32	2.02	10.74	2.64	176	0.97	1.20	0.78	1,320
7-26-65	1097	142	10.68	5.34	2.01	10.72	2.66	176	0.98	1.21	0.79	1,944
9-10-65	1095	144	10.60	5.30	2.06	10.92	2.57	--	0.97	1.17	0.81	3,048
10-26-65	1097	147	10.56	5.28	2.05	10.81	2.58	180	0.97	1.16	0.82	4,152
12- 1-65	1102	151	10.58	5.29	2.10	11.11	2.52	--	0.98	1.13	0.84	5,016
1-28-66	1094	149	10.56	5.28	2.14	11.30	2.47	180	0.98	1.11	0.86	6,408
3-28-66	1094	152	10.54	5.27	2.16	11.38	2.44	180	0.98	1.10	0.87	7,821
4-28-66	1074	151	10.20	5.10	2.19	11.17	2.33	176	0.97	1.07	0.87	8,565
6-21-66	1073	151	10.24	5.00	2.18	10.90	2.40	174	0.97	1.10	0.86	9,834
8-12-66	1078	161	10.15	5.07	2.20	11.15	2.30	178	0.97	1.04	0.89	11,081
9-14-66	1075	161	10.16	5.07	2.19	11.10	2.32	175	0.97	1.06	0.89	11,873
12-27-66	1077	153	10.22	5.11	2.19	11.19	2.33	184	0.97	1.07	0.87	14,369
1-31-67	1073	159	10.12	5.06	2.20	11.13	2.30	179	0.96	1.05	0.90	15,209
4- 1-67	1074	148	10.20	5.10	2.24	11.42	2.28	175	0.97	1.05	0.89	16,649
5-24-67	1076	150	10.28	5.14	2.20	11.31	2.34	179	0.97	1.08	0.88	17,921
6-30-67	Power Failure, Emergency Power Came On at 8:28 PM to 10:30 PM											
7- 1-67	1067	159	10.00	5.00	2.19	10.95	2.28	175	0.95	1.00	0.88	18,833
8- 5-67	1069	164	10.01	5.00	2.22	11.10	2.26	170	0.95	1.01	0.90	19,673
9-26-67	1068	160	10.04	5.02	2.17	10.89	2.31	172	0.96	1.05	0.88	20,921
11- 6-67	1067	158	10.08	5.04	2.19	11.04	2.30	174	0.96	1.00	0.89	21,953
12-29- 7	1066	150	10.20	5.10	2.22	11.32	2.30	175	0.97	1.06	0.90	23,225
1-15-68	Power Failure, Emergency Power Came On for One Hour											
1-30-68	1070	151	9.90	4.95	2.21	10.94	2.26	175	0.94	1.01	0.87	23,993
2-17-68	Power Failure, Emergency Power Came On for Five Hours											
2-19-68	1068	149	10.10	5.05	2.17	10.96	2.33	177	0.96	1.00	0.87	24,473
3-14-68	1052	156	9.96	4.98	2.19	10.91	2.27	177	0.98	1.03	0.90	25,049
5-22-68	1077	154	10.02	5.02	2.22	11.14	2.25	176	0.95	1.04	0.87	26,705
6-17-68	1042	157	9.92	4.96	2.14	10.61	2.32	171	0.98	1.06	0.90	27,329
6-17-68	Reduced Input Power											
8-13-68	1044	166	9.80	4.90	2.09	10.24	2.34	169	0.98	1.14	0.87	28,697
9-16-68	1050	164	9.82	4.90	2.09	10.24	2.35	169	0.97	1.14	0.86	29,513

* Begin test on 4-19-65.
Turned off from 5-20-65 to 6-7-65.

1. Based on average of two N leg Seebeck voltages.
2. Based on average of four cold electrode thermocouples.

Figure 2. 4. 4. SNAP-21B 48-Couple Prototype Generator P5 Performance Ratios (Experimental/Calculated)

Table 2.4.3. Typical Performance Data SNAP-21B Prototype P6*

Date	T _h ¹ (°F)	T _c ² (°F)	E _o (volts)	E _L (volts)	I _L (amp)	P _o (watts)	R (ohms)	P _I (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
6- 2-65	1095 ¹	132	10.88	5.44	2.58	14.03	2.10	204	1.03	1.02	1.02	24
6-30-65	1095 ²	145	10.88	5.44	2.34	12.73	2.32	206	1.04	1.11	0.96	720
7-29-65	1095 ²	157	10.88	5.44	2.28	12.40	2.38	--	1.04	1.13	0.96	1,416
9- 1-65	1095 ²	162	10.80	5.40	2.20	11.88	2.45	201	1.04	1.16	0.93	2,184
9-30-65	1095 ²	166	10.72	5.36	2.19	11.74	2.45	198	1.04	1.15	0.93	2,880
11-17-65	1095 ²	169	10.80	5.40	2.16	11.66	2.50	201	1.05	1.16	0.94	4,032
12-28-65	1095 ²	171	10.78	5.39	2.18	11.75	2.47	200	1.05	1.15	0.95	5,016
2- 5-66	1095 ²	171	10.74	5.37	2.14	11.49	2.51	197	1.04	1.17	0.93	5,952
3-28-66	1095 ²	171	10.74	5.39	2.13	11.44	2.52	197	1.04	1.17	0.92	7,173
4-28-66	1095 ²	172	10.76	5.38	2.11	11.35	2.55	201	1.04	1.19	0.92	7,941
8-12-66	1075 ²	181	10.52	5.23	2.05	10.72	2.58	191	1.05	1.20	0.92	10,452
9-14-66	1075 ²	182	10.53	5.24	2.06	10.79	2.57	190	1.05	1.20	0.93	11,244
12-27-66	1075 ²	176	10.82	5.41	2.09	11.28	2.59	192	1.07	1.22	0.95	13,740
1-27-67	1075 ²	176	10.84	5.42	2.10	11.38	2.58	199	1.08	1.22	0.96	14,484
3-13-67	1075 ²	173	10.86	5.43	2.09	11.35	2.60	198	1.08	1.23	0.95	15,564
4-27-67	1075	168	10.38	5.19	2.07	10.72	2.51	194	1.03	1.20	0.89	16,524
6-16-67	1075	176	10.58	5.29	2.05	10.84	2.58	194	1.05	1.23	0.90	17,844
6-22-67	Power Input Reduced							186				17,988
6-30-67	1055 Bldg Power Failure, Emergency Power for Approx. 2 Hours											
7- 1-67	1055	172	10.10	5.05	2.04	10.28	2.48	184	1.03	1.20	0.88	18,204
8- 4-67	1055	178	9.95	4.98	2.03	10.11	2.45	185	1.02	1.18	0.90	19,020
9-26-67	1055	175	10.08	5.04	2.02	10.18	2.50	186	1.03	1.21	0.88	20,292
11- 6-67	1055	172	10.08	5.04	2.02	10.18	2.50	185	1.03	1.21	0.87	21,324
11-30-67	1055	166	10.00	5.00	2.04	10.20	2.45	190	1.02	1.20	0.86	21,900
1-15-68	Bldg. Power Was Off --Emergency Power Came On for One Hour											
1-17-68	1055	166	10.04	5.02	2.03	10.19	2.47	192	1.02	1.20	0.86	23,052
2-17-68	Bldg. Power Was Off --Emergency Power Came On for 5 Hours											
3-14-68	1055	171	10.02	5.01	2.04	10.22	2.46	192	1.02	1.19	0.88	24,420
5- 9-68	1055	169	10.00	5.00	2.04	10.20	2.45	192	1.01	1.19	0.87	25,764
7-10-68	1035	173	9.76	4.88	1.97	9.61	2.48	188	1.03	1.23	0.87	27,252
8-13-68	1035	182	9.76	4.88	1.99	9.71	2.45	188	1.04	1.21	0.89	28,068
9-16-68	1035	175	9.76	4.88	1.98	9.66	2.46	188	1.03	1.22	0.87	28,884

Begin test 6-1-65.

1. Based on average of two hot electrode thermocouples.
2. Based on hot frame thermocouple referenced to 6-2-65.
3. Based on average of two cold electrode thermocouples.

Figure 2.4.5. SNAP-21B 48-Couple Prototype Generator P6 Performance Ratios (Experimental/Calculated)

Table 2.4.4. Typical Performance Data SNAP-21B Prototype P7*

Date	T _h ¹ (°F)	T _c ² (°F)	E _o (volts)	E _L (volts)	I _L (amp)	P _o (watts)	R (ohms)	P _i (watts)	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	Hours on Test
6- 8-65	1099 ¹	127	10.80	5.40	2.44	13.17	2.21	200	1.01	1.08	0.95	168
7-14-68	1098 ¹	142	10.80	5.40	2.21	11.95	2.44	194	1.01	1.18	0.88	1,032
8-24-65	1100 ³	152	10.82	5.41	2.13	11.52	2.54	192	1.03	1.21	0.88	1,968
10-12-65	1100 ³	156	10.86	5.43	2.11	11.47	2.57	194	1.04	1.22	0.82	3,144
11-17-65	1095 ³	158	10.80	5.40	2.08	11.23	2.60	188	1.04	1.23	0.87	4,008
12-28-65	1095 ³	159	10.78	5.39	2.07	11.16	2.60	191	1.04	1.23	0.88	4,992
2-10-66	1095 ³	158	10.82	5.41	2.06	11.14	2.63	191	1.04	1.24	0.88	6,048
3-28-66	1095 ³	160	10.80	5.40	2.05	11.07	2.63	191	1.04	1.24	0.87	7,149
5-16-66	1095 ³	163	10.82	5.41	2.02	10.93	2.68	189	1.04	1.26	0.86	8,324
6- 4-66	Reduced Input Power											
6-21-66	1075 ³	158	10.72	5.40	1.99	10.75	2.67	186	1.06	1.28	0.87	9,181
6-28-66	Moved Test from T. C. A. to Space Center											
8-12-66	1075 ³	173	10.56	5.26	1.96	10.31	2.55	188	1.05	1.26	0.86	10,428
10- 3-66	1075 ³	178	10.62	5.31	1.95	10.35	2.72	185	1.05	1.27	0.89	11,676
12-28-66	1075 ⁴	165	10.70	5.35	1.94	10.37	2.76	186	1.05	1.31	0.84	13,760
1-31-67	1075	171	10.70	5.35	1.96	10.49	2.73	186	1.06	1.30	0.86	14,576
3-13-67	1075	173	10.60	5.30	1.94	10.26	2.74	186	1.06	1.29	0.86	15,560
5-13-67	1075	175	10.61	5.30	1.91	10.11	2.78	186	1.06	1.31	0.85	17,024
6-22-67	Input Power was Reduced											
6-23-67	1055	171	10.30	5.15	1.91	9.84	2.70	180	1.05	1.31	0.84	18,008
6-30-67	Bldg. Power Failure, Emergency Power was on for Approx. 2 Hours											
7- 1-67	1055	165	10.30	5.15	1.86	9.58	2.77	180	1.05	1.35	0.81	18,192
8- 8-67	1055	182	10.19	5.10	1.92	9.79	2.65	178	1.05	1.27	0.86	19,110
9-26-67	1055	166	10.26	5.13	1.92	9.85	2.67	179	1.04	1.30	0.83	20,286
10-20-67	1055	171	10.14	5.07	1.91	9.68	2.65	176	1.03	1.29	0.83	21,091
1-15-68	Bldg. Power was off - Emergency Power came on for One Hour											
1-17-68	1055	169	10.40	5.20	1.92	9.98	2.71	177	1.06	1.32	0.85	23,203
2-17-68	Bldg. Power was off - Emergency Power came on for about 5 Hours											
2-19-68	1055	164	10.20	5.10	1.92	9.79	2.66	180	1.04	1.30	0.83	23,997
3-20-68	1055	169	10.28	5.14	1.92	9.87	2.68	181	1.05	1.30	0.85	24,717
4-18-68	1055	177	10.20	5.10	1.93	9.84	2.64	189	1.04	1.28	0.85	25,384
5- 9-68	1055	179	10.28	5.14	1.93	9.92	2.66	180	1.06	1.28	0.87	25,917
6-17-68	1055	182	9.94	4.97	1.90	9.44	2.62	176	1.02	1.26	0.83	26,853
8-13-68	1035	177	9.78	4.89	1.91	9.34	2.56	174	1.04	1.27	0.85	28,221
9-16-68	1035	173	9.75	4.88	1.90	9.27	2.56	174	1.03	1.27	0.84	29,037

* Begin test 6-2-65.

1. Based on average of two hot electrode thermocouples.
2. Based on average of two cold electrode thermocouples.
3. Based on hot frame thermocouple referenced to 6-30-65.
4. Based on average input power from 7-13-66 to 11-12-66.

Figure 2. 4. 6. SNAP-21B 48-Couple Prototype Generator P7 Performance Ratios (Experimental/Calculated)

2.4.2.1 A10D1

Generator A10D1 continued to leak this past quarter. It has been leaking for approximately four months at a rate of about 1.7 psi per month. The Conax fittings were tightened and the generator backfilled to design pressure of 25 psia, but the generator continues to leak at the same rate.

The Seebeck voltage ratio has remained stable throughout the quarter, while the resistance ratio has continued to rise slowly. The rate of increase is shown in Table 2.4.5 and Figure 2.4.7. This rise is probably due to effects from the loss of the generator's hermetic seal. The power ratio is dropping slightly with the rise in resistance.

2.4.2.2 A10D2

Generator A10D2 accumulated one year of testing on September 4, 1968. This generator is being run at constant power input rather than at constant hot junction temperature because the degradation of internal instrumentation makes control by temperature impossible. At the end of the first year of operation, the power input to the generator was reduced to simulate radioisotope decay. Since the test station does not closely simulate the HTVIS used in the system, the power input was reduced to obtain a 20° F reduction in hot junction temperature. This 20° F reduction is the decrease in hot end temperature based on the decay rate of the isotope fuel (approximately 2.5 percent). The new operating temperatures are $1080 \pm 10^\circ \text{F}$ and $85 \pm 10^\circ \text{F}$ at the hot junction and cold junction, respectively. These new operating temperatures are estimates determined by applying a known temperature drop to measured external temperatures.

As shown in Table 2.4.6 and Figure 2.4.8, the Seebeck ratio and resistance have held essentially constant through this quarter. At about 6,000 hours of operation, a slight (0.15 percent) drop in Seebeck occurred, along with a rise (3 percent) in resistance. It was at this time, however, that it became impossible to monitor hot electrode temperatures internally. A new method of data interpretation was thus started, correlating hot electrode temperatures with the external hot frame temperatures early in life. Differences between edge and center couples were also noted as a function of difference between edge and center hot frame temperatures to calculate hot electrode temperatures. Thus, the slight change occurring

at 6,000 hours is possibly due to temperature effects only. The above discussed method of estimating hot electrode temperatures has since been initiated on all the Phase II generators. This effect has not been noted on the other Phase I generators.

2.4.2.3 A10D6

On August 14, it was noticed that generator A10D6 had decreased in internal pressure. It was found that a pin in one of the instrumentation headers was leaking. The entire header was potted, but the internal pressure caused the potting compound to bubble. To stop this, the operating temperature of the generator was decreased to where the internal pressure was just above atmospheric. When this condition was reached, the potting compound was allowed to cure for about 24 hours. After curing, the generator was brought back to operating temperature. The leak was stopped and the generator was operated with an internal pressure of about 15.7 psia. The generator was pressurized to 25 psia at operating temperature but the additional pressure caused the generator to begin leaking again.

On September 23, 1968, the glove box was prepared with an argon atmosphere. A10D6 was removed from the test console, at operating temperature, and immediately placed in the glove box. The generator was allowed to cool to ambient temperature in a positive argon atmosphere. The pinch-off tube was cut off as near as possible to the pinched end and a pre-assembled valve and extension tube was soldered to the pinch-off tube. A subsequent leak check was not conclusive because of the discovery of a leak in the flexible transducer tube. A repair attempt was made by soldering the flexible tube but was not successful. Forms were placed around the transducer and the entire tube was sealed in Scóth Weld 2216. The next leak check indicated leaks at the instrumentation headers. Rather than try to individually pot each header, all were potted in one operation. The next leak check indicated no detectable leak.

The generator was then cold pumped for a 24-hour minimum period and backfilled to 17.6 psia. It was then pumped for an additional four hours and once again backfilled to 17.6 psia. The generator was then heated to operating temperature, stabilized, and gas pressure was adjusted to 25.0 psia. The extension tubes were pinched and the generator was returned to the test group for continuation of long-term test.

During the time the generator was operating, all Seebeck ratios held constant. While N leg resistance has not changed, the P leg resistance has increased about 5 percent and thermopile resistance has risen slightly. The rise in resistance was probably caused by an increase in hot junction temperature to about 1180° F when a short circuit developed in the generator. This was reported in detail in the Quarterly Report No. 8 (MMM 3691-35). Another possible cause is a leak which developed in one of the instrumentation header seals on the cold frame. This leak was repaired in September. As in all generators, the power ratio is falling slightly with the rise in resistance. Performance data for this generator is shown in Table 2.4.7 and Figure 2.4.9.

2.4.2.4 A10D7

The Seebeck ratios for N legs, P legs, and thermopile have held constant since the start of test. The resistance of the N legs has been fairly stable, while that of the P legs has increased rapidly (21 percent from 1500 hours to 5300 hours into test). The use of Min-K 1999 in this generator is considered to be the cause of the P leg resistance increase. This same phenomenon occurred in two SNAP-23 10-couple modules containing Min-K 1999 thermal insulation. The rate of the increase in the P leg resistance of these modules was very similar to that found in A10D7. Thermopile resistance is increasing also, but not as rapidly as that of the P legs. Power ratios are decreasing due to the resistance increase. Refer to Table 2.4.8 and Figure 2.4.10 for the generator performance data.

2.4.2.5 A10D8

Generator A10D8 underwent short-term testing with very good results. At the start of testing of A10P2, it was found that after placing the generator into the efficiency fixture the external hot frame thermocouples were broken (see section 2.4.2.7). Because of the possibility that the three thermocouples on A10D8 were also severed, they were checked and it was found that all three thermocouples were cut. The thermocouples were then replaced, and to check the data, the generator was run-in to EOL conditions. Data from this test was compared with previous test data. It was found that the data agreed, indicating a good generator. See Table 2.4.9 for a summary of these tests.

Generator A10D8 was acceptance tested in June. One objective of this test was to determine the thermal profile of the final design SNAP-21 generators at the hot and cold end. Temperature differences were established between the external hot frame and hot electrode and the external cold frame and cold electrode at BOL and EOL conditions. The temperature correlations are shown in Table 2.4.10.

The test was performed in a Phase I Linde HTVIS (generator efficiency fixture). The values presented in the following table represent the differences between the average external hot frame temperature and average hot electrode temperature, and between the average external cold frame and the average cold electrode temperature. These values will be used for future testing of the "P" series of thermoelectric generators, A10P1 through A10P5.

A relationship was established so that these correction factors can be determined for any test conditions which may arise in the testing of the "P" series generators or future systems. In Figure 2.4.11 the parameters are plotted as a function of $T_{HFE} - T_{CFE}$; they are thus directly related to the actual heat flux through a generator.

After acceptance testing and short term testing, generator A10D8 was integrated into system S10D3.

Table 2.4.5. SNAP-21 Generator A10D1 Normalized Performance
 Data Expressed in Ratios ($\frac{\text{Experimental}}{\text{Calculated}}$)

Test Hours	N Leg			P Leg			Thermopile		
	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$
212	1.015	0.99	1.035	0.99	0.93	1.045	0.97	0.98	0.95
415	1.01	0.985	1.025	1.00	0.935	1.065	0.97	0.98	0.96
885	1.015	1.00	1.03	0.98	0.90	1.06	0.96	0.97	0.95
2370	1.015	0.99	1.04	0.94	0.825	1.045	0.96	0.99	0.93
3235	1.015	0.97	1.055	0.945	0.81	1.07	0.95	0.95	0.96
5207	1.015	1.00	1.02	0.935	0.87	1.00	0.96	0.97	0.95
6023	1.00	1.00	1.00	0.93	0.885	0.965	0.96	1.03	0.89
6956	1.01	1.04	0.98	0.935	0.95	0.92	0.96	1.06	0.86

SEEBECK VOLTAGE RATIO

$$\left(\frac{E_X}{E_C}\right)$$

RESISTANCE RATIO

$$\left(\frac{R_X}{R_C}\right)$$

POWER OUTPUT RATIO

$$\left(\frac{P_X}{P_C}\right)$$

- △ N LEG
- P LEG
- THERMOPILE

Figure 2. 4. 7 SNAP-21 Generator A10D1 Normalized Generator Performance Ratios (Experimental/Calculated)

Table 2.4.6. SNAP-21 Generator A10D2 Normalized Performance
Data Expressed in Ratios ($\frac{\text{Experimental}}{\text{Calculated}}$)

Test Hours	N Leg			P Leg			Thermopile		
	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$
476	0.99	0.95	1.02	0.99	0.90	1.07	0.98	0.97	0.99
1184	0.99	0.98	0.99	0.96	0.87	1.05	0.99	0.98	0.99
1656	1.00	0.99	0.98	0.96	0.87	1.07	1.00	0.99	0.98
2195	0.99	0.95	1.01	0.95	0.88	1.03	1.00	1.00	0.99
3130	0.98	0.95	1.00	0.94	0.86	1.01	0.98	0.98	0.96
4153	0.98	0.96	0.99	0.92	0.84	0.98	0.97	0.98	0.96
5018	0.97	0.94	1.01	0.93	0.93	1.03	0.97	0.98	0.96
6215	---	---	---	---	---	---	0.95	1.01	0.90
7365	---	---	---	0.91	0.86	0.94	0.96	1.01	0.92
8795	---	---	---	0.91	0.88	0.93	0.96	1.02	0.91

SEEBECK VOLTAGE RATIO

$\left(\frac{E_X}{E_C}\right)$

RESISTANCE RATIO

$\left(\frac{R_X}{R_C}\right)$

POWER OUTPUT RATIO

$\left(\frac{P_X}{P_C}\right)$

Figure 2. 4. 8. SNAP-21 Generator A10D2 Normalized Performance Ratios (Experimental/Calculated)

Table 2.4.7. SNAP-21 Generator A10D6 Normalized Performance
Data Expressed in Ratios ($\frac{\text{Experimental}}{\text{Calculated}}$)

Test Hours	N Leg			P Leg			Thermopile		
	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$
26	0.995	0.995	0.99	0.98	1.00	0.965	0.97	0.98	0.95
499	0.99	0.965	1.015	0.985	0.99	0.985	0.97	0.95	0.97
1044	0.975	0.945	1.01	0.965	0.955	0.98	0.97	0.96	0.98
2198	0.985	0.89	1.085	0.97	0.94	1.00	0.95	0.92	0.97
3592	0.995	0.91	1.085	0.94	0.97	1.01	0.95	0.93	0.95
5633	0.975	0.895	1.065	0.98	1.00	0.96	0.98	0.97	0.98

SEE BECK VOLTAGE RATIO

$$\left(\frac{E_X}{E_C}\right)$$

1.3
1.2
1.1
1.0
0.9
0.8
0.7

RESISTANCE RATIO

$$\left(\frac{R_X}{R_C}\right)$$

1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7

POWER OUTPUT RATIO

$$\left(\frac{P_X}{P_C}\right)$$

1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7

TEST HOURS X 10⁻³

△ N LEG
□ P LEG
○ THERMOPILE

Figure 2 4 9. SNAP-21 Generator A10D6 Normalized Generator Performance Ratios (Experimental/Calculated)

Table 2.4.8. SNAP-21 Generator A10D7 Normalized Performance
Data Expressed in Ratios ($\frac{\text{Experimental}}{\text{Calculated}}$)

Test Hours	N Leg			P Leg			Thermopile		
	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$	$\frac{E_x}{E_c}$	$\frac{R_x}{R_c}$	$\frac{P_x}{P_c}$
21	0.975	0.91	1.04	0.98	1.055	0.895	0.99	0.98	0.99
1553	0.965	0.86	1.09	0.975	1.045	0.895	0.99	1.01	0.97
1962	0.965	0.90	1.035	0.965	1.095	0.84	0.98	1.01	0.95
3236	0.975	0.91	1.05	0.98	1.195	0.79	0.99	1.07	0.91
4144	0.97	0.91	1.03	0.96	1.22	0.735	0.98	1.08	0.88
5271	0.995	0.935	1.06	0.985	1.26	0.745	1.00	1.11	0.89

SEEBECK VOLTAGE RATIO

$\left(\frac{E_X}{E_C}\right)$

1.3
1.2
1.1
1.0
0.9
0.8
0.7

RESISTANCE RATIO

$\left(\frac{R_X}{R_C}\right)$

1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7

POWER OUTPUT RATIO

$\left(\frac{P_X}{P_C}\right)$

1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7

TEST HOURS X 10⁻³

- △ N LEG
- P LEG
- THERMOPILE

Figure 2.4 10. SNAP-21 Generator A10D7 Normalized Generator Performance Ratios (Experimental/Calculated)

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Table 2.4.9. SNAP-21 Generator A10D8, Thermoelectric Performance Check

Parameter	Short-Term Performance (EOL)	
	Before Thermocouple Failure	After Thermocouple Failure
T_H	897°F	890°F
T_C	105°F	103°F
E	8.11 vdc	8.02 vdc
V_L	4.73 vdc	4.13 vdc
I	2.42 amp	2.37 amp
R_i	1.40 ohms	1.39 ohm
P_o	11.45 watts	11.21 watts

Figure 2.4.11. Hot and Cold Junction Temperature Correlation for Final Design A10D8 and A10P1 through A10P5

Table 2.4.10. Hot and Cold Electrode Temperature Correlations for Generator A10D8

Condition	Design Values						Correction Factor	
	T_h (°F)	T_c (°F)	T_h (°F)	T_c (°F)	T_{HFE} (°F)	T_{CFE} (°F)	T_h (°F)	T_c (°F)
BOL	1005	115	1005	108	1064	80	-59	+28
EOL	900	105	907	105	963	80	-56	+25

T_{HFE} = Average hot frame temperature, external.

T_{CFE} = Average cold frame temperature, external.

T_h = Average hot junction temperature.

T_c = Average cold junction temperature.

2.4.2.6 A10P1

Generator A10P1 did not meet the acceptance specification requirements because of a low power ratio. The generator was examined by radiography and a reversed couple in the 41-couple section was found. (Refer to Quarterly Report No. 8, MMM 3691-35 for details.) The decision was made to build an addition prototype generator, A10P5, and to put A10P1 on a long term test as a 46-couple generator. On August 21, generator A10P1 was put on test in the normal test console operating at final design conditions: hot junction temperature, $1005 \pm 10^\circ \text{F}$; cold frame temperature, $85 \pm 10^\circ \text{F}$; load voltage, 4.73 vdc.

Tentative plans call for removing the generator from the test fixture and mating it with the HTVIS which is to go on long term test. This will present a more realistic environment for the generator.

2.4.2.7 A10P2

After finding that generator A10P1 had a reversed couple, an additional inspection was implemented before final assembly of generator A10P2. A template of the thermopile was made with small holes in the center of this template for each N leg location and soft probes were inserted into the caps of the N legs. After assembly of the thermopile, the template was placed over the caps as shown in Figure 2.4.12. Correct orientation of the legs was insured when all the N leg probes passed through the template. This inspection was made in addition to the normal electrical P and N leg polarity check.

After completing the generator assembly the correct position of the legs was further assured by radiographic examination. Two radiographs were made with the source directly above and in alignment with the cold frame and at a distance of 72 inches. The source was 1,000,000 volts at 2 ma. Kodak type M film was used with 0.010 inch intensifier screens. The exposure time was varied from 2.5 minutes to 1.75 minutes. The 2.5 minute exposure was selected because of clarity and contrast; the density difference between N and P legs is clearly shown in Figure 2.4.13, a print of the 2.5 minute exposure. The technique has been established as an acceptable process, should the need arise for additional SNAP-21 generator radiography.

Figure 2. 4. 12. Template Placed over N Leg Probes for Polarity Check

Figure 2.4.13. Generator A10P2 Thermoelectric Element Orientation as Shown by Radiography (P legs appear less dense than N legs)

Processing of A10P2 was extended due to outgassing. Normally, the increase in pressure during a 3-minute blank-off is within one micron after the fifth or sixth 4-hour pump period. A10P2 required 21 such 4-hour pump periods before a difference of one micron between readings could be achieved.

After completing fabrication and processing, A10P2 was placed in the efficiency fixture for the acceptance test. As the unit was being run-in, it appeared that the external hot end instrumentation was open. The run-in operation was stopped and the generator was removed from the fixture for inspection of the thermocouples. It was found that the thermocouples were severed. Measurements indicated an interference fit between the emitter and hot frame. This resulted in the thermocouples being severed when the generator was mounted into the fixture.

The three thermocouples were replaced and the generator was put back into the fixture. This time a 0.095-inch thick shim was placed between the cold frame and efficiency fixture. This held the hot frame further away from the emitter to allow clearance for the thermocouples. The unit was then run-in and the test progressed smoothly. Table 2.4.11 gives the results of efficiency testing and the design values. At the present time, generator A10P2 is in Bonded Stock awaiting system integration.

2.4.2.8 A10P3

Generator A10P3 passed the acceptance test early in August. Data from this test is given in Table 2.4.11. At present the generator is in Bonded Stock awaiting system integration.

2.4.2.9 A10P4

Generator A10P4 also passed the acceptance test early in August, as indicated by the data in Table 2.4.11. The generator is in Bonded Stock awaiting system integration.

Table 2.4.11. Acceptance Test Results, SNAP-21 Thermoelectric Generators

Parameter	A10P2	A10P3	A10P4	Design Values
Hot Junction Temperature, T_h (°F)	904	897	897	900
Cold Junction Temperature, T_c (°F)	106	104	105	105
Open Circuit Voltage, E_o (vdc)	8.26	8.16	8.17	7.99
Load Voltage, V_L (vdc)	4.73	4.73	4.73	4.73
Thermopile Resistance, R_1 (ohms)	1.44	1.41	1.45	1.35
Power Output, P_o (watts)	11.54	11.49	11.18	11.4
Power Output Ratio, $\frac{P_x}{P_c}$	1.02	1.02	0.99	*
*Design requirement for $\frac{P_x}{P_c}$ ratio is a minimum of 0.95.				

2.4.2.10 A10P5

After completing Generator A10P2, the decision was made to build a fifth generator, designated A10P5. An inventory check of parts of generator A10P5 disclosed that the following parts were needed to complete the generator:

- 1) Generator long case
- 2) Insulation pad
- 3) Hot frame insulator
- 4) Relief board
- 5) Fiber spacer

An "A" Rev. long case was returned to the shop for minor modifications to upgrade it to a "C" Revision. The insulation pad (Micro-quartz) was on hand but needed processing. One hot frame insulator was upgraded. The relief board and fiber spacer were fabricated from raw material. All parts were inspected to ensure that they were acceptable for use in a prototype generator. The cold frame for generator A10P5 was found to be out of specification in that the holes used for attaching the cooling manifold for processing were drilled too deep. Two of the holes pushed metal into the bottom end of the follower hole. New holes were drilled and tapped and the old holes were plugged and soldered.

After the generator was assembled, a leak was discovered in the seal area between the generator short case and the cold frame. The leak was indicated by a mass spectrometer leak detector and located in the braze material which fixes the short case to the cold frame. A visual examination of the area indicated a circular void or pore opening through the braze material. The area was cleaned and, using a medium temperature silver solder, was TIG welded into the void area to seal it from the atmosphere. The cause of this void was determined to be the presence of foreign material in this area during the brazing operation. After completing the sealing operation, the unit was leak-checked and found satisfactory.

2.5 POWER CONDITIONERS

2.5.1 Phase I Power Conditioners

Phase I electronic component testing continued this past quarter. Included in this test effort are the converters MP-B and MP-C, Trio-Lab regulators, high power regulator A, Phase I Regulator I, and automatic selector switches using converters MP-A and MP-D.

The automatic selector switch was taken off test to be transferred to another test cabinet and was restarted on August 27, 1968.

Power conditioner MP-B was taken off test for further experimental testing. These tests were primarily concerned with the improvement of the starting characteristics. This unit will be back on test early next quarter.

Tables 2.5.1, 2, 3, 4 and 5 are the life data for the Phase I electronic units. Figure 2.5.1 shows the power and life test set-up. The performance of all units has been stable throughout the past quarter.

2.5.2 Phase II Power Conditioners

As mentioned in Quarterly Report No. 8 (MMM-3691-35), power conditioner H10P3 experienced a starting problem. The problem was detected during assembly when various functional tests are performed on the units prior to sealing. The power conditioner failed to start at a load equal to 150 percent of rated load which is applied gradually after the unit had been stalled by the near short-circuit condition. This problem was solved by replacing the transformer with one from the same lot but with different high frequency response starting characteristics. It should be noted that although both transformers were within acceptable limits when individually tested for starting characteristics, they were checked at different points in the tolerance zone. This conditioner has been on test 2278 hours. Performance data for the conditioner is given in Table 2.5.6.

Power conditioner H10D5 was completed and acceptance tested during the past quarter. The power conditioner met the acceptance test specification and was subsequently put on short term test. The results of the acceptance test are given below:

Starting characteristics:

Voltage - 19.63 vdc
Current - 0.0530 amp
Starting load - 37.03 ohms

Ratio accuracy:

Output voltage - 24.00 vdc
Input voltage - 4.78 vdc
Actual load - 57.14 ohms
Output ripple (See Figure 2.5.2)
0.65 volt at 1.10 rated load; 0.04587 amp

Figure 2. 5. 1. Life Test Arrangement for Phase I and Phase II Power Conditioners

Table 2.5.1. Phase I Regulator Test Fixture Performance Data

Operating Hours	TRIO-LAB Regulators				High Power Regulator-A HPR-A	
	A Output (vdc)	C Output (vdc)	D Output (vdc)	F Output (vdc)	Output (vdc)	Operating Hours
18,369	21.75	21.86	22.49	21.93	26.78	17,552
18,729	21.72	21.79	22.47	21.90	26.77	17,912
19,257	21.72	21.78	22.46	21.89	26.80	18,440
19,401	21.72	21.78	22.46	21.88	26.81	18,584
19,881	21.54	21.63	22.41	21.88	26.46	19,064
20,265	21.53	21.55	22.42	21.90	26.47	19,448
20,673	21.53	21.46	22.42	21.88	26.51	19,856
21,117	21.49	21.39	22.40	21.84	26.51	20,360
21,161	21.52	21.37	22.39	21.85	26.51	21,344
22,617	21.60	20.79	22.40	21.88	26.48	21,800
23,145	21.46	21.45	22.35	21.82	26.45	22,328
23,769	21.46	21.13	22.31	21.82	26.36	22,952
24,297	21.35	21.52	22.41	21.82	26.31	23,480
24,777	21.43	20.93	22.33	21.76	26.34	23,960
25,137	21.49	21.00	22.36	21.83	26.47	24,320
25,449	21.49	21.00	22.39	21.84	26.53	24,632
25,929	21.50	20.97	22.39	21.83	26.56	25,112
26,381	21.51	20.95	22.40	21.84	26.60	25,564
26,693	21.74	21.81	22.46	21.92	26.93	25,876
28,061	21.52	21.30	22.41	21.83	26.52	27,244
28,541	21.51	21.27	22.38	21.81	26.56	27,724
29,525	21.48	21.00	22.33	21.75	26.52	28,708
30,773	21.46	21.01	22.31	21.75	26.52	29,956
31,733	21.48	20.82	22.32	21.76	26.53	30,916
32,189	21.49	20.28	22.33	21.80	26.51	31,372
33,029	21.51	20.25	22.36	21.78	26.55	32,212

Table 2.5.2. Performance of Phase I Power Conditioner MP-B

Converter Performance Power Conditioner	E_I (volts)	I_I (amps)	P_I (watts)	E_O (volts)	I_O (amps)	P_O (watts)	Efficiency	Hours on Test	Notes
MP-B	4.844	2.491	12.167	24.00	0.451	10.824	88.96	16,212	
	4.839	2.456	11.986	24.00	0.444	10.656	88.90	16,572	
	4.842	2.471	12.066	24.00	0.447	10.728	88.91	17,100	
	4.843	2.470	12.063	24.00	0.447	10.728	88.93	17,224	
	4.841	2.464	12.029	24.00	0.446	10.704	88.98	17,244	
	4.840	2.463	12.022	24.00	0.445	10.680	88.84	18,108	
	4.838	2.443	11.920	24.00	0.442	10.608	88.99	18,516	
	4.843	2.478	12.102	24.00	0.449	10.776	89.04	19,020	
								19,620	Unit shut down for experimental testing (6-7-67)

Table 2. 5. 3. Performance of Phase I Power Conditioner MP-C

Converter Performance Power Conditioner	E _I (volts)	I _I (amps)	P _I (watts)	E _O (volts)	I _O (amps)	P _O (watts)	Efficiency %	Hours on Test	Notes
MP-C	4.913	2.395	11.809	24.00	0.436	10.464	88.61	15,783	Note: Unit accidentally shut down. Dis- covered on 12/22/67. Power restored 12/22/67.
	4.908	2.360	11.606	24.00	0.429	10.296	88.71	16,143	
	4.909	2.374	11.757	24.00	0.432	10.368	88.19	16,671	
	4.910	2.378	11.779	24.00	0.433	10.392	88.22	16,815	
	4.906	2.372	11.740	24.00	0.432	10.368	88.31	17,295	
	4.905	2.374	11.747	24.00	0.432	10.368	88.26	17,679	
	4.904	2.353	11.642	24.00	0.428	10.272	88.23	17,087	
	4.909	2.389	11.831	24.00	0.439	10.416	88.04	18,591	
	4.912	2.395	11.867	24.00	0.436	10.464	88.18	19,575	
	4.913	2.396	11.878	24.00	0.436	10.464	88.10	20,031	
	4.910	2.375	11.764	24.00	0.432	10.368	88.13	20,559	
	4.908	2.371	11.740	24.00	0.431	10.344	88.11	21,183	
	4.909	2.375	11.762	24.00	0.432	10.368	88.15	21,811	
	4.909	2.376	11.767	24.00	0.432	10.368	88.11	22,098	
	4.910	2.375	11.764	24.00	0.432	10.368	88.13	22,485	
	4.912	2.403	11.907	24.00	0.438	10.512	88.28	22,770	
	4.911	2.377	11.776	24.00	0.433	10.380	88.92	23,250	
	4.909	2.357	11.674	24.00	0.428	10.270	87.99	24,066	
	4.908	2.368	11.725	24.00	0.431	10.344	88.22	25,434	
	4.908	2.368	11.725	24.00	0.430	10.320	88.02	25,914	
	4.908	2.374	11.755	24.00	0.432	10.368	88.21	26,898	
	4.908	2.376	11.764	24.00	0.432	10.368	88.13	28,146	
	4.910	2.378	11.779	24.00	0.433	10.384	88.16	29,106	
	4.910	2.395	11.862	24.00	0.435	10.440	88.01	29,562	
	4.909	2.395	11.860	24.00	0.435	10.440	88.03	30,402	

Table 2.5.4. Phase I Automatic Selector Switch Performance Data

Notes	Hours	Output Voltage	
		Conditioner MP-A (vdc)	Conditioner MP-D (vdc)
Note: System turned off from 4/24/67 to 6/6/67	13,583	24.54	24.59
	13,943	24.55	24.60
	14,471	24.56	24.60
	14,615	24.55	24.59
	15,095	24.62	24.58
	15,479	24.62	24.58
	15,887	24.50	24.59
	16,343	24.46	24.58
	16,799	24.45	24.57
	17,327	24.47	24.55
	17,951	24.50	24.55
	18,479	24.47	24.59
	18,959	24.47	24.57
	19,319	24.48	24.59
	19,631	24.48	24.58
	20,111	24.47	24.58
	20,687	24.45	24.56
	20,999	24.48	24.56
	22,367	24.49	24.60
	22,895	24.49	24.56
Note: At 22,367 hours system shut down to install into cabinet type mount (2/28/67).			
Note: 8/27/68 unit put back on test.			

Table 2.5.5. Phase I Regulator I Performance Data

Operating Hours	No-Load Voltage (vdc)
15,783	24.54
16,143	24.54
16,671	24.54
16,815	24.53
17,295	24.54
17,679	24.54
18,087	24.53
18,591	24.53
19,575	24.52
20,031	24.52
20,559	24.51
21,183	24.52
21,811	24.52
22,098	24.51
22,485	24.51
22,770	24.50
23,250	24.51
24,066	24.51
25,434	24.49
25,914	24.48
26,898	24.52
28,146	24.52
29,106	24.52
29,562	24.52
30,402	24.51

Table 2.5.6. Power Conditioner H10D3 Performance Data

E_I Primary (volts)	I_I Primary (amps)	P_I Primary (watts)	E_I Bias (volts)	I_I Bias (amps)	P_I Bias (watts)	E_o (volts)	I_o (amps)	P_o (watts)	Efficiency (%)	Temp. (F°)	Test* Hours
5.06	2.17	11.02	0.646	0.132	0.085	23.77	0.424	10.08	90.77	82	1296
5.06	2.17	11.00	0.657	0.132	0.085	23.76	0.423	10.05	90.66	82	1413
5.08	2.18	11.07	0.658	0.134	0.087	23.80	0.422	10.04	89.99	82	1576
5.08	2.18	11.07	0.647	0.132	0.085	23.81	0.422	10.05	90.09	80	1894
5.08	2.18	11.07	0.648	0.132	0.086	23.83	0.422	10.06	90.18	81	2106

*Includes 1241 hours of short-term tests.

Figure 2.5.2. Power Conditioner H10P5 Output Voltage Ripple:
0.020 volt/cm, 1.10 amps rated load circuit

Voltage regulation (see Figure 2.5.2):

Open circuit - 24.54 vdc

Rated load - 24.00 vdc

Voltage Drift - 0.01 volt drift

Overload - Recovered to normal operation within one second

Efficiency (η):

$$\eta = \frac{E_O I_O}{E_i I_{iC} + E_B I_B}$$

Where:

$$E_O = 24.0 \text{ vdc}$$

$$I_O = 0.421 \text{ amp}$$

$$E_i = 4.795 \text{ vdc}$$

$$I_{iC} = 2.312 \text{ amp}$$

$$E_B = 0.6351 \text{ vdc}$$

$$I_B = 0.117 \text{ amp}$$

In the equation,

$$\frac{(24)(0.421)}{(4.795)(2.312) + (0.6451)(0.117)} = 90.5 \text{ percent efficiency}$$

After completion of short term testing, H10D5 was integrated into system S10D3.

Power conditioner H10D6 was also completed and acceptance tested. After acceptance testing, the conditioner was short term tested and subsequently put on long term test with H10D3. The following comments can be made regarding the performance of H10D3 and H10D6 after 2278 hours test:

- The primary input voltages are different for the two power conditioners due to the different design input characteristics. However, the test operating conditions are valid because the long-term test is designed to detect any changes in performance rather than to operate at optimum efficiency. System testing covers more accurately the long-term optimum testing.
- The operating temperature is slightly higher than expected. This is due to the influence of the test console components on the power conditioners.
- Both units appear to be stable.

Refer to Table 2.5.7 for the performance data for H10D6.

All of the prototype power conditioners (H10P1 through H10P4) were assembled and acceptance tested. The performance of these conditioners during acceptance testing is summarized in Table 2.5.8. These conditioners have been placed in Bonded Stock.

2.6 ELECTRICAL RECEPTACLE AND STRAIN RELIEF PLUG

All the electrical cables, receptables and plugs, with the exception of one high pressure cable, were received from Vector Cable Company. The inspection test reports and the X-ray film supplied by Vector were reviewed and evaluated by 3M and found acceptable. A mechanical fit-up between the receptacles and plugs showed no discrepancies.

During a dielectric and continuity check, one of the double ended test cables which contains a mixture of copper power conductors and chromel-alumel thermocouple leads was found to have 2 chromel-alumel thermocouple pairs shorted together. This was an intermittent condition that could be duplicated when the cable was bent or flexed. The chromel-alumel thermocouple leads are covered by glass braid insulation. This type of insulation is susceptible to chafing. It is suspected that this is what occurred and that it was caused by compression of the wires during hydrotest or when the cable was molded and vulcanized during fabrication.

Table 2.5.7. Power Conditioner H10D6 Performance Data

E_I Primary (volts)	I_I Primary (amps)	P_I Primary (watts)	P_I Bias (volts)	I_I Bias (amps)	P_I Bias (watts)	E_O (volts)	I_O (amps)	P_O (watts)	Efficiency %	Temp. (°F)	Test* Hours
4.81	2.35	11.30	0.646	0.122	0.079	24.00	0.430	10.32	90.69	82	1296
4.81	2.35	11.30	0.646	0.122	0.079	24.00	0.430	10.32	90.69	82	1437
4.82	2.35	11.33	0.648	0.122	0.079	24.08	0.425	10.23	89.67	82	1600
4.83	2.35	11.35	0.648	0.122	0.079	24.20	0.430	10.41	91.08	80	1968
4.83	2.35	11.35	0.648	0.122	0.079	24.09	0.425	10.24	89.60	81	2278

*Includes 1271 hours of short-term tests.

Table 2.5.8. Performance Summary for Prototype Power Conditioners

		H10P1	H10P2	H10P3	H10P4	Acceptance Criteria
Starting Characteristics		20.6 ohm	32.8 ohm	34.9 ohm	33.7 ohm	Must begin to operate with load of 50 ohm/max
Ratio	V_{out}	24.00V	24.00V	24.00V	24.00V	Input voltage shall be $4.73 \pm 0.17V$ and load voltage be $24.00 \pm 0.02V$ at rated load (57.6 ohm)
Accuracy	V_{in}	4.80V	4.80V	4.798V	4.804V	
	R_{load}	57.2 ohm	58.0 ohm	57.2 ohm	57.4 ohm	
Output Filtering		0.068V @ 1.10 x rated load	0.065V @ 1.10 x rated load	0.060V @ 1.10 x rated load	0.065V @ 1.10 x rated load	Output ripple less than 0.10V peak-to-peak
Voltage	V_{open}	24.50V	24.45V	24.51V	24.52V	Output voltage shall be $24 \pm 0.6V$ from open circuit to rated load. At open circuit, voltage shall be $24.5 \pm 0.1V$
Regulation	$V_{rated load}$	24.11V	24.11V	24.12V	24.08V	
Voltage Drift		No drift noted	No drift noted	No drift noted	No drift noted	The drift after rated load to no load shall be 0.1V from its initial no load over 2 one-minute periods
Efficiency		90.66%	90.24%	90.42%	90.10%	Efficiency must be greater than 88%
Overload		Recovered within one second	Recovered within one second	Recovered within one second	Recovered within one second	Return to normal operation within one second after operating under short circuit

It was decided to replace the chromel-alumel wires with the same teflon coated copper wire which was used for the power conductors. This will make it necessary to correct the temperature readings for the difference between the pressure vessel temperature and the room temperature where the reference thermocouple junction is located. It was felt that this condition was more desirable than risking the possibility of further shorts in the instrumentation leads and thereby losing the data completely. Refer to Section 2.9.2 for results of tests to determine the temperature error induced by copper wire. The cables were returned to the vendor, Vector Cable Company, for rework.

To date, both double ended cables and one single ended cable have been rebuilt incorporating the teflon coated copper wire. The last single ended cable will be finished during the next quarter.

2.7 PRESSURE VESSELS

2.7.1 Status

The last five pressure vessels were hydrostatically pressure tested at Southwest Research Institute, San Antonio, Texas, during this report period. The last pressure vessel test incorporated the use of the test cable and receptacle. A pressure chamber interface adapter was fabricated and tested to provide the electrical instrumentation feed-through necessary for systems testing.

The pressure vessel satisfactorily completed three hydrostatic pressure test cycles to 11,000 psi. After being returned to 3M Company, the pressure vessels were inspected for deformation and put in Bonded stock to await system integration.

Pressure vessel long cover serial No. 5 was radiographed at Twin City Testing Laboratory, St. Paul, Minnesota. This second radiograph was required to examine a questionable area which was on the film supplied by Wyman-Gordon. After reviewing the radiograph it was concluded that the indication on Wyman-Gordon's film was either a minute pore in the basic material which was removed at the finish machine operation, or an artifact in the film cassette screen used by Wyman-Gordon. No indication of a flaw was present in the final film.

2.7.2 Radiographic Inspection Summary

All of the pressure vessels fabricated during this program were radiographically inspected as a part of the Quality Assurance provisions. The reasons for performing this inspection were to ensure that the vessels were sound and to establish accept-reject criteria for future units. It is necessary to establish accept-reject criteria because very few Berylco-165 forgings of this size have been fabricated and established radiographic criteria were not available.

The radiographic inspection of the pressure vessels indicated no flaws of any kind. In view of this, accept-reject criteria cannot be established, but the data does indicate that sound forgings of this configuration can be produced on a repetitive basis if the same procedures are followed. It is recommended that the 100 percent radiographic inspection be continued on any future units and that disposition of any abnormalities be handled on an individual basis until valid criteria are established.

2.7.3 Comparison of Analytical and Experimental Stress

All of the data from the hydrostatic test of the instrumented pressure vessel were included in Quarterly Report No. 8 (MMM-3691-35, July 1968). Comparisons have been made between calculated values of stress and those obtained from test. The data is contained in Table 2.7.1; Figure 2.7.1 shows the location of strain gages on the pressure vessel. The test results as shown in Table 2.7.1 are in every case below the calculated stress value. At the locations where discontinuity stresses exist, the results of calculation are in general not entirely satisfactory. To obtain better agreement, much more sophisticated analysis would have to be employed. However, it is felt that the additional work involved is not warranted since the test results were well below calculated values and therefore the design is conservative.

The test and calculated data in Table 2.7.1 corresponds to an applied external pressure of 11,000 psi. The mechanical properties of Berylco-165 are as follows:

Modulus of elasticity	19.3×10^6 psi
Compression yield stress (0.20% offset)	140,000 psi
Proportional limit (0.01% offset)	113,500 psi

Table 2. 7. 1. Pressure Vessel Stress – Experimental and Calculated

Strain Gage Location	Inside Hoop Stress (psi)		Outside Hoop Stress (psi)		Inside Longit. Stress (psi)		Outside Longit. Stress (psi)	
	Test	Calc	Test	Calc	Test	Calc	Test	Calc
1	75,228	91,177	64,292	85,677	76,415	91,177	65,705	85,677
2	75,079	92,795	58,929	88,639	82,354	92,297	57,147	84,608
3	78,366	93,759	57,380	90,355	84,305	89,952	60,350	86,953
4	66,426	**	23,330	**	22,630	**	52,354	**
5	72,704	89,876	58,483	76,629	28,759	44,938	33,467	44,938
6	59,788	**	35,016	**	51,325	**	9,926	**
7	74,167	89,876	58,791	76,629	29,777	44,938	31,919	44,938
8	75,440	91,177	63,838	85,677	80,339	91,177	64,507	85,677
9	80,106	91,177	63,075	85,677	87,529	91,177	60,996	85,677
10	80,042	**	67,486	**	93,107	**	60,583	**
11	101,251	101,626	—	66,496	* 4,751	15,911	—	—
12	91,155	101,626	—	66,496	* 6,235	15,911	—	—
13	74,782	92,795	59,692	88,639	82,651	92,297	57,762	84,608
14	77,073	**	—	**	88,356	**	—	**
15	77,645	91,171	63,361	85,677	80,615	91,177	56,811	85,677
16	69,268	91,177	66,447	85,677	82,926	91,177	62,587	85,677

*Gages Inside Only

**Location of Discontinuity Stresses

— No Data

Figure 2. 7. 1. Pressure Vessel Hydrostatic Test – Strain Gage Location

The maximum recorded stress level from test is 101,250 psi, which is well below the proportional limit. It is not surprising then, that all of the test data from zero to 11,000 psi plotted very linearly since the proportional limit was not exceeded.

Agreement between calculated and test values of elastic deformation are in reasonable agreement as shown in the following tabulation:

Total longitudinal compression:

Test	0.055 in.
Calculated	0.058 in.

Change in cylinder diameter:

Test	0.039 in.
Calculated	0.048 in.

2.8 SHIPPING CONTAINER

2.8.1 Status

During this report period all shipping containers were received. Shock and vibration tests were conducted on one container as called for by the procurement specification, with all requirements being met. See Appendix A for the formal test report.

Some superficial damage occurred to the containers during shipment and this was subsequently repaired by the 3M Company. Minor modifications were made to provide storage for auxiliary equipment and also to provide protection against damage to the system.

A holding fixture was installed inside one container to verify interface requirements between these components. See Figure 2.8.1.

A complete set of fin assemblies was attached to system S10D3 to verify thermal performance and assembly procedures. The SNAP-21 system with fin assemblies attached was integrated with the shipping container as shown in Figure 2.8.2.

Figure 2.8.1. SNAP-21 System Shipping Container with Holding Fixture

Figure 2.8.2. SNAP-21 System with Fin Assemblies – Integrating with Shipping Container

The status of other auxiliary equipment required for system shipment is as follows:

- Holding Fixture – All units have been fabricated and inspected. A functional fit of the shipping container and the holding fixture was performed.
- Cooling Fins – Fabrication was completed for long cover and short cover fin assemblies. The long cover assemblies were installed on system S10D3 to verify the interfaces and assembly procedures.
- Electrical Shipping Cable – These have been received and inspected to drawing requirements. These were returned to the vendor and reworked to include all copper with teflon covered wires (see Section 2.6).

2.8.2 Thermal Test

One of the shipping containers was selected to be used in conjunction with system S10D2 for conducting the shipping container thermal verification test. The primary objectives of this test were to determine the optimum cooling configuration of the shipping container circulation vents and to verify the cooling fin design. The elevated temperature test to 130°F will be conducted using system S10D3 after the system has completed dynamic and hydrostatic testing.

Prior to the shipping container test, system S10D2 was operating in a water tank at stable BOL conditions (218 watts actual input power). A 0.1 ohm resistor was placed across the thermoelectric generator output leads to short circuit the generator and the power conditioner output leads were open circuited. In this condition the power conditioner is inoperative. These conditions will also exist during normal fueled system shipment.

The thermal response of the system due to the short circuit condition is shown in Figure 2.8.3. As shown, the hot junction temperature drops approximately 90°F while the cold junction temperature rises approximately 5°F. This is due to the Peltier heat pump effect at high current conditions.

The short circuit thermal equilibrium condition of system S10D2 is shown in Table 2.8.1 for the system in the water tank and in air with cooling fins attached. The thermocouple locations of the indicated temperatures are shown in Figure 2.8.4.

After the system stabilized, power input was interrupted and the system placed on a test stand. The upper and center cooling fin sections were attached. The lower fin section was not yet completed at this time. Thermocouples were attached to the pressure vessel exterior and cooling fin base. Temperature data was taken every 30 minutes for the first three hours and thereafter every hour during the normal work day until the system became thermally stable.

Table 2.8.1 gives the temperature profile of the system in a short circuit condition with the top two cooling fins. Use this table in conjunction with Figure 2.8.5.

Figure 2.8.3. System S10D2 Thermal Response to Short Circuit Conditions (BOL Heat Input)

Table 2. 8. 1. System S10D2 Temperature Profile

Thermocouple Location*	Identification	System in Air with Two Cooling Fins Attached Reading (°F)	System in Water Reading (°F)
1	Segmented Ring at Pressure Vessel Wall	100	47
2	TEG Manufacturing Plate (inner)	111	59
3	TEG Cold Frame Center (external)	121	69
4	TEG Hot Frame Center (external)	992	952
5	TEG Hot Frame Edge (external)	999	960
6	Emitter Center	1249	1228
7	Emitter Midway	1257	1236
8	Emitter Edge	1301	1284
9	Insulation System Upper	154	103
10	TEG Cold Frame Outer (external)	116	62
11	TEG Mounting Plate	105	52
12	Heater Block Bottom	1 444	1428
13	Power Conditioner Base	—	43
14	Pressure Vessel, Cover Upper	94	43
15	Pressure Vessel, Cover Center	94	43
16	Pressure Vessel, Body Lower	93	41
	TEG Hot Frame (internal) — edge	964	924
	TEG Hot Frame (internal) — center	948	906
	Hot Electrode — edge	952	911
	Hot Electrode — center	927	986
	Cold Electrode — edge	153	104
	Cold Electrode — center	152	102
	Cold Frame (internal) — edge	137	87
	Cold Frame (internal) — center	128	78
	Follower — edge	138	89
	Follower — center	137	88
17	Pressure Vessel Interface (water - top)	95	42
18	Fin Interface Upper (water - middle)	95	42
19	Fin Interface Lower (water - bottom)	93	42
20	Air	74	

*See Figures 2. 8. 4 and 2. 8. 5

Figure 2.8.4. System S10D2 Thermocouple Locations, Water

Figure 2.8.5. System S10D2 Thermocouple Locations, Air

It should be noted that the heat transfer grease between the system and cooling fins resulted in an immeasurable drop between the pressure vessel and the cooling fin base.

The system was then placed in the shipping container with all three cooling fin sections attached. The air conditioning in the test laboratory was shut off during the shipping container ventilation test to give a stable room environment with a minimum amount of air turbulence. The room was allowed to seek its own equilibrium temperature. A true convection environment was needed to evaluate the shipping container ventilation performance. Thermocouples were attached to the shipping container in the positions shown in Figure 2.8.6. The optimum ventilation configuration (lowest system equilibrium temperature) was to be determined by collecting temperature data at various vent opening combinations according to the following matrix:

Test	Shipping Container Ventilation Screens		
	Top	Sides	Bottom
1	Open	Open	Open
2	Open	Closed	Open
3	Open	Open	Closed
4	Closed	Open	Open
5	Closed	Closed	Closed

For each of the ventilation configurations, the temperature data was taken every 30 minutes for the first three hours and thereafter every hour during the normal work day until the system reached thermal equilibrium.

The maximum allowable temperatures established to prevent system damage during the test were:

- a) Average cold junction temperature 180°F, maximum
- b) Average hot junction temperature 1100°F, maximum

Figure 2.8.6. Shipping Container Thermal Verification – Thermocouple Locations

The reduction in average cold junction temperature limit from 225°F to 180°F is because of the bare copper cold caps used in generator A10D4, the generator in system S10D2. The nickel plated cold caps used in the final design generators increases the maximum allowable temperature to 225°F.

The method used to block cooling air flow through the ventilation screens was to tape mylar over them. The temperature data is shown in Table 2.8.2. An additional test was conducted when all the ventilation screens were closed. This configuration would not be expected in normal shipping and storage, but the test was conducted for informational purposes as a worst possible situation.

The final test with all the screens covered was conducted during an 8-hour period. The temperatures were continuing to increase slightly when the last reading was taken. Temperatures might have reached the critical electrode temperature of 180°F if the test had continued. See Figure 2.8.7.

The temperature data taken from the four configurations during the shipping container ventilation test revealed little variation. The only temperature changes were linear with the room ambient temperature.

The objectives of the shipping container test were satisfied in that the cooling fins were found to be satisfactory for proper system heat transfer and that covering any of the ventilation screens resulted in no significant temperature increase.

The system was removed from the shipping container and placed on a test stand with the cooling fins still attached.

The system is presently at BOL input power, short circuited, awaiting placement into the water tank in preparation for long-term performance testing. Prior to placement into the water tank, the cooling fins will be removed and the system temperatures will be closely monitored to determine the maximum amount of handling time before the maximum allowable cold junction temperature is exceeded.

Table 2.8.2. Temperature Profile of Shipping Container Test System S10D2

Thermocouple Location Figure 2.8.5	Ventilation Configuration						Identification
	Top Side Bottom	Open Open Open	Open Closed Open	Open Open Closed	Closed Open Open	Closed Closed Closed	
		Test #1 Temp °F	Test #2 Temp °F	Test #3 Temp °F	Test #4 Temp °F	Test #5 Temp °F	
-		83	81	82	82	82	Ambient temperature
1		82	84	82	87	100	Shipping container top inside air
2		100	99	101	101	115	Holding fixture top inside air
3		87	87	87	86	93	Shipping container top center air
4		82	81	82	83	97	Between holding fixture and shipping container (air)
5		82	81	81	82	89	Shipping container bottom surface
6		81	80	81	82	87	Shipping container bottom center air
7		97	97	98	100	114	Air top center between shipping container and holding fixture
8		81	81	81	83	91	Air external top screen
9		81	80	81	82	90	Shipping container bottom screen air
10		86	84	86	86	97	Holding fixture surface
14		105	104	105	105	118	Pressure vessel cover, upper
15		106	104	105	105	119	Pressure vessel cover, center
16		100	100	99	100	112	Pressure vessel body, lower
20		106	105	106	106	119	Pressure vessel cover interface
21		107	105	106	106	119	Cooling fin interface, base
1		107	106	107	107	121	Segmented retaining ring at pressure vessel
3		130	128	129	130	142	Cold frame center
		162	161	162	162	174	Average cold caps
		947	946	946	946	952	Average hot buttons
		1015	1014	1014	1014	1020	Average hot frame
		1284	1284	1284	1284	1285	Average emitter

Figure 2.8.7. Shipping Container Temperature Rise vs Time — All Vents Closed

2.9 10-WATT SYSTEMS

2.9.1 System S10D2

After replacing the pressure vessel long cover with the thin-walled short cover, the assembly of System S10D2 was completed. The system was placed into a water tank for short-term testing while awaiting shipping container thermal testing. This system had previously been subjected to dynamic and hydro testing with the long cover.

Prior to the start of the short-term test, the watts transducer was recalibrated and was found to be indicating high (approximately 6 watts). Because of this, the power input to the system during dynamic and hydro test was actually 224* watts rather than the indicated 230 watts. The transducer was corrected and the system heat-up procedures started on 26 July 1968 with 224* watts input (see Figure 2.9.1 for heat-up curve). The system was allowed to stabilize and continued on test until early September when the system was placed into a shipping container for thermal testing. Refer to the shipping container section (section 2.8) for these test results.

The thermal and electrical performance of system S10D2 is shown in Tables 2.9.1 through 2.9.3. Shown in these tables is the pre- and post-environmental test performance of the system. The tables show the cold end temperatures to have increased by about 3 or 4 degrees. Refer to Figure 2.9.2 for thermocouple locations.

This change may be attributed to the disassembly of the system and changing from a long cover to a short cover on the pressure vessel. The emitter and hot block have also increased in temperature. The exact reason for this is not known, but it appears that these changes have not greatly affected the system performance.

Tables 2.9.2 and 2.9.3 show the total system electrical performance. It should be noted that the power input for 24 April 1968 has been changed to reflect the recalibration of the watts transducer. Figures 2.9.3 and 2.9.4 summarize the

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*This includes the 6.0 watts extraneous losses due to heater leads and thermocouple wire.

Figure 2.9.1. System S10D2 Heat-Up in Water at 40°F

Table 2.9.1. System S10D2 Temperature Profile in Water

Thermocouple Location (See Figure 2.9.2)	Identification	Pre-Dynamic Test 4/24/68 (°F)	Post-Hydro Test 9/4/68 (°F)
1	Segmented Ring at Pressure Vessel Wall	39	43
2	TEG Mounting Plate (inner)	50	54
3	TEG Cold Frame Center (external)	58	63
4	TEG Hot Frame Center (external)	1042	1040
5	TEG Hot Frame Edge (external)	1047	1046
6	Emitter Center	1254	1277
7	Emitter Midway	1262	1287
8	Emitter Edge	1305	1332
9	Insulation System Upper	97	103
10	TEG Cold Frame Outer (external)	53	59
11	TEG Mounting Plate Male	42	47
12	Heater Block Bottom	1435	1470
13	Power Conditioner Base	44	41
14	Pressure Vessel, Cover Upper	40	40
15	Pressure Vessel, Cover Center	40	41
16	Pressure Vessel Body Lower	40	41
	TEG Hot Frame (internal) - edge	1012	1014
	TEG Hot Frame (internal) - center	999	998
	Hot Electrode - edge	999	1001
	Hot Electrode - center	774	789
	Cold Electrode - edge	95	98
	Cold Electrode - center	91	94
	Cold Frame (internal) - edge	82	83
	Cold Frame (internal) - center	74	72
	Follower - edge	81	84
	Follower - center	80	81
17	Water - top	40	40
18	Water - middle	40	40
19	Water - bottom	39	40

Figure 2.9.2. System S10D2 Instrumentation

Table 2.9.2. System S10D2 Electrical Performance

Item	4/24/68	9/4/68
System Power Input (corrected-watts)	218*	218*
Generator Primary Load Voltage (vdc)	5.32	5.29
Generator Bias Load Voltage (vdc)	0.739	0.734
Generator Primary Load Current (amperes)	2.89	2.80
Generator Bias Load Current (amperes)	0.142	0.138
Generator Primary Power Output (watts)	15.30	14.81
Generator Bias Power Output (watts)	0.105	0.101
Generator Total Power Output (watts)	15.405	14.91
Conditioner Primary Voltage Input (vdc)	5.31	5.26
Conditioner Bias Voltage Input (vdc)	0.734	0.724
Conditioner Primary Current Input (amperes)	2.89	2.80
Conditioner Bias Current Input (amperes)	0.142	0.138
Conditioner Primary Power Input (watts)	15.25	14.73
Conditioner Bias Power Input (watts)	0.104	0.099
Conditioner Total Power Input (watts)	15.35	14.82
System Load Voltage (vdc)	24.6	24.5
System Load Current (amperes)	0.428	0.426
System Load (ohms)	57.48	57.38
System Power Output (measured)* (watts)	10.53	10.46
Test Hours	233.0	1771

*Actual power input after watts transducer was recalibrated and lead losses subtracted.

Table 2.9.3. Thermoelectric Performance, Generator A10D4 in System S10D2

Parameter	4/24/68	9/4/68
Primary Open Circuit (volts)	9.46	9.40
Primary Load Voltage (volts)	5.32	5.29
Primary Load Current (amps)	2.87	2.80
Bias Open Circuit (volts)	1.39	1.37
Bias Load Voltage (volts)	0.739	0.734
Bias Load Current (amps)	0.142	0.138
Internal Resistance (ohms)	1.43	1.46
Total Power Output (watts)	15.40	14.91

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Figure 2.9.3. System S10D2 Performance

Figure 2.9.4. Generator A10D4 – Seebeck and Resistance Ratios vs Time

system life performance. It is apparent that the system performance is stable in all respects.

Following the completion of the shipping container verification test, the system will begin long-term performance testing.

2.9.2 System S10D3

2.9.2.1 System Assembly

System S10D3 was successfully assembled in September. This is the first system with the final generator design. A summary of the system component and weights is given below:

Pressure Vessel Cover - Long	183.1 lbs
Pressure Vessel Body	181.5 lbs
Generator (A10D8)	18.1 lbs
Receptacle	4.4 lbs
Segmented Retaining Ring	24.0 lbs
Power Conditioner (H10D5)	5.5 lbs
Insulation System (B10D2)	
Spider	7.5 lbs
Inner Liner	3.5 lbs
Shield	247.0 lbs
Outer Case, Bolts, Rods, Foils	51.1 lbs
	309.1 lbs
Electric Heater Block Assembly	16.1 lbs
Miscellaneous (Bolts, O-Rings, etc.)	<u>10.2 lbs</u>
Weight of Electrically Heated Long Cover System	752.0 lbs

A fueled system will use a fuel capsule and radiation plug instead of the electric heater. The difference in weight will be as follows:

Fuel Capsule	-	4.3
Radiation Plug	-	<u>17.5</u>
Total		21.8 lbs

Less Weight of Electric Heater	-	<u>16.10</u>
Net Increase		+ 5.7 lbs

Weight of fueled long cover system	=	752.0
		<u>+ 5.7</u>
		757.7 lbs

The only difference in weight between the long and short cover models is the difference in cover weight. This difference is 113.10 lbs.

	757.7 lbs
	<u>-113.1 lbs</u>
Weight of fueled short cover system	644.6 lbs

This system was the first one assembled using the electrical receptacle (Figure 2.9.5). Systems previously assembled were wired through standpipes directly from interiors to test panels.

The assembly of the system is shown at various stages of completion in Figures 2.9.6 through 2.9.11. The heater block assembly is pictured alone in Figure 2.9.6 and after it has been installed into the biological shield cavity (Figure 2.9.7). The wiring of the body section is shown in Figure 2.9.8. The assembly operation showing the upper cover section being joined to the lower body section is shown in Figure 2.9.9. A view of completed system S10D3 is shown in Figure 2.9.10. Figure 2.9.11 shows the system being placed in the environmental test tank.

2.9.2.2 Short Term Testing — System S10D3

The system was put on short term performance test on September 19, 1968. The system test sequence is the same as for S10D2 (see Table 2.9.4).

Figure 2.9.5. Electrical Receptacle,
System S10D3

Figure 2.9.6. Heater Block Assembly –
System S10D3

Figure 2.9.7. Heater Block Assembly
Installed in Biological
Shield

Figure 2.9.8. Wiring-Body of System

Figure 2.9.9. Joining Pressure Vessel Body to Cover

Figure 2.9.10. System S10D3 Complete

Figure 2.9.11. System S10D3 Being Placed in Environmental Test Tank

Table 2.9.4. System S10D3 Test Sequence

Test	Facility	Comments
Short-Term Performance	3M Co	Water tank with the temperature of the water at 38°F - 42°F
System Check-Out	3M Co	Cooling manifold used to maintain cold end temperatures
System Check-Out and Shock and Vibration	Sandia	Shock and vibration to specification
Check-Out and Hydrostatic	Southwest Research Institute	Hydrostatic test to specification
Check-Out and Long-term Test	3M Co	Check out complete. System modified for long-term test.

An analysis of the system instrumentation and short-term performance is given in the following pages and Appendix B.

System Instrumentation

Because of the shorting of the chromel-alumel lead wire in the system test cables it was necessary to replace them with copper. The copper wire in the thermocouple circuit introduced an error in the indicated temperatures. This error is caused by the reference junction in the readout which is at room ambient temperature while the thermocouple lead-copper wire junction is at the temperature of the electrical receptacle. The temperatures are, therefore, compensated for the difference between the temperature of the electrical receptacle and room ambient temperature. A complete discussion of this compensation is contained in Appendix B.

System Performance

Short term performance testing was done on system S10D3 to determine the BOL performance characteristics. Thus a change in system performance can be determined as it goes through environmental testing.

Table 2.9.5 gives the temperature distribution of the system and should be used in conjunction with Figure 2.9.12. Tables 2.9.6 and 2.9.7 give the thermoelectric and electrical performance for the system.

Table 2.9.5. System S10D3 Temperature Distribution (Short Term)

Thermocouple Location*	Identification	BOL (°F)	EOL (°F)	Corrected for Reference Junction Temperature	
				BOL (°F)	EOL (°F)
1	Segmented Retaining Ring at Pressure Vessel Wall	77	81	41	44
3	TEG Cold Frame Center (External)	97	98	63	61
4	TEG Hot Frame Center (External)	1031	976	997	939
5	TEG Hot Frame Edge (External)	1043	986	1009	949
6	Emitter Center	1273	1222	1239	1185
7	Reference	42	44	42	44
8	Water Top	41	44	41	44
9	Water Center	41	44	41	41
10	Water Bottom	41	44	41	41
	Average Cold Junction (Estimated)	—	—	88	86
	Average Hot Junction (Estimated)	—	—	943	884
	Room Temperature	67	80	67	80

*See Figure 2.9.12

Figure 2.9 . 12. System S1003 Instrumentation

Table 2.9.6. System S10D3 Electrical Performance – Initial

Item	Experimental	
	BOL*	EOL*
System Power Input (Corrected) (watts)	209	185
Generator Primary Load Voltage (vdc)	4.97	4.94
Generator Bias Load Voltage (vdc)	0.675	0.679
Generator Primary Load Current (amperes)	2.67	2.35
Generator Bias Load Current (amperes)	0.114	0.114
Generator Primary Power Output (watts)	13.37	11.69
Generator Bias Power Output (watts)	0.0771	0.0774
Generator Total Power Output (watts)	13.44	11.76
Conditioner Primary Voltage Input (vdc)	4.96	4.93
Conditioner Bias Voltage Input (vdc)	0.666	0.668
Conditioner Primary Current Input (amperes)	2.67	2.35
Conditioner Bias Current Input (amperes)	0.114	0.114
Conditioner Primary Power Input (watts)	13.14	11.59
Conditioner Bias Power Input (watts)	0.076	0.076
Conditioner Total Power Input (watts)	13.24	11.66
System Load Voltage (vdc)	24.4	24.4
System Load Current (amperes)	0.425	0.425
System Load (ohms)	57.41	57.41
System Power Output (measured)* (watts)	10.37	10.37
Test Hours	134.8	155.2

*Lower Limit of Fuel Loading

Table 2.9.7. Thermoelectric Performance in System S10D3 of Generator A10D-8

Parameter	BOL*	EOL*
Primary Open Circuit	8.98	8.19
Primary Load Voltage	4.97	4.94
Primary Load Current	2.67	2.35
Bias Open Circuit	1.31	1.19
Bias Load Voltage	0.675	0.679
Bias Load Current	0.114	0.114
Internal Resistance	1.48	1.37
Total Power Output	13.44	11.76

*Lower Limit of Fuel Loading

The following comments can be made with regard to S10D3 short term performance:

- BOL hot and cold junction temperatures are lower than the design temperature of 1010°F and 100°F, respectively. This is due to the low heat input (lower limit of BOL fuel capsule) and what appears to be good heat transfer at the cold end. It should be noted that the system has a long cover.
- Observation of the EOL test results shows that the system is capable of producing the specified power output (10 watts at EOL fuel loading).

The system was taken off short term performance testing and check out was completed on September 27.

Although the system, because it is electrically heated, is capable of being shipped cold, cooling fins were attached following completion of assembly to more closely simulate actual shipping conditions expected during transportation of fueled systems.

It was also desirable to gain experience in the manipulation and handling of the fins during attachment and removal. The system is shown in Figure 2.9.13 with the lower and center cooling fin sections in position. Figure 2.9.14 shows the system being installed in its shipping container in readiness for transportation to Sandia.

System S10D3 will be shipped to Sandia for shock and vibration testing. These tests will be completed in mid-October and hydrostatic testing will be completed later in the month.

Figure 2.9.13. System S10D3 with Cooling Fins

Figure 2.9.14. System S10D3 Being Placed in Shipping Container

2.10 QUALITY ASSURANCE

2.10.1 Thermopile Assembly

New inspection techniques were developed to assure the correct placement of N and P legs in the thermopile. Figures 2.10.1 and 2.10.2 show the equipment and technique. The detail data for inspector's use is defined in the newly issued QA-STD-67, Thermoelectric Couple Polarity Inspection.

The following is a brief summary of the inspection technique used:

Two leads are inserted into a Honeywell Digit altmeter, Model 630-S. Controlled temperature is applied to **each leg** for a millivolt output reading. One end of a lead from a temperature **controlled** probe is placed on a leg in the thermopile that can be visibly **verified** as to an N or P leg (at the outermost edge of the pile assembly). The other end of the lead is placed on the next leg in the circuit. The digital voltmeter is read, in millivolts, for a positive or negative reading to verify the visibly checked leg. After this has been done, each leg in the thermopile is checked for polarity according to the drawing requirements, verifying P leg and N leg orientation by a plus for P legs or a minus for N legs, reading the sign from the digital voltmeter.

If a Triplet, Model 630NS VOM equipment is used, as shown in Figure 2.10.2, in place of digital voltmeter equipment, the VOM is adjusted at the time of set-up so as to obtain the appropriate positive or negative readings.

2.10.2 Followers

BeO followers were supplied by American Lava Corporation. 3M provided this supplier with a bearing race curvature gage (see Figures 2.10.3 and 2.10.4) to measure the actual spherical radius of each follower (100 percent inspection).

Figure 2. 10. 3. Measurement of BeO Follower Spherical Radius

Figure 2. 10. 4. Enlarged View of Measuring Operation

This inspection equipment, designed for use in the bearing industry and manufactured and calibrated by Sheffield Company, traces the actual spherical surfaces of the item to be inspected. The readings of the measurements are viewed on an Accutron electronic instrument, which is scaled in ten millionths of an inch.

A Sheffield master block together with gage blocks are used, prior to follower set-up, to ensure accuracy of follower measurement readings. All equipment is calibrated with standards traceable to the National Bureau of Standards.

Upon receipt of the followers, 3M performed a verification receiving inspection using an established acceptable quality level (AQL). The AQL was determined by evaluating the vendors inspection reports and the use of classification of characteristics.

2.10.3 Other Activities

Quality Assurance activities continued throughout the past quarter are listed below:

- Prepare inputs for and review all Purchase Requisitions
- Auditing activities
- Monitor instrument calibrations
- Conduct and attend training sessions
- Perform inspection and surveillance activities
- Prepare reports for management and monitor corrective actions.

3.0 NAVSHIPS R&D CENTER MODULES

3.0 NAVSHIPS R&D CENTER MODULES

3.1 FABRICATION

Modules 2, 3, and 4 were assembled, inspected, processed and delivered to the Test group during the quarter.

Module 4 was assembled and processed with personnel from NAVSHIPS R&D Center in attendance. They were instructed in the assembly and processing procedures used by 3M.

Test results on Modules 2 and 3 indicated possible cold end heat transfer difficulties if the cooling water temperatures were too high. To prevent this from becoming a problem in Module 4, Dow Corning heat transfer grease was used between the cold frame and cold end heater block and between the cold end heater block and the cold base.

Approximately 1000 grams of Min-K 1301 were processed for Modules 5 and 6.

All manufacturing and processing documents were updated as required to correct various minor discrepancies.

The following items were shipped to NAVSHIPS R&D Center:

1. Modules 1 through 4 with test cabinets.
2. One copy of test documents for Modules 1 through 4.
3. Original manufacturing and processing documents for Modules 1 through 4.
4. Inspection documents for Modules 1 through 4.

5. Thermoelectric hardware for Modules 5 through 9.
6. Thermoelectric couples and legs for test purposes.
7. Approximately 1000 grams processed Min-K 1301.
8. Six copies of manufacturing and processing documents for NAVSHIPS R&D Center's use for Modules 5 through 9.

NAVSHIPS R&D Center has indicated that they will not assemble Module 5 until early 1969. No reportable activity is expected in the next quarter.

3.2 TEST

During the past quarter NAVSHIPS Modules 2, 3, and 4 were tested. These Modules and Module 1, which had been tested in the previous quarter, were all evaluated.

Some difficulty was encountered in obtaining the nominal operating temperatures of 1050°F and 120°F for the hot and cold junction, respectively, for Modules 2 and 3. It was found that by using tap water the hot button temperature could only be increased to about 925°F without exceeding the upper limit of 130°F on the cold button. A water and alcohol refrigeration system was then used to cool the modules. This method produced the desired results, but the temperature of the cooling fluid was about 25°F. It was decided that this was impractical and the modules were taken off test and cooled to room temperature.

An analysis of test data indicated a high thermal impedance between the thermopile and cold base assembly. The test plan was modified to allow a hot junction temperature of 1000°F and to stabilize the cold junction temperature at some point below 180°F. This made it possible to use tap water as a cooling fluid. Modules 2 and 3 were then run-in. Module 2 operated at a hot junction temperature of 997°F and a cold junction temperature of 133°F; Module 3 operated at hot and cold junction temperatures of 1000°F and 128°F, respectively. The modules were operated at these temperatures for the duration of the test. To preclude any cold end heat transfer problems with Module 4, heat transfer grease was used

between the thermopile and cold base assembly. This improved the heat transfer and the module operated with hot and cold junction temperatures of 999°F and 125°F, respectively.

Tables 3.2.1 through 3.2.4 show the performance data for the four modules. The following comments can be made with regard to the performance of the modules:

- Performance for the modules were stable.
- Leg 4P of Module 2 appears to have a high resistance of about 50 percent above that expected. The exact cause of this is not known at this time.
- The operating temperatures varied for each module. This was due to the cold end thermal impedance between the thermopile and cold base assembly.

3.3 QUALITY ASSURANCE

Quality Assurance participated in all phases of the manufacturing process including inspection of detail parts, assemblies, process and testing for this effort. Records of inspection data for all 3M supplied materials and inspection results for the NAVSHIPS fabricated detail parts are on file and available for review.

During this reporting period the assembly of the fourth module was completed. Personnel from the NAVSHIPS R&D Center observed all phases of the manufacturing process including testing, data acquisition, test controls, and data reduction analysis. Instructions on the assembly and processing operations were given to these personnel to provide a background for the assembly of the additional modules at NAVSHIPS R&D Center.

Prior to preparing the modules for shipment a visual inspection was performed of the modules and cabinets for module internal pressure, cabinet instrument calibration, and physical damage. During packaging, the shock indicators on the units were checked and an inspection verified that adequate packaging and labeling was used for shipment.

Table 3.2.1. Data Summary NAVSHIPS 10-Couple Module No. 1

Component	T _c (°F)	T _h (°F)	E _x * (mv)	E _c (mv)	E _x /E _c	R _x * (mΩ)	R _c *** (mΩ)	R _x /R _c	P _x *** (mw)	P _c ** (mw)	P _x /P _c
3N	125	1046	115	114.6	1.00	20	19.9	1.00	168	164.9	1.02
7N	123	1048	116	115	1.00	19	19.9	0.95	174	166.1	1.04
6N	123	1047	114	114.8	0.99	19	19.9	0.95	172	165.5	1.03
8N	169	1053	115	112.5	1.02	19	21.5	0.88	176	165	1.07
3P	122	1046	96	99	0.97	16	15.3	1.04	143	145.0	0.98
7P	122	1048	98	99.3	0.98	15	15.3	0.98	156	161.1	0.97
4P	118	1046	97	99.3	0.97	15	15.2	0.98	160	162.1	0.98
6P	157	1047	95	96.8	0.98	16	15.7	1.01	139	149.2	0.93
Odd Circuit	124	1050	1.063	1.062	1.00	174	177	0.98	1620	1590	1.01
Even Circuit	130	1048	1.057	1.067	0.99	172	177.5	0.97	1620	1600	1.01

* Data at 77 hours of test.

** Matched load.

*** Material resistance only.

Table 3.2.2. Data Summary NAVSHIPS 10-Couple Module No. 2

Component	T _c (°F)	T _h (°F)	E _x [*] (mv)	E _c (mv)	E _x /E _c	R _x [*] (m Ω)	R _c ^{***} (m Ω)	R _x /R _c	P _x ^{***} (mw)	P _c ^{**} (mw)	P _x /P _c
3N	127	992	107	105.7	1.01	19	18.4	1.03	153	151.8	1.00
7N	126	997	107	106.5	1.00	18	18.5	0.97	156	153.3	1.01
6N	139	988	106	104.2	1.01	19	18.6	1.02	150	145.9	1.02
8N	135	1000	106	106.5	0.99	18	18.9	0.95	156	150.0	1.04
3P	129	992	90	91.7	0.98	14	14.4	0.97	142	146.0	0.97
7P	136	997	89	91	0.98	16	14.5	1.10	124	142.7	0.87
4P	132	1002	88	92.1	0.95	22	14.6	1.50	76	145.2	0.52
6P	141	988	88	90.4	0.97	16	14.5	1.10	122	140.8	0.87
Odd Circuit	130	995	983	986.5	0.99	166	164.5	1.00	1450	1480	0.98
Even Circuit	137	997	977	984	0.99	173	166.5	1.04	1380	1450	0.95

* Data at 95 hours of test.

** Matched load.

*** Material resistance only.

Table 3.2.3. Data Summary NAVSHIPS 10-Couple Module No. 3

Component	T _c (°F)	T _h (°F)	E _x * (mv)	E _c (mv)	E _x /E _c	R _x * (mΩ)	R _c *** (mΩ)	R _x /R _c	P _x *** (mw)	P _c ** (mw)	P _x /P _c
3N	124	999	107	107.3	0.99	18.6	18.8	1.00	154	153.9	1.00
7N	130	1004	107	107.4	0.99	18.3	18.8	0.97	157	156.4	1.00
6N	129	998	106	106.6	0.99	18.7	18.6	1.00	150	150.2	0.99
8N	125	1003	107	107.7	0.99	18.3	18.7	0.98	156	156.4	0.99
3P	130	999	89	92	0.97	14.5	14.5	1.00	136	136.5	0.99
7P	130	1004	89	92.5	0.96	14.1	14.6	0.96	139	140.4	0.99
4P	125	995	90	91.5	0.98	15.3	14.4	1.06	132	132.3	0.99
6P	128	998	89	91.7	0.97	14.0	14.5	0.96	141	141.4	0.99
Odd Circuit	128	1001	989	995.5	0.99	170	166.0	1.02	1430	1490	0.96
Even Circuit	127	997	987	992.5	0.99	164	164.0	0.99	1480	1490	0.99

* Data at 124 hours of test.

** Matched load.

*** Material resistance only.

Table 3.2.4. Data Summary NAVSHIPS 10-Couple Module No. 4

Component	T _c (°F)	T _h (°F)	E _x [*] (mv)	E _c (mv)	E _x /E _c	R _x [*] (m _Ω)	R _c ^{***} (m _Ω)	R _x /R _c	P _x ^{***} (mw)	P _c ^{**} (mw)	P _x /P _c
3N	122	996	108	106.7	1.01	18.2	18.4	0.99	161	154.7	1.04
7N	118	995	107	106.6	1.00	18.5	18.2	1.01	161	156.1	1.03
6N	121	996	108	106.6	1.01	18.1	18.3	0.99	161	155.2	1.04
8N	125	1000	108	107.1	1.01	18.1	18.6	0.97	161	154.1	1.04
3P	126	996	92	91.7	1.00	14.5	14.4	1.00	145	146.0	0.99
7P	125	995	92	91.7	1.00	14.9	14.4	1.03	142	146.0	0.97
4P	122	1000	91	92.5	0.98	14.0	14.5	0.96	147	147.5	0.99
6P	127	996	91	91.7	0.99	14.3	14.4	0.99	144	147.0	0.98
Odd Circuit	123	999	992	997.5	0.99	164	165	0.99	1500	1500	1.00
Even Circuit	123	998	989	997.5	0.99	169	165	1.02	1450	1500	0.96

* Data at 97 hours of test.

** Matched load.

*** Material resistance only.

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4.0 TASK II – 20-WATT SYSTEM

4.0 TASK II – 20-WATT SYSTEM

4.1 CONCEPTUAL DESIGN

The conceptual design effort has continued on two basic concepts proposed for the 20-watt system. As discussed in the last quarterly report (Quarterly Report No. 8, MMM-3691-35) the two concepts are: Concept I, a system using two 10-watt thermoelectric generators (See Figure 4.1.1) and Concept II, a system which has a single 20-watt thermoelectric generator (See Figure 4.1.2). A thermal analysis of each concept is not included because the HTVIS design and analysis has not been completed. This information will be available during the next quarter at which time each concept will be evaluated and the two concepts, with their analyses, will be presented to the AEC. Preliminary comparisons show that the Concept II HTVIS heat leak is lower than that of Concept I HTVIS. Analyses also indicate that a single 20-watt thermoelectric generator or power conditioner is more efficient than using two existing 10-watt units. Obviously the use of more efficient components will result in a more efficient system. This is illustrated in Figure 4.1.3 which shows the required BOL fuel loading as a function of HTVIS efficiency for both Concept I and Concept II. From this curve it is readily apparent that for a common HTVIS efficiency, Concept II is the more efficient system.

4.1.1 Concept I – Dual Generator Configuration

This concept is basically two 10-watt thermoelectric generators mounted at opposite ends of the heat source. This concept provides the following interchangeability of components with the 10-watt system:

- Thermoelectric Generators.
- Power Conditioners.
- Pressure vessel cover forgings (machined part will be different).

Figure 4. 1. 1 SNAP-21 20-Watt System Conceptual Design, Concept I

Figure 4.1.2. SNAP-21 20-Watt System Conceptual Design, Concept II

Figure 4.1.3. BOL Fuel Loading vs HTVIS Efficiency – Concepts I and II, 20-Watt System

Several arrangements for the HTVIS and shield support system were evaluated, and the one shown in Figure 4.1.1 is the best from a thermal efficiency standpoint. A summary of the various shield support systems that were considered is as follows:

- Two neck tubes with shield part of support system.
- Two neck tubes with shield not a part of support system.
- One neck tube, one bellows and tension tie rods with shield part of support system.
- One neck tube, one bellows and tension rods with shield not a part of support system.

A new shield support system would have to be developed which would consider the unequal thermal expansion of individual components. This could be overcome by using bellows and sliding joints. Verification of new techniques for assembly and handling would be necessary before integration into a system.

4.1.2 Concept II –Single Generator Configuration

Since this concept is basically a scaled up 10-watt system, maximum use can be made of the existing analytical procedures and other techniques developed for the 10-watt system. This would minimize the necessary development work for a 20-watt system.

The major problem with this concept is the rejection of heat from the generator cold frame to the pressure vessel. The system diameter is only slightly greater than the 10-watt system, consequently the thermal resistance is not greatly changed, however the reject heat is approximately doubled. An unacceptably large temperature drop due to the increased heat flow would exist with the present segmented retaining ring assembly. An improvement in the heat rejection system was obtained by doubling the number of segments in the segmented retaining ring, and the addition of a copper plate between the generator mounting plate and the pressure vessel cover interfaces (See Figure 4.1.4). Calculations using a one dimensional heat flow analysis show that the temperature drop between the generator

Figure 4.1.4. SNAP-21 20-Watt System Concept II Heat Rejection Path

mounting plate interface and sea water to be 28°F. This is about the same temperature drop determined analytically and experimentally in the 10-watt system.

In determining the 20-watt generator design, an estimation of the heat flow through the generator is made to assist in the analyses. The first step is to determine the diameter of the generator hot frame or shield emitter plate. A basic assumption was made that the biological shield in the 20-watt system would operate at the same temperature as in the 10-watt system. This temperature was selected so that the existing shield support system technology could be utilized. The hot frame diameter can then be calculated from the expression:

$$q = \sigma F_{1-2} A (T_1^4 - T_2^4)$$

where:

q = total heat flow to the generator

σ = Stefan-Boltzmann Constant

F_{1-2} = Shape factor (Effective emissivity of hot frame-to-emitter plate interface obtained empirically from 10-watt system performance)

A = Generator hot frame or emitter plate area = $0.7854D^2$
(D = generator diameter)

T_1 = Absolute temperature of emitter plate

T_2 = Absolute temperature of generator hot frame

Solving this expression for "D" yields a generator diameter of 5.8 inches. From a design layout, a maximum of 96 couples of the 10-watt generator configuration could be arranged into this diameter. Using 96 as the number of couples, a thermoelectric materials computer program was used to further verify the initial temperatures and heat flow estimate.

Table 4.1.1 summarizes the design parameters of the 20-watt generator.

Table 4.1.1. Summary of 20-watt Generator Design Parameters

Number of couples	96
Leg Diameter –inches	0.188
Leg Length –inches	0.515
Hot Junction Temperature –°F	900
Cold Junction Temperature –°F	105
Followers	Beryllium Oxide
Spring Pressure	150
*Load Voltage –volts	9.11
*Power Output –watts (e)	23.0
*Heat Input –watts (th)	277
*Generator Efficiency - %	8.3
*EOL performance at maximum efficiency load conditions	

After analyzing several arrangements of the HTVIS and shield support system the one shown in Figure 4.1.2 appeared to be the best. A summary of the various arrangements that were considered is as follows:

- One neck tube and three tension rods with shield part of support system.
- One neck tube and three tension rods with shield not a part of support system.
- Two neck tubes (one internal) with shield part of support system.
- Two neck tubes (one internal) with shield not a part of support system.
- One neck tube and three adjustable tension rods with shield part of support system.

5.0 PLANNED EFFORT

5.0 PLANNED EFFORT

- Complete plans for final assembly and fueling of first two fueled systems and coordinate activity at Oak Ridge.
- Complete top cover, power conditioner and receptacle assembly.
- Complete shipping container modification.
- Complete System Handling and Operation Manual.
- Complete the updating of system drawings for Procurement Package.
- Evaluate system test data.
- Complete System Acceptance Test Specification.
- Complete HTVIS B10D4 Failure Report.
- Process Min-K thermal insulation for the NAVSHIPS R & D Center module due for assembly at NAVSHIPS.
- Continue testing Phase I and II thermoelectric generators.
- Continue testing system S10D2.
- Complete dynamic and hydrostatic testing of system S10D3.
- Begin testing of first fueled systems.
- Continue long term tests on Phase II power conditioners.
- Quality Assurance to review specifications, plans and system assembly test process routings and procedures.

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APPENDIX A

TEST REPORT NO. 2313A ON THE APPLIED DESIGN COMPANY
MODEL 922A METAL SHIPPING CONTAINER FOR
THE 3M COMPANY SNAP-21

Test Report No. 2313A
on the
Applied Design Company Model 922A
Metal Shipping Container
for the
3M Company
SNAP-21

APPLIED DESIGN COMPANY, INC.
Tonawanda, New York 14150

August 8, 1968

Test Report No. 2313A
on the
Applied Design Company Model 922A
Metal Shipping Container
for the
3M Company
SNAP-21

The Applied Design Company Model 922A Container employs rubber shock mounts and hydraulic dampers to isolate and protect the 3M Company SNAP-21 Radioisotope Fueled Thermoelectric Generator System from shock due to abnormal or rough handling and vibration encountered in transit. The container is a vertical style container with a centerline split. The upper and lower sections of the container are vented so as to provide a free flow of convecting air over the SNAP-21 unit.

Work involved in the design, fabrication and testing of the container is covered by Minnesota Mining and Manufacturing Company's Purchase Order No. TC-04417 with the Applied Design Company and was accomplished in accordance with Specification No. 3M-37-IPP-106, Shipping Container, SNAP-21.

It is the purpose of this report to summarize the results of the test performed on the subject container with the dummy unit having the same weight, moment of inertia and simulated exterior configuration as the heavy SNAP-21 system.

I. SUMMARY AND CONCLUSIONS

1. Examination of the dummy unit and the container at the conclusion of the rough handling tests showed they were in good condition.
2. There was no interference noted between the dummy unit and the container shell.
3. The maximum accelerations imposed on the dummy unit during the rough handling tests follow:
  - 3.5 g's vertical, 6-inch rotational edgewise drop, forward end falling and 3rd 3-inch flat drop.
  - 4 g's lateral and impact test, aft end striking.
  - 5.5 g's longitudinal and impact test, aft end striking.
4. The container was subjected to the vibration test in all three directions (vertical, lateral and longitudinal). Maximum transmissibility incurred as follows:
  - Vertical Translation   1 at 6 c.p.s.
  - Longitudinal Translation 1.85 at 11 c.p.s.
  - Lateral Translation   2.50 at 11 c.p.s.

5. It is concluded that the Model 922A Metal Shipping Container passed all the qualification tests and is capable of protecting the SNAP-21 unit from damage due to shock or vibration that may be encountered in handling and shipping.

II. DISCUSSION

The subject container was tested as follows:

Rough Handling Tests, Applied Design Company, North Tonawanda, New York on July 23, 1968 with the following personnel in attendance:

Mr. R. McCurdy, Minnedota Mining and Manufacturing Company
Mr. T. Bienias, Applied Design Company
Mr. J. B. Aikman, Applied Design Company

Vibration Test conducted at Ogden Technology Laboratories, Deer Park, Long Island on August 1 and 2, 1968 with the following people in attendance:

Mr. D. Lindsad, Minnesota Mining and Manufacturing Company
Mr. A. Helfand, Ogden Technology Laboratory
Mr. J. Aikman, Applied Design Company

For clarity, the discussion portion of this report is divided as follows: A. Container Description and Weights Employed; B. Test Equipment; C. Rough Handling Tests; D. Vibration Tests.

A. Container Description and Weights Employed

The container is a verticle style cylindrical container with a centerline split. The upper and lower sections of the container are open to allow free passage of convecting air. The container is constructed of low carbon steel and utilizes wood skids. The container upper section is fitted with lifting eyes, tie-down eyes, record receptacle and tool storage box. The overall dimensions of the container are 67-inches high by 52-inches in diameter. The front of the container is identified by the location of the tool box. Left and right are those directions viewed left and right by an observer looking from the aft end of the container forward.

The weights employed during the tests are summarized as follows:

Container	700 lbs.*
Dummy	<u>1,080 lbs.</u>
Total	1,780 lbs.

A certified scale was used to obtain the weights of the container and the dummy unit.

B. Test Equipment

The test equipment employed for measuring and recording shock loads on the dummy unit during the Free Fall Shock (Drop) Tests follows:

Three non-bonded Strain Gauge Cantilever beam type accelerometers with the following characteristics:

Range:	Plus or minus 50 g's
Natural Frequency:	550 cps.
Damping:	0.6 to 0.8
Response:	Flat to approximately 400 cps.

A six channel Brush Development Company Recorder, Model 8000-99, Serial No. 125, was employed to record the acceleration.

A calibrated resistor is utilized to check the equipment before and after the tests.

C. Rough Handling Tests

The container was subjected to the Rough Handling Tests as described in Specification 3M-37-IPP-106, Paragraphs 4.3.1, 4.3.2 and 4.3.3. During the rough handling tests, three accelerometers were placed on the dummy unit. These accelerometers were oriented to record the acceleration parallel to the vertical, lateral and longitudinal axes. The vertical axis being the axis perpendicular to the plane of the base of the container. The longitudinal axis being the axis parallel to the direction of the skids. The lateral direction being the axis perpendicular to the direction of the skids. On the rotational drop tests, vertical accelerometer was placed on the side of the dummy that was falling.

A complete tabulation of the accelerations recorded during this test is presented in Table I of this report. This table notes that the maximum accelerations imposed are as follows:

- 3.5 g's vertical, 3" flat drop, 3rd drop and 6" rotational edgewise drop, forward end falling
- 4 g's lateral and impact test, aft end striking
- 5.5 g's longitudinal and impact test, aft end striking

Prints of the acceleration-vs-time traces for the samples of all types of the drops are presented in figures 1 and 2 of this report. These figures indicate g accelerations imposed on the unit as a function of the time from the moment of release during impact and subsequent damping of free vibrations of the shock mounted system.

The figures are labeled to indicate the calibration of the coordinates and the type test conducted. Examination of the container and the dummy unit at the conclusion of this test showed that there was no damage resulting from the rough handling tests. The accelerations recorded were within the allowable limits of the specification.

D. Vibration Tests

The vibration test was conducted in accordance with Paragraph 4.3.4 of the subject specification. The frequency range span was from 2 to 50 cps. The test was conducted along each of the three major axis. The first test was conducted along the vertical axis. This is an axis which is perpendicular to the plane of the skids. The second test was conducted along the lateral axis. This is an axis which is perpendicular to the direction of the skids. The third test was conducted along the longitudinal axis. This is an axis which is parallel to the direction of the skids.

Vertical Vibration - A scan of 2 to 50 cycles per second in the vertical direction showed no resonant points. In most cases the vibration response was attenuated. At a frequency of 6 cps, the input to output ratio was basically 1. There were no frequency where the amplification was larger than 1. With no resonance resulting from the vibration scan; no resonant dwell was required in the vertical direction.

Azimuth Vibration - The lateral vibration scan was run from 2 to 50 cps. At 11 cps there was an amplification (ratio of output to input) of 2.5 to 1. This point was the only significant resonant point resulting from the lateral vibration scan. A resonant dwell of 15 minutes was conducted at 11 cps. At the completion of the lateral vibration test the container was rotated and the vibration test conducted in the longitudinal direction. Again, the maximum response was found at 11 cps with an amplification of 1.84. This again was the only significant resonant point in the longitudinal direction. A resonant dwell of 15 minutes was conducted at this frequency. During this resonant dwell test an acceleration record was made at the beginning, at 5 minutes, 10 minutes and at the conclusion after 15 minutes. This record showed absolutely no change in the accelerations of the input or output from the beginning to end of the 15 minute period. This indicated no change in the vibration characteristics as a result of the resonant dwell.

The results of the vibration test appear in Table II of this report. During the test along each of the three axes little or no response was noted in the other two axes.

A-5

Written By

J. B. Aikman

Approved By

H. E. Johnson

TABLE NO. 1

Test Report No. 2313A
 Rough Handling Test Results

<u>Type Test</u>	<u>Height of Drop Inches</u>	<u>Acceleration in g's</u>		
		<u>Vertical</u>	<u>Longitudinal</u>	<u>Lateral</u>
Flat	3	3	1	2-1/2
Flat	3	3	1	1-1/2
Flat	3	3-1/2	1-3/4	2
Edgewise Fwd End Falling	6	3-1/2	1	1
Aft End Falling	6	3	1	1
End Impact Aft End Striking	-	2	5-1/2	4
Fwd End Striking	-	3	5	3-1/2

TABLE NO. II

Test Report No. 2313A
Vibration Test Results

Frequency in CPS (Vertical)	Input Acceleration in g's	Vertical Vibration Test Response Acceleration in g's		
		Vertical	Lateral	Longitudinal
2	2.0	0.8	-	-
3	1.5	0.8	-	-
4	2.0	1.3	-	-
5	2.2	1.8	-	-
6	2.1	2.0	-	-
7	2.05	1.8	-	-
8	1.7	1.5	-	-
9	Isolation from 9 to 50 cps			

(Lateral)

2	1.0	-	1.0	-
3	1.3	-	1.5	-
4	1.6	-	1.9	-
5	2.5	-	2.0	-
6	1.5	-	1.7	-
7	1.8	-	1.6	-
8	1.5	-	1.6	-
9	1.5	-	1.9	-
10	0.9	-	2.0	-
11	0.7	-	1.75	-
12	3.1	-	3.1	-
13	Isolation from 13 to 50 cps			

(Longitudinal)

2 -	3.0	-	-	3.0
3	3.4	-	-	3.0
4	2.8	-	-	2.8
5	4.5	-	-	3.7
6	4.25	-	-	3.7
7	2.8	-	-	2.6
8	2.5	-	-	2.5
9	3.0	-	-	3.7
10	2.7	-	-	4.7
11	2.5	-	-	4.6
12	2.3	-	-	3.8
13	Isolation from 13 to 50 cps			

END IMPACT
FWD. END STRIKING

END IMPACT
AFT END STRIKING

VERTICAL ACCEL.

FREE FALL
IMPACT

$\frac{1}{5}g's$

1 SEC.

LONGITUDINAL ACCEL.

$\frac{1}{5}g's$

N

(1st DROP)

LATERAL ACCEL.

$\frac{1}{5}g's$

VERTICAL ACCEL.

FREE FALL
IMPACT

1 SEC.

LONGITUDINAL
ACCEL.

2

LATERAL ACCEL.

6" FWD. EDGEWISE

FIG NO. 1

APPENDIX B

EVALUATION OF INSTRUMENTATION FOR SYSTEM TESTING

APPENDIX B

EVALUATION OF INSTRUMENTATION FOR SYSTEM TESTING

Because of the shorting of the chromel-alumel lead wire in the system cables it was necessary to replace them with copper wire. Figure B-1 shows the electrical circuit for one of the thermocouples.

Figure B-1. Thermocouple Circuit

Because of the copper leads the temperature meter No. 1 will not necessarily indicate the true temperature at T_h . Some corrections must be made.

For any one thermocouple, the equivalent circuit for that shown in Figure B-1 is:

Figure B-2. Thermocouple Equivalent Circuit

Assuming:

- The copper wire inside the test console is isothermal.
- The thermocouple wire between temperature meter No. 1 and the test console is isothermal.
- All pins are isothermal.
- The pins are at the same temperature as receptacle.

The voltage equation for the equivalent circuit in Figure 2.9.6 is:

$$E = \int_{T_m}^{T_p} S_{Cu} dt + \int_{T_p}^{T_h} S_{Cr} dt + \int_{T_h}^{T_p} S_{Al} dt + \int_{T_p}^{T_m} S_{Cu} dt \quad (1)$$

Where:

S_{Cu} = Seebeck coefficient of copper

S_{Cr} = Seebeck coefficient of chromel

S_{Al} = Seebeck coefficient of alumel

T_p = Temperature of the pins

T_m = Temperature of the meter

T_h = Temperature to be measured

T = Temperature

Equation 1 can be rewritten as:

$$E = \int_{T_p}^{T_h} S_{Cr} dt - \int_{T_p}^{T_h} S_{Al} dt \quad (2)$$

$$= \int_{T_p}^{T_h} (S_{Cr} - S_{Al}) dt \quad , \quad \text{or:} \quad (3)$$

$$E = (S_{Cr} - S_{Al}) (T_h - T_p) \quad (4)$$

From equation 4 it can be seen that the voltage that the meter reads is that voltage generated due to the temperature difference between the receptacle pins and T_h . If the pins and meter reference junction were at the same temperature the meter reading would be correct. The amount of error introduced is the difference in temperature between the meter reference junction and the pins. Therefore, if it is possible to determine the temperature of the pins, then the proper correction can be made to get the actual temperature at the sensing element (T_h).

One of the initial assumptions was that the pins were at the same temperature as the external receptacle temperature (T_r), (see Figures B-1 and B-3). This seems a reasonable assumption from previous system S10D2 data. It was found for S10D2 that thermocouple No. 1 (TC 1, Figure B-3) was at the same temperature as the water when the long cover was used (refer to SNAP-21 Quarterly No. 8,

Figure B-3. System S10D3 Instrumentation

MMM 3691-35). Temperature T_r as measured on S10D3 is the same as the water temperature.

The temperature difference between the pins (TC 7 and TC 1) is zero. Therefore, when the meter was reading TC 1 the temperature that was read was the reference junction temperature of the meter. Therefore, knowing the temperature of the meter and the temperature of the pins the proper corrections can be factored into the readings. It should be pointed out that this method of correction is more valid for water than for system check out in air when the cooling coils are used. The actual skin temperature next to the cooling coils cannot be determined; and there may be temperature gradients at the plug and receptacle.

For long term testing of S10D3 a modification will be made to the instrumentation circuit. Instead of going directly to the meter (see Figure B-1) additional thermocouple wire will be added into the circuit. This wire will then be mounted where the receptacle temperature is now monitored (see Figure B-4).

Figure B-4. Long Term Instrumentation Circuit

A test was conducted to evaluate this method of instrumentation readout. Figure B-5 shows the test setup and Table B-1 shows the test results.

From the results it can be seen that if the receptacle temperature is at the same as that of the pins, the meter will indicate the true temperature.

Figure B-5. Instrumentation Readout Test

Table B-1. Instrumentation Readout Test

T/C #1 Condition	Meter Reading "K"	Meter Reading "J"	Temperature of Junction "A"	Temperature of Junction "B"
Placed in hot water (145° F)	145° F	32	33	33
Placed in cold water (32° F)	32° F	141	141	141
Placed in cold water (32° F)	138° F	139	141	33
Placed in cold water (32° F)	95° F	136	136	73
Placed in hot water (170° F)	170° F	70	70	32
Placed in air (68° F)	103° F	68	68	33