285
10/2

SNAP-21 PROGRAM, PHASE II

DEEP SEA RADIOISOTOPE-FUELED
THERMOELECTRIC GENERATOR
POWER SUPPLY SYSTEM

MASTER

QUARTERLY REPORT NO. 5

3M Isotope Power Products
MINNESOTA MINING & MANUFACTURING CO.
3501 HUDSON ROAD, ST. PAUL, MINN. 55118 PH. 631-2500

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Report No. MMM 3691-23

UC-33

AEC RESEARCH AND DEVELOPMENT REPORT

This report has been prepared under Contract AT(30-1)3691
with the U.S. Atomic Energy Commission

SNAP-21 PROGRAM, PHASE II

**DEEP SEA RADIOISOTOPE-FUELED
THERMOELECTRIC GENERATOR
POWER SUPPLY SYSTEM**

QUARTERLY REPORT NO. 5

OCTOBER 1967

Period Covered
July 1, 1967 to September 30, 1967

Prepared by
F. Fox

Approved by
J. Brandt
Program Manager
SNAP-21 Program

Issued by
ISOTOPE POWER PRODUCTS

MINNESOTA MINING AND MANUFACTURING COMPANY
ST. PAUL, MINNESOTA 55119

Reg.

Report No. ~~MM-3601-23~~

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

~~THIS DOCUMENT IS FOR OFFICIAL USE ONLY PENDING PATENT CLEARANCE~~

DISTRIBUTION

Distribution of this document is in accordance with TID-4500 (50th Edition) category UC33.

Blank

TABLE OF CONTENTS

Section	Page
1.0 SUMMARY	1-1
2.0 TASK I – 10-WATT SYSTEM	2-1
2.1 Integrated System Design and Analysis	2-1
2.1.1 Quantitative Thermal Analysis of SNAP-21 System	2-1
2.2 Component Design and Development	2-8
2.2.1 Fuel Capsule	2-8
2.2.2 Biological Shield, Spider and Plug	2-10
2.2.2.1 Biological Shield and Spider	2-10
2.2.2.2 Encapsulated Plug	2-17
2.2.3 Insulation System	2-17
2.2.3.1 Linde Subcontract	2-17
2.2.4 Segmented Retaining Ring	2-27
2.2.5 Pressure Vessel	2-29
2.2.5.1 Design	2-29
2.2.5.2 Marine Fouling Investigation	2-56
2.2.6 Thermoelectric Generator	2-62
2.2.6.1 Design – In-Line	2-62
2.2.6.2 Generator Performance Comparison	2-65
2.2.6.3 Fabrication	2-70
2.2.6.4 Generator Quality Control	2-72
2.2.7 Power Conditioner	2-73
2.2.8 Electrical Receptacle and Plug	2-74
2.3 Component and Subassembly Testing	2-75
2.3.1 Fuel Capsule	2-75
2.3.2 Biological Shield	2-75
2.3.2.1 Material Testing	2-75
2.3.2.2 Compatibility Test	2-78
2.3.3 Insulation System	2-89
2.3.3.1 Offgassing Investigation	2-89

TABLE OF CONTENTS (Continued)

Section	Page
2.3.3.2 Vacuum Seal-Off and Getter Retention	2-89
2.3.3.3 Hydrocarbon Getter Enclosure Development	2-93
2.3.3.4 Material Compatibility Test	2-96
2.3.3.5 Getter Evaluation Test	2-106
2.3.3.6 Static Proof Test	2-108
2.3.4 Segmented Retaining Ring — Dynamic Test	2-109
2.3.5 Pressure Vessel	2-111
2.3.6 Thermoelectric Generator	2-111
2.3.6.1 Cold End Heat Transfer	2-111
2.3.6.2 Leg and Couple Testing	2-114
2.3.6.3 Leg Inspection Development Testing	2-118
2.3.6.4 Generator Development Testing	2-119
2.3.6.5 Generator Processing	2-132
2.3.6.6 Phase I Continuation Testing	2-133
2.3.7 Power Conditioner	2-135
2.3.8 Electrical Receptacle	2-135
2.4 System Fabrication, Assembly and Test	2-142
2.4.1 Phase I Continuation Testing	2-142
2.4.2 Phase II System	2-142
2.5 Safety and Testing	2-142
2.5.1 Laboratory Corrosion Testing of SNAP-21 Materials	2-142
2.5.2 Electrically Heated Fuel Capsule Test Systems	2-144
2.5.3 Ocean Exposure Studies of SNAP-21 Radioisotope Loaded Fuel Capsule	2-146
2.6 Navships Research and Development Center 10-Couple Modules	2-146
3.0 TASK II — 20-WATT SYSTEM	3-1
4.0 EFFORT PLANNED NEXT QUARTER	4-1
Appendix A SEGMENTED RETAINING RING SPRING DESIGN	
Appendix B REPORT ON DYNAMIC TESTS FROM ENVIRON LABORATORIES, INC.	
Appendix C REPORT ON DYNAMIC TESTS FROM ENVIRON LABORATORIES, INC.	

LIST OF FIGURES

Figure		Page
2-1	Schematic of Typical Nodal Point	2-2
2-2	Nodal Point Showing Conducting Areas	2-4
2-3	Fuel Capsule and Liner – Assembly	2-9
2-4	Method of Support of Biological Shield in the Hot and Cold Conditions	2-11
2-5	Biological Shield Assembly - Force Diagram (Hot or Cold Condition)	2-13
2-6	Shield Plug Assembly	2-18
2-7	Effect of Heat-Up on Radial Clearance Between the Mating Shoulder of Inner Liner and Radiation Shield	2-21
2-8	Segmented Retaining Ring Showing Revised Contour	2-28
2-9	Load Deflection Curves	2-31
2-10	Preliminary Design Stress versus Strain Berylco-165 Forged Bar (AT) in Compression	2-32
2-11	Preliminary Modulus versus Stress Design Compression for Berylco-165 Forged (AT) Material Based on Reduced Values from Tests by Beryllium Corp.	2-33
2-12	Preliminary Stress-Strain Curves for Forged 621.8 Titanium Alloy	2-34
2-13	Preliminary Tangent and Secant Modulus versus Compression Stress for Forged 621.8 Titanium Alloy	2-35
2-14	Comparison of Tangent Modulus Curves for Design Values of Ti 621.8 and Berylco-165	2-36
2-15	Pressure Vessel with Short Cover	2-39
2-16	Geometry of Reinforcing Ring	2-42
2-17	Distribution of Stresses Across Wall of Pressure Vessel Cover Penetration Ring	2-46

LIST OF FIGURES (Continued)

Figure		Page
2-18	Distribution of Stresses Across Pressure Vessel Cover – Penetration-Ring – Wall for 721 Titanium Vessel	2-47
2-19	Geometry of Pressure Vessel	2-48
2-20	In-Line Concepts	2-63
2-21	Assembly Fixture to Hold Couples	2-71
2-22	Temperature vs. Tensile Strength – U-8% Mo	2-76
2-23	Temperature vs. Elongation at Break – U-8% Mo	2-77
2-24	Photographs of Tensile Specimens After Test	2-79
2-25	Short-Term Test Specimens	2-82
2-26	Oven Placement of SNAP-21 Compatibility Test Specimens	2-83
2-27	Temperature vs. Pressure for Short-Term Compatibility Tests	2-84
2-28	Short Term Compatibility Test Specimen – Tantalum	2-85
2-29	Short Term Compatibility Test Specimen – Molybdenum	2-85
2-30	Short Term Compatibility Test Specimen – Tungsten	2-86
2-31	Short Term Compatibility Test Specimen – Aluminum Oxide	2-86
2-32	Short Term Compatibility Test Specimen – Copper	2-87
2-33	Short Term Compatibility Test Specimen – No Barrier	2-87
2-34	Getter Fill Apparatus – Demonstration Test No. 1	2-92
2-35	Getter Fill Apparatus – Demonstration Test No. 2	2-92
2-36	Macrograph of Hydrocarbon Getter Enclosure Weld	2-95
2-37	Hydrocarbon Getter Enclosure Welded in Enclosure Head	2-95
2-38	Compatibility Test Materials after 2000 Hours of Test	2-103
2-39	Nuclear Radiation Shield Material after 2000 Hours of Test	2-103
2-40	Schematic of Getter Evaluation Test Set-Up	2-107
2-41	Schematic Static Proof Test Fixture	2-108

LIST OF FIGURES (Continued)

Figure		Page
2-42	Buckled Neck Tube	2-110
2-43	Schematic of Segmented Retaining Ring Components for Dynamic Test	2-112
2-44	Comparative Results of Heat Transfer Testing	2-117
2-45	Performance Evaluation Map of SNAP-21 Generator 10D2	2-120
2-46	Performance Evaluation Map of SNAP-21 Generator 10D2	2-121
2-47	Post-Test Shock and Vibration Performance Evaluation of SNAP-21 Generator 10D2	2-123
2-48a	Performance Evaluation Map of SNAP-21 Generator 10D3, Input – 454 Watts	2-124
2-48b	Performance Evaluation Map of SNAP-21 Generator 10D3, Input – 424 Watts	2-125
2-49	Installation Drawing Showing Couple Location	2-126
2-50	Photographs of Components from SNAP-21 Generator 10D3 After Disassembly	2-129
2-51	Access Tube for Adding Pressure to Generator After Pinch-Off	2-134
2-52	Performance Data, SNAP-21 6-Couple Module A1	2-136
2-53	Performance Data, SNAP-21 6-Couple Module A3	2-137
2-54	Performance Data, SNAP-21 6-Couple Module A4	2-138
2-55	Performance of Prototype 48-Couple Generator 3M-37-P5, P6, P7 (E = voltage, R = resistance, P = power, x = experimental, C = computer)	2-139
2-56	SNAP-21 Residual Pressure Vessel: Temperature and Pressure versus Time	2-143
2-57	Electrically Heated Fuel Capsule Assembly	2-145

Blank

LIST OF TABLES

Table		Page
1	Summary of Biological Shield Support Conditions	2-12
2	Summary of Neck Tube and Three Tension Rod Support System Analysis	2-24
3	Materials Property Comparison	2-40
4	Reinforcing Ring Dimensions for Various Alloys	2-44
5	Stresses for 621.8 Titanium Alloy Hemispheres	2-51
6	Stresses for 621.8 Titanium Cylinder	2-54
7	Pressure Vessel Deformations for 621.8 Titanium and Berylco 165	2-56
8	Comparison of Generators 10D2 and P6	2-67
9	Comparison of Generators 10D2 and P6 Using Calculated Differences	2-70
10	Summary of Offgassing Test Data	2-90
11	Comparison of Compatibility Samples	2-98
12	Data from Mass Spectrometer Analysis Material Compatibility Test	2-101
13	Getter Demonstration Test Gas Composition	2-106
14	Test Data Summary of the Effects of Spherical Mismatch and Non-Hardcoated Socket Followers	2-113
15	Test Data Summary for Indium-Plated Caps and Hardcoated Socket Followers	2-115
16	Test Data Summary for Beryllium Oxide Followers	2-116
17	Test Results for Initial Leg and Couple Acceptance Test	2-118
18	Results of Tear-Down, SNAP-21 Generator 10D3	2-130
19	6-Couple Module Performance Test Data	2-140
20	Prototype 48-Couple Generator Performance Test Data	2-141

)

Blank

)

1.0 SUMMARY

1.0 SUMMARY

Significant highlights which occurred during this report period are summarized below.

- A quantitative system thermal analysis computer program has been written.
- Method of support of the biological shield has been finalized.
- Final dimensions of the fuel capsule have been determined.
- It has been determined that electron beam welding will be used for the fuel capsule closure.
- Insulation system on test has held a vacuum of 0.3 microns at 1285°F for 2200 hours.
- Insulation system shipping container has been designed and fabricated.
- An insulation wrapping technique has been demonstrated which will speed up wrapping of the insulation system.
- The segmented hold down ring springs were redesigned to withstand 6 g's.
- An analysis of the pressure vessel material was made comparing titanium with a beryllium-copper alloy.

- A change in the circuit design of the power conditioner has been made so that the power conditioner will start under all expected load conditions.
- Evaluation of offgassing data was completed for the insulation system and the getter requirements were determined.
- Cold end heat transfer tests were completed and recommendations were made for an in-line follower design.
- ✓ ● Couple testing and inspection was started on a production basis.
- Static proof test fixture for insulation system has been completed and the static proof test has been performed.
- Design drawings of the in-line generator were released and component procurement has begun.
- Six specimens of depleted uranium 8 percent molybdenum were tensile tested.
- Vacuum seal-off and getter retention tests were completed.
- ✓ ● Material compatibility test for insulation materials was completed.
- 3M material compatibility tests have been initiated and preliminary results have been obtained.
- Completed assembly and processing of Generators 10D1, 10D3, and 10D4.
- Short term performance testing, current-voltage mapping and shock and vibration testing to specification have been completed on Generators 10D1, 10D2, and 10D3.
- Shock and vibration to 20 g has been completed on Generator 10D3.
- ✓ ● Wrapping of insulation was completed on insulation system 10D1.
- Assembly of insulation system 10D2 was initiated.

2.0 TASK I – 10-WATT SYSTEM

2.0 TASK I – 10-WATT SYSTEM

2.1 INTEGRATED SYSTEM DESIGN AND ANALYSIS

2.1.1 QUANTITATIVE THERMAL ANALYSIS OF SNAP-21 SYSTEM

A quantitative thermal analysis of the SNAP-21 system has been initiated to analyze the entire integrated system. The method of analysis used is that of a system of equations which describe the heat flow according to Kirchoff's Law at various modes in the configuration. These equations will be solved on a computer by an iterative technique known as the Gauss-Seidel method. This method will accommodate any number of equations and, hence, any number of nodes.

The analysis will consider conductivity, convection and radiation processes as a function of temperature. These functions have been determined analytically or, where appropriate, by fitting data with linear expressions or Lagrange polynomials. Some features of this method are:

- (a) A complete isothermal mapping of the system can be determined.
- (b) All three heat transfer processes, conduction, convection and radiation, can be considered.
- (c) Coefficients of thermal conductivity, convection and radiation can be considered.
- (d) Boundary conditions can be varied.
- (e) Inputs and unknowns can be interchanged (i.e., T can be considered as a function of Q or Q as a function of T).

Approximately 400 equations have been set up to describe the heat flow at various nodes in the SNAP-21 system. A checking procedure is now underway to assure that the equations are correct.

The computer program has been written to solve the system of equations by Gauss-Seidel iteration; however, it has not been completely debugged.

A brief discussion of the analysis technique being used for this effort is presented in the following paragraphs.

Heat Transfer Analysis Method

Heat flow, being analogous to electric currents, may be analyzed in the same manner as an electrical circuit network. Kirchoff's rule regarding currents flowing into a point is applicable to heat transfer processes. This may best be demonstrated by regarding Figure 2-1.

Figure 2-1. Schematic of Typical Nodal Point

- (a) The enclosed volume represents a heat conducting material.
- (b) Several points, or nodes, are shown in the material. Heat flows between the nodes, the lines of path being indicated by solid and broken lines.
- (c) Taking one node into consideration, we consider the heat flowing into the node from other nodes. Indicate this node by zero, the other nodes as shown in the diagram.
- (d) Denote the heat flowing from node #4 to node #0 by

$$q_{4,0}$$

similarly with the rest.

- (e) Kirchoff's Law: The total algebraic sum of heat flowing into a node is equal to zero; i. e. ,

$$q_{1,0} + q_{2,0} + q_{3,0} + q_{4,0} + q_{5,0} + q_{6,0} = \sum_{i=1}^6 q_{i,0} = 0 \quad (1)$$

q in this case may be regarded as a vector; when flowing toward a source, q becomes negative.

The relationship for the quantity of heat flowing through a body is given by:

$$q = -kA \frac{dt}{d\xi},$$

where ξ is any curvilinear coordinate, k is the thermal conductivity of the body, t is the temperature, and A is the cross sectional area of the body. Re-examining Figure 2-1 in greater detail (Figure 2-2), we apply the above relationship for q . Here the conduction paths between nodes are shown with their corresponding cross sectional areas and thermal conductivities.

$q_{1,0}$ becomes

$$q_{1,0} = k_1 \frac{A_1}{L_1} (T_1 - T_0)$$

Figure 2-2. Nodal Point Showing Conducting Areas

where A_1 is the cross sectional area of the conducting path from node #1 to node #0, L_1 the distance between node #1 and node #0, T_1 is the temperature at node #1, T_o the temperature at node #0, k_1 the thermal conductivity along the path from node #1 to node #0. Equation (1) then becomes

$$\sum_{i=1}^6 \frac{k_i A_i}{L_i} (T_i - T_o) = 0$$

or

$$\frac{k_1 A_1}{L_1} T_1 + \frac{k_2 A_2}{L_2} T_2 + \frac{k_3 A_3}{L_3} T_3 + \frac{k_4 A_4}{L_4} T_4 + \frac{k_5 A_5}{L_5} T_5 + \frac{k_6 A_6 T_6}{L_6} - \sum_{i=1}^6 \frac{k_i A_i T_o}{L_i} = 0 \quad (2)$$

Simplifying:

$$A_{10}T_1 + A_{20}T_2 + A_{30}T_3 + A_{40}T_4 + A_{50}T_5 + A_{60}T_6 - A_{70}T_7 = 0 \quad (3)$$

If there is a heat source at node #0, equation (3) is written:

$$A_{10}T_1 + A_{20}T_2 + A_{30}T_3 + A_{40}T_4 + A_{50}T_5 + A_{60}T_6 - A_{70}T_7 = q_0 \quad (4)$$

We can develop a similar equation for each node in the volume. Boundary conditions (temperature at the surface or heat flux into the volume) are denoted at nodes laying on the surface.

The relations for each node form a set of simultaneous linear equations which may be written in matrix form:

$$[A][T] = [Q]$$

The vector $[Q]$ contains heat source and boundary temperature terms.

If the variation of k as a function of temperature is to be considered, an initial k is assumed for the material and placed in the coefficients of the nodal equations. The matrix solution is then called in the program and an initial temperature distribution determined. A new set of k 's are then calculated and re-introduced in the nodal equations. The scheme is repeated until some criteria of convergence has been met.

All heat transfer processes may be "linearized" by writing the heat flow terms as

$$q_{ij} = \left\{ P(T_i - T_j) \right\} (T_i - T_j)$$

where P is some polynomial in $(T_i - T_j)$. P may be the thermal conductivity or it may represent radiative heat transfer by writing

$$q_{\text{radiation}} = \epsilon \sigma T^4$$

as

$$q_{\text{radiation}} = (\epsilon \sigma T^3) T$$

In many books, $q_{\text{radiation}}$ is written as:

$$q_{\text{radiation}} = h_r (T_i - T_j)$$

where h_r is a function of temperature and other factors such as the "gray body shape factor".

Method of Solution

Solutions to matrix systems have been well studied. There is a variety of techniques ranging from matrix inversion to Gaussian elimination. The method to be applied is dictated by:

- (a) Acquisition convenience
- (b) Computer time and cost
- (c) Properties of convergence – will it have a solution?
- (d) Applicability to the specific problem – are the equations few or many?
Is it a sparse matrix?

The Gauss-Seidel method has been chosen because:

- (a) It is immediately available.
- (b) It ignores zero elements in the matrix; hence, saves time and money.
- (c) If the matrix exceeds computer core capacity, input may be placed on tape and a vast number of equations can be handled.

Conditions of convergence for the Gauss-Seidel iterative scheme are:

- (1) Sufficient:

$$A_{ii} \geq \sum_{j \neq i} A_{ij}$$

where A_{ii} is the diagonal element in a row of the matrix:

$$\begin{bmatrix} A_{11} & A_{12} & \dots & \dots & \dots & A_{1n} \\ A_{21} & A_{22} & \dots & \dots & \dots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ A_{1n} & \dots & \dots & \dots & \dots & A_{nn} \end{bmatrix}$$

(2) Necessary:

$$\text{At least one diagonal element } A_{ii} = \sum_{i \neq j} A_{ij}.$$

Since there is one term in a nodal equation which is the sum of the rest (see equation 2), these conditions will most likely be met in every case by suitable arrangement of the equations in the matrix (i. e., the dominant element in the equation falling on the diagonal). At least one equation will meet the "necessity" conditions which is all that is required. There are cases in which $|A_{ii}| \nless \sum |A_{ij}|$. These occur in radial geometry, but if there is one case in a system in which this does not happen, the necessity is satisfied.

There is a question regarding rapidity of convergence, i. e., is the rapidity of convergence dependent upon the magnitude of the inequality?

$$A_{ii} > \sum_{i \neq j} A_{ij}$$

This will have to be studied. Intuitively, it would seem so, and if so, a method has been employed in attempting to force the convergence. Normally, in the Gauss-Seidel method, all starting values are zero. In this program provision is made to assign reasonable initial temperatures to all unknowns. This places the system close to solution, both aiding convergence and cutting computer time. The fewer number of iterations also eases the influence of round-off error generated in the machine. This error could conceivably override the satisfaction of the necessity conditions.

2.2 COMPONENT DESIGN AND DEVELOPMENT

2.2.1 FUEL CAPSULE

During this report period the fuel capsule design to be used for the sea exposure test units and the weld qualification test units was completed. This design, as shown in Figure 2-3, consists of a cylindrical pellet of strontium 90 double encased with an inner liner and outer shell. The inner liner, made from 304L stainless steel, is used primarily as a fabrication aid to minimize the amount of contamination during fuel capsule fabrication. The outer shell of Hastelloy C provides structural and corrosion protection for the pellet so that the fuel will be contained for a design life of 300 years when subjected to the hydrostatic pressure loads and corrosive sea water environment specified for the SNAP-21 system.

The inner liner will be fabricated from a section of thin-wall tubing with end plates TIG (tungsten-inert gas) welded in place. The outer shell cylindrical section will be machined from Hastelloy C bar stock and the end plates machined from Hastelloy C plate. The end plates will then be electron beam welded to the cylindrical section.

Electron beam (EB) welding was selected as the final closure welding technique after evaluation of both TIG welding and EB welding. Results of this weld investigation revealed that TIG welding was marginal with respect to achieving the required penetration of 0.1 inch and was susceptible to root cracking. Electron beam welding, on the other hand, showed a capability for full penetration (up to 0.3 inch) with no apparent root cracking. In addition, the EB weld technique causes less weld joint distortion and thus is better suited to ultrasonic inspection techniques than is TIG welding.

There are inherent problems with leak checking when the electron beam welding method is used. Welding is done in a vacuum and consequently there is no gas enclosed in the fuel capsule after the welding operation is completed. On the other hand, the shielding gas used in TIG welding provides a built-in source of helium gas for leak detection.

Figure 2-3. Fuel Capsule and Liner — Assembly

Two possible methods of leak detection are being considered. One method uses weight differential. The electron beam welded fuel capsule is placed in a fluid and pressurized. The capsule is then removed and its weight checked. A gain in weight indicates a leak. This method would be effective for the larger leaks. The other method requires that the fuel capsule be in a pressurized atmosphere of helium for a period of time. The capsule is then removed and leak checked with a mass spectrometer leak detector, the same as a TIG welded capsule. If any helium is detected, there is obviously a leak present. This method is effective in detecting the small leaks.

2.2.2 BIOLOGICAL SHIELD, SPIDER AND PLUG

2.2.2.1 Biological Shield and Spider

The design effort during this report period was concerned with the design and preparation of drawings for the biological shield and the shield support spider. Relative shield movement with respect to the insulation system outer case must be kept to a minimum (0.003 inch) to ensure that the system will withstand 6 g shock loads without causing neck tube buckling.

The method used to support the biological shield is shown in Figure 2-4. As shown, the method of support is different in the hot and cold conditions. In the cold condition, the shield support bolts and spider support bolt are torqued to a specified value which results in a compressive load at surfaces A and B. This creates a radial friction force which prevents movement of the shield with respect to the neck tube and support spider. In this condition there is clearance at diameters A and B. Thus, in the cold condition, the shield is supported axially by the shield support bolts and the three tension tie rods and positioned radially by friction at surfaces A and B.

The clearances at diameters A and B and the thickness of the molybdenum expansion washers under the shield and spider support bolts are such that there will be an interference fit at diameters A and B and the bolts will be loose when the shield temperature is increased to its operating temperature. Thus the shield will be positioned radially by the diametral interference and will be supported in the axial direction by the combined axial friction force at diameter A and the tension tie rods. Table 1 summarizes the hot and cold condition of the support. Since this

Figure 2-4. Method of Support of Biological Shield in the Hot and Cold Conditions

concept does not require that the U-8 molybdenum bolts carry any tensile loads at operating temperature, the problem of high creep rates exhibited by this material at the shield operating temperature of 1400°F + is eliminated.

Table 1. Summary of Biological Shield Support Conditions

Condition of Component or Interface	Shield Temperature	
	Cold	Hot
Shield Support Bolts	Tension due to assembly torque	Loose due to difference in expansion of bolt and washer
Surface A	Compression due to support bolt tension creates radial friction force	Loose
Diameter A	Clearance	Interference creating an axial friction force
Spider Support Bolt	Tension due to assembly torque	Loose due to difference in expansion of bolt and washer
Surface B	Compression due to support bolt tension creates radial friction force	Loose
Diameter B	Clearance	Interference

Note: Tension tie rods are in tension in both the hot and cold conditions since the tie rod angle has been selected so that thermal expansion of the shield assembly and tie rod assembly do not introduce additional stress in the tie rods.

To prevent radial movement of the shield with respect to the neck tube and spider in the cold condition, the sum of the clamping forces at surfaces A and B times their respective coefficients of friction must equal the weight of the shield times the maximum horizontal acceleration.

Using the nomenclature and assumptions shown in Figure 2-5:

$$F_1 + F_2 = W_s \text{ times max horizontal acceleration times safety factor}$$

$$F_1 + F_2 = 290 \times 6 \times 1.5 = 2610 \text{ lbs}$$

Figure 2-5. Biological Shield Assembly - Force Diagram
(Hot or Cold Condition)

For analytical purposes the shield CG is equidistant between F1 and F2, $F1 = F2$.

Therefore,

$$F1 = F2 = \frac{2610}{2} = 1305 \text{ lbs}$$

Using a coefficient of friction of 0.3, the total axial clamping force required to produce 1305 pounds of frictional force is:

$$\frac{1305}{0.3} = 4350 \text{ lbs}$$

At the neck tube end, this force is provided by 8 bolts; therefore, the force required per shield support bolt is:

$$\frac{4350}{8} = 544 \text{ lbs}$$

The minimum cross sectional area of the shield support bolt is 0.0388 in^2 ; therefore, the tensile stress will be:

$$t = \frac{544}{0.0388} = 14,000 \text{ psi}$$

The torque required to produce this axial load can be closely approximated by the following equation:

$$T = KDL$$

where:

T = torque, in-lbs

D = major diameter of thread, in.

L = axial load, lbs

K = factor dependent on the coefficient of friction, 0.2 used for unplated screws

For a 5/16 - 24 bolt, $D = 0.3125$ inch.

By substitution, $T = (0.2) (0.3125) (544) = 34$ in-lbs

At the spider end, the axial clamping force must be provided by the single spider support bolt. The minimum cross sectional area of this bolt is 0.3403 in^2 ; therefore, tensile stress will be:

$$t = \frac{4350}{0.3403} = 12,800 \text{ psi}$$

The torque required to produce an axial force of 4350 pounds with a 3/4-inch bolt will be:

$$\begin{aligned} T &= (0.2) (0.75) (4350) = 653 \text{ in-lbs} \\ &= 54.5 \text{ ft-lbs} \end{aligned}$$

Torque levels of this magnitude are relatively low for a 3/4-inch bolt with conventional head dimensions. However, because of insulation space requirements, it was necessary to design the spider support bolt with a head of minimum thickness. A bolt head thickness of 0.125 inch was selected since it provided the insulation clearance required by Linde. To verify that this thickness would withstand the required bolt torque, torque tests were conducted on two standard 3/4-inch hex-head steel bolts. The bolt heads were machined to a thickness of 0.125 inch. One bolt was torqued three times to 60 ft-lbs and showed negligible deformation. The second bolt was torqued three times to 70 ft-lbs and then once to 80 ft-lbs. This bolt exhibited some deformation at the hex points; however, it was still completely functional.

Since the tensile strength of standard steel bolts is in the range of 60,000 to 80,000 psi as compared to the 115,000 psi strength of U-8 molybdenum, it was concluded that the 0.125-inch thick bolt head was satisfactory.

Known

W_s = weight of shield assembly = 290 lbs

F_{A2} = clamping force of spider support bolt, lbs

F_{A1} = total clamping force of shield support bolts, lbs

F_1 = friction force of neck tube-to-shield surface, lbs

F_2 = friction force of shield to spider surface, lbs

Bolts are made from U-8 molybdenum with room temperature yield strength of 115,000 psi.

Spider support bolt is 3/4-16 UNF-2A.

Shield support bolts are 5/16-24 UNF-2A.

Maximum horizontal acceleration — 6g x 1.5 safety factor.

Assumptions

1. Coefficient of friction for both surfaces = 0.3.
2. Shield center of gravity is equidistant between neck tube and spider interfaces (this is very close to being true and is accurate enough for this calculation).

Design calculations show that the maximum diametral clearance that can exist in the cold condition at diameters A and B is 0.0015 inch. Since it is not practical to assign tolerances to both components to ensure maintaining this clearance, the shield will be machined and measured first. A neck tube and spider will then be final machined on an individual basis to provide the proper assembly clearance. This will require matching components by serial number for a specific assembly.

The inner liner and spider surfaces which contact the biological shield will be flame sprayed with 0.010-inch thick molybdenum to prevent a eutectic formation at high temperatures.

The shield plug was designed to use minimal space between the generator case and the radiation disc of the shield plug. This space varies from 0.050 to 0.150 inch. However, there is a protruding welded lip on the generator case which is in close proximity to the heads of the bolts holding the shield plug in place. The lip is

longer than would be necessary for welding to minimize the possibility of MIN-K powdered insulation from working its way between the generator and radiation disc. To make room for the lip, a countersunk socket head screw is used to hold the shield plug down.

2.2.2.2 Encapsulated Plug

The configuration of the encapsulated shield plug has been established; however, the compatibility barrier material to prevent eutectic formation between the plug and encapsulating body has not been determined. This decision is awaiting the outcome of isothermal compatibility tests currently being performed. These tests are being performed at 3M Company to examine the effectiveness of the various barrier materials for use between the shield material and the inner liner and between the stainless steel encapsulating material of the shield plug. The candidates for barrier materials are: tantalum, tungsten, molybdenum, copper and alumina. The coating used will be flame or plasma sprayed directly on the shield plug.

The configuration of the shield plug assembly is shown in Figure 2-6. This figure shows an indentation in the bottom of the plug to accommodate the handle of the fuel capsule.

2.2.3 INSULATION SYSTEM

2.2.3.1 Linde Subcontract

Linde has continued work under subcontract AT(30-1)-3691-5511. Work has progressed on fabrication of development insulation system 10D1, insulation application development, structural analysis of the biological shield support system, the system assembly fixture and the shipping container.

a) SNAP-21B Prototype

The SNAP-21B prototype insulation system was placed on thermal test in the 3M laboratory. The temperature was maintained at approximately 1285°F and the internal pressure was monitored. After 2200 hours of test the internal pressure was stabilized at 0.3 micron of mercury. The insulation system was then removed from test so the pressure vessel could be used for the segmented retaining ring dynamic test.

Figure 2-6. Shield Plug Assembly

b) Development Insulation System 10D1

The insulation system was assembled and wrapped. A method of applying the insulation material was developed which has considerably decreased the wrapping time from what was experienced on the SNAP-21B prototype unit. Design of the outer enclosure shells was completed and the order was placed.

(1) Assembly

The insulation system assembly fixture has been designed to perform a variety of functions during the assembly of the insulation system. The fixture ensures concentricity of components of the insulation system and provides control of radial and angular positioning of the tension tie rods.

The following is a summary of the operations which will be performed using the assembly fixture:

- Locate and align inner liner and shield with shaft.
- Locate and secure spider to biological shield plus inspect length.
- Insulation application.
- Locate and weld inner liner to top head enclosure.
- Locate and weld top and bottom head enclosure and inspect length.

Fabrication of the assembly fixture was completed. The hub which fits over the shaft was machined to a close tolerance with the shaft so that proper alignment could be maintained. Both the shaft and the hub were constructed of carbon steel. When the hub was fitted onto the shaft during assembly of the components, the two parts seized and the hub could not be moved on or off of the shaft by hand. A wheel puller was used to remove the hub from the shaft. Both parts were galled. After the parts were cleaned up a new hub and shaft was made to be used for alignment of the tension rods. These parts also have close tolerance but the hub has been constructed of brass to prevent galling.

After Linde received the components for the insulation system, inspection of critical dimensions revealed that the molybdenum compatibility barrier had built up to a crown of 0.021 inch on the bottom of the inner liner. It was necessary to grind the excess molybdenum from this surface. It was also noted that the diametrical clearance between the interference fit shoulders on the inner liner and radiation shield ranged from 0.0018 inch to 0.0028 inch. As the maximum clearance allowable to prevent looseness at operating temperature was 0.0013 inch (see Figure 2-7), the inner liner was returned to 3M Company for respraying and regrinding. After rework the inner liner was reinspected and it was found that the diametrical fit ranged from 0.0008 inch interference to 0.0012 inch clearance.

It was determined that the original dimensions of the biological shield were not taken at ambient temperature. To ensure proper fit of inner liner and shield on future units the biological shields are being shipped to 3M Company so that both components can be measured at the same temperature.

The ball on the tension rod was lapped into the socket in the spider to minimize any chance for deflection in this connection. After lapping, approximately 80 percent of the ball and socket surface area was in contact. Rod Nos. 1 and 2 were lapped in socket Nos. 1 and 2 while rod No. 4 was lapped in socket No. 3.

The first step in the assembly of the unit components was to install the inner liner in the biological shield. The inner liner bolts were threaded into the shield before assembly to ensure that there would be no seizures. The shield was oriented in an upright position with the base resting on a wood platform. Because of the slight interference fit, the inner liner was filled with ground dry ice to cause the liner to shrink slightly and allow a fit into the shield. However, it was found that when the liner was inserted into the shield, the liner could not be rotated as required to provide the required alignment of the flange bolt holes. To provide more shrinkage to allow line-up, the dry ice was removed and the inner liner was filled with liquid nitrogen (LN_2). This additional temperature drop provided sufficient shrinkage to allow proper alignment of the flange bolt holes. The

Figure 2-7. Effect of Heat-Up on Radial Clearance Between the Mating Shoulder of Inner Liner and Radiation Shield

LN₂ was removed from the inner liner and the components were allowed to come to ambient temperature before proceeding with the assembly.

The eight molybdenum washers were located in the inner liner flange and the U-8 Mo bolts were installed. The bolts were torqued and a molybdenum lock wire was installed. The completed assembly was then bolted to the assembly fixture.

To assemble the tension tie rod spider to the shield it was necessary to chill the spider. The spider was first slow cooled in saturated nitrogen vapor and then slowly submerged in LN₂. At LN₂ temperature the spider was installed on the biological shield. During handling the spider was purged with helium gas to prevent an accumulation of condensation on the mating surfaces. The angular alignment between the spider and shield was set with the use of two alignment pins which project from the assembly fixture and mate with the alignment holes in the spider. The spider and shield were allowed to return to ambient temperature before installing the spider holding bolt.

The molybdenum spider bolt washer was installed on the spider and the U-8 Mo spider bolt was threaded into the shield. The spider bolt was torqued to the specified 60 ft-lb torque and a double molybdenum lock wire anchored the bolt to the spider.

Following the installation of the spider on the shield, the assembly fixture was removed from the shaft and a tension rod positioning fixture was installed. The ball on the tension rod and the socket in the spider were coated with Molykote Type Z dry lubricant powder to prevent cold welding of these components with the unit at temperature in a vacuum. The tension rods were installed in the spider and held in the proper angular orientation by the tension rod positioning fixture. The tension rod anti-rotation clips were installed in the spider through the drilled hole in the rod ball.

(2) Insulation Application

After the 3M supplied components were assembled, two layers of processed quartz cloth were installed to completely cover the biological

shield, spider, outside of inner liner, and tension rods. This quartz cloth physically separates the first nickel foil of the multi-layer insulation system from the U-8 Mo shield. Two layers of quartz cloth were wrapped around the tension tie rods to prevent the foils from thermally shorting against the rods. Wrapping of nickel, copper and aluminum foils with quartz paper spacers was completed using a Linde proprietary application technique.

(3) Outer Enclosure Shells

The Phoenix Production Company of Milwaukee, Wisconsin, has been selected as the manufacturer of the outer enclosure shells. These components will be made by first spinning and then machining. An order for spinning eleven units has been placed. The first two units will be machined immediately; the other nine will be machined as required. The first two units will be delivered to Linde the first week of the next reporting period.

c) Structural Analysis of Biological Shield Support System

Linde has revised the calculations to determine the rod length, rod angle, rod diameter and neck tube wall thickness. After analysis it was decided to use Inconel 625, which has a low creep rate on the hot end of the tension rod, and Inconel 718, which has high strength (117,000 psi at 1000°F) on the cold end of the tension rod. The proportional limit of the solution annealed Inconel 625 material is 30,000 psi at 1450°F.

A summary of the neck tube and the tension rod support system analysis is shown in Table 2.

d) Shipping Container

The shipping container to be used for transporting the Model A HTVIS units to the dynamic test location and for delivery to 3M Company was designed based on a suspension system recommended by Lord Manufacturing Company. The suspension system uses three shear type rubber supports and is designed so that the HTVIS unit will not receive more than 6 g when the shipping container experiences a 4-inch flat drop (free fall) on any side or end of the container. A complete set of shipping

Table 2. Summary of Neck Tube and Three Tension Rod Support System Analysis

1.	<u>Total supported weight:</u>	289 lbs	
2.	<u>Dynamic loading:</u>	3 g vibration at 50 cps and 6 g shock at 6 ms time duration	
3.	<u>Materials:</u>	Neck tube - Hastelloy X Hot end spider - Hastelloy X Tension rod male end - Inconel 625 solution, annealed 2100°F/1 hr Tension rod female end - Inconel 718 solution, annealed at 1800°F/1 hr and age hardened at 1325°F	
		<u>Design with 1.5 Safety Factor</u>	<u>Design with 1.75 Safety Factor</u>
4.	<u>Neck tube wall thickness, inch (straight neck tube)</u>	0.012 min - 0.01275 max	0.01324 min - 0.014 max
	Safety factor with minimum wall thickness cold end	1.68	2.09
	Safety factor with minimum wall thickness hot end	1.41	1.75
	Safety factor with maximum wall thickness cold end	1.90	2.3
	Safety factor with maximum wall thickness hot end	1.62	1.93
5.	<u>Tension rod angle in the cold condition</u> (angle between rod and line perpendicular to axial centerline)	27° 49'	27° 49'
6.	<u>Tension rod angle in the hot condition</u>	30° 6'	30° 6'
7.	<u>Tension rod diameter male end, inch</u>	0.273 + 001 -0.000	0.273 + 001 -0.000
8.	<u>Cross sectional area of tension rod, male end, in.²</u>	0.0585	0.0585
9.	<u>Load in tension rod, lbs (male and female ends)</u>		
	Loading Condition I	800	783
	Loading Condition II	1030	1011

Table 2. Summary of Neck Tube and Three Tension Rod Support System Analysis (Continued)

	Design with 1.5 Safety Factor	Design with 1.75 Safety Factor
10. <u>Maximum applied stress in tension rod male end with 1.2 amplification factor due to shock loading, psi</u>		
Loading Condition I	16,410	16,061
Loading Condition II	21,128	20,738
11. <u>Maximum allowable stress in tension rod male end (proportional limit), psi</u>	30,000	30,000
12. <u>Safety factor tension rod male end</u>		
Loading Condition I	1.82	1.86
Loading Condition II	1.41	1.44
13. <u>Tension rod diameter female end, inch</u>		
Inside diameter	0.201	0.201
Outside diameter	0.246	0.246
14. <u>Cross sectional area of tension rod female end, in.²</u>	0.01579	0.01579
15. <u>Maximum applied stress in tension rod female end with 1.2 amplification factor due to shock loading</u>		
Loading Condition I	60,797	59,506
Loading Condition II	78,277	76,833
16. <u>Maximum allowable stress in tension rod (proportional limit), psi</u>	≈117,000	117,000
17. <u>Safety factor tension rod, female end</u>		
Loading Condition I	1.92	1.96
Loading Condition II	1.49	1.52
18. <u>Heat loss through neck tube, watt</u>	20.4 - 21.7	22.5 - 23.8

Table 2. Summary of Neck Tube and Three Tension Rod Support System Analysis (Continued)

	Design with 1.5 Safety Factor	Design with 1.75 Safety Factor
19. <u>Heat loss through tension rods</u>	14.6 - 14.7	14.6 - 14.7
20. <u>Total system heat leak including 9-watt insulation heat loss, watt</u>	44.0 - 45.4	46.1 - 47.5

*Loading Condition I (Horizontal Position)

Maximum loading occurs in the neck tube under this loading condition.

*Loading Condition II (Horizontal Position)

Maximum loading occurs in the tension rod under this loading condition.

container drawings was transmitted to 3M Company for review. The drawings were approved with comments and the shock mounts were purchased. Fabrication of the shipping container has been completed. During the next reporting period a 4-inch flat drop dynamic tests will be performed using a dummy insulation system. The dummy insulation system will be instrumented to ensure that the shock has been attenuated to levels which are at or below those specified.

2.2.4 SEGMENTED RETAINING RING

Design effort during this report period was devoted to the design and analysis of the segments and compression springs to ensure that there will be no relative movement between the insulation system and the pressure vessel under 6 g dynamic loads. To meet this requirement, the compression springs were redesigned to give a spring rate of 640 lbs/in. The old spring has a 420 lbs/in. spring rate. The increased spring force, in conjunction with a change in the curved contour of the segments, provides a more controlled contact between the pressure vessel, segments, and the insulation system. This ensures better heat transfer from the generator cold frame to the pressure vessel. The resultant force is also controlled to produce forces in the direction and magnitude required to resist dynamic loads. Figure 2-8 shows the configuration of the contoured surface of the segments of the segmented retaining ring assembly.

Design calculations for the redesigned spring are shown in Appendix A.

Figure 2-8. Segmented Retaining Ring Showing Revised Contour

2.2.5 PRESSURE VESSEL

2.2.5.1 Design

Since the last reporting period, additional test data have been obtained for Berylco-165 material. The Beryllium Corporation has provided 3M Company with results of very recent compression tests on two specimens of forged, aged and heat treated Berylco-165. Compression data have been lacking in the past. The indications are that the original strength properties in compression, as used for the preliminary calculations are too conservative. In addition to the test results for the forged material, data from two compression tests, each for cast and extruded Berylco-165 samples, were provided. For the forged material, compression yield values at 0.20 percent offset were 173,000 and 178,000 psi. Additional compression tests are presently scheduled to be performed by the Beryllium Corporation in the very near future. An attempt is being made to obtain a set of test samples of forged and heat treated Berylco-165 material with a view to performing independent tests to serve as a check.

Results of the expected increase in strength properties are not expected to produce any drastic changes in the pressure vessel design. It is anticipated that a small reduction in weight for the Berylco-165 pressure vessel can be achieved.

The preliminary strength data reported here will be considered valid for the present. This is conservative.

A preliminary thermal analysis of the 20-watt generator concept was initiated using titanium 621.8 alloy for the pressure vessel. Results of the analysis indicate a potential problem in that the pressure vessel may not be able to transfer heat to the exterior environment at a sufficiently rapid rate to make the system entirely satisfactory. Additional analysis indicated that use of a Berylco-165 pressure vessel would provide good heat transfer for the 20-watt system. In accordance with the goal of the Commission that maximum commonality between the 10-watt and the 20-watt units be achieved, use of Berylco-165 as a pressure vessel material for the 10-watt generator is being re-evaluated.

For design use, an "average" stress-strain curve based on the two original load-deflection curves (from test) was constructed. The design curve was then obtained by drawing it through the design yield stress (at 0.20 percent offset) and making it affine to the test "average" curve. This was accomplished analytically by determining two constants from the test curve, which, together with the modulus of elasticity, provide sufficient information for writing an analytical expression for stress versus strain. Figure 2-9 shows the relationship of the two curves.

A design yield at 0.20 percent offset for compression was determined from the ratio existing between tension and compression yield values (for six reported tests) plus the published minimum tension yield of 120,000 psi for Berylco-165. Results of this computation give 129,000 psi at 0.20 percent offset as the design value. The derived stress-strain curve is presented as Figure 2-10. Figure 2-11 shows curves of tangent and secant modulus versus stress. Figures 2-12 and 2-13 provide similar information for Titanium 621.8 alloy.

Note that the compression modulus of elasticity for Berylco-165 is considerably lower than that for Ti-621.8 (14×10^6 versus 18.5×10^6 psi). Critical buckling pressure is a function of the compression modulus and at first glance it might appear that an increased thickness penalty would occur when using the beryllium-copper alloy. Actually, however, for any stress level above proportional limit, the secant and tangent moduli are of greater importance and the shapes of the modulus curves, together with the compression yield stress, can modify the effect of differences in Young's modulus. Figure 2-14 shows a comparison between the tangent modulus curve for Ti-621.8 and that for Berylco-165.

Cylinder buckling pressures were computed from the expression

$$P_{cr} = \frac{2K E_t}{1 - \mu^2} \left(\frac{T}{D_o} \right) \left(\frac{T}{D} \right)^2 \quad (5)$$

and maximum combined stress in the cylinder walls is given by

$$f = \frac{\sqrt{3}}{4} \left(\frac{PD_o^2}{TD} \right) \quad (6)$$

Figure 2-9. Load Deflection Curves

where:

- K = Empirical factor for length-diameter ratio of cylinder (=2 for our design)
- μ = Poisson's ratio
- E_t = Tangent modulus (psi)
- T = Wall thickness (in.)
- D = Mean diameter of cylinder (in.)

Figure 2-10. Preliminary Design Stress versus Strain Berylco-165 Forged Bar (AT) in Compression

Figure 2-11. Preliminary Modulus versus Stress Design Compression for Berylco-165 Forged (AT) Material Based on Reduced Values from Tests by Beryllium Corp.

Figure 2-12. Preliminary Stress-Strain Curves for Forged 621.8 Titanium Alloy

Figure 2-13. Preliminary Tangent and Secant Modulus versus Compression Stress for Forged 621.8 Titanium Alloy

Figure 2-14. Comparison of Tangent Modulus Curves for Design Values of Ti 621.8 and Berylco-165

D_o = Outer diameter of cylinder (in.)

P = Design external pressure (psi)

A separate value of T for each material was found for each of the two criteria obtained by setting $P_{cr} = P$ in (5) and $f = F_{cy}$ in (6).

Hemisphere buckling pressures were computed from

$$P_{1\ cr} = \frac{0.8\sqrt{E_S E_T}}{\sqrt{1 - \mu^2}} \left(\frac{T_1}{R_o} \right)^2 \quad (7)$$

and stress in the hemisphere is given by

$$f_1 = \frac{3P}{2} \left(\frac{R_o^3}{R_o^3 - R_i^3} \right) = \frac{0.75P}{T_1} \frac{(2R + T_1)^3}{(12R^2 + T_1^2)} \quad (8)$$

where:

E_S = Secant modulus (psi)

R = Mean radius of hemisphere (in.)

R_o = Outer radius of hemisphere (in.)

R_i = Inner radius of hemisphere (in.)

T_1 = Hemisphere thickness (in.)

P = Design external pressure (psi)

Again, a separate value of T_1 for each material was found as above from (7) and (8).

The final result of these calculations gave the following set of values:

	<u>Hemisphere</u>		<u>Cylinder</u>	
	T(7)	T(8)	T(5)	T(6)
Titanium 621.8	0.554	0.581	1.121	1.019
Berylco-165	0.461	0.479	0.996	0.834

The difference between the thicknesses of the two materials can be seen on Figure 2-15.

Design thicknesses are taken as the larger of two calculated values from (5) and (6) for the cylinder wall, and the larger from (7) and (8) for the hemisphere wall. It can be seen that the cylinder thickness is designed by buckling while the hemisphere is designed by compression yield stress. In view of these facts it is seen that with the cylinder wall thickness sized for buckling, the stress level will be below yield. Also, for the hemisphere wall thickness sized for yield stress, the critical buckling pressure will be higher than the basic design value.

Since only the cylinder appears critical in buckling, we examine differences in values of tangent modulus from Figure 2-14 to see why the lower modulus of elasticity for Berylco-165 does not impose an additional penalty. For the 621.8 Ti alloy with a stress level of 101,691 psi, E_T is found to be 9.25×10^6 psi. For the Berylco-165 alloy with a stress level of 111,629 psi E_T is equal to 10.0×10^6 psi, which is actually higher than the other one. For stress levels below approximately 97,000 psi, Figure 2-14 shows that there will be a reversal between the two materials, but at these stress levels the external pressures would of necessity be less than the design value.

Table 3 gives a comparison of modulus of elasticity, yield stress, proportional limit, cylinder wall thickness, hemisphere wall thickness, cylinder wall stress, hemisphere wall stress, cylinder collapse pressure, hemisphere collapse pressure, and vessel weight, for each material.

Actual computations were performed on a computer programmed for the purpose. To do this it was necessary to express stress versus strain, stress versus tangent modulus, and stress versus secant modulus as analytical functions.

* Ti 621.8
** BERYLCO-165

Figure 2-15. Pressure Vessel with Short Cover

Table 3. Materials Property Comparison

Material		Ti-621.8	Berylco-165
Modulus of elasticity	(psi)	18.5×10^6	14.0×10^6
0.20 percent offset compression yield stress	(psi)	109,645	129,000
0.01 percent offset proportional limit	(psi)	95,687	107,165
Cylinder wall thickness	(in.)	1.121	0.996
Hemisphere wall thickness	(in.)	0.581	0.479
Cylinder wall stress	(psi)	101,691	111,629
Hemisphere wall stress	(psi)	114,500	134,200
Collapse pressure for cylinder	(psi)	16,574	16,551
Collapse pressure for hemisphere	(psi)	17,200	17,200
Weight of body plus short cover	(lbs)	141	230

The design value for critical external pressure is taken as $10,000 \times 1.5 \times 1.1 = 16,500$ psi. The additional 10 percent factor has been added to account for manufacturing inaccuracies (the buckling phenomenon for externally pressurized curved shells is strongly dependent on imperfections in thickness and contour), stress concentrations, and material inhomogeneities. Poisson's ratio was taken as 0.30 for both materials. Material densities used in weight determinations are 0.162 lbs/in^3 for the titanium alloy and 0.295 lbs/in^3 for Berylco-165.

Weight of a complete generating unit using titanium alloy for the pressure vessel (body with short cover) was estimated as 516 pounds for Phase I design. This weight would be increased by approximately 102 pounds if Berylco-165 is used. Increase would then be $100 \times 102/516 = 19.7$ percent.

Possible use of Berylco-165 material for the pressure vessel has an interesting parallel in the Bell Labs repeater housing development. The first experimental housing units were supplied in 1957 and it is understood that they have been in service since that time. This item has been in continuous production since 1962

and to date there has been no reported evidence of either corrosive attack or fouling. Physically, the item is of comparable diameter but of greater length and is subjected to approximately the same undersea environment.

There are further reports of submerged beryllium copper components that have been used in minesweeper equipment for at least 15 years.

The reinforcing ring for penetration through the hemispherical cover was designed in accordance with the procedure recommended in "An Experimental Investigation of Closures and Penetrations for Pressure Vessels of Composite Construction", by T. J. Kiernan and M. A. Krenzke, DTMB Report 1732, February 1964. Figure 2-16 shows the geometry and nomenclature used.

Treating the ring as a thick-walled cylinder, radial deflection at the outer radius (loaded by external pressure), neglecting the Poisson effect of the end load is:

$$W_o = \frac{r_2 p^1}{E} \left(\frac{r_2^2 + r_1^2}{r_2^2 - r_1^2} - \nu \right)$$

where E = Young's modulus, ν = Poisson's ratio, and other symbols as defined on Figure 2-16.

Deflection of the hemisphere in the direction radial to the ring is:

$$W_{sr} = \frac{PR_o r_2 (1 - \nu)}{2Eh}$$

To avoid discontinuity stresses at the membrane-ring intersection, set $W_o = W_{sr}$, giving:

$$\left(\frac{r_2^2 + r_1^2}{r_2^2 - r_1^2} - \nu \right) \left(\frac{2a + R_m \cos \phi}{d} \right) = \frac{R_o (1 - \nu)}{h} \quad (9)$$

Figure 2-16. Geometry of Reinforcing Ring

To provide against rotation at the intersection, the sum of moments about the centroid of the ring cross-section is set equal to zero.

$$Pa \left(\frac{d-a}{2} \right) + \frac{PR_m}{2} \sin \phi \left(\frac{t}{2} \right) - \frac{PR_m}{2} \cos \phi \left(a - \frac{d}{2} \right) = 0$$

$$\sin \phi = \frac{r_2}{R_m}, \cos \phi = \frac{\left(R_m^2 - r_2^2 \right)^{1/2}}{R_m}$$

by substitution and algebraic manipulation,

$$2a(d-a) + tr_2 - (2a-d) \left(R_m^2 - r_2^2 \right)^{1/2} = 0 \quad (10)$$

Simultaneous solution of (9) and (10) provides values for "a" and "d".

Table 4 gives dimensions and resulting values of "a" and "d" for both the design using 621.8 Titanium alloy and the one using Berylco-165. For comparison, the results of the computation based on the prototype dimensions with 721 Titanium alloy material has also been included.

The actual stresses in the penetration ring are obtained from the expression for the average pressure acting on the ring height "d". The formula as defined on Figure 2-16, is:

$$P^1 = \frac{Pa + \frac{PR_m}{2} \cos \phi}{d}$$

Table 4. Reinforcing Ring Dimensions for Various Alloys

Dimension Computed	Values		
	621.8 Ti	Berylco-165	721 Ti
Ring Inner Radius, r_1	1.2475	1.2475	1.2475
Ring Outer Radius, r_2	2.1275	2.1275	2.1275
Ring Wall Thickness, t	0.880	0.880	0.880
Hem. Outer Radius, R_o	7.1005	6.9871	7.0480
Hem. Mean Radius, R_m	6.8103	6.7478	6.7920
Hem. Wall Thickness, h	0.5804	0.4789	0.5120
Poisson's Ratio, ν	0.30	0.30	0.30
Ring Height, d	1.7918	1.4118	1.5304
Dimension, a	1.1543	0.9226	0.9930

which reduces to

$$P^1 = \frac{P}{2a} \left[2a + \left(R_m^2 - r_2^2 \right)^{1/2} \right] \quad (11)$$

For a thick-walled cylinder with external pressure $P = 16,500$ psi.

$$\text{Hoop Stress} = f_h = -P^1 \frac{r_2^2}{r^2} \left(\frac{r_1^2 + r^2}{r_2^2 - r_1^2} \right) \quad (12)$$

$$\text{Radial Stress} = f_r = -P^1 \frac{r_2^2}{r^2} \left(\frac{r^2 - r_1^2}{r_2^2 - r_1^2} \right) \quad (13)$$

$$\text{Longitudinal Stress} = f_1 = -P^1 \frac{r_2^2}{r_2^2 - r_1^2} \quad (14)$$

Using (11) with each of (12), (13), and (14), and values of $r = r_1$ to $r = r_2$, distributions of hoop, radial, and longitudinal stresses were obtained for both 621.8 Ti and Berylco-165 material designs. Plots of these values are presented as Figure 2-17. Similar calculations for the 721 Titanium prototype provided the curves of Figure 2-18. Also shown on Figures 2-17 and 2-18 are the results obtained for tri-axial stress combination in accordance with the "Maximum-Distortion - Energy Theory." In Figures 2-17 and 2-18, the values for the combined stress were determined by the equation:

$$f = \left[f_h^2 + f_r^2 + f_1^2 - (f_h f_r + f_r f_1 + f_1 f_h) \right]^{1/2}$$

An approximation to the discontinuity stresses existing at the juncture of the pressure vessel body cylinder and hemispherical end cap was obtained using formulas presented in "Theoretical Elastic Stress Distributions Arising from Discontinuities and Edge Loads in Several Shell-Type Structures" by R. H. Johns, and T. W. Orange, NASA Technical Report R-103, 1961.

Figure 2-19 defines the geometry and nomenclature used in the above referenced report, as applied to the SNAP-21 pressure vessel. It should be noted that the figure shows internal pressurization (agrees with referenced report). For computations, external pressure is used as a negative quantity.

$$H_o = \left\{ \frac{[1 - \nu - (2 - \nu) c] \left[\frac{1}{1 + c^{2.5}} \right] \frac{1}{\lambda_s}}{(1 + c^2)^2 + 2c^{1.5}(1 + c)} \right\} \frac{PR}{2}$$

$$M_o = \left\{ \frac{[1 - \nu - (2 - \nu) c] \left[\frac{1 - c^2}{2 \lambda_s^2} \right]}{(1 + c^2)^2 + 2c^{1.5}(1 + c)} \right\} \frac{PaR}{2}$$

Figure 2-17. Distribution of Stresses Across Wall of Pressure Vessel Cover Penetration Ring

Figure 2-18. Distribution of Stresses Across Pressure Vessel Cover — Penetration-Ring — Wall for 721 Titanium Vessel

Figure 2-19. Geometry of Pressure Vessel

where:

$$c = \frac{h_s}{h_c}$$

ν = Poisson's ratio

$$\lambda_s = \left[3 (1 - \nu^2) R^2 / h_s^2 \right]^{1/4}$$

The actual conditions at the juncture are those of different thicknesses for cylinder and hemisphere with a fillet radius for making the transition. To avoid an excessive amount of computation, two bracketing assumptions are made, with the understanding that the actual conditions will lie somewhere between the two. The cases considered are: (1) two unequal thicknesses with no fillet radius (i. e., an abrupt thickness change), and (2) both thicknesses the same.

Computer programmed solution of the two equations gave the following set of numbers:

	$h_s = h_c$		$h_s \neq h_c$	
	H_o (lbs/in)	M_o (in-lb/in)	H_o (lb/in)	M_o (in-lb/in)
Ti 621.8	4435	0	1006	477
Berylco-165	4160	0	630	292

With the above values of " H_o " (edge shear), and " M_o " (edge moment) applied to the hemisphere, stresses were computed at the juncture in accordance with formulas (42) and (43) from the previously referenced report. The two formulas have been modified for the 180° hemisphere used in our design, to give meridional discontinuity stress:

$$f_\phi = - \left[\frac{2\lambda_s}{Rh_s} (\tan \phi) \Omega(\lambda_s \phi) \mp \frac{6}{h_s^2} \Phi(\lambda_s \phi) \right] M_o$$

$$- \left[\frac{1}{h_s} (\tan \phi) \psi (\lambda_s \phi) \pm \left(\frac{6R}{\lambda_s h_s^2} \right) \Omega (\lambda_s \phi) \right] H_o$$

and circumferential discontinuity stress

$$f_\theta = - \left[\frac{2\lambda_s^2}{Rh_s} (\tan \phi) \Omega (\lambda_s \phi) \mp \frac{6\nu}{h_s^2} \Phi (\lambda_s \phi) \right] M_o$$

$$- \left[\left(\frac{2\lambda_s}{h_s} \right) \theta (\lambda_s \phi) \pm \left(\frac{6\nu}{\lambda_s h_s^2} \right) \Omega (\lambda_s \phi) \right] H_o$$

where:

Angle $\phi = 0$ (at juncture for our case)

$$\Omega (\lambda_s \phi) = e^{-\lambda_s \phi} \sin (\lambda_s \phi)$$

$$\theta (\lambda_s \phi) = e^{-\lambda_s \phi} \cos (\lambda_s \phi)$$

$$\psi (\lambda_s \phi) = e^{-\lambda_s \phi} [\cos (\lambda_s \phi) - \sin (\lambda_s \phi)]$$

$$\Phi (\lambda_s \phi) = e^{-\lambda_s \phi} [\cos (\lambda_s \phi) + \sin (\lambda_s \phi)]$$

other symbols as previously defined.

It should be noted that the angle " ϕ " is equal to zero only for the special case right at the juncture. Only this special condition is being reported on here. As presented above, the same computer program can be used (if desired) to find the distribution of stresses as we consider sections away from the juncture.

Where the signs ($\pm$) and ($\mp$) appear, the upper sign refers to stresses on the inner surface and the lower sign is used for stresses at the outer surface.

The four values of discontinuity stress determined from the above relations are algebraically added to the corresponding elastic membrane stresses.

For the hemisphere, the membrane stresses in the two directions are equal to each other, and are given by:

$$\text{at the inner surface} \quad \left(\frac{3P}{2} \right) \frac{(R + h_s/2)^3}{(R + h_s/2)^3 - (R - h_s/2)^3}$$

$$\text{at the outer surface} \quad \left(\frac{P}{2} \right) \frac{(R - h_s/2)^3 + 2 (R + h_s/2)^3}{(R + h_s/2)^3 - (R - h_s/2)^3}$$

Radial membrane stress at inner surface = 0, and at outer surface = P.

Net stresses are then combined by the "Maximum Distortion-Energy Theory" (as in previous cases), for the final values. Table 5 gives the complete set of numbers for a 621.8 titanium alloy hemisphere for the cases where $h_s = h_c$ and $h_s \neq h_c$.

Table 5. Stresses for 621.8 Titanium Alloy Hemispheres

Stress Mode	$h_s = h_c$		$h_s \neq h_c$	
	Inner (psi)	Outer	Inner (psi)	Outer
Merid.Elast. Memb. Stress	-109647	-101397	-109647	-101397
Circumf. Elast. Memb. Stress	-109647	-101397	-109647	-101397
Radial Elast. Memb. Stress	0	- 16500	0	- 16500
Merid. Discontinuity Stress	0	0	+ 8472	- 8472
Circumf. Discont. Stress	- 25069	- 25069	- 8008	- 13091
Merid. Net Stress	-109647	-101397	-101175	-109869
Circumf. Net Stress	-134716	-126466	-117655	-114488
Combined Stress	-124095	- 99821	-110342	- 95762

It will be noted from Table 5 that in two cases the combined stresses are somewhat higher than the design compression yield of the material (109,400 psi). The values obtained by calculation are not considered to be in the least detrimental to the structural integrity of the pressure vessel for the following reasons:

- a) Actual geometry is intermediate between the two bracketing assumptions used for the calculations. Conditions approach the case of the abrupt thickness change more nearly than the other.
- b) Design pressure was taken as 16,500 psi which is 10 percent above the $1.5 \times 10,000$ psi originally established as a strength requirement.
- c) It is a known fact that above the proportional limit, plasticity permits redistribution of stresses at points of high stress concentration. In this connection it should be noted from Table V, that the maximum stress values occur at the inner surface and there can be a redistribution across the wall thickness.
- d) During DTMB tests on the 1/4 scale model, extremely high stresses were recorded for the juncture area but a failure actually occurred away from this location.

An examination of conditions on the cylinder side of the juncture was next made. In the previously referenced report formulas (26) and (27) provide the means for calculating the meridional (longitudinal) and circumferential (hoop) stresses at any given distance "X" from the juncture. With the values of " H_o " and " M_o " found earlier, and for $X = 0$ (right at juncture), the stress values are:

$$\text{Longitudinal Stress} = \pm \frac{6M_o}{h_c^2} = \pm 2550 \text{ psi for } h_c \neq h_s$$

$$\text{Hoop Stress} = \left(23^2 R/h_c \pm 6\nu/h_c^2 \right) M_o + (23 R/h_c) Q_o$$

where:

$$\delta = \left[3(1 - \nu^2)/R^2 h_c^2 \right]^{1/4}$$

Hoop stress at inner surface = +7,585 psi for $h_c \neq h_s$

Hoop stress at outer surface = +6,220 psi for $h_c \neq h_s$

For the case of $h_c = h_s$ the discontinuity stresses on both sides of the juncture are equal.

Elastic membrane stresses in the cylinder are:

$$\text{Longitudinal} = \frac{P(R + h_c/2)^2}{h_c \left[(R + h_c/2)^2 - (R - h_c/2)^2 \right]} \quad \text{Uniform}$$

$$\text{Hoop} = \frac{2P(R + h_c/2)^2}{\left[(R + h_c/2)^2 - (R - h_c/2)^2 \right]} \quad \text{at inner surface}$$

$$\text{Hoop} = \frac{P \left[(R + h_c/2)^2 + (R - h_c/2)^2 \right]}{\left[(R + h_c/2)^2 - (R - h_c/2)^2 \right]} \quad \text{at outer surface}$$

Radial = 0 at inner surface

Radial = -16,500 psi at outer surface

In the same manner as for the hemisphere, stresses are combined for the 621.8 titanium cylinder to give the results tabulated in Table 6.

A short study was performed to determine the internal dimensional changes which would occur when the complete pressure vessel is subjected to an external hydrostatic pressure loading of 11,000 psi ($1.1 \times 10,000$ psi = proof pressure).

Table 6. Stresses for 621.8 Titanium Cylinder

Stress Mode	$h_c = h_s$		$h_c \neq h_s$	
	Inner (psi)	Outer	Inner (psi)	Outer
Merid. Elast. Memb. Stress	- 52371	- 52371	- 52371	-52371
Circumf. Elast. Memb. Stress	-104742	-100915	-104742	-100915
Radial Elast. Memb. Stress	0	- 16500	0	- 16500
Merid. Discontinuity Stress	0	0	+ 2550	- 2550
Circumf. Discontinuity Stress	- 25069	- 25069	+ 7585	+ 6220
Merid. Net Stress	- 52371	- 52371	- 49821	- 54921
Circumf. Net Stress	-129811	-125984	- 97157	- 94695
Combined Stress	-113116	- 96676	- 84150	- 67722

a) Radial Deformation of Hemisphere at Inside Radius

From Table XIII, case 37 in Roark's "Formulas for Stress and Strain",

$$\delta_r = \frac{3P (R + h_s/2)^3 (R - h_s/2) (1 - \nu)}{2E [(R + h_s/2)^3 - (R - h_s/2)^3]}$$

where all symbols have the same meaning as before.

We replace Young's modulus "E" by the secant modulus " E_s ", and evaluate " E_s " for the stress level at the inner surface.

$$F = \left(\frac{3P}{2} \right) \frac{(R + h_s/2)^3}{[(R + h_s/2)^3 - (R - h_s/2)^3]}$$

$$E_s = \frac{E}{1 + 0.42857 \left(\frac{F}{F_{0.70}} \right)^{n-1}}$$

b) Longitudinal Deformation of Cylinder

$$\delta_1 = \frac{L}{E} [F_1 - \nu (F_r + F_t)]$$

Ref: "Theory of Elasticity"
by R. V. Southwell.

where:

$$F_1 = \text{longitudinal stress in cyl.} = \frac{P (R + h_c/2)^2}{[(R + h_c/2)^2 - (R - h_c/2)^2]}$$

$$F_r = \text{radial stress in cyl.} = \frac{(R + h_c/2)^2 P \left[1 - \frac{(R - h_c/2)^2}{r^2} \right]}{[(R + h_c/2)^2 - (R - h_c/2)^2]}$$

$$F_t = \text{tangential (hoop) stress in cyl.} = \frac{(R + h_c/2)^2 P \left[1 + \frac{(R - h_c/2)^2}{r^2} \right]}{[(R + h_c/2)^2 - (R - h_c/2)^2]}$$

Substitution of these stress values gives:

$$F_1 = \frac{(1 - 2\nu) LP (R + h_c/2)^2}{E_s [(R + h_c/2)^2 - (R - h_c/2)^2]}$$

"E_s" is evaluated for the stress level at the mean radius "R", obtained by combining stresses in the three directions using the "Maximum-Distortion-Energy Theory".

c) Radial Deformation of Cylinder

$$S_r^1 = \left(\frac{r}{E} \right) [F_t - \nu (F_r + F_1)]$$

Ref: "Theory of Elasticity"
by R. V. Southwell.

where " F_t ", " F_r ", and " F_1 " are the stresses as for the case of " δ_1 ".

The individual stresses are evaluated at r = inner radius = $(R - h_c/2)$, and again combined as before to obtain the proper stress level for use in determining a new secant modulus for use in the above formula to find S_r^1 .

All of the indicated computations were performed by means of a computer program and the final results obtained are listed in Table 7.

Table 7. Pressure Vessel Deformations for 621.8 Titanium and Berylco 165

Component	Ti 621.8	Berylco-165
Hem. Radial Deformation (in.)	0.01803	0.02800
Cyl. Longitudinal Deformation (in.)	0.00815	0.01183
Cyl. Radial Deformation (in.)	0.02248	0.03263

A meeting was held at David Taylor Model Basin on 17 August 1967 between DTMB and 3M personnel. A resume of the methods of analysis used for design of the SNAP-21 pressure vessel using 621.8 titanium alloy was the subject of discussion. DTMB personnel were in general agreement with the analysis approach. The present design is so closely related to the prototype, that no structural problems are anticipated.

2.2.5.2 Marine Fouling Investigation

An investigation of the marine fouling characteristics of the two candidate materials, 621.8 titanium and Berylco-165, was conducted as part of the pressure vessel design effort.

Marine fouling of the pressure vessel is an important system consideration since it provides an additional barrier to the transfer of reject heat from the generator cold frame to the sea water. This in turn increases the temperature of the cold end of the thermoelectric couples and thus reduces system output and efficiency.

There are several factors which influence the attachment and adherence of fouling organisms. These factors are the following*:

a. Geographical and seasonal distribution.

The location and season determine the intensity of fouling (ref. 1, p. 231).

b. Movement of water relative to the surface

Water moving at less than 2 to 4 knots is necessary for sedentary organisms to attach themselves. Consequently, moving water tends to inhibit fouling (ref. 3, 4).

c. Texture of the surface

Smooth surfaces offer some protection. However, it will not prevent fouling (ref. 1, p. 233 and ref. 3, 5).

d. Effect of gravity

The underside of a horizontal surface tends to accumulate more fouling. This is possibly due to a geotropic response combined with the response of the larvae to light (ref. 1, p. 234).

e. Light and illumination

Fouling tends to be greater on the least illuminated or darker colored surfaces (ref. 1, p. 236, and ref. 6).

f. The use of electricity

Studies have been made on the use of electric currents as a marine fouling inhibitor. The fouling surface is made cathodic. "Fouling was delayed on coatings formed by current densities in

*References are listed at the end of Section 2.2.5.

excess of 300 milliamperes per square foot. The delay or prevention of fouling by the high current densities was attributed to the rapid formation of the deposits formed on the surface." (Ref. 1, p. 236.) This method is not practical for our purposes.

g. Wetting the surfaces

A waxy or oily surface does not allow the organisms to obtain a secure footing. It is effective for short periods of time (ref. 1, p. 236).

h. Exfoliation

Exfoliation is the physical disintegration of the surface. "Such a surface is unsubstantial and offers the organisms an insecure footing." (Ref.1, p. 237.) "The results of the tests of exfoliation indicate that, whereas fouling can be completely prevented by this process, it is a wasteful mechanism and would require very thick applications in order to afford prolonged protection." (Ref. 1, p. 239.)

i. Slime or primary films

A surface exposed to a fouling environment becomes coated in a few days with a slimy film. This film is favorable for fouling on nontoxic surfaces (ref. 1, p. 239). "Bacteria are the first organisms to foul and accompany adsorbed organic material and dissolved substances. This primary film grows, and in doing so, enmeshes additional detritus, bacteria, and next diatoms. Larvae of sedentary organisms then appear in rapid succession." (Ref. 1, p. 8.)

k. Temperature

"It is reported by ship personnel that where the temperature is from 70° to 100°F, growth is prevalent, with the greatest concentration between 80° and 90°F. At higher temperatures, the amount of fouling diminishes, and it is non-existent where the water temperature is maintained at 150°F. The intensity also diminishes greatly at temperatures below 60°F." (Ref. 1, p. II-12.)

Furthermore, the U.S. Naval Civil Engineering Lab at Port Hueneme, California, conducted a 120-day shallow water corrosion and fouling test. The test was intended to determine the effect of temperature under conditions of maximum corrosion and biological growth. The test elements were held at temperatures of ambient, 100, 120, and 140°F, respectively. No fouling took place on the elements above 100°F. (Ref. 6, p. II-11.)

1. Distance from shore

"A change in both the kind and intensity of fouling is found in passing from coastal to oceanic situations." (Ref. 1, p. 107.) Fouling is less severe at sea than at inshore areas.

There are inherent differences between metals with respect to fouling. Metals with a high content of copper are considered nonfouling. "Titanium, on the other hand, is not considered antifouling", (Ref. 6, p. II-51). In order that copper or copper alloys be resistant to fouling, a certain amount of corrosion must take place. The corrosion suppresses fouling by a toxic effect or by sloughing off organisms with non-adherent corrosion products. "The required corrosion to prevent fouling is that which will yield copper in corrosion products at a rate of about 5 mg of copper per square decimeter of surface area per day." (Ref. 3, p. 401.) "Fouling will occur to an increasing extent as the rate of solution of copper decreases", (Ref. 3, p. 401). However, "when copper is coupled to zinc or iron it fails to prevent fouling". (Ref. 1, p. 241.) When two metals are "brought in contact with one another and the sea water, an electrochemical couple is set up, with the result that the baser metal dissolves and the solution of the nobler metal is inhibited." (Ref 1, p. 360.) Consequently, it appears that a beryllium copper pressure vessel would not require any treatment to prevent fouling due to its high copper content. However, titanium would probably require an antifouling paint or a toxic metal cladding.

"The common antifouling paints contain copper, mercury, or arsenic in various combinations." (Ref. 1, p. 241.) "It is now well established that the antifouling efficiency of a paint is substantially a linear function of the percentage of

dissolvable toxic pigment carried in the dry paint film. The copper content of a representative group of commercial bottom paints selected at random averaged 20 to 25% calculated as Cu_2O . The mercury content of a random group of fortified bottom paints averaged 3.5% calculated as Hg . These paints seldom last longer than 6 months without fouling. Research over a period of years has indicated that antifouling performance in excess of 6 to 7 months requires copper concentrations of about twice that found in most commercial paints." (Ref. 3, p. 443.) "The plastic type of antifouling paint developed by the Navy resists fouling from six to eighteen months." (Ref. 1, p. 313.) Consequently, it appears that there is no commercial paint that will resist fouling for a five year period, the length of time that the SNAP-21 system could be left unattended. The design life of the generator is five years.

Because the pressure vessel exterior surface is 10 to 20°F higher than the surrounding water, it can be concluded that titanium will probably foul in shallow ocean water. However, titanium does not corrode or pit under the fouling layer as do some of the stainless steels such as aluminum bronze alloys and MONEL. On the other hand, beryllium copper (Berylco-165) appears to be one of the most resistant metals with respect to marine fouling. (Ref. 1, p. 350, Table 1.) In addition, the corrosion resistance of beryllium copper is generally considered to be equal to or slightly better than that of pure copper (Ref. 3, p. 110).

SOURCES OF INFORMATION

1. "Marine Fouling and Its Prevention"

Prepared for Bureau of Ships, Navy Department. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

2. Milligan, S., Effect of Deep Ocean Environment. U. S. Naval Under Ordnance Station, 1965.
3. Uhlig, H., Corrosion Handbook. John Wiley and Sons, 1948.
4. Wood, E.J., Effect of Temperature and Rate of Flow on Some Fouling Organisms. Australian J. Sci 18, No. 1, 1955, pages 34-37.
5. ZoBell, C.E., The Sequence of Events in the Fouling of Submerged Surfaces. Scripps Inst. Ocean, No. 35, 1938, page 18.
6. Study of Heat Transfer and Fouling of Heat Transfer Surfaces in the Deep Ocean. U.S. Naval Civil Engineering Lab. Port Hueneme, California, Nov. 26, 1965.

2.2.6 THERMOELECTRIC GENERATOR

2.2.6.1 Design - In-Line

During this report period development generator Design No. 2 was completed for Phase II. The basic differences of this design as compared to Design No. 1 (ball and socket concept) is that the couples will be of the "in-line" concept and ceramic instrumentation and power feedthrough headers will replace the CONAX fittings used in Design No. 1.

During the preliminary design of the in-line thermoelectric couple three concepts were considered (Figure 2-20). Concepts Nos. 1 and 3 are similar with respect to the combination of materials at the leg-to-follower interface. These concepts both have the aluminum follower joined directly to the thermoelectric leg. Both concepts were eliminated from further consideration because of the lack of data on the long-term compatibility of direct aluminum-thermoelectric leg contact. Concept No. 2 has a copper cold junction electrode as an intermediate material between the thermoelectric leg and the follower. This configuration was selected for the in-line design because it has been used extensively at 3M and consequently there is back-up data to verify the compatibility of the materials to be joined.

Another important consideration of the in-line concept is the structural integrity of the thermoelectric couple. In this respect, concept No. 1 appears to be the most desirable. This is because the cold junction electrode is joined directly to both followers, consequently any forces applied to the followers or legs during handling and assembly will be transmitted from the electrode directly to the follower rather than to one of the leg joints. However, when reviewing data from other 3M generators, there is no evidence to indicate that joints between the electrode and the thermoelectric leg of concept No. 2 are inferior structurally to the leg-follower-joint of concept No. 1.

In the in-line couple concept, the thermoelectric leg is bonded directly to the follower and is therefore a rigid assembly. Because of this, it is necessary to have adequate clearance between the follower and follower hole in the cold frame to compensate for relative motion between the hot and cold frames. To insure that adequate clearances existed, an analysis was conducted to determine the alignment requirements and movement limits possible under various operating conditions.

Figure 2-20. In-Line Concepts

As a result of this analysis it was determined that components and clearances used for the first development design would result in severe structural loadings on the joint between the thermoelectric leg and follower during thermal cycling and shock and vibration testing. Consequently, three changes were incorporated in the design to enable the in-line concept to tolerate relative motion between the hot and cold frames without overstressing the thermoelectric leg joints. The first change was to increase the diametrical clearance between the follower and cold frame to allow more side movement of the thermoelectric leg. This increase in clearance was made on the basis of the cold end heat transfer tests (paragraph 2.3.6.1). The second change was to remove the circular recess in the hot junction button and to make it flat, allowing the thermoelectric leg to find its true center without restriction during assembly. The reason for the recess in the hot junction buttons of the ball and socket concept couples is to locate the thermoelectric leg properly at the hot end because it is not attached to the follower. The third change was to reduce the diameter of the centering pin of the hot junction button to provide more clearance between it and the hot junction electrode.

The net result of these changes is a clearance of slightly more than 0.001 inch at operating temperature between the components making up the leg assembly (leg-follower assembly, hot junction button, hot junction electrode) when all components are in nominal location in the cold condition. A potential problem exists if a leg is installed in a cocked position so that all diametrical clearance between the follower and follower hole is eliminated in the cold condition. This could cause high bending stresses in the leg due to unequal thermal expansion between the hot and cold frames if the leg is cocked in precisely the same direction as the relative motion between the hot and cold frame. If the bending stress exceeds the strength of the thermoelectric leg-to-cold electrode bond, the joint would separate and cause high thermopile electrical resistance.

This possibility has been identified as a potential problem, however, experience at 3M with similar concepts and experience while testing in-line couples and during the cold end heat transfer tests have not found it so. There are several factors which could explain this:

- (a) It is unlikely that a condition will exist where all components are at the extremes of tolerance limits,

- (b) The thermoelectric leg becomes partially plastic at operating temperature and can therefore compensate for some misalignment, and
- (c) The coefficient of friction of various components is not well known, consequently some slippage between hot end components could be occurring at loads below the calculated value so that the friction forces exerted on the thermoelectric leg is much lower than expected.

The instrumentation required for each in-line couple is less than for the first design because the follower and cold cap thermocouples can be combined, consequently it was decided to utilize the four additional thermocouples by instrumenting one additional couple to ensure a more complete thermal and electrical profile of the generator. The addition of the third instrumented couple required modification of several components, however they will still be interchangeable with the first design.

The remaining components used were identical to the ball and socket (design No. 1), with the exception of minor improvements resulting from manufacturing and assembly experience of the first four generators.

2.2.6.2 Generator Performance Comparison

During this report period the short-term performance of the ball and socket generators (design No. 1) has been determined. These generators incorporated two major improvements, from a performance standpoint, over the generators fabricated during the previous development contract. These improvements are the improved cold end heat transfer which increases the $\Delta\tau$ across the thermoelectric legs, and the soft-nose P-leg contacting technique which reduces the extraneous resistance of the thermopile. In addition, improvements in leg manufacturing techniques and quality control methods have been implemented which result in thermoelectric materials that more nearly approach their theoretical capability.

To compare performance of the generators before and after the improvements were incorporated, a computer program was used to predict thermoelectric performance. This program, used extensively at 3M, calculates generator performance for a given thermoelectric couple configuration and operating temperatures. It also has provision for changing the internal thermopile resistance so that various values of extraneous resistance can be accounted for.

Generator 10D2 was selected as representative of the new ball and socket design. This generator was selected because it had the most extensive performance data.

Generator P6 was selected for comparison from the previous contract. This generator was selected because it was of the same leg and couple geometry as that used in Generator 10D2.

Generator P6 use simultaneously pressed legs while the Generator 10D2 uses individually pressed segments which are bonded together to form the leg. Generator 10D2 also exhibited a high power output and low thermopile resistance, in comparison to the other Phase I generators, throughout the time it has been on test.

The method used to compare performance of the two generators was first to compare the actual performance of each generator to a theoretical performance for the same operating temperatures. The difference between the actual and theoretical performance was then analyzed to determine what portion of the difference is attributable to lower thermopile resistance and what portion to lower cold end temperature, which would be reflected in higher Seebeck voltage.

The difference between actual and theoretical power output for each generator can then be used to explain the differences between one generator and the other.

To minimize the error in this analysis, experimental data points for each generator were selected at operating temperatures that were as close to each other as possible.

The method of analysis and results are described in the following paragraphs.

The data presented in Table 8 was obtained from recorded data for actual performance measurements (experimental) and from computer calculations (theoretical) based upon actual temperature and load voltage conditions associated with both generators. For this analysis, only one set of data will be shown for each generator. Data chosen will be such that the temperature conditions are as close as the available data permits.

Table 8. Comparison of Generators 10D2 and P6

	P-6 : $T_c = 132$, $T_h = 1095$				10D2 : $T_c = 130$, $T_h = 1103$			
	E	I	R	P	E	I	R	P
Experimental	10.88	2.58	2.10	14.0	11.10	3.26	1.84	16.6
Theoretical	10.54	2.89	1.82	15.2	10.66	2.91	1.83	15.5
Difference $\Delta = \text{Exp.} - \text{Theo.}$	0.34	-	0.28	-1.2	0.44	-	0.01	1.1

E = Open-Circuit (Seebeck) Voltage (volts)

I = Load Current (amps)

R = Total Generator Resistance (ohms)

P = Power Output (watts)

T = Temperature ($^{\circ}\text{F}$)

Note that the table lists different values of load current (experimental vs. theoretical). We ignore this difference by observing that I is established for maximum power or matched load conditions for each case (from the relationship $I = E/2R$) and in the following analysis only the theoretical I need be considered.

Given the power output relationship

$$P = I (E - IR)$$

we have that

$$\Delta P = \frac{\partial P}{\partial E} \Delta E + \frac{\partial P}{\partial R} \Delta R + \frac{\partial P}{\partial I} \Delta I$$

such that

$$\Delta P = I \Delta E - I^2 \Delta R + (E - 2IR) \Delta I$$

and note that with $I = E/2R$, the result is:

$$\Delta P = I \Delta E - I^2 \Delta R$$

This relationship is used in two ways:

- 1) Each generator may be compared to a theoretical base, and reasons for power output difference (experimental vs. theoretical) observed.
- 2) This relationship provides a means for establishing a common base such that performance difference between the two generators can be accounted for and an explanation given.

Note the sign convention established in the given table such that ΔI Experimental – Theoretical, and that the theoretical I will be used in the given relationship,

$$\Delta P = I \Delta E - I^2 \Delta R$$

P-6 Analysis

In the attempt to explain the Experimental vs Theoretical ΔP , we have

$$\Delta P = I \Delta E - I^2 \Delta R = 2.89 (0.34) - (2.89)^2 (0.28)$$

$$\Delta P = 0.98 - 2.34 = -1.36$$

which agrees reasonably well with the tabular difference shown, $\Delta P = -1.2$.

These results indicate that in comparing experimental to theoretical data, the higher E would result in a power increase of 0.98 watt, but that this is offset by the greater R such that the net effect is a power decrease of approximately 1.4 watts.

10D2 Analysis

Here we have

$$\Delta P = I \Delta E - I^2 \Delta R = 2.91 (0.44) - (2.91)^2 (0.01)$$

$$\Delta P = 1.28 - 0.08 = 1.20$$

which is in near agreement with the tabular difference shown, $\Delta P = 1.1$.

As with P-6 above, these results indicate a higher E, since this is only slightly offset by power reduction due to higher R, a power increase of approximately 1.2 watts results.

The above analyses only compared each generator separately to a theoretical value, however, the results for each are explainable. The following analysis is presented to show how the two generators' performance may be compared to one another to explain performance differences and to assign a measure to this difference (power output of 10D2 vs. P-6). This measure will be described as a certain percent of the power difference attributed to both resistance changes and Seebeck voltage, which in turn, is related to the cold junction temperature-difference. Table 9 shows the comparison of 10D2 with P-6 using a common base — that is, using those calculated differences from above (Δ 's) and considering those values as representing terms "normalized" to the same base, the theoretical data. In this table, the convention is that

$$\Delta \Rightarrow (10D2 \text{ differences}) - (P-6 \text{ differences}),$$

and that

$$\Delta P_{\Delta E} \text{ and } \Delta P_{\Delta R}$$

represent the difference in power output (10D2 vs. P-6) due to the effects of Seebeck voltage (or lower cold junction temperature) and resistance, respectively.

Table 9. Comparison of Generators 10D2 and P6 Using Calculated Differences

	10D2	P-6	$\Delta = (10D2) - (P-6)$
$\Delta P_{\Delta E}$	1.28	0.98	0.30
$\Delta P_{\Delta R}$	-0.08	-2.38	+2.26
Sum = ΔP	1.20	-1.36	2.56

From this table we may observe that the total $\Delta P = 2.54$ watts, which is in close agreement with the experimental difference observed as shown in the first table:

$$\Delta P = 16.6 - 14.0 = 2.6 \text{ watts}$$

The following conclusions are drawn to provide the percent measure of the power difference, based upon the Table 9.

- 1) the portion of increased power of 10D2 over P-6 due to higher Seebeck voltage (lower cold junction temperature) is:

$$\Delta P_{\Delta E} = \frac{0.30}{2.56} = 12\%$$

- 2) the portion of increased power of 10D2 over P-6 due to reduced extraneous resistance is:

$$\Delta P_{\Delta R} = \frac{2.26}{2.56} = 88\%$$

This means that of the experimental-value difference in power of 2.6 watts, approximately 0.3 watt is attributable to the Seebeck voltage increase and 2.3 watts is attributable to the reduction in extraneous resistance.

2.2.6.3 Fabrication

2.2.6.3.1 Generator Fabrication Development

Generators A10D-3, A10D-1, and A10D-4 were assembled and processed in this report period. The Conax fittings leaked during assembly of the first generator,

A10D-2. To eliminate leakage and facilitate assembly of Generator 10D-3, the thermocouple wires were installed in the Conax fittings and then leak checked prior to assembly of the thermopile. The instrumentation wires from various data points were then joined to proper junction wires by welding. During the assembly of this second generator, a fixture was made to hold all the couples simultaneously and in a free state (Figure 2-21). This eliminated the problem of couple breakage which occurred while assembling the first generator by means of individual couple insertion against the spring pressure of the follower. The fixture also reduced assembly time of the thermopile by 2 days.

Figure 2-21. Assembly Fixture to Hold Couples

After thermopile assembly, Generator 10D-3 was to be moved into the controlled environment (dry) box for insulation packing and final weld enclosure. A special process routing was written for this procedure and additional holding fixtures and tools were designed. In the process of evacuating and backfilling the box, a valve was inadvertently left open and the interior of the box was exposed to the atmosphere. However, the procedure was continued in the exposed atmosphere condition to prove the assembly methods for future use.

While Generator 10D-4 was being assembled, a method was devised for checking couple orientation before bringing the hot frame to the final assembled dimension. This was necessary to prevent incorrect couple insertion, such as occurred with Generator 10D-3.

2.2.6.3.2 Leg and Couple Fabrication Development

Couple development during this report period was concerned with the design of in-line couples and the adaptation of a commercial thermocouple soldering fixture to SNAP-21 couples.

Couple development parts were received late in the quarter and the first development run was made. Indications were that the nickel plating on the cold strap was of the wrong type. The problem is being investigated.

A new series of operating procedures and the material routing sheets have been rewritten for in-line couples.

Instrumentation of the SNAP-21 in-line follower required an "in-line" type iron-constantan thermocouple wire. Product Control has developed a production type welder to achieve a satisfactory electrically welded lap joint. Instrumentation is used on all development generators and the variability of the instrumenting wires has been a contributing factor in couple reject.

The commercial production welder provides complete control of current, time, pressure, and atmosphere. This basic welder is being modified to adapt to the SNAP-21 couple configuration.

2.2.6.4 Generator Quality Control

The shipping instructions for the Biological Shields were changed in that they will be shipped to 3M rather than directly to Linde. This was done because of the problems with the interface fit of the shield, liner and spider support.

Tension support rods, male and female, were fabricated in-house to Linde drawings to expedite delivery to Linde for assembly of the insulation system. The spider and inner liner were also fabricated in-house for the same reason.

An Inspection Logbook system has been instituted for recording departures from normal assembly and processing procedures for SNAP-21, Task I generators. The departures will be recorded on a continuous Report of Condition form to be reviewed by the responsible functional groups and assigned Corrective Actions.

Vendor Inspection reports were evaluated to reduce receiving inspection time. Data collected to date is not sufficient to make definite conclusions, however first indications are favorable.

Two Sequential Sampling Plans were prepared and put into use. These were QA-STD-48 for lot sizes of over 150 pieces and QA-STD-53 for smaller lot sizes. Both standards have AEC concurrence.

A Source Inspection of the first shield body, shield mounting bolts and spider support bolts was made at National Lead before the parts were shipped to Linde. All parts were found acceptable.

2.2.7 POWER CONDITIONER

Details of tests performed as presented in Section 2.3.7 have resulted in a number of design changes in the modified Royer circuit developed in Phase I. These changes include the following:

- a. To improve starting characteristics a small inductor is incorporated in the transformer assembly. The inductor is wound with extensions of the output windings and is cast with the main transformer.
- b. To improve filter efficiency a filter resistor is replaced by an inductor. This inductor will also be cast in the main transformer assembly.
- c. The transistors used in the driven rectifier design of Phase I are no longer manufactured. The circuit has been changed to use one junction of a germanium power transistor as a rectifier in a full wave center tap configuration.
- d. To improve the stability of the voltage regulator the output stage has been changed from a common collector to a common emitter configuration and a number of capacitor resistor networks have been added to the circuit.

The above changes have been incorporated in the design and a revised enclosure arrangement to incorporate a single power conditioner has been prepared.

The electronic components required to build the first six power conditioners have been defined for procurement to meet scheduled delivery dates.

A procurement specification for the power conditioner has been prepared. This specification fully defines the power conditioner design requirements and will be used to investigate the possibility of obtaining a high efficiency high reliability power conditioner from an outside vendor.

Design effort in the succeeding period will be in the following areas:

- a. Define circuit component assemblies as required to provide a more compact enclosure.
- b. Investigate further vendor sources for high reliability components and secure second sources where possible.
- c. Review supplier proposals of the entire power conditioner in accordance with the prepared specification.

2.2.8 ELECTRICAL RECEPTACLE AND PLUG

A complete set of specifications was prepared for an electrical receptacle housing of either beryllium-copper or titanium. In conjunction with a trip to the Wyman-Gordon Forge Co., in Worcester, Mass., a call was made upon the D.G. O'Brien Company to discuss receptacle manufacture. It was pointed out that there was no problem in making a 37-pin receptacle, but that if the choice of material were to be Berylco-165 some development effort would have to be expected since there have been difficulties in sealing cupreous materials with glass or ceramic insulating materials.

Requests for quotes, based on the specifications, were sent out to six vendors in September:

Revere Corp. of America	Wallingford, Connecticut
Vector Cable Company	Houston, Texas
South Bay Cable Company	Gardena, California
Marsh & Marine Mfg. Co.	Houston, Texas
Eitel McCullough	San Carlos, California
D.G. O'Brien Inc.	Kramingham, Massachusetts

These quotes will be evaluated when received and surveys will be made by vendor qualification teams.

Design effort during this report period consisted of the preparation of a procurement specification which will be used to solicit bids for the design, development and fabrication of the electrical receptacle and mating strain relief plug.

Since the electrical receptacle housing material is determined by the pressure vessel material which has not yet been selected, a separate specification has been written for both a 621.8 titanium and a Berylco-165 housing. This will enable quotations to be requested on both models before the pressure vessel material is selected.

2.3 COMPONENT AND SUBASSEMBLY TESTING

2.3.1 FUEL CAPSULE

No work was done in this area during the past quarter.

2.3.2 BIOLOGICAL SHIELD

2.3.2.1 Material Testing

Due to the limited information on high temperature properties of the biological shield material, depleted uranium-8 percent molybdenum alloy, six tensile specimens were tested. The configuration of the specimens was according to Federal Test Method Standard No. 151a. The tested outside diameter was 0.252 inch. The test was conducted in a vacuum of 10^{-5} mm of mercury at elevated temperatures ranging from 900°F to 1500°F.

The results of these tests are shown in Figures 2-22 and 2-23. Figure 2-22 presents ultimate tensile strength versus the temperature. In addition, data obtained from a report by M. B. Waldron, R. C. Burnett, and S. F. Pugh of the United Kingdom Atomic Energy Authority Research Group was plotted on this graph for 7.8 percent molybdenum and 10 percent molybdenum. These tests were performed in an argon atmosphere. Figure 2-23 shows the percent elongation at

Figure 2-22. Temperature vs. Tensile Strength — U-8% Mo

Figure 2-23. Temperature vs. Elongation at Break – U-8% Mo

breaking versus temperature for the test performed by 3M. Note that the specimen tested at 1500°F was not tested to the breaking point. This was due to the fact that the equipment was limited to 37.7 percent elongation. Further testing of this material will be conducted to determine the thermal expansion characteristics at elevated temperatures.

Photographs of the specimens were taken following the tensile tests. They are shown in Figure 2-24.

The description of the samples is as follows:

Chemical composition	8.3% molybdenum <0.5% total impurities
Density	17.4 gm/cc
Form	Cast

2.3.2.2 Compatibility Test

Background — Six isothermal tests (Figure 2-25) were oven treated in vacuum at 1785°F for 100 hours. The furnace placement of the test fixtures is shown in Figure 2-26; the temperature (°F) and pressure (μ of Hg) vs. time are shown in Figure 2-27. Pre- and post-test photos of the assemblies are shown in Figures 2-28 through 2-33.

Testing — Testing began with a 4-hour pump down of the sealed quartz tubes followed by two argon gas flushes and subsequent pump down to 15 μ of Hg. The temperature was raised 50°F every one-half hour until 1785°F was reached. At this point, cooling fans were directed at the greased glass to seal the glass and prevent sealant loss. After a 100-hour soak the furnace power was turned off to allow the test fixtures to cool inside the furnace.

About 4 hours of cool-down (1250°F), the specimen containing the molybdenum barrier cracked open, admitting air to all 6 fixtures for a period of 5 minutes. The fixtures were then blanked off and the remainder of the tests were subsequently pumped down to 10 μ of Hg. However, the molybdenum test was open to the air for the remainder of the cool down (18 hours).

(a)
Specimen No. 1
Tested at 900° F

(b)
Specimen No. 2
Tested at 992° F

Figure 2-24. Photographs of Tensile Specimens after Test

(c)
Specimen No. 3
Tested at 1097° F

(d)
Specimen No. 4
Tested at 1204° F

Figure 2-24. Photographs of Tensile Specimens after Test (Continued)

(e)
Specimen No. 5
Tested at 1292° F

(f)
Specimen No. 6
Tested at 1500° F

Figure 2-24. Photographs of Tensile Specimens after Test (Continued)

Barrier Materials Tested:

Tantalum
 Tungsten
 Molybdenum
 Copper
 Aluminum Oxide
 No Barrier

Figure 2-25. Short-Term Test Specimens

Figure 2-26. Oven Placement of SNAP-21 Compatibility Test Specimens

Figure 2-27. Temperature vs. Pressure for Short-Term Compatibility Tests

(a) Pre-Test

(b) Post-Test

Figure 2-28. Short Term Compatibility Test Specimen - Tantalum

(a) Pre-Test

(b) Post-Test

Figure 2-29. Short Term Compatibility Test Specimen - Molybdenum

(a) Pre-Test

(b) Post-Test

Figure 2-30 Short Term Compatibility Test Specimen - Tungsten

(a) Pre-Test

(b) Post-Test

Figure 2-31. Short Term Compatibility Test Specimen - Aluminum Oxide

(a) Pre-Test

(b) Post-Test

Figure 2-32. Short Term Compatibility Test Specimen - Copper

(a) Pre-Test

(b) Post-Test

Figure 2-33. Short Term Compatibility Test Specimen - No Barrier

Results – Examination of the post-test photographs show the following:

Tantalum – Coating: Sound and adherent

Aluminum Oxide Coating: Sound and adherent

Copper – Coating: Sound but lifted off substrate

Tungsten – Coating allowed formation of eutectic reaction.

Molybdenum – Heavily oxidized, no conclusions

No barrier – Formation of expected eutectic melt.

The test samples will be metallographically mounted for further examination. The molybdenum test is being rerun and the long-term tests are underway.

2.3.3 INSULATION SYSTEM

Evaluation of the offgassing data was completed. The vacuum seal off and getter retention tests, the material compatibility test and the static proof test were also completed.

2.3.3.1 Offgassing Investigation

The offgassing rates previously presented for 304 stainless steel, Hastelloy X, U-8 molybdenum and quartz paper, along with the offgassing rates for nickel foil, copper foil, aluminum foil and 106 paper, taken from the Linde Division Quarterly Report ALO 3632-14, AEC Research and Development Report, January-March 1967, were used to calculate the development unit getter requirements and the gas composition to be used for the getter evaluation test. Table 10 presents the compiled offgassing data in summary form. The table shows, for each material, the surface area used in a HTVIS unit, the offgassing rate at operating temperature, the total offgassing during a 5-year period, the offgassing component percent, and the total offgassing subdivided into gas components for getter calculation. The acceptable leak rate was calculated to be 6×10^{-8} std. cc/sec-air, assuming a 10-micron pressure rise over a 5-year period due to non-getterable argon buildup. The getterable portion of air leakage has been factored into the getter requirement. The total getter requirement for a 5-year period has been calculated to be 6.438 grams plus 0.181 gram of hydrocarbon getter.

2.3.3.2 Vacuum Seal-Off and Getter Retention

A test was performed to determine whether the welding for the permanent seal-off would cause any leakage around the gold "O" ring in the temporary seal-off. It was found that the leak rate of the temporary seal-off was not changed either during or after the final seal-off was performed.

To perform the test, a female seal-off unit was edge welded to a stainless steel plate. A gold "O" ring was fitted into a male seal-off unit and the two parts were assembled. A torque of 75 ft-lbs was applied to the male unit. A leak rate check was made and the leak rate was less than 3.77×10^{-11} std. cc/sec-air. A 1-inch length of weld was made and a leak check was again performed. No leakage was

Table 10. Summary of Offgassing Test Data

Calculated Results	Nickel Foil	Copper Foil	Aluminum Foil	Quartz Paper	106 Glass Paper	Hastelloy-X	Stainless Steel	Biological Shield	Total
Surface area based on both sides of the material-ft ² .	291.35	464.57	565.6	856.58	565.6	0.875	4.26	--	2748.83
Offgassing rates based on surface area (both sides) Micron-liters/hr. ft ² .	0.0005	0	0.0225	0	0	2.3×10^{-3}	9.5×10^{-3}	0	--
Total offgassing during 5 year period - Micron-liters.	638	0	557,398.8	0	0	88,147	1772.58	0	--
Mass spectrometer analysis on gas composition of the material - percent.	H ₂ = 79.47% CO ₂ = 0.14% N ₂ -CO = 19.31% CH ₄ = 1.06%	--	H ₂ = 99.42% N ₂ -CO = 0.15% CH ₄ = 0.42%	--	--	H ₂ = 95.37% N ₂ -CO = 4.61%	H ₂ = 91.87% N ₂ -CO = 6.54% CO ₂ = 1.54%	--	--
Gas constituents from test material - Micron-liters.	H ₂ = 507 CO ₂ = 0.87 N ₂ -CO = 123.2 CH ₄ = 6.76	--	H ₂ = 554,165.9 N ₂ -CO = 836.1 CH ₄ = 2341	--	--	H ₂ = 84.06 N ₂ -CO = 4.06	H ₂ = 91.87 N ₂ -CO = 6.54 CO ₂ = 1.55	--	H ₂ = 556,385.4 CO ₂ = 28.36 N ₂ -CO = 1079.27 CH ₄ = 2347.8

Leakage air based on allowable pressure rise of the system due to the presence of argon only of 10 μ at the end of 5 year period = 7225 μ -liters.
This corresponds to an allowable leakage rate of 6.03×10^{-8} atm. cc/sec. air.

Gas composition of the leakage air - N₂ = 5630 μ -liters, O₂ = 1515 μ -liters, CO₂ = 2.16 μ -liters.

Total system gas composition @ 5 year period.

H ₂	= 556,385.41 μ -liter	- 98.10%	O ₂	= 1,515.00 μ -liter	- 0.267%
CO ₂	= 30.52 μ -liter	0.0053%	CH ₄ group	= 2,347.83 μ -liter	- 0.414%
N ₂ -CO	= 6,709.27 μ -liter	1.183%	Argon	= 163.1 μ -liter	- 0.0287%

Amount of getter requirement based on the following getter capacity.

H ₂	- 100,000 μ -liter/gm
CO	- 8,000 μ -liter/gm
N ₂	- 45,000 μ -liter/gm
O ₂	- 40,000 μ -liter/gm
CO ₂	- 5,000 μ -liter/gm
CH ₄ group	- 13,000 μ -liter/gm

Getter for H ₂	- 5.56 gm
N ₂ -CO based on all CO	- 0.835 gm
CO ₂	- 0.006 gm
O ₂	- 0.037 gm

Total getter for above = 6.438 gms

Total Hydrocarbon getter = 0.181 gm

indicated at this point. Welding was again begun and with approximately 3/4-inch left to weld a leak check was again made with no leak indicated. The weld was completed and the joint was leak checked and found to be satisfactory.

Weld parameters for the above edge weld are as follows:

HW-20 Torch, 1/16 tungsten with gas lens, 20 cfh argon and 2 cfh helium, manual weld

Current - 50 to 52 amps; 9.5 to 11.5 volts

Speed - 6 to 7 IPM; heat input 5.7 kilojoules

To determine the leak rate of the gold "O" ring seal after welding, a hole 0.046 inch diameter was drilled through the male seal-off unit into the volume between the two seals. The volume between the two seals was evacuated and a leak check was performed on each seal separately. The leak rate for the welded joint was less than 4.14×10^{-11} std. cc/sec-air while the leak rate of the gold "O" ring seal was less than 4.2×10^{-11} std. cc/sec-air.

Two getter fill demonstration tests were performed to check out the operation of the seal-off device and associated getter fill hardware. A bottom enclosure head similar to that to be used for the HTVIS units was supplied by 3M Company for the test. The head was machined to the required dimensions for the female portion of the seal-off device. The seal-off device was then edge welded to the head. The getter fill test apparatus for the demonstration tests are shown in Figures 2-34 and 2-35.

The getter installation and seal-off test apparatus was modified to provide a flange with an "O" ring for making a vacuum seal with the outside surface of the spherical enclosure head. A 5/8-inch thick plexiglass sheet, beveled on its edge to the inside head contour, was adhered to the inside of the head to simulate the getter retainer material. A spacing of 1/2-inch was provided between the inside edge of the female seal-off unit and the surface of the plexiglass sheet.

The first getter installation demonstration test was started by mounting the enclosure head on a tilt table and securing the getter fill apparatus to the head as shown in Figure 2-34. The glass getter feeding device was filled with 15 grams of

Figure 2-35. Getter Fill Apparatus —
Demonstration Test No. 2

Figure 2-34. Getter Fill Apparatus —
Demonstration Test No. 1

regular getter and evacuated into the getter fill apparatus before installation. The object of the test was to demonstrate that the getter is being inserted through the female seal-off unit and that it flows freely and does not pile just below the seal-off unit and thereby stop the flow. The getter fill was accomplished with the axis of the test head parallel to the direction of gravity. The spread of the getter blackened the plexiglas surface and the experiment was not conclusive enough to state that the problem of pile-up does not exist. At this point the table containing the test setup was tilted gradually from 0 to $\pm 25^\circ$ angle from the direction of gravity. The getter spread was quite substantial after tilting.

For the second demonstration test the inside of the plexiglas sheet was located 3/8-inch from the inside flat of the female seal-off unit. The volume available for getter was calculated to be 12.5 in.³. The calculations are shown in Appendix A. Ten grams of regular getter will occupy a volume of 1.22 in.³, therefore sufficient getter space is available.

The enclosure head, with associated getter fill hardware, was mounted to a tilt table as shown in Figure 2-35. The angle between the axis of the head and the direction of gravity was approximately 60° . Ten grams of regular getter was inserted into the getter cavity. The getter did not pile up under the female seal-off device causing restriction in flow. When the glass valve on the getter fill tube was opened, the getter flowed smoothly into the unit. This test demonstrated that the required amount of getter can be inserted into the unit if the unit is oriented as shown in the second test.

2.3.3.3 Hydrocarbon Getter Enclosure Development

After reduction of the offgassing data it became apparent that a hydrocarbon getter is required in the HTVIS units in addition to the regular getter. The hydrocarbon getter to be used for this application cannot be physically mixed with the regular getter and therefore requires a separate getter enclosure. This separate getter enclosure must be located in the unit so that the hydrogen gas constituent of the system offgassing will be gettered by the regular getter before it reaches the hydrocarbon getter as the hydrocarbon getter also has a capacity for hydrogen gas.

To meet the above requirements the hydrocarbon getter will be located inside a 3/8-inch O. D. Type 304 stainless steel tube formed into a partial ring to fit around the circumference of the getter tube. This will be welded to the bottom enclosure head using stainless steel tabs. The getter will be retained within the tube by welding the getter retainer material over each end of the tube. This retainer material, with its somewhat low vacuum conductance and small area, will insure that the hydrogen gas from the offgassing will be gettered by the regular getter before it can reach the hydrocarbon getter. The conductance of the retainer material covering the ends of the tube is three orders of magnitude greater than required.

Four getter retainer disks were welded to the 3/8-inch O. D. Type 304 stainless steel tube to determine the required weld parameters. A macrograph of the weld with the screen next to the tube and of the weld with the screen away from the tube is shown in Figure 2-36.

To secure the tube to the enclosure head, three lugs made from 0.048 inch thick Type 304 stainless steel formed in an angle 5/16-inch x 5/16-inch, were welded to the enclosure tube at approximately a 120 degree spacing. Figure 2-37 shows a getter enclosure, complete with retainer ends, welded to an enclosure head. The enclosure tube circumscribes the female seal-off device.

The procedure for preparing the hydrocarbon getter enclosure will be as follows:

- a) Bend tube and cut to length, cut getter retainer material disk.
- b) Weld retainer material to one end of the tube using the parameters of Weld No. 2 above.
- c) Weld the three lugs to tube for welding tube to enclosure head.
- d) Fill tube with required quantity of hydrocarbon getter (can be handled in air).
- e) With getter in welded end of tube, wrap tube with a wet cloth, and weld retainer material on other end of tube.

Figure 2-37. Hydrocarbon Getter Enclosure Welded in Enclosure Head

Figure 2-36. Macrograph of Hydrocarbon Getter Enclosure Weld

2.3.3.4 Material Compatibility Test

At the conclusion of the 500 hour test the temperature controller malfunctioned and the temperature rose to 1980°F. Power was then removed from the test. The compatibility test apparatus was opened for examination after 500 hours of operation, as discussed in Quarterly Report Number 4, and the infrared spectrophotometer analysis of the test materials was performed. The test instrument plotting shows the ratio of the intensity of radiation incident upon it at any wavelength. When an incident radiation (infrared) is imposed on a surface, some part is absorbed, some part is transmitted, some part is reflected, and some part is scattered. This instrument only measures the reflected part of the incident infrared energy. The optical system is split symmetrically into two beams after the source: the beam where the sample is placed and the referenced beam. The two beams are joined in the monochrometer. If any difference in intensity of two beams occurs, a pulsating voltage appears which is proportional to the difference in intensity. This off-balance signal is amplified and used to adjust the calibrated wedge aperture to maintain equality between the two beams. The plotting denotes the movement of this wedge. In this test, the standard is first tested against air. Then the sample is tested against the standard. The Reflectance Index is obtained by multiplying the percent reflectivity of the standard with that of the sample. For example, if the reflectivity of the standard versus air is 20 percent, and reflectivity of the sample against the standard is 50 percent, then the sample for infrared is only 50 percent reflective compared to the standard and has a reflectance index of 0.1. This is in no way related to emissivity of the material and should not be used as a comparator in terms of more reflective or less reflective against visible wave lengths.

Infrared spectrophotometer measures the spectral reflection characteristics by infrared energy source, and therefore the surface condition of the foil (degrees of wrinkles and flatness of the surface) has great bearing as to the value of reflectance index. If the infrared energy beam is impinged on a flat piece of foil, a great portion of the impinged light will be reflected. On the other hand, if the beam is impinged on a wrinkled foil, depending on the amount of wrinkling, a comparatively large portion of the beam will be scattered and only a small portion will be reflected. This makes it difficult to compare the reflectance index of two foils having different surface characteristics (i. e. , wrinkles). For heat transfer characteristics of the foils (emissivity), hemispherical reflectance is a much better indicator of performance than the spectral reflectance used in this test.

The upper and lower limits of reflectance index of the representative samples have been tabulated in Table 11. It is evident from this data that the attempt to determine the degradation or improvement of the radiative quality of the shield materials by the infrared spectrophotometric method was not successful.

The chemical analysis of the discolored Type 106 paper used between the aluminum layers revealed the following:

Sample Identification	Description	Contents
No. 47589	106 paper color – white	C – 0.23% ± 0.01% Na – 0.03%
No. 47590	106 paper spots of gray	C – 0.17% ± 0.01% Na – 1.24% ± 0.05%
No. 47591	106 paper – gray	C – 0.08% ± 0.01% Na – 6.9% ± 0.3% (first test) 1.7% ± 0.1% (second test)

An emission spectrographic analysis was also conducted on Sample No. 47591, showing that this sample contains from 1 to 9 percent sodium and boron. It is not known at this time what is causing the sodium and/or boron in the gray colored Type 106 paper.

A new furnace controller system was installed. The new controllers consist of a Wheelco Limitrol, Serial No. 77190 and a Honeywell Circular Chart controller 0-2000°F. The Wheelco Limitrol is a manually reset instrument that is used in conjunction with Brown controller to provide override protection. If for any reason, the circular chart controller fails to shut off the power, the Limitrol controller, set at a desired override temperature, will shut off all power to the system.

The test was continued at 1400°F. The mass spectrometer data is given in Table 12. The additional 1500 hours of the test, amounting to a total of 2000 hours was then completed. At this point, the temperature controller was turned off and the power plug was pulled out. The chamber vacuum was broken back with argon to

Table 11. Comparison of Compatibility Samples

Material and Roll Identification	Test Results	As Received Condition – Foil				Flattened Foil			
		6μ High	6μ Low	8μ High	8μ Low	6μ High	6μ Low	8μ High	8μ Low
IR 22622 Roll C "START" 0 Hours Standard No. 2 1/4 Mil Aluminum Foil	% Reflectance of the standard used in test	8.5	8.5	10.5	10.5	8.5	8.5	10.5	10.5
	% Reflectance of the sample against the standard	30	27.5	22.5	21	Above 100	44	Above 100	35
	Reflectance Index	2.55	2.33	2.36	2.205	---	3.74	---	3.67
IR 22897 Roll C "FINISH" 2000 Hours Standard No. 2 1/4 Mil Aluminum	% Reflectance of the standard used in test	8.5	8.5	10.5	10.5	8.5	8.5	10.5	10.5
	% Reflectance of the sample against the standard	24.5	11.5	17.5	11	Above 100	31	Above 100	25
	Reflectance Index	2.08	0.977	1.785	1.15	---	2.635	---	2.625

Table 11. Comparison of Compatibility Samples (Continued)

Material and Roll Identification	Test Results	As Received Condition - Foil				Flattened Foil			
		3.33 μ High	3.33 μ Low	4 μ High	4 μ Low	3.33 μ High	3.33 μ Low	4 μ High	4 μ Low
IR 22624 Roll C "START" 0 Hours Standard No. 2 1/2 Mil Copper Foil	% Reflectance of the standard used in test	7.2	7.2	7.5	7.5	7.2	7.2	7.5	7.5
	% Reflectance of the sample	20.5	12.8	20.0	12	60	31	59	28
	Reflectance Index	1.476	0.92	1.5	0.90	4.32	2.23	4.42	2.10
IR 22899 Roll C "FINISH" 2000 Hours Standard No. 2 1/2 Mil Copper	% Reflectance of the standard used in test	7.2	7.2	7.5	7.5	7.2	7.2	7.5	7.5
	% Reflectance of the sample	26	21.5	24	19	62	26	52	24
	Reflectance Index	1.87	1.548	1.8	1.425	4.46	1.872	3.90	1.80

Table 11. Comparison of Compatibility Samples (Continued)

Material and Roll Identification	Test Results	As Received Condition – Foil				Flattened Foil			
		2.77μ High	2.77μ Low	3.12μ High	3.12μ Low	2.77μ High	2.77μ Low	3.12μ High	3.12μ Low
IR 22612 Roll A "START" 0 Hours Standard No. 1 1/2 Mil Nickel Foil	% Reflectance of the standard used in the test	30	30	32	32	30	30	32	32
	% Reflectance of the sample	65	19.5	64	19	-----Above Scale-----			
	Reflectance Index	19.5	5.85	20.48	6.08	-----			
IR 22894 Roll A "FINISH" 2000 Hours Standard No. 1 1/2 Mil Nickel Foil	% Reflectance of the standard used in test	30	30	32	32	30	30	32	32
	% Reflectance of the sample	7.5	0	7.5	0	31.5	22	32	22.5
	Reflectance Index	2.25	0	2.4	0	9.45	6.60	10.24	7.20

Table 12. Data from Mass Spectrometer Analysis Material Compatibility Test

Date	Temperature	Percent Composition						Hydrocarbons	Remarks
		CO ₂	H ₂	A ₂	H ₂ O	O ₂	N ₂ -CO		
May 1, 1967	Room Temp.	0.467	10.24	0.237	80.93	3.01	5.14	----	
May 9, 1967	1400°F	-----	88.90	0.073	8.62	----	2.42	----	
May 12, 1967	1400°F	0.062	86.6	0.216	7.65	----	5.46	----	
May 16, 1967	1400°F	0.336	59.75	-----	8.83	----	29.78	1.28	
May 19, 1967	1400°F	-----	72.2	0.24	11.25	----	16.2	----	
May 22, 1967	1400°F	-----	56.47	0.227	25.6	----	17.6	----	
June 7, 1967	1400°F	-----	87.6	0.068	2.47	----	8.62	1.23	
June 9, 1967	1400°F	-----	86.3	-----	3.28	----	10.4	----	
June 13, 1967	1400°F	-----	86.8	-----	3.11	----	10.0	----	
June 16, 1967	1400°F	-----	45.3	-----	18.6	----	36.0	----	Possible error while taking reading
June 19, 1967	1400°F	-----	77.50	-----	8.59	----	13.86	----	
June 23, 1967	1400°F	-----	74.6	-----	4.53	----	20.84	----	
June 26, 1967	1400°F	-----	75.5	-----	3.3	----	19.9	1.2	
June 30, 1967	1400°F	-----	34.7	-----	22.2	----	43.0	----	Possible error while taking reading

one atmosphere. The chamber flange was opened and the one-inch cooling tube with the compatibility insulation was removed. The rear 15-inch section of the insulation again remained in the furnace when the tube was taken out. The insulation section appeared to have been caught by the U-8 Mo rods as shown in Figure 2-38. One rod adhered to the nickel foil wrappings. The 15 rods and the 15-inch section of the insulation which had slipped off the cooling tube were then removed. The condition of the test materials as removed from the chamber is shown in Figure 2-38.

Figure 2-39 shows the U-8 Mo rods as taken out of the chamber and restacked on the tantalum sheets. Two of the rods which were virtually unchanged in color at the end of 500 hours of test were discolored to some extent. The copper sheathing had failed at several points on some of the rods at the end of 500 hours but this was not aggravated to any extent by the additional 1500 hours of test. The spot holes on the rods were of approximately same dimensions as at the end of 500 hours. The tantalum foil (0.0003 inch thick) under the rods was not shredded as much as at the end of 500 hours of test. The Hastelloy-X sheet was discolored in several spots and there was an overall increase in discoloration of the copper sheathing of the rods as compared to after 500 hours.

Rolls A and C were in the chamber for 2000 hours, while Roll B had been re-wrapped with new insulation materials at the end of 500 hours of test and was in the chamber for an additional 1500 hours. The entire wrapping from each of the test rolls A, B, and C was removed and samples of each of the radiation insulation materials (Al, Cu and Ni) were collected from the Start and Finish section of the roll for infrared spectrophotometer tests. The Start section is the first material put on as the insulation was originally wrapped on the mandrel; i. e., the Start section is closest to the mandrel for any given material. As a roll is unwrapped, the Finish section comes off first and the Start section is the last portion of the individual wrapping. The physical conditions of the insulation were observed as the rolls were unwrapped are given in the following paragraphs.

Figure 2-38. Compatibility Test Materials after 2000 Hours of Test

Figure 2-39. Nuclear Radiation Shield Material after 2000 Hours of Test

ROLL A: TEST RUN TIME - 2000 HOURS

Nickel Foil: Similar in appearance from start to finish. Part way into the roll, quartz paper was adhered to the nickel foil and left fuzzy surfaces.

Copper Foil: Difficult to unwrap because of welding effect in many little spots. Material looked bright except for 5 to 10 inches adjacent to aluminum foil.

Aluminum Foil: The 106 glass paper spacer was dark brown and gradually lightened until it faded completely about 1 ft. from the start. Aluminum foil is found to be thin at Finish section and aluminum powder deposit was noted on 106 glass paper. The thinness of the aluminum foil was evident by the fact that light could be seen through the foil at the Finish section. The 106 glass paper roll edges were not as dark brown as at the center.

Nickel - 5 Turns Roll: Uniform in color.

ROLL B: TEST RUN TIME - 1500 HOURS

Nickel Foil: Quartz material adhered to foil leaving fuzzy surface until shortly before Start. There was some slight discoloration on edges. Heat leak due to discontinuity of rolls between A and B and between B and C may have caused discoloration.

Copper Foil: Welding effect same as noted for Roll A. Not discolored at Start portion of the foil.

Aluminum Foil: The 106 glass paper had a brown color but not as dark as Roll A. Aluminum foil at Finish section is porous and light could be seen through it, but did not seem as porous as Roll A.

Nickel Foil - Turns Roll: Slight discoloration where it touched the stainless steel mandrel.

ROLL C: TEST RUN TIME – 2000 HOURS

Nickel Foil: Quartz paper stuck to foil for short distance only. Other features same as Roll A.

Copper Foil: Color was bright, but welding effect similar to Rolls A and B was noted. For about 6 inches at the Start there was discoloration where the copper came in contact with aluminum foil and 106 glass paper.

Aluminum Foil: Same features as observed for Roll A.

Nickel Foil – 5 Turns Roll: Same as for Roll A.

The mass spectrometer analysis of the offgassing composition collected during the period of from 500 hours to 2000 hours is given in Table 13. The samples of the radiation shield insulation materials from Rolls A, B, and C were tested by infrared spectrophotometer. The data obtained from the infrared spectrophotometer analysis was found to be not valid.

2.3.3.5 Getter Evaluation Test

The gas composition required to simulate the unit offgassing, as previously determined, was prepared by the Linde Special Gas Laboratory. Before using the gas, its composition was determined with the mass spectrometer used during the offgassing test. A summary of the gas required, gas prepared, and mass spectrometer determined compositions is shown in Table 13.

Table 13. Getter Demonstration Test Gas Composition

Gas	Gas Composition as Determined by Off-gassing Calculations (Percent)	Composition of Gas as Prepared by Gas Laboratory (Percent)	Mass Spectrometer Determination of Gas Composition Prior to Getter Demonstration Test (Percent)
H ₂	98.1	98.4	94.8
CO ₂	0.0053	0.0065	0.0047
N ₂ -CO	1.183	1.2	2.02
O ₂	0.267	0.22	0.197
CH ₄ group	0.414	0.41	1.78
Ar	0.0287	0.026	0.0203

The table shows that the prepared gas closely matches that required; however, the mass spectrometer composition determination shows that the CH₄ group is higher than specified. The reason for the higher CH₄ group is probably that an incorrect correction factor was used in the data reduction. To determine the correct correction factor for the CH₄ group a cylinder of 50 percent nitrogen in methane has been prepared. This gas will be evaluated with the mass spectrometer to determine the CH₄ group correction factor. The N₂ correction is well known to be 1.00.

In addition to the test gas composition determination, preliminary test runs were conducted to check out the test procedure and test apparatus. The getter evaluation test was performed using the gas composition as prepared by the gas laboratory. One gram of getter and 0.1 gram of hydrocarbon getter was used in this test.

A schematic of the getter evaluation test setup is shown in Figure 2-40. The test was successful in that 109,000 micron liters of test gas was gettered per gram of

Figure 2-40. Schematic of Getter Evaluation Test Set-Up

getter. The test ran approximately as predicted. All gases were gettered except the argon. Details of this test will be reported on after the results have been completely analyzed.

2.3.3.6 Static Proof Test

The static proof test apparatus was assembled and instrumented for test during this period. A schematic of the static proof test fixture is shown in Figure 2-41.

Figure 2-41. Schematic Static Proof Test Fixture

Twelve Type SR-4 strain gauges were attached to the 3M supplied inner liner (Inconel X-750 - 0.011 inch wall) to measure the strain in the axial direction. The location of the strain gauges is such that with the inner liner in the test position (horizontal), three gauges are mounted on the top, bottom, and each side. One strain gauge was mounted on the tension rod.

The inner liner was bolted to the dummy biological shield (stainless steel) and the unit was installed in the test fixture by bolting the inner liner top flange to the fixture and installing the single tension rod to support the bottom of the biological shield. Dial indicators were installed on the test fixture to measure the deflection of the inner liner at the shield, the deflection of the bottom end of the shield at the tension rod attachment point, and the deflection of the inner liner top flange where it is attached to the test fixture.

The neck tube was pressurized on the inside to 14.5 psig and the load was applied to the shield through the hydraulic jack in increments of 100 pounds. It became apparent that the test fixture was deflecting excessively. The test was discontinued and the test apparatus was disassembled.

Gusset plates were added to the frame to reduce the deflection in the top beam. The test was started again and the neck tube was buckled with an applied load of 4060 pounds. This load is within 2 percent of the load at which the neck tube was calculated to buckle at ambient temperature. The buckled neck tube is shown in Figure 2-42.

2.3.4 SEGMENTED RETAINING RING – DYNAMIC TEST

A dynamic test of the segmented retaining ring is being prepared. The test will be conducted to ensure that the redesigned compression springs are adequate to restrain the insulation system during dynamic test. Testing will be performed to specification requirements of 3 g vibration and 6 g shock and to 1.5 times these requirements.

Various components were designed to simulate the dynamic characteristics of the SNAP-21 system. To simulate the mass of the actual biological shield, a dummy shield made up of a layer of lead and a layer of mild steel will be used. The thickness of each layer is calculated to approximate the center of gravity and weight of the actual biological shield. The weight of the dummy shield is 289 pounds. The shield is supported at the upper end by a simulated neck tube. Tension tie rods will be attached to the bottom of the shield. A residual insulation envelope and pressure vessel will make up the remainder of components to be used in the dynamic mockup of the system. A reasonable effort was made in the design of these components to simulate the actual shield suspension system so that any dynamic amplification that may exist will be experienced in the test.

Figure 2-42. Buckled Neck Tube

A schematic of the components to be used in this test, including the placement of the accelerometers, is illustrated in Figure 2-43. A total of nine accelerometers will be used. This test is scheduled for the next report period.

2.3.5 PRESSURE VESSEL

Quotes were received from three sources for forging and machining pressure vessels and covers from both 621.8 type titanium and Berylco 165. A qualification team was sent to the apparent low bidder, Taylor Forge and Pipe Works, in Cicero, Ill. It was then discovered that Taylor's quote included forging and rough machining only. Since our request for quote was based on the delivery of a finished and acceptable part, we requested their cost for finish machining to be included in their final quote.

The Wyman-Gordon Forge Co. of Worcester, Massachusetts, was also visited after receiving the final quotes from Taylor Forge and Pipe Works. Both companies possess excellent facilities and technology to perform the required work. At this time the contract award is awaiting the decision of material selection.

2.3.6 THERMOELECTRIC GENERATOR

2.3.6.1 Cold End Heat Transfer

The SNAP-21 cold end heat transfer testing was completed in September. A final summary report is presently being prepared.

Testing during the past quarter included completion of the in-line testing, effects of spherical mismatch in tests of non-hardcoated followers, beryllium oxide followers, and indium plated cold caps with hardcoated followers. Recommendations for the in-line generators were made on July 24 in SNAP-21 Report No. 3691-0659.

The following is a description of the test work on the other three concepts:

- a) Effects of spherical mismatch – non-hardcoated socket followers (Tests 25 and 28). The range of spherical mismatch studied was from 0.000 to 0.003 inch with the cap radius both larger and smaller than the follower radius. Details of these tests appear in Table 14.

Table 14. Test Data Summary of the Effects of Spherical Mismatch with Nonhardcoated Socket Followers

Test No.	Leg No.	Follower-Hole Clearance	Follower Spher. Radius (in.)	Cold Cap Spher. Radius (in.)	Radial Mismatch $\Delta r \times 10^{-3}$	Hot Button Temp	Cold Cap Temp	Cold Frame Avg Temp	$T_{\text{Cap}} - T_{\text{Cold Frame}}$	Comments
25	1	0.0005	0.1255	0.1248	0.7	1107	106	86	20	Thermo-couple Suspected Bad
	2	0.0005	0.1255	0.1248	0.7	1107	100	86	14	
	3	0.0005	0.1260	0.1248	1.2	1107	105	86	19	
	4	0.0005	0.1260	0.1248	1.2	1107	103	86	17	
	5	0.0005	0.1265	0.1248	1.7	1110	103	86	17	
	6	0.0005	0.1265	0.1248	1.7	1108	103	86	17	
	7	0.0005	0.1275	0.1280	-0.5	1110	106	86	20	
	8	0.0005	0.1275	0.1280	-0.5	1109	117	86	31	
	9	0.0005	0.1270	0.1280	-1.0	1110	105	86	19	
	10	0.0005	0.1270	0.1280	-1.0	1092	107	86	21	
	11	0.0005	0.1265	0.1280	-1.5	1108	104	86	18	
	12	0.0005	0.1265	0.1280	-1.5	1108	100	86	14	
28	1	0.0005	0.1218	0.1248	-3.0	1099	97	85	12	
	2	0.0005	0.1218	0.1248	-3.0	1099	98	85	13	
	3	0.0005	0.1228	0.1248	-2.0	1099	98	85	13	
	4	0.0005	0.1228	0.1248	-2.0	1097	98	85	13	
	5	0.0005	0.1238	0.1248	-1.0	1097	97	85	12	
	6	0.0005	0.1238	0.1248	-1.0	1097	97	85	12	
	7	0.0005	0.1258	0.1248	1.0	1097	97	85	12	
	8	0.0005	0.1258	0.1248	1.0	1097	97	85	12	
	9	0.0005	0.1268	0.1248	2.0	1099	104	85	19	
	10	0.0005	0.1268	0.1248	2.0	1097	99	85	14	
	11	0.0005	0.1278	0.1248	3.0	1100	104	85	19	
	12	0.0005	0.1278	0.1248	3.0	1100	104	85	19	

The results of this testing showed very little degradation of heat transfer with increasing mismatch over an even larger range of variables than in the test data previously reported. Better heat transfer is obtained when the cap radius is larger than the follower radius. This could have been expected since this would assure ring contact rather than point contact.

- b) Indium plated caps – hardcoat socket followers (Tests 26 and 27). The range of mismatch investigated was the same as above. Test details are given in Table 15.

These tests showed excellent heat transfer over the entire range of variables. Figure 2-44 shows that it is somewhat better than the bare aluminum seat followers over most of the range of variables.

- c) Beryllium oxide followers (Tests 26 and 27). Only 0.1250 inch radius followers were available, thus only well matched radii were tested. These followers were tested with bare caps and indium plated caps. Test details can be found in Table 16.

Test results indicate that good contact can be achieved with the BeO. Though the fit was measured to be very close, an area of ring contact was noticed after testing. Plating caps with indium gave the best results of the entire program, an average drop from cap to cold frame of 10°F (Figure 2-44).

As Figure 2-44 shows, several concepts show very nearly equal thermal merit. The final development report on this effort is now being prepared. This report will include all concepts investigated for thermal efficiency, relative cost, ease of assembly, etc. A final recommendation must be based on all these factors.

2.3.6.2 Leg and Couple Testing

Ingradient testing on SNAP-21 production couples was initiated in this quarter. The first test was run in July, but only one couple was available for test at that

Table 15. Test Data Summary for Indium-Plated Caps and Hardcoat Socket Followers

Test No.	Leg No.	Follower-Hole Clearance	Follower Spher. Radius	Cold Cap Spher. Radius	Radial Mismatch $\Delta r \times 10^{-3}$	Hot Button Temp	Cold Cap Temp	Cold Frame Avg Temp	$T_{\text{Cap}} - T_{\text{Cold Frame}}$	Comments
26	7	0.0005	0.1250	0.1250	0.0	1101	106	86	20	
	8	0.0005	0.1252	0.1250	0.2	1099	112	86	26	
	9	0.0005	0.1265	0.1250	1.5	1100	111	86	25	
	10	0.0005	0.1265	0.1250	1.5	1100	102	86	16	
	11	0.0005	0.1269	0.1250	1.9	1103	107	86	21	
	12	0.0005	0.1270	0.1250	2.0	1102	107	86	21	
27	5	0.0005	0.1261	0.1280	-1.9	1096	96	83	13	
	6	0.0005	0.1261	0.1280	-1.9	1096	96	83	13	
	7	0.0005	0.1268	0.1280	-1.2	1096	96	83	13	
	8	0.0005	0.1272	0.1280	-0.8	1095	95	83	12	
	9	0.0005	0.1250	0.1280	-3.0	1100	99	83	16	
	10	0.0005	0.1252	0.1280	-2.8	1094	96	83	13	
	11	0.0005	0.1253	0.1280	-2.7	1094	96	83	13	
	12	0.0005	0.1252	0.1280	-2.8	1094	95	83	12	

Temperatures are in °F.

Linear dimensions are in inches.

Table 16. Test Data Summary for Beryllium Oxide Followers

Test No.	Leg No.	Follower-Hole Clearance	Follower Spher. Radius	Cold Cap Spher. Radius	Radial Mismatch $\Delta r \times 10^{-3}$	Hot Button Temp	Cold Cap Temp	Cold Frame Avg Temp	$T_{\text{Cap}} - T_{\text{Cold Frame}}$	Comments
26 Bare Copper Caps	1	0.0005	0.1250	0.1248	0.2	1102	96	86	10	
	2	0.0005	0.1250	0.1248	0.2	1099	102	86	16	
	3	0.0005	0.1250	0.1248	0.2	1103	96	86	10	
	4	0.0005	0.1250	0.1248	0.2	1101	107	86	21	
	5	0.0005	0.1250	0.1248	0.2	1101	98	86	12	
	6	0.0005	0.1250	0.1250	0.0	1099	---	86	--	T/C Out
27 Indium Plated Caps	1	0.0005	0.1250	0.1250	0.0	1097	95	83	12	
	2	0.0005	0.1250	0.1250	0.0	1097	93	83	10	
	3	0.0005	0.1250	0.1250	0.0	1094	93	83	10	
	4	0.0005	0.1250	0.1250	0.0	1096	91	83	8	

Temperatures are in °F.

Linear dimensions are in inches.

Figure 2-44. Comparative Results of Heat Transfer Testing

time. The results are summarized in Table 17. Full scale testing was initiated when couples and the cold end heat transfer test station became available. Six couples are now on test, but data is not yet available.

Table 17. Test Results for Initial Leg and Couple Acceptance Test

Couple			N-Leg			P-Leg		
E(mv)	R(m Ω)	P(mw)	E(mv)	R(m Ω)	P(mw)	E(mv)	R(m Ω)	P(mw)
219	35	343	119	19	186	100	15	167

$$T_h = 1087^\circ\text{F}$$

$$\text{Avg. } T_c = 117^\circ\text{F}$$

$$T_{cf} = 80^\circ\text{F}$$

2.3.6.3 Leg Inspection Development Testing

During this period improvement continued on the fixture and techniques used for direct resistance testing of legs and couples. One of the more significant goals for this effort, that of increasing the rate of testing, has definitely been approached. The techniques used at the beginning of this period were considered to have improved when the rate of 2 legs per minute could be tested. At present a rate of 10 per minute has been achieved.

The initial assembly and testing of the new Seebeck test fixture was accomplished during this period. At first there was excessive heat cycling of the temperature controlled hot block. This was overcome by improving the heat transfer between the heater and control sensor. A complete analysis of the thermal shock effects on the elements has not yet been made. No conclusions have as yet been reached.

The direct resistance technique of leg and couple testing at room ambient temperature must be correlated to various other tests now in use. Some work was done in this area and there is definitely good correlation with the R/L resistivity test method. Some work was done to correlate with the "in gradient tests". No definite conclusion could be drawn due to the small quantities of material available for the purpose.

Hastelloy standards have been established with correction factors to eliminate errors due to flux density variations or end effects. New acceptance limits may be established as data continues to be accumulated and evaluated.

During the next period the Seebeck fixture will be tested further and improved. More study will be done along the lines of thermal shock effects on the materials tested and more correlation data will be collected and analyzed.

2.3.6.4 Generator Development Testing

The family of 4 ball and socket type thermoelectric generators have been fabricated, processed and short-term performance tested.

The order of fabrication of the 4 generators is as follows:

- A10D-2
- A10D-3
- A10D-1
- A10D-4

The test sequence and the current status of each generator is as follows:

2.3.6.4.1 Generator 10D-2

The thermoelectric generator was stabilized at design temperatures for a period of approximately 72 hours. At this point, a current-voltage (I-V) performance evaluation was completed. Various load-voltages at design temperatures simulated BOL and EOL conditions of the generator. Figures 2-45 and 2-46 give a graphic representation of generator performance before dynamic testing.

The generator then was subjected to specification level shock and vibration testing. No effect was noted during the dynamic test sequence. The generator was operated at design temperatures (1100°F hot button and 80°F cold frame) during dynamic testing.

Figure 2-45. Performance Evaluation Map of SNAP-21 Generator 10D2

Figure 2-46. Performance Evaluation Map of SNAP-21 Generator 10D2

A detailed report of the shock and vibration testing of Generator 10D-2 is given in Appendix B.

Generator 10D-2 was subjected to a post-dynamic I-V performance evaluation. The results of this evaluation are graphically presented in Figure 2-47. A slight power reduction of about 0.46 watt was noted in generator output as compared to a pre-dynamic performance. Total thermopile resistance decreased, as did the Seebeck voltage, indicating that dynamic testing was not a factor in the minor decrease in power.

A slight off-design temperature at the hot end of the generator could account for this small power loss. The unit was placed on test to await integration with System S10D-1; while on test a drop in the internal gas pressure was discovered. Immediate steps were taken to correct the leak. The generator was backfilled to design pressure with argon gas and removed to a dry-box to reach ambient temperature. The leak was then found to be in the Conax electrical feedthrough fittings. The pump-down port on the generator was replaced in the dry-box in an argon atmosphere. When the pump-down port on the generator was repaired and the generator again sealed, the unit was removed from the dry-box and the Conax fittings retorqued to 50 in-lbs.

The unit was then cold-pumped for 72 hours and placed on test where it was brought to operating temperatures.

During the next quarter, when a successful hermetic seal is realized, the unit will be placed on test to await residual system integration.

2.3.6.4.2 Generator 10D-3

SNAP-21 Generator 10D-3 was fabricated, processed, and placed on test. The unit was stabilized at design temperatures and an I-V performance evaluation was made (see Figures 2-48 and 2-49). During the performance evaluation, it became apparent that the generator was not performing as planned, nor performing to the level of Generator 10D-2.

Figure 2-47. Post-Test Shock and Vibration Performance Evaluation of SNAP-21 Generator 10D2

Figure 2-48a. Performance Evaluation Map of SNAP-21 Generator 10D3, Input - 454 watts

Figure 2-48b. Performance Evaluation Map of SNAP-21 Generator 10D3, Input - 424 watts

From the existing internal instrumentation and an analysis of data collected during the short-term performance evaluation, the probable cause of low power output of the generator was reasoned to be two reversed thermocouples. Subsequent tear-down of A10D-3 at the close of dynamic testing validated this conclusion (see Figure 2-50).

The generator had accrued a total of 248.8 hours of test at operational temperatures. The internal components (thermoelectric couples) showed a slight amount of oxidation. It is highly probable that this slight amount of oxidation was formed when the generator failed mechanically (loss of hermetic seal) in later dynamic testing and exposed the couples to atmosphere while at elevated temperature.

In addition to the foregoing, 3 thermoelectric couples were found to be "cocked" at the junction of the thermoelectric leg hot end entry into the hot button. This skewed placement of couples was not a result of dynamic testing, but was due to improper assembly. The hot end of the thermoelectric leg had bonded to the hot button and this could only have happened at elevated temperature processing or test, early in the test sequence.

The skewed placement of couples apparently had no noticeable effect on generator performance. However, it does point up a potential failure mode which could drastically affect future generators or systems.

Discrepancies found while dismantling Generator 10D-3 are tabulated in Table 18. (Refer to Figure 2-49 for couple identification.) Note that the term "Follower sticking in cold frame" does not indicate total seizure or the lack of the follower to exert spring pressure on the thermoelectric couple, but rather indicates a minor resistance to complete follower removal from the cold frame by mechanical means. It is suspected that minute quantities of finely divided MIN-K 1301 was the major cause of this.

Before tearing down Generator 10D-3, the unit was subjected to dynamic testing at specification level, then to "destruct". Destruct is defined as a 25 percent reduction in power out or a 20g level of shock and vibration. One of the two parameters would dictate the end of test.

a) COUPLE #10: with hot button misaligned

b) COUPLE #27: showing two "P" legs on same hot junction electrode

c) COUPLE #35: showing two "N" legs on same hot junction electrode

Figure 2-50. Photographs of Components from SNAP-21 Generator 10D3 After Disassembly

d) COUPLE #29: showing hot junction button misaligned

e) COUPLE #28: showing imprint of hot junction buttons on legs

f) COUPLE #28: showing hot button with leg residue

Figure 2-50. Photographs of Components from SNAP-21 Generator 10D3 After Disassembly (Continued)

Table 18. Results of Teardown SNAP-21 Generator 10D3

Couple Number				
Hot Button Bonded to N-Leg				
Hot Button Bonded to P-Leg				
N-Hot Button Bonded to Hot Strap				
P-Hot Button Bonded to Hot Strap				
1				Leg bond broken in dismantling
2				
3	X		X	
4	X		X	
5	X			
6	X		X	
7	X		X	
8	X			
9	X			
10	X		X	Leg "cocked" in hot button
11	X			
12	X			
13	X			Follower sticking in cold frame*
14	X			
15	X		X	
16	X			
17	X		X	Follower sticking in cold frame*
18	X			
19	X			Follower sticking in cold frame*
20	X			
21	X			
22	X		X	
23	X			
24	X			
25	X			
26	X		X	
27		X		Couple <u>reversed</u>
28	X			Hot end bonding defective in hot button ("cocked" leg)
29	X		X	P-leg in hot button defective ("cocked" leg)
30	X			
31	X			Follower stuck in cold frame causing P-leg to break during dismantling*
32	X			
33	X		X	
34	X		X	
35			X	Couple <u>reversed</u>
36	X		X	
37	X		X	
38	X			
39	X			
40	X			
41	X			
42	X		X	
43	X		X	
44	X		X	
45	X		X	Followers sticking in cold frame*
46	X		X	Followers sticking in cold frame*
47	X		X	
48	X		X	
49	X		X	

NOTE: Refer to Figure 2-54 for Couple Identification.

The photographs in Figure 2-50 (a through f) illustrate some of the discrepancies found. The photographs were taken during and after tear-down.

Specification level shock and vibration testing at design temperatures was completed with no apparent effects on generator performance. Incremental steps of shock and vibration continued until a 20g level was attained.

No effect on generator performance was noted at any level of dynamic testing; however, during the final vibration cycle an external mechanical failure of the pressure transducer tube resulted in the loss of hermetic seal (backfill gas) and thus dictated the end of test.

A detailed account of the dynamic test effort is given in Appendix C.

After tear-down all internal components of A10D-3 thermoelectric generator were identified, stored in Mylar envelopes and placed in storage for future reference and/or study.

2.3.6.4.3 Generator 10D-1

Generator 10D-1 was fabricated, processed and placed on test. During the initial short-term stabilization, a slow decrease in the internal gas pressure was noted. The leak was caused by the Conax (instrumentation feedthrough) fittings. The generator was backfilled with argon gas to design pressures and the fittings re-torqued to 60 in-lbs at design temperatures. Since the fittings have been tightened the unit has not leaked, and when it is reasonable to assume that the leaking Conax fittings have been permanently corrected, the I-V performance testing will begin. After performance testing the unit will undergo dynamic testing to specification level and then be placed on long-term performance testing.

2.3.6.4.4 Generator 10D-4

Generator 10D-4 was fabricated, processed and placed on test. During the initial stabilization in the test area, a slow decrease of the internal gas pressure was noted. The leak was caused by the Conax fittings. The generator was back-filled with xenon gas and the Conax fittings were re-torqued. The leak persisted and the Conax fittings were again re-torqued to 60 in-lbs at design temperatures. This effort will continue until the leak is corrected within the torque limits of the Conax fittings.

When the generator has been made leak-tight, the I-V performance test will be begin. The dynamic test effort for Generator 10D-4 will be determined by the results of the dynamic testing of Generator 10D-1. Generator 10D-1 is of identical construction and should validate the dynamic test effort for this family of thermoelectric generators. During the next quarter, Generator 10D-4 will be made leak-tight and placed on long-term test.

2.3.6.5 Generator Processing

Generator 10D-2 began processing on July 19, 1967. Processing was completed on July 28, 1967. Various difficulties were experienced while processing the first two generators. On 10D-2, it was difficult to maintain the specified cold end temperatures. Heat conduction through the test station and through the restraining ring on the generator long case (used to prevent case collapse during vacuum) kept the cold

end temperature up. Cold water used for cooling had an intake temperature of about 64°F and an outlet temperature of about 67°F. An auxiliary tank of water and ice was used to bring the temperature down.

Before processing of Generator 10D-3, an additional cooling ring was added and the line size for coolant was increased. The heat source was also lowered in an effort to maintain cold end temperatures. However, the problem with Generator 10D-3 turned out to be in attaining the hot end temperature. The heat source was moved closer, the coolant flow was practically stopped and the entire outer case was wrapped with fiberglass insulation. These changes brought the hot end temperatures to the desired level.

The test and process stations were reworked before processing Generators 10D-1 and 10D-4. The heater support was insulated with asbestos spacers, reducing the heat transfer area of the support; a stainless steel restraining ring was used in place of the aluminum ring, and additional MIN-K insulation was put around the heater area. After these changes were made, no problems were encountered on either the hot or cold end temperatures while processing Generators 10D-1 and 10D-4.

Conax fittings began leaking on all generators. Generators 10D-2 and 10D-1 were found to be leaking during test. Since they had already been pinched off, the only way in which pressure could be increased was by providing an access tube. This was done in the dry box with a tee and two Hoke valves (Figure 2-51). This configuration was added to Generator 10D-4 while it was still on the process station. The Conax fittings were tightened in an attempt to stop the leakage and the required pressure added. The Conax fittings have had to be tightened several times because the viton in them seems to flow. It is expected that after several retightenings that the plastic flow will cease and that sealing will be effected. The access valve will remain and no final pinch-off will be made until there is no detectable leakage.

2.3.6.6 Phase I Continuation Testing

During this report period the monitoring and analysis of thermoelectric and electronic test work initiated during Phase I of the SNAP-21 program continued. The units being tested are:

Figure 2-51. Access Tube for Adding Pressure to Generator After Pinch-Off

6-couple modules — A_1 , A_3 , and A_4

Prototype generator units — P_5 , P_6 , and P_7

(See enclosed normalized data on respective units.)

All units are performing with no significant change in performance. Performance data for these units are shown in Figures 2-52 through 2-55 and in Tables 19 and 20.

Two power failures in June and August necessitated lowering the auxiliary input power to all systems for approximately two hours in each instance. Data recorded after the failures indicated a return to normal operating conditions.

Laboratory water supply interruptions occurred on September 5 and September 9, 1967. During the water supply failures the input power to all systems and modules was lowered to prevent overheating. Data recorded after the water supply had resumed indicated that, after a reasonable period for stabilization, operating conditions had returned to normal.

During the next report period the input power to 6-couple modules A_1 , A_3 , and A_4 will be reduced to simulate the decay of the radioactive isotope. This will begin the fourth year of operation for the modules.

The analysis of Prototype P₃ is in the final stages of completion and will be published separately during October 1967.

2.3.7 POWER CONDITIONER

The residual Phase I power conditioners have been on test throughout the report period. There has been no significant change in performance. The conditioners and related control equipment have accrued over 21,000 hours of actual test.

2.3.8 ELECTRICAL RECEPTACLE

No test effort was expended in this area during this time period.

Figure 2-52 Performance Data, SNAP-21 6-Couple Module A1

Figure 2-53. Performance Data, SNAP-21 6-Couple Module A3

Figure 2-54. Performance Data, SNAP-21 6-Couple Module A4

Prototype 3M-37-P5

Prototype 3M-37-P6

Prototype 3M-37-P7

Figure 2-55. Performance of Prototype 48-Couple Generator 3M-37-P5, P6, P7 (E = voltage, R = resistance, P = power, x = experimental, C = computer)

Table 19. 6-Couple Module Performance Test Data

Module	Date	T-Hot (est)	T-Cold	E _O (volts)	E _L (volts)	I _L (amps)	P _O (watts)	R (M-ohms)	P _I (watts)	Hours
A1	6-30-67	Power	Failure	Emergency	Power	was on for Approximately 2 Hours				
	6-30-67	1060	124	1.28	0.63	1.81	1.14	368	34	25,749
	7-1-67	1060	113	1.29	0.63	1.80	1.14	365	34	25,773
	7-25-67	1060	114	1.30	0.64	1.83	1.17	361	34	26,349
	8-5-67	1060	115	1.30	0.64	1.84	1.17	360	34	26,613
	8-7-67	1060	115	1.30	0.64	1.84	1.17	360	34	26,661
	8-23-67	1060	115	1.32	0.64	1.84	1.17	372	34	27,045
	9-5-67	1060	116	1.31	0.64	1.84	1.18	364	34	27,357
	9-26-67	1060	116	1.30	0.64	1.84	1.17	360	34	27,861
A3	6-30-67	Power	Failure	Emergency	Power	was on for Approximately 2 Hours				
	6-30-67	1060	115	1.29	0.65	1.83	1.19	350	47	24,393
	7-1-67	1060	118	1.30	0.65	1.82	1.18	359	47	24,417
	7-24-67	1060	119	1.31	0.65	1.83	1.19	361	47	24,993
	8-5-67	1060	117	1.29	0.65	1.80	1.16	358	47	25,281
	8-7-67	1060	118	1.31	0.65	1.85	1.21	355	47	25,329
	8-23-67	1060	118	1.32	0.65	1.85	1.21	361	47	25,713
	9-4-67	1060	117	1.31	0.65	1.85	1.21	356	47	26,001
	9-26-67	1060	118	1.32	0.65	1.84	1.20	363	47	26,529
A4	6-30-67	Power	Failure	Emergency	Power	was on for Approximately 2 Hours				
	6-30-67	1060	106	1.24	0.65	2.29	1.50	256	39	23,553
	7-1-67	1060	117	1.28	0.66	2.29	1.50	273	40	23,577
	7-24-67	1060	116	1.30	0.67	2.34	1.57	270	40	24,153
	8-5-67	1060	118	1.29	0.68	2.36	1.60	258	40	24,441
	8-7-67	1060	117	1.31	0.68	2.38	1.61	266	40	24,489
	8-23-67	1060	117	1.31	0.68	2.38	1.61	266	40	24,873
	9-5-67	1060	117	1.31	0.68	2.39	1.63	262	40	25,185 Bldg. water was off
	9-26-67	1060	117	1.31	0.68	2.36	1.60	269	40	25,689

Table 20. Prototype 48-Couple Generator Performance Test Data

Module	Date	T-Hot (est)	T-Cold	E _O (volts)	E _L (volts)	I _L (amps)	P _O (watts)	R (M-ohms)	P _I (watts)	Hours
P5	6-30-67	Power	Failure	Emergency	Power	Came on at 8:28 p. m. to 10:30 p. m.				
	6-30-67			9.50	4.81	2.17	10.46	2.16	168	
	7-1-67	1067	159	10.00	5.00	2.19	10.95	2.28	175	18,833
	7-24-67	1063	165	10.00	5.00	2.18	10.90	2.29	167	19,385
	8-5-67	1069	164	10.01	5.00	2.22	11.10	2.26	170	19,673
	8-8-67	1063	165	9.98	5.00	2.20	11.10	2.26	178	19,745
	8-23-67	1068	168	9.98	4.98	2.23	11.11	2.24	178	20,105
	9-5-67	1106	168	10.49	5.05	2.28	11.51	2.39	178	20,417
	9-13-67	1103	170	10.48	4.98	2.26	11.25	2.43	178	20,609
	9-26-67	1068	160	10.04	5.02	2.17	10.89	2.31	172	20,921
P6	6-30-67	1055	Building Power Failure Emergency Power for Approximately 2 Hours							
	6-30-67	1055	176	9.80	4.97	2.01	9.99	2.40	183	18,180
	7-1-67	1055	172	10.10	5.05	2.04	10.28	2.48	184	18,204
	7-24-67	1055	192	9.68	4.92	1.96	9.64	2.43	195	18,756
	8-4-67	1055	178	9.95	4.98	2.03	10.11	2.45	185	19,020
	8-8-67	1055	181	9.92	4.96	1.98	9.82	2.57	189	19,116
	8-23-67	1055	180	9.73	4.90	1.98	9.70	2.44	190	19,476
	9-5-67	1055	176	9.60	4.89	1.97	9.63	2.39	183	19,788
	9-13-67	1055	172	9.58	4.90	1.93	9.46	2.42	183	19,980
	9-26-67	1055	175	10.08	5.04	2.02	10.18	2.50	186	20,292
P7			Building Power Failure Emergency Power Was on for Approximately 2 Hours							
	6-30-67	1055	175	10.00	5.05	1.89	9.54	2.62	178	18,176
	7-1-67	1055	165	10.30	5.15	1.86	9.58	2.77	180	18,192
	7-24-67	1055	190	10.27	5.12	1.86	9.52	2.77	184	18,750
	8-4-67	1055	188	10.26	5.12	1.92	9.83	2.68	180	19,014
	8-8-67	1055	182	10.19	5.10	1.92	9.79	2.65	178	19,110
	8-28-67	1055	185	10.18	5.09	1.89	9.62	2.69	178	19,470
	9-5-67	1055	179	10.22	5.21	1.86	9.69	2.69	178	19,782
	9-13-67	1055	184	10.40	5.28	1.89	9.98	2.71	178	19,974
	9-26-67	1055	166	10.26	5.13	1.92	9.85	2.67	179	20,286

2.4 SYSTEM FABRICATION, ASSEMBLY AND TEST

2.4.1 PHASE I CONTINUATION TESTING

SNAP-21B system is continuing on test with no significant change in performance. The system has accrued 21,150 hours of actual test time as of this report period.

The entire system is now being analyzed. The analysis will consider the loss of instrumentation during the test period. This analysis may precipitate the dismantling of the system and will be reported in detail in a later report.

2.4.2 PHASE II SYSTEM

The residual pressure vessel and the Linde Phase I HTVIS Insulation System have been on test with a simulated fuel capsule (electrically heated) for a period of over 2200 hours. The test was terminated on September 29 to permit using the residual pressure vessel in the dynamic testing of the segmented retaining ring for the SNAP-21 Program.

The pressure vessel, the Linde system, Generator 10D-2, and the residual Phase I power conditioner will be brought together to fabricate the first system on the current SNAP-21 Program during the next report period.

A plot of pressure and operational temperature versus time of the Linde HTVIS system is shown in Figure 2-56.

2.5 SAFETY AND TESTING

2.5.1 LABORATORY CORROSION TESTING OF SNAP-21 MATERIALS

Laboratory corrosion studies of SNAP-21 materials are being conducted by the U.S. Naval Radiological Defense Laboratory. Due to the possibility of using beryllium-copper alloy pressure vessel material rather than titanium, beryllium corrosion samples have been procured and sent to NRDL. The laboratory studies have already been started; consequently, it is too late to integrate these samples with the others. However, these samples can be included under the SNAP-23 test program.

Figure 2-56. SNAP-21 Residual Pressure Vessel: Temperature and Pressure vs Time

The Hastelloy X laboratory corrosion samples were sent to NRDL July 13. Except for the beryllium samples, the Hastelloy X samples completed the list of sample materials to be sent to NRDL.

2. 5. 2 ELECTRICALLY HEATED FUEL CAPSULE TEST SYSTEMS

A design change was required for NRDL's electrically heated fuel capsule mockup. The containment shell was too long to be welded in Oak Ridge's electron beam welding chamber. Consequently, one additional weld joint was provided. 3M is to supply the Hastelloy C parts for the containment shell. These parts will be sent to Oak Ridge National Laboratory where the internal parts will be inserted and electron beam enclosure welds will be performed.

The parts comprising the containment shell of the electrically heated fuel capsule are being fabricated. Some braze seal plugs were sent to NRDL for brazing. The configuration of the assembly is illustrated in Figure 2-57.

While machining the parts for the electrically heated fuel capsules for NRDL, a large void of approximately 3/4-inch diameter was observed in one of the pieces of bar stock along with other lesser porosity. Part blanks cut from the same bar were examined and found to have gross porosity from primary piping. Machining was stopped and all of the remainder of the material was radiographically inspected. The results indicate no voids or imperfections in the capsule stock. The faulty bar stock had been noted to be difficult to cut and when tested, a hardness of Rockwell B88 was indicated. Discussions with Union Carbide indicate that the distributor had supplied cast material rather than wrought. Replacement material for backup has been ordered. These and all future capsule parts will be ultrasonically inspected. All subsequent development and actual fueled capsules will be fabricated from Hastelloy C-276.

The marine fouling test systems mockup utilizes an end plate which is made of the same material as the pressure vessel. This mockup may be delayed because of the decision yet to be made on the pressure vessel material.

NRDL has prepared prints of the galvanic coupling test system mockup for 3M review. The prints have been approved and test samples of the pressure vessel

Figure 2-57. Electrically Heated Fuel Capsule Assembly

material will be forwarded to NRDL. The test system mockup will be fabricated and the test will be performed by NRDL.

2.5.3 OCEAN EXPOSURE STUDIES OF SNAP-21 RADIOISOTOPE LOADED FUEL CAPSULE

Two (2) full-size fuel capsules will be used in NRDL's ocean exposure test. Each capsule will contain 30,000 curies of fuel. These capsules will be of the design shown in Figure 2-57.

2.6 NAVSHIPS RESEARCH AND DEVELOPMENT CENTER 10-COUPLE MODULES

An interface meeting was held at 3M Company on September 22, 1967 with NAVSHIPS R&D center personnel to review the SNAP-21 10-couple module program. The meeting consisted of a design review to establish component schedules, tooling requirements, and to point out interface responsibilities.

Design effort was initiated on this task during this reporting period. This effort consisted of reviewing the drawings used to fabricate the SNAP-23 10-couple modules to identify areas that require redesign to incorporate the SNAP-21 thermoelectric couples. In addition, the drawings were reviewed with fabrication and assembly personnel to identify certain problem areas that were encountered while fabricating the SNAP-23 modules. Drawings are being changed to incorporate the required redesign. A package of the fabrication drawings will be submitted to NAVSHIPS R&D Center.

3.0 TASK II – 20-WATT SYSTEM

3.0 TASK II – 20-WATT SYSTEM

No effort was expended on this subtask during this report period.

Blank

4.0 EFFORT PLANNED NEXT QUARTER

4.0 EFFORT PLANNED NEXT QUARTER

The following items are planned for the next quarter:

- Complete test plans for fuel release (ocean environment) studies.
- Encapsulate two fuel capsules at ORNL.
- Weld test two fueled capsules at PNL.
- Hydro-test two fueled capsules to destruction.
- Deliver biological shields, numbers three and four.
- Assemble the SNAP-21 residual Phase I system.
- Complete the design analysis for final release of the power conditioner enclosure and seal-off device.
- Establish welding specifications, design necessary fabrication tooling, and select vendors for the power conditioner.
- Complete assembly and dynamically test insulation system 10D1 to specification and destruction.
- Complete assembly of insulation system 10D2.
- Complete wrapping of insulation on insulation systems 10D3 and 10D4.
- Complete dynamic test of first two segmented retaining rings.
- Complete forgings for first test pressure vessel.

- Complete assembly and processing of thermoelectric generators A10D5, A10D6, and A10D7.
- Complete performance testing of generators A10D1, A10D2, A10D3 and A10D4.
- Assemble, process and dynamically test power conditioner H10D1.
- Assembly, process and start long term performance test of power conditioners H10D2 and H10D3.
- Complete design and procure components for electrical receptacle and strain relief plug.

APPENDIX A
SEGMENTED RETAINING RING
SPRING DESIGN

APPENDIX A SEGMENTED RETAINING RING SPRING DESIGN

D - Mean coil diameter = 0.625 inch

P - Load = 250 pounds

$\frac{D}{d}$ - C - Spring Index = 3.5

K - Wahl stress factor = 1.46

d - Wire diameter

For steel spring music wire the allowable stress at the working height of the spring is 100,000 psi.

Solving for d

$$S_s = \frac{K8PC}{d^2} = d^2 = \frac{3.14 \times 1.46 \times 8 \times 250 \times 3.5}{100,000}$$

$$d^2 = 0.310$$

$$\underline{d = 0.177 \text{ inches}}$$

Solving for No. Coils - N

$$G - \text{Modulus of rigidity} = 11,500,000$$

$$\alpha - \text{Spring deflection} = 0.390$$

$$P - \text{Load} = 250 \text{ pounds}$$

$$= \frac{8PC^3N}{Gd}$$

$$N = \frac{0.390 \times 11,500,000 \times 0.177}{8 \times 250 \times (3.5)^3}$$

$$N = \underline{9 \text{ Active Coils}}$$

$$N_T = \text{Total number of coils}$$

$$N_t = 2 + 9 = \underline{11 \text{ total coils for ground and squared ends}}$$

Spring Rate

Spring rate is the ratio of

$$\frac{\text{Load - Pound}}{\text{Deflection - Inch}} = \text{Spring Rate}$$

$$\frac{0.250}{0.390} = 640 \text{ pound/inch} = \text{spring rate}$$

Determining solid height of spring

$$L_{\text{solid}} = \text{Number coils} \times \text{diameter wire}$$

$$L_{\text{solid}} = 11 \times 0.177$$

$$\underline{L_{\text{solid}} = 1.947 \text{ inches}}$$

Checking for Stress Level at Solid Height

The allowable stress level when spring is compressed to solid height is 150,000 psi.

The stress level at working deflection is 100,000 psi.

Compressing the spring to solid height the stress level will be the ratio of the following:

$$\frac{\text{Total deflection to solid height}}{\text{deflection @ load}} = \frac{\text{stress @ solid height}}{\text{stress @ load}}$$

$$\text{Stress @ solid height} = \frac{100,000 \times (0.390 + 0.150)}{0.390}$$

$$\text{Stress @ solid height} = 138,000 \text{ psi}$$

This stress level does not exceed the allowable stress of the material so the design is acceptable.

APPENDIX B
REPORT ON DYNAMIC TESTS
FROM ENVIRON LABORATORIES, INC.

APPENDIX B
REPORT ON DYNAMIC TESTS
FROM ENVIRON LABORATORIES, INC.

SHOCK TEST

1. ABSTRACT

1.1 Object

To subject one Thermoelectric Generator, identified 10-D-2, to the Shock Test outlined in MIL-STD-810A, Method 516.1. The test unit shall be subjected to 6 G's at a duration of 6 ms in lieu of 20 G's at 10 ms and at design temperatures of 1100°F hot button and 80°F cold frame.

1.2 Conclusions

Visual examination during and following the Shock Test revealed no evidence of damage to the test unit.

2. UNIT TESTED

One Thermoelectric Generator, identified 10-D-2, was submitted for testing by the 3M Company to Environ Laboratories.

3. TEST REQUESTED

The test specimen shall be subjected to a transient decelerating force produced by dropping the assembly from a height such that when the assembly is decelerated by resilient impact, a peak deceleration of 6 gravitational units shall be obtained in a duration of 6 ms. The test unit shall be subjected to a total of eighteen impacts, three in each of three mutually perpendicular axes.

4. PROCEDURE AND RESULTS

4.1 Instrumentation

L. A. B. Corporation Pneumatic Shock Machine, Type 24-400,
S/N 63402

Endevco Charge Amplifier, Model 2708

Endevco Accelerometer, S/N LA61

Tektronix Oscilloscope, Type 564

Tektronix Vertical Pre-Amplifier, Type 3A72

Tektronix Horizontal Pre-Amplifier, Type 2B67

Hewlett-Packard Oscilloscope Camera, Model 196A

4.2 Procedure

Equivalent weight of the test fixture and test unit and the accelerometer were attached to the shock machine carriage. The accelerometer was connected to the charge amplifier and the charge amplifier was connected to the oscilloscope. Trial drops were then conducted to produce a sawtooth shock signature of 6 G's amplitude and 6 ms duration. The test fixture and test unit were attached to the shock machine carriage and subjected to three impact shocks in each of three mutually perpendicular axes for a total of eighteen impact shocks.

4.3 Results

The results of the Shock Test are given in Table I. Pictures of the shock waveforms follow the text of this report.

Visual examination of the test unit following the Shock Test revealed no evidence of damage.

Upon completion of the Shock Test, the test unit was returned to the 3M Company for further evaluation.

TABLE I
RESULTS OF THE SHOCK TEST

<u>Axis</u>	<u>Drop No.</u>	<u>"G" Level</u>	<u>Duration</u>	<u>Visual Results</u>
Z	1	6.5	6 ms	Satisfactory
Z	2	6.0	6 ms	"
Z	3	6.0	6 ms	"
Z ₁	1	6.0	6 ms	"
Z ₁	2	6.5	6 ms	"
Z ₁	3	6.0	6 ms	"
Y	1	6.5	6 ms	"
Y	2	6.5	6 ms	"
Y	3	6.0	6 ms	"
Y ₁	1	6.0	6 ms	"
Y ₁	2	6.0	6 ms	"
Y ₁	3	5.8	6 ms	"
X	1	7.5	6 ms	"
X	2	6.5	6 ms	"
X	3	7.0	6 ms	"
X ₁	1	6.0	6 ms	"
X ₁	2	5.8	6 ms	"
X ₁	3	6.0	6 ms	"

Figure I. Orientation of Axes for Shock Test

"X" Axis

"X₁" Axis

"Y" Axis

"Y₁" Axis

"Z" Axis

"Z₁" Axis

Figure II. Shock Waveforms (2.5 G's/cm Vertical,
5 ms/cm Horizontal)

VIBRATION TESTING

1. ABSTRACT

Subject one thermoelectric generator at operational temperatures to the vibration test requirements of the SNAP-21 program.

The generator appeared to have functioned satisfactorily both during and at the completion of this test.

2. UNIT TESTED

One thermoelectric generator identified as Unit No. 10-D-2 was submitted for testing to Environ Laboratories, Inc.

3. TEST REQUESTED

Subject the test sample to the following vibration test requirements in its three mutually perpendicular axes:

Input Levels:

5 cps to 26 cps at 1.3 G's peak acceleration

26 cps to 40 cps at 0.036 inch displacement

40 cps to 50 cps at 3.0 G's peak acceleration

Duration:

Sweep thrice from 5 cps to 50 cps to 5 cps in a period of 45 minutes.

4. INSTRUMENTATION

M-B Model C-50 Vibration Exciter

M-B Model T-665 Vibration Amplifier

M-B Model T-88 Vibration Control Console consisting of:

M-B Model N-572 Oscillator

Varian Model F-50 X-Y Plotter

Environ No. 300-005 Oscilloscope

Endevco Model 2226 Accelerometer

Endevco Model 2614B Accelerometer Amplifier

Environ No. 201-001 Oscillograph Recorder (Sanborn)

Environ No. 201-501 Amplifier (Sanborn)

Environ No. 201-502 Amplifier (Sanborn)

5. PROCEDURE AND RESULTS

5.1 Axis Orientation of the Test Sample

Figure III. Orientation of Axes for Vibration Test

5.2 Device Testing

5.2.1 "X" Axis

The generator was mounted to its holding fixture and this assembly was attached to the exciter in such a manner that the applied vibration would be through and parallel to its X axis.

A monitor accelerometer was affixed to the generator, near the cold side, in such a manner that its sensing axis was parallel to the applied vibrations.

Vibration was applied as outlined in paragraph 3 for a period of 45 minutes, the time necessary to complete three cycles.

During the second cycle on the sweep from 5 cps to 50 cps, Graph No. 3 (3738-2) was plotted in db versus frequency.

The generator appeared to function satisfactorily both during and at the completion of this test period.

5.2.2 "Y" Axis

The generator was mounted to its holding fixture and this assembly was attached to the exciter in such a manner that the applied vibrations would be through and parallel to its Y axis.

A monitor accelerometer was affixed to the generator, near the cold side, in such a manner that its sensing axis was parallel to the applied vibrations.

Vibration was applied as outlined in paragraph 3 for a period of 45 minutes, the time necessary to complete three cycles.

During the second cycle on the sweep from 5 cps to 50 cps, Graph No. 1 (3738-2) was plotted in db versus frequency.

The generator appeared to function satisfactorily both during and at the completion of this test period.

5.2.3 "Z" Axis

The generator was mounted to its holding fixture and this assembly was attached to the exciter in such a manner that the applied vibrations would be through and parallel to its Z axis.

A monitor accelerometer was affixed to the generator, near the cold side, in such a manner that its sensing axis was parallel to the applied vibrations.

Vibration was applied as outlined in paragraph 3 for a period of 45 minutes, the time necessary to complete three cycles.

During the second cycle on the sweep from 5 cps to 500 cps, Graph No. 2 (3738-2) was plotted in db versus frequency.

The generator appeared to function satisfactorily both during and at the completion of this test period.

Vibration testing on this generator is complete.

6. WITNESSING PERSONNEL

Mr. J. Young, Mr. D. Messmer, Mr. J. Brandt, Mr. Q. Brandt, Mr. L. Abenson, Mr. D. Lindblad, Mr. G. Bunde and Mr. D. Field representing the 3M Company and Mr. J. Stefano representing A.E.C. witnessed this test.

Figure IV. Vibration Test Resonance Survey

Figure IV. Vibration Test Resonance Survey (Continued)

Figure IV Vibration Test Resonance Survey (Continued)

APPENDIX C
REPORT ON DYNAMIC TESTS
FROM ENVIRON LABORATORIES, INC.

APPENDIX C
REPORT ON DYNAMIC TESTS
FROM ENVIRON LABORATORIES, INC.

VIBRATION TESTING

1. ABSTRACT

Subject one thermoelectric generator, while at operational temperatures, to the vibration test requirements of the SNAP-21 Project.

The generator appeared to have functioned satisfactorily both during and at the completion of this test.

2. UNIT TESTED

One thermoelectric generator identified as Unit No. 10-D-3 was submitted for testing by 3M Company to Environ Laboratories, Inc.

3. TEST REQUESTED

Subject the test sample to the following vibration test requirements in its three mutually perpendicular axes.

3.1 Level I

Input:

5 cps to 26 cps at 1.3 G's peak acceleration

26 cps to 40 cps at 0.036 inch displacement

40 cps to 50 cps at 3.0 G's peak acceleration

Duration:

Sweep thrice from 5 cps to 50 cps to 5 cps in a period of 45 minutes.

3.2 Level II

Input:

5 cps to 26 cps at 2.0 G's peak acceleration

26 cps to 40 cps at 0.054 inch displacement

40 cps to 50 cps at 4.5 G's peak acceleration

Duration:

Sweep thrice from 5 cps to 50 cps to 5 cps in a period of 45 minutes.

3.3 Level III

Input:

5 cps to 11 cps at 1.0 inch displacement

11 cps to 26 cps at 6.0 G's peak acceleration

26 cps to 50 cps at 0.18 inch displacement

Duration:

Sweep thrice from 5 cps to 500 cps to 5 cps in a period of 45 minutes.

4. INSTRUMENTATION

M-B Model C-50 Vibration Exciter

M-B Model T-665 Vibration Amplifier

M-B Model T-88 Vibration Control Console consisting of:

M-B Model N-572 Oscillator

M-B Model N-163 X-Y Plotter

Environ No. 300-005 Oscilloscope

Endevco Model 2272 Accelerometer

Endevco Model 2614B Accelerometer Amplifier

Environ No. 201-001 Oscillograph Recorder (Sanborn)

Environ No. 201-502 Amplifier (Sanborn)

5. PROCEDURE AND RESULTS

5.1 Axis Orientation of the Test Sample

5.2 Device Testing

5.2.1 "X" Axis Level I

The generator was mounted to its holding fixture and this assembly was attached to the exciter in such a manner that the applied vibrations would be through and parallel to its X axis.

Vibration was applied as outlined in paragraph 3.1 for a period of 45 minutes, the time necessary to complete three cycles.

During the second cycle on the sweep from 5 cps to 50 cps, Graph No. 1 (3768-1) was plotted in db versus frequency from the output of the control accelerometer.

The generator appeared to function satisfactorily both during and at the completion of this test period.

5.2.2 "Y" Axis Level I

The generator was mounted to its holding fixture and this assembly was attached to the exciter in such a manner that the applied vibrations would be through and parallel to its Y axis.

Vibration was applied as outlined in paragraph 3.1 for a period of 45 minutes, the time necessary to complete three cycles.

During the second cycle on the sweep from 5 cps to 50 cps, Graph No. 2 (3768-1) was plotted in db versus frequency from the output of the control accelerometer.

The generator appeared to function satisfactorily both during and at the completion of this test period.

5.2.3 "Z" Axis Level I

The generator was mounted to its holding fixture and this assembly was attached to the exciter in such a manner that the applied vibrations would be through and parallel to its Z axis.

Vibration was applied as outlined in paragraph 3.1 for a period of 45 minutes, the time necessary to complete three cycles.

During the second cycle on the sweep from 5 cps to 50 cps, Graph No. 3 (3768-1) was plotted in db versus frequency from the output of the control accelerometer.

The generator appeared to function satisfactorily both during and at the completion of this test period.

5.2.4 "Y" Axis Level II

The generator was mounted to its holding fixture and this assembly was attached to the exciter in such a manner that the applied vibrations would be through and parallel to its Y axis.

Vibration was applied to the capabilities of the test equipment as outlined in paragraph 3.2 for a period of 45 minutes, the time necessary to complete three cycles.

During the second cycle on the sweep from 5 cps to 50 cps, Graph No. 5 (3768-1) was plotted in db versus frequency from the output of the control accelerometer.

The generator appeared to function satisfactorily both during and at the completion of this test period.

5.2.5 "Z" Axis Level II

The generator was mounted to its holding fixture and this assembly was attached to the exciter in such a manner that the applied vibrations would be through and parallel to its Z axis.

Vibration was applied (to the capabilities of the test equipment) as outlined in paragraph 3.2 for a period of 45 minutes, the time necessary to complete three cycles.

During the second cycle on the sweep from 5 cps to 50 cps, Graph No. 4 (3768-1) was plotted in db versus frequency from the output of the control accelerometer.

The generator appeared to function satisfactorily both during and at the completion of this test period.

5.2.6 "Y" Axis Level III

The generator was mounted to its holding fixture and this assembly was attached to the exciter in such a manner that the applied vibrations would be through and parallel to its Y axis.

Vibration was applied (to the capabilities of the test equipment) as outlined in paragraph 3.3 for a period of 12 minutes and 33 seconds. Testing in this orientation was stopped by the witnessing personnel.

During the first cycle on the sweep from 5 cps to 50 cps, Graph No. 7 (3768-1) was plotted in db versus frequency from the output of the control accelerometer.

5.2.7 "Z" Axis Level III

The generator was mounted to its holding fixture and this assembly was attached to the exciter in such a manner that the applied vibrations would be through and parallel to its Z axis.

Vibration was applied (to the capabilities of the test equipment) as outlined in paragraph 3.3 for a period of 30 minutes and 4 seconds. Testing in this orientation was stopped by the witnessing personnel.

During the first cycle on the sweep from 5 cps to 50 cps, Graph No. 6 (3768-1) was plotted in db versus frequency from the output of the control accelerometer.

5.2.8 Summary

This completes this portion of the testing on this test sample and it was returned to the 3M Company by the witnessing personnel for post vibration evaluation.

6. WITNESSING PERSONNEL

Mr. J. Young, Mr. D. Lindblad and Mr. D. Messmer representing the 3M Company witnessed this test.

3768-1

21 AUGUST 1967

7 JAN 1971

Wife

3.0
upward

Vertical Classification - 100%

10/10/10

$$\Omega$$

SHOCK TEST

1. ABSTRACT

1.1 Object

To subject one thermoelectric generator, SNAP-21, Serial Number 10-D-3, to shock test as requested by 3M Company in accordance with MIL-STD-810 and SNAP-21 program requirements.

1.2 Conclusions

The thermoelectric generator, SNAP-21, Serial Number 10-D-3, satisfactorily met the requirements of the shock test as requested by the 3M Company.

2. UNITS TESTED

One thermoelectric generator, SNAP-21, Serial Number 10-D-3, as submitted for testing by the 3M Company to Environ Laboratories, Inc.

3. TEST REQUESTED

Subject the thermoelectric generator to the following five step shock test:

Step 1 - Three drops, each at 6 G's for 6 ms in each direction of the three major axes.

Step 2 - Three drops, each at 9 G's for .6 ms in each of the Z and Y axes.

Step 3 - Three drops, each at 12 G's for 6 ms in each of the Z and Y axes.

Step 4 - Three drops, each at 15 G's for 6 ms in each of the Z and Y axes.

Step 5 - Three drops, each at 20 G's for 6 ms in each direction of the three major axes.

The test unit shall be wired electrically and the output shall be monitored continuously throughout the test. All readings shall be recorded by 3M Company personnel.

4. PROCEDURE AND RESULTS

4.1 Instrumentation

L. A. B. Corporation Pneumatic Shock Machine, Type 24-400, S/N 63402

Endevco Charge Amplifier, Model 2708

Tektronix Type 564 Oscilloscope

Tektronix Type 3A72 Vertical Preamp

Tektronix Type 2B67 Horizontal Preamp

Endevco Accelerometer, S/N LA61

Hewlett-Packard Oscilloscope Camera, Model 196A

Sanborn Recorder, Model 296, 2 Channel DC

Two Sanborn DC Coupling Preamps, Model 350-1300

Kron-Hite Band-Pass Filter, Model 330-M

Also associated monitoring equipment was supplied and operated by 3M Company personnel.

4.2 Procedure and Results

Weights equivalent to the combined weight of the test unit and fixture were attached to the shock machine table. Trial drops were conducted to obtain the desired shock levels, 6 G's, 9 G's, 12 G's, 15 G's, and 20 G's with each level having a duration of 6 ms. The test unit was then attached to the shock machine table and, in an operating condition, subjected to the following five step shock test.

Step 1 - Three drops, each at 6 G's for 6 ms in each direction of the three major axes.

Step 2 - Three drops, each at 9 G's for 6 ms in each of the Z and Y axes.

Step 3 - Three drops, each at 12 G's for 6 ms in each of the Z and Y axes.

Step 4 - Three drops, each at 15 G's for 6 ms in each of the Z and Y axes.

Step 5 - Three drops, each at 20 G's for 6 ms in each direction of the three major axes.

The test unit was monitored continuously throughout the entire shock test by 3M Company personnel. All the output data was recorded and retained by 3M Company personnel. No damage to the test unit was reported by 3M Company personnel (see Table I, pages 5-7 for results of each shock pulse). Pictures of the shock pulse waveforms are included on pages 8-10.

Upon completion of the shock test the test unit was returned to the 3M Company personnel for further test and evaluation. Axes orientation was as shown on page 4.

Figure I. Orientation of Axes for Shock Test

TABLE I
RESULTS OF FIVE STEP SHOCK TEST

<u>Step</u>	<u>Axis</u>	<u>"G" Level</u>	<u>Duration</u>	<u>Drop No.</u>	<u>Visual Results</u>
1	Z	6.0	6 ms	1	Satisfactory
		6.0	6 ms	2	"
		6.5	6 ms	3	"
	Z ₁	6.0	6 ms	1	"
		6.0	6 ms	2	"
		6.0	6 ms	3	"
	Y	6.5	6 ms	1	"
		6.5	6 ms	2	"
		6.0	6 ms	3	"
	Y ₁	6.0	6 ms	1	"
		6.0	6 ms	2	"
		6.0	6 ms	3	"
	X	6.5	6 ms	1	"
		6.0	6 ms	2	"
		6.0	6 ms	3	"
	X ₁	7.0	6 ms	1	"
		5.0	10 ms	2	"
		6.5	6 ms	3	"
2	Z	7.5	6 ms	1	"
		8.5	6 ms	2	"
		8.0	6 ms	3	"
	Y	9.0	6 ms	1	"
		8.0	6 ms	2	"
		9.0	6 ms	3	"
3	Z	14	6 ms	1	"
		13	6 ms	2	"
		12	6 ms	3	"
	Y	12	6 ms	1	"
		12	6 ms	2	"
		12	6 ms	3	"

TABLE I (Continued)

<u>Step</u>	<u>Axis</u>	<u>"G" Level</u>	<u>Duration</u>	<u>Drop No.</u>	<u>Visual Results</u>
4	Z	15	6 ms	1	Satisfactory
		15	6 ms	2	"
		15	6 ms	3	"
	Y	15	6 ms	1	"
		15	6 ms	2	"
		15	6 ms	3	"
5	Z	19	6 ms	1	"
		20	6 ms	2	"
		18	6 ms	3	"
	Z ₁	18	6 ms	1	"
		22	6 ms	2	"
		21	6 ms	3	"
	Y	23	6 ms	1	"
		18	6 ms	2	"
		21	6 ms	3	"
	Y ₁	20	6 ms	1	"
		22	6 ms	2	"
		19	6 ms	3	"
	X	22	6 ms	1	"
		22	6 ms	2	"
		22	6 ms	3	"
6	X ₁	23	6 ms	1	"
		21	6 ms	2	"
		20	6 ms	3	"

Waveforms of Five Step Shock Test of the
Thermoelectric Generator, S/N 10-D-3

STEP I

"Z" Axis

"Z₁" Axis

"Y" Axis

"Y₁" Axis

"X" Axis

"X₁" Axis

Waveforms of Five Step Shock Test of the
Thermoelectric Generator, S/N 10-D-3

STEP 2

"Z" Axis

"Y" Axis

STEP 3

"Z" Axis

"Y" Axis

STEP 4

"Z" Axis

"Y" Axis

Waveforms of Five Step Shock Test of the
Thermoelectric Generator, S/N 10-D-3

STEP 5

"Z" Axis

"Z₁" Axis

"Y" Axis

"Y₁" Axis

"X" Axis

"X₁" Axis