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NUMEC 3731-21

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DATE 1/23/70

Phase I

**RADIOISOTOPE POWERED CARDIAC PACEMAKER
DESIGN OBJECTIVE OPTIMIZATION**

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Prepared Under
CONTRACT AT(30-1)-3731

September 1969

Submitted To

United States Atomic Energy Commission

Mr. Leonard Wasser, Chief
Development Contracts Branch II
New York Operations Office
United States Atomic Energy Commission
376 Hudson Street
New York, New York 10014

Cdr. J. M. Prosser
Division of Reactor Development
and Technology
Headquarters - Germantown
Washington, D. C. 20545

by

Nuclear Materials and Equipment Corporation
A Subsidiary of the Atlantic Richfield Company
Apollo, Pennsylvania 15613
Energy Conversion Division

Approved By:

T. F. Hursen
T. F. Hursen, Manager
Cardiac Pacemaker Program

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Radioisotope Powered Cardiac Pacemaker
Design Objective Optimization

The purpose of this section is to examine the optimal attainment of all of the design objectives of the RPCP contract. For ready reference Table A which contains a list of the various design objectives was taken directly from the contract document, Modification #7, Contract AT(30-1)-3731. Each objective is numbered 1 through 16 using the same method as the contract itself. Let us consider the attainment of these objectives as follows:

- 1-2. Reliability, Quality Assurance & Quality Assurance Provisions - These objectives were met early in Phase I by the submittal and approval of NUMEC Reports 3731-2 and 3731-12 which were prepared for the general guidance of the Phase I effort in reliability, quality assurance and quality control matters.
- 3-4. Plutonium-238 Fuel Data Sheets - Since this refers to Pu-238 which is government furnished material, this design objective is achieved simply by using the "standard" Mound Pu-238 metal. A detailed description of the encapsulating components that surround the plutonium may be found in Section 2 of the system design description and the basis for design of these components from a safety point of view may be found in Section 4 of the system design description.
5. Contractor Drawing - This item refers to the original NUMEC drawing of the originally proposed design of RPCP and does not reflect the development and improvements which have occurred since. For these reasons, NUMEC Drawing 15-D-3731-293 which illustrates the recommended prototype design represents the latest objective in this regard.

6. Size - The size objectives of 6 and 5 centimeters are met by the recommended prototype design with nominal dimensions of 6 and 4.82 centimeters; however, the factors affecting system thickness need to be examined in some detail in order to obtain a minimum system thickness that is consistent with (a) the design objective of an electrical power output of 160 microwatts (minimum at the end of eleven years), (b) a minimization of the radioisotope fuel requirements, (c) the maximum dose rate, (d) state-of-the-art of the component development, and (e) a proper weighing of the significance of the thickness design objective. Based upon these factors, as examined herein, a minimum nominal system thickness of 3.10 centimeters was determined.

Let us now examine how each of the system dimensions was determined.

Length - Since it was apparent from the experimental model work, the associated parametric system analyses and the results of the tests conducted to verify these analysis that all of the system dimensions could not be achieved consistent with the other objectives, the system length was established at the design objective maximum of 6 centimeters. This provided the maximum available volume within this length objective while at the same time tending to produce a shape of minimum thickness which is desired for implantation purposes.

It should be noted at this point that a longer system length than six centimeters should not be considered for two basic reasons: (1) to take advantage of a longer length so as to reduce the thermopile outside diameter and thus reduce the system thickness would require an increase

in the fuel capsule length. This in turn would seriously curtail the manufacturability of the fuel capsule components since it would increase the machined L/D ratio of these components. Furthermore, it is well known that radioisotope powered thermoelectric generators tend to reduce in efficiency of thermal conversion as the L/D of the thermal system increases away from an L/D of one. This would effectively require more fuel for the same output power and would increase the dose rate at the outer surface since presumably increasing the fuel load and system length would reduce the system width and thus reduce the spacing between the fuel capsule and the nearest outer surface. As will be seen later, increasing the dose rate would result in an out-of-specification condition.

Height - From the cylindrical shape of the fuel capsule and surrounding thermopile, it can be seen that those efforts aimed at the minimization of the thermopile width will also contribute to a minimization of the thermopile height and thus the system height since the thermopile is roughly circular in cross-section. For this reason the actual prototype height of 4.82 centimeters betters the objective of 5 centimeters.

This advantage was achieved while providing a generous space allotment within the system envelope for the cardiac lead termination plus an increase in the volume available for the electronic circuit over the experimental model design. The volume available for the electronics circuit in the experimental model was approximately 3.7 cc, whereas, the recommended prototype design has 5.4 cc available. This permits room for expansion for other types of circuits.

Thickness - In considering system thickness, the thermopile design as a whole must be considered. A parametric analysis of the experimental model thermopile was contained in the NUMEC Report 3731-13 entitled Mid-Term Report, Phase I and was the basis for the parametric experimentation that lead to a determination of the prototype thermopile design. This analysis is contained within pages B-29 through B-44 of that report and determined a thermopile characterized on pages B-37 and B-43 of the mid-term report as follows:

Calculated Characteristics

Thermal Input Power (EOL)	0.123 watts
Support, Wire diameter	6.0 mils
Number of thermocouple tapes	6
Number of thermocouples per tape	88
Thermocouple redundancy	None
Thermocouple length	22.75 cm (8.96 inches ~9 inches)
Cupron Special wire diameter	2.0 mils
Tophel Special wire diameter	2.5 mils
Number of thermal radiation shields	29

As we know the electrical power output of this design as determined by test was below the specification requirement. Thereafter, a large number of parametric tests were conducted with the following resulting changes in the thermopile design at the prototype stage.

Support Wire - The support wires were eliminated from the experimental model designs that were fabricated when it was determined that (1) the amount of energy absorption capacity represented by the wires at an

acceptable level of thermal loss did not add significantly to the energy absorption capacity represented by the thermopile and end shield assemblies, (2) the wires represent a small thermal loss for which no compensatory value is received, (3) the presence of the wires add, unnecessarily, to the complexity of the thermopile, and (4) the support wires represent a potential source of electrical shorting at the edges of the thermopile. The comparative spring constants and energy absorption capabilities (free fall) are as follows:

K $\left(\frac{\text{grams}}{\text{inch}} \right)$	<u>Support Wire</u>	<u>One End Shield Assembly</u>	<u>Thermopile</u>
	465×10^3	2.18×10^3	10.58×10^3
Energy Absorption (inch-grams)	0.03	29.9	17.7

The spring constant of the support wire was calculated for a wire of .006 inch diameter, 3/8 inch long using the properties of Ti-BV-11Cr-3Al at 392°F whereas the spring constants for the end shield assembly and the thermopile were taken from test data plotted in Figure A using a simulated thermopile and end shield assembly of the recommended prototype design. Although the spring constant of a support wire is relatively large, its ability to absorb energy from the fuel capsule it supports is virtually insignificant in comparison to either the end shield assemblies or the thermopile. The total energy to be absorbed after a three foot free fall (the specification requirement) for a prototype heat source weighing 16.1 grams is 579.6 inch grams. Depending upon

the direction of impact, this means that either the end shields or the thermopile must go solid after such a drop in compression. This obviously does not damage these elements (reference the drop tests discussed later in this section) but would risk breakage of a support wire since it would be loaded in tension.

The following comparative tests were conducted to demonstrate the difference in performance that occurs with and without wires.

Table i
T/C Unit #5

<u>Fuel</u>	<u>Input Power (watts)</u>	<u>Tape Length (inches)</u>	<u>Number of Wires</u>	<u>Output Power (Microwatts)</u>
1-C-4	0.137	11.5	None	67.2
1-C-4	0.137	11.5	4	61.8
1-C-4	0.137	11.5	4	64.0

The only differences between the tests was the presence or lack of wires plus the fact that each test point represented a separate assembly operation. The variation of 61.8 to 64.0 microwatts is not unusual for these separate assembly operations. The small but favorable variation in thermal performance is indicated.

Thermal Radiation Shields

Side Shields - The original experimental model cardiac pacemaker design contained six 0.0005 inch thick thermal radiation shields interleaved with the thermocouple and insulation tapes. When wrapped spirally about the heat source, these foils would produce about 29 radial layers of

thermal radiation insulation. To maximize performance the foils needed a low emissivity and low thermal conductivity. Titanium was excellent for this purpose and was used in the first three completed experimental models (#3,4,and 5). However, the foils presented difficulties in causing electrical shorting to the thermocouple wires and since they did represent a significant thermal conduction loss along their length, an extensive series of parametric tests were conducted with various side shield materials (stainless, aluminum and monel) and geometries (i.e., segmented combinations to reduce spiral conduction). It was found experimentally that the system performance was not changed significantly by eliminating the metal foil side shields. Some specific data illustrating these results are shown in the following.

Table ii

<u>Test No.</u>	<u>Test Date</u>	<u>Input Power (watts)</u>	<u>Resistance* (ohms)</u>	<u>Power* Output μ (watts)</u>	<u>ΔT Across Tapes $^{\circ}C$</u>	<u>Conditions</u>
1	7-23-68	0.246	65,560	176	168	Segmented Ti side shields
2	7-24-68	0.124	66,430	60	102	"
3	7-26-68	0.246	66,810	174	166	No side shields
4	7-29-68	0.124	65,250	65	105	"

The ΔT and output power of tests 1 and 3 can be compared to each other since they used the same input power (.246). Similarly, tests 2 and 4 can be compared.

* - Based on three individual tape measurements.

Since there is no significant reduction in thermal performance results from the elimination of these spiral shields, and since they represented a potential source of electrical shorting of the thermocouples, it was concluded they they were an unnecessary complexity and expense. The recommended prototype design does not contain any metallic circumferential thermal radiation shields.

The tests conducted without metallic side shields were obtained with 1.5 inch wide insulation tapes. An aluminum oxide coating was used to give the tapes strength and prevent electrical shorts. This coating may also help as a thermal radiation shield. Two inch wide insulation tapes were obtained for intermediate units #9 and 10 and high fuel units #12 through 17 and cut on a taper from 2.0 inches at the cold strap to 1.5 inches at the hot strap. No metallic side shields were used. The thermal performance with this design has been excellent. For example, Unit #9 has a lower fuel than #3 and 4 (all 9 inch units) but the temperature difference is as follows:

Table iii

<u>T/C Unit</u>	<u>Fuel (watts)</u>	<u>$\Delta T, ^\circ C$</u>
3	0.132	109
4	0.138	102
9	0.122	110

End Shields - A series of tests designed to establish the relationship between end shield materials, number of shields, and the thermal performance of the unit were performed. The first test was made using assembly #5. The results (Figures B & C) show that the titanium end shields had an optimum performance with 15 end shields. More extensive tests were made to evaluate other materials than titanium. The smoothed data is shown in Figure D. Certain trends can be seen in the general peaking using titanium and monel shields at 10 to 15 shields. Also, the very low values using aluminum are indicative of the low strength and high contact conduction losses. All data is without support wires.

It should be pointed out that the change from the peak value of titanium end shields to the peak for monel represents a thermal improvement in temperature difference across the tapes of 100°C to 106°C or only six percent. This difference is not statistically significant when replication data is considered. The significant factor in these tests is that improved performance was obtained by reducing the number of end shields (for a fixed spacing) and that monel, titanium or stainless steel would be essentially equivalent in thermal performance. Since the radiation loss is increased by increasing the number of end shields, the decreased thermal performance is the result of increased conduction losses induced by the higher contact pressures that are induced by assembling more shields in the same length.

But because of the significance of the radial conduction through the end shields, tests were performed varying the total spacing across the end shield assembly. It was found that fifteen monel end shields peaked well

beyond the nominal spacing available in the unit. The titanium end shield tests peaked very close to the nominal spacing available. This might be expected since the monel shields had an effective shield spacing near that of the rollers, of about 0.015 inch, whereas the titanium shields which have a higher spring constant (another advantage) rolled to an effective thickness of 0.009 inch. Thus the recommended prototype design contains 15 titanium end shields at each end of the fuel capsule.

Thermocouple Tapes (length and number) - During the extensive tests to evaluate end and side insulation shields a number of tests were performed to evaluate changes in the number of thermocouple tapes. A test was performed on Unit #7 to determine the effect of running the unit with only four tapes. The same perimeter was used as for six tapes, and so it was expected that radial conduction would be reduced with a possible improvement in thermal performance. Since this unit had only four tapes connected electrically the two inoperative tapes were removed. The results were as follows:

Table iv

<u>Number of Tapes Per Unit</u>	<u>Number of Active Tapes</u>	<u>Number of Insulation Tapes</u>	<u>Output Power μ Watts</u>	<u>Fuel Number Power Watts</u>	<u>ΔT Across Tapes °C</u>
6	4	24	56	1-C-7 (0.12216)	127
4	4	16	59	1-C-9 (0.12400)	131

Since the increase in temperature was only about as expected from the fuel difference, it is obvious that no improvement was obtained by removing two thermocouple tapes and their insulation. Unfortunately, the voltage produced by 4 tapes is about 2/3 of the voltage produced by 6 tapes, since the

ΔT for the same fuel load is similar. This would be much too low for the electronics units. But this did provide some insight, experimentally, into the effect of a gross variation in the number of tapes.

Subsequently, parametric tests were conducted specifically to determine the optimum design in terms of the number and length of the thermocouple tapes. The tests were performed on thermopile units containing tapes of 7.0, 9.0 and 11.5 inches in length with five or six thermocouple tapes.

The thermal performance results are presented in Table B. The temperature differences were plotted versus input power and the nominal and minimum end of life fuel values used to determine the operating temperature across the thermopile.

Then from curves of peak output power and open circuit voltage, the values were obtained for each unit tested. The end of life minimum fuel data was plotted for perimeter, peak power, and voltage in Figure E as a function of tape length.

Some additional tests were performed on the 11.5 inch tapes from a completed thermopile #13 that had sufficient shorts that it couldn't be used for a sealed system. The five tape results were almost identical to those of previous units. However, the six tape results were significantly lower, but the results were within the $\pm 5^{\circ}\text{C}$ estimate of the repeatability on temperature difference. Including these results the curves were drawn on Figure E and show a distinct reduction in output power with increased tape

length, with an increasing voltage. The effect of tape length on perimeter seemed to be rather consistent with the amount of thermocouple tape in the unit.

Although five tape units were naturally smaller in perimeter and thus would produce a slightly smaller pacer thickness, these units also produced less power and voltage over the tape lengths tested. The lower power outputs did not achieve the minimum end of life requirement, and the lower voltage detrimentally affects the electronic circuit operation. Seven tapes would unnecessarily increase the pacer thickness, and so were not tested.

Note from the shape of the six tape test curves on Figure E that the output power and voltage tend to vary at cross purposes with decreasing tape length. As the tape length decreases, the power increases slowly, a desirable trend, but the voltage tends to reduce more rapidly. Since the reducing voltage tendency is a relatively severe problem for the electronics, and since the variation in output power between tape lengths of seven and nine inches is not large, the optimum tape length should be selected at the minimum length that will produce the minimum desirable electronic operating voltage that deviates the least from the output power objective.

This is a tape length of 8.5 inches which is very close to the experimental model tape length of 9 inches for which a great amount of test data exists. Furthermore, the slight reduction in tape length tends to produce a prototype

pacers which are slightly thinner than the experimental models fabricated from nine inch tapes. Although strictly speaking the output power shown in Figure E for an 8.5 inch tape length is 158 microwatts or 2 microwatts below the end of life objective, these results are minimum figures based upon end of life conditions (11 years) with the minimum fuel load. Furthermore, these tests were conducted with thermopiles in an open case half which has been confirmed by the fabrication and test of experimental models to be low, or conservative results. Thus, the results shown in Table B and Figure E are conservative, minimum results that were selected to show parameter trends involving tape length and number of tapes.

A wrapping test using nominal 8.5 inch prototype tapes fit well into a case with an outside dimension of 1.22 inches (3.1 cm). Experimentally, the cupron tape length was determined as 8.35 inches and the tophel as 8.5 inches. This difference in length is the same as currently used for the experimental model 9 inch tape. The number of cycles in the tape spiral was about 3.3 which is about a third of a wrap greater than that of the experimental model. This should give a little more thermal radiation shielding and help thermal performance slightly.

A precise method for determining the expected operating characteristics of the prototype units would be to use the ratio of voltages and power from 9 to 8.5 inches as correction factors for the sealed 9 inch unit data. The voltage correction factor from 9 to 8.5 inches is 0.977 and the power correction is 1.006. It is felt that these changes are not significantly

different from the 9 inch data. Also, it is expected that some thermal performance improvement will occur in the prototype design. This hypothesis is based on the fact that the spiral wrap on a cylindrical fuel will have less radial conduction since it will not have the areas of high pressure between layers at corners. Therefore, a conservative estimate of prototype operating performance can be obtained using data for the performance of thermopiles fabricated from 9-inch thermocouple tapes of the latest experimental model design with a .95 factor for possible inactive thermocouples. Confidence in this 9-inch data is enhanced by the utilization of performance data from thermopiles that were constructed in such a way that two heat sources could be assembled side by side within the same unit. An example of the results of this type of testing is shown in Figure F where the temperature difference across the thermopile is plotted as a function of the power input. By entering the curve at the known, end of life, ΔT requirement of 145°C the necessary required input power of 0.200 watts is determined to achieve an end of life power output of 160 microwatts. Based on this extrapolation, and the $\pm 10\%$ tolerance required on fuel loading, a new thermal source size of 0.238 watts $\pm .024$ watts was determined. Subsequently, a series of heat sources of the same geometry as the original experimental models, but containing a higher fuel load was fabricated and assembled into experimental model generators. Subsequent tests performed with these units confirmed this selection of fuel loading as indicated in Figure G. Note the two types of data shown in Figure G that is a best estimate curve of the actual system performance of the completed units in combination with the minimum performance that was measured before sealing of the outer case. This difference illustrates a tendency of the completed units to produce better performance than the same units tested in vacuum before electron beam welding of the outer case.

Using a combination linear and quadratic curve fit of the data from the best estimate shown in Figure G of the form:

$$Q_T = 0.000494 (T_H - T_C) + 0.0003166 \left[\left(\frac{T_H}{100} \right)^4 - \left(\frac{T_C}{100} \right)^4 \right]$$

the relative amounts of radiation and conduction were computed as 63.8% and 36.2% respectively at the nominal, beginning of life, fuel size of 0.238 watts. The corresponding, beginning of life, temperatures are $T_C = 43^\circ\text{C}$ and $\Delta T = 175^\circ\text{C}$.

Using These functional relationships and the data plotted in Figure G, the performance of thermopiles constructed of 9-inch tapes was determined and is shown in Table C. Then using the data in Table C to determine the expected prototype performance with an 0.95 factor for possible inactive thermocouples, results in the data shown in Table D. The nominal resistance of 47,900 ohms was obtained by multiplying the nominal resistance of a 9-inch unit by the tape length ratio as follows:

$$(50,718) (8.5/9.0) = 47,900 \text{ ohms}$$

In summary then, the recommended prototype system dimensions are 6.00 x 4.82 x 3.10 centimeters.

7. Weight - The design objective is approximately 100 grams in combination with a Specific Gravity of approximately 1.4. Since the objective is stated as approximate and since the weight objective of 100 grams is substantially lighter than the weight of the most common mercury battery powered pacers presently in service, the design philosophy has been to design the system to a minimum weight that is consistent with the other design objectives. A table of component weights for the recommended prototype design is contained in Table E, with an indication of whether each figure was measured or calculated. The total weight, exclusive of the cardiac lead, is 105.9 grams. The experimental models fabricated from 9-inch thermocouple tapes weighed approximately 102 grams. The major difference between the system weights and the objective is a result of (1) a 1.67 gram increase in the heat source weight, (2) an increased epoxy (2.0 grams) and electronics case weight (1.329 grams), and (3) the addition of a beryllium copper heat sink and thermopile holder (3.860 grams) within the nuclear battery. The increase in the weight of the heat source occurred as a result of the change in its configuration which offered a number of advantages which heavily over-balance any weight change. These include manufacturability, reduced number of components, and improved assembly. An increase in the epoxy volume produced an improved weldability, and permits an enlargement of the electronics case contained therein; and, thus, greatly enhances the flexibility of the system in the use of other electronics circuits. The use of a beryllium-copper heat sink and thermopile holder serves two purposes, (1) the heat sink avoids excessive ΔT between the cold

junctions of the thermocouples and the outer case surface, and

(2) it provides a means of positioning the thermopile in an assembled position for final inspection before insertion into the deep drawn outer case. The holding and positioning function is essential; however, a determination of the absolute value of the use of beryllium-copper which was selected for its excellent thermal conductivity will be evaluated by test with the first prototype thermopile. If the use of beryllium copper is not essential, titanium will be substituted. This will reduce the total weight by 2.126 grams to 103.818 grams

Of more significance is the specific gravity of the system since this determines how well the system simulates the flesh and/or fat it displaces. The specific gravity objective is 1.4 and any lesser value is a desirable direction of variation. The volume of the RPCP is 81.7 centimeters³; therefore, the specific gravity is $105.9/81.7$ or 1.30 which meets the specific gravity objective.

8. Design Life - Ten years plus one year shelf life. The gettering ability of the Cerralloy 400 and the use of all inorganic materials degassed before closure in combination with appropriate helium leak testing should assure that the vacuum is maintained in the case for the 11 year life. Accelerated life tests on components indicate that the RPCP life will not be limited by corrosion in body fluid as demonstrated by accelerating the pulsing rate on both a gold and nickel-titanium feedthrough in Ringer's solution to the equivalent of approximately 50 years at the end of June. The gold-titanium feedthrough test is being conducted as part

of a complete cardiac lead assembly with a titanium terminal block.

Either feedthrough material combination meets the design life requirement. It's recommended that life testing continue and a selection between these two alloy combinations be made at the time of the prototype fabrication based upon the relative condition of the feedthrough samples in the corrosion test. The gold feedthrough is the reference design at this time.

9. Reliability - The reliability of the system will be demonstrated by system and component testing. The details of this testing, such as the environment, number of units, etc. is more appropriate to the Phase II Program Plan than this document. The calculated reliability of the nuclear battery, which is contained in the Reliability Study and Test Plan, is 97.5% for eleven years.
10. External Radiation - The fuel and fuel capsule were designed for minimum dose rates. Based upon experimental testing on the experimental models, the surface dose rate for "typical Mound metal" will vary between 4.09 to 5.03 millirads per hour at contact depending upon the specific amount of fuel in each unit. The range was calculated by using the lower fueled experimental model measurements (BOL) and ratioing up for the increased fuel loading for both the maximum and minimum fuel loading permitted by the prototype heat source specification.

Using the same calculation technique for the dose rate at 5 centimeters and the neutron content of the dose at each location, the following results were obtained.

Table v

	<u>Contact (mrad/hr)</u>			<u>5 cm (mrad/hr)</u>		
	<u>γ</u>	<u>n</u>	<u>Total</u>	<u>γ</u>	<u>n</u>	<u>Total</u>
Fuel Loading						
.214 mwatts	3.16	0.926	4.086	.11	0.077	0.187
.262 mwatts	3.90	1.130	5.030	.136	0.094	0.230
Specification	-	1.5	5.0	-	0.1	0.3

11. Sterilization - The RPCP is capable of conventional gas sterilization per the instructions contained within the preliminary issue of the implantation manual. The radioisotope battery would be able to withstand autoclaving sterilization; however, the electronic components have temperature limits which precludes steam sterilization.
12. System Electrical Output - All of the required electrical output parameters have been met and the design has been optimized as follows. The only variation that cannot be determined precisely, in advance, is the possible unit to unit fabrication variations in manufacturing. However, an allowance has been included in the parametric analysis discussion in the section dealing with system dimensions.

Based on the prototype operating characteristics of Table D the electronic circuit shown in Figure H is for the RPCP prototype systems. This circuit is essentially the present unit used in the high fueled experimental models. The values of R_3 , R_4 , and R_5 may change and a different VR-2 may be selected. These changes are due to the new predicted performance of the prototype RTG, the modified pacing specs, and the fact that the magnitude of the rate sensitivity may be reduced.

Based on present data it appears that the pacing requirements will easily be achieved. Even with no modifications to the existing circuit, the output current pulse would be only slightly out of spec over the entire range of anticipated RTG performance throughout life which is a maximum B.O.L. open circuit voltage of 7.1 and a minimum E.O.L. value of 5.7 volts with a possible range of 44,550 to 48,860 ohms internal resistance. Four present Cordis production units were tested parametrically over this range of RTG performance as well as the specified body load range. The variation of body load and RTG resistance had negligible effect. The effects on current pulse rate of variation in RTG open circuit voltage are summarized in the following data.

Table vi

<u>Cordis Unit</u>	<u>Rate at 7.1 Volts</u>	<u>Rate at 5.6 Volts</u>	<u>Net Rate Change</u>	<u>Net R/ V</u>
135A-13	130.5 bpm	116.0 bpm	14.5 bpm	9.67 bpm/volt
135A-19	126.0 bpm	115.5 bpm	10.5 bpm	7.00 bpm/volt
135A-27	131.0 bpm	116.0 bpm	15.0 bpm	10.00 bpm/volt
135A-28	128.5 bpm	118.5 bpm	10.0 bpm	6.67 bpm/volt

The effect on current pulse amplitude of variations in RTG open circuit voltage are summarized as follows:

Table vii

<u>Cordis Unit</u>	<u>Amp. at 7.1 Volts (Change)</u>		<u>Amp. at 5.6 Volts (Change)</u>	
	<u>(Milliamps)</u>	<u>(%)</u>	<u>(Milliamps)</u>	<u>(%)</u>
135A-13	6.2-5.3	85.5	4.8-4.15	86.5
135A-19	8.0-6.5	81.3	6.25-5.15	82.4
135A-27	8.1-6.2	76.5	6.3-5.1	81.0
135A-28	8.1-6.5	80.2	6.2-5.1	80.2

The results of Table vi show that in order to insure the pulse rate is 120 ± 5 bpm under the most extreme possible RTG performance variation, the rate sensitivity of all units must be no greater than that of unit 135A-28. This can probably be achieved by selecting a different Zener Diode for VR-2 of Figure H. It should be pointed out that for the nominal expected variation of RTG performance (6.6-6.2 volts open circuit), the present circuit is adequate in terms of rate.

The results of Table vii show that the current pulse amplitude meets the old specification of 10-4 milliamperes to which the circuits were designed even under the most extreme possible RTG performance variations. It is concluded that the new spec of 7-4 milliamperes can also be achieved with a minor change of component parameters in Figure H. Table vii also points out that the pulse amplitude easily meets the criteria of being rectangular since the amplitude never decreases to 70% of its initial value.

The variations of pulse rise time and width were negligible for all RTG variations. The rise time remained at about 1 micro-second, and the width was between 1.64 and 1.62 milli-second for all units.

It is, therefore, concluded that the circuit of Figure H with a reduction of rate sensitivity and slightly reduced current pulse amplitude output be utilized for the prototype systems and will meet all of the specification requirements in Table A.

This will insure that all pacing specs are achieved even for the most extreme possible RTG performance variation. The possible exception to this condition would occur if the Cordis Corporation experienced some variability from unit to unit in this reduced rate sensitivity. Should this occur, it will be necessary to consider either eliminating the rate sensitivity or restricting the fuel loading tolerance to $\pm 5\%$ from its present $\pm 10\%$. Should individual unit manufacturing variability require a consideration of these alternatives, the most convenient and least difficult course would indicate an elimination of the rate sensitivity feature.

The Cordis electronics is pre-potted in epoxy 0.290 x 0.380 x 1.490 inches. In the prototype solder connections will be made to the platinum output, input feedthrough, and to the ground wire with the bottom but not the top lid welded onto the electronics case. The connections and electronics pre-pot will be then potted with RTV.

13. Component Characteristics - All specifications have been met. The specific manner in which each of the component characteristics is achieved can be obtained by referring to the detailed system description. The capability of the prototype capsule to contain the helium buildup of plutonium oxide as an alternate fuel form is delineated in Section 4.0 of the System Design Description. Since the radiation design objective of 5 mrad/hr at the pacemaker surface is just achieved by conventional Mound plutonium metal, practical dose rate considerations would limit the alternative fuel to PuO_2^{16} made from LASL electro-refined plutonium metal.
14. Environmental Conditions - Operation
1. The in-vivo surface temperature ΔT in humans will be approximately 0.25°F which is well within the specification maximum of 3°F .
 2. The case for the experimental model has been tested to more than double the required pressurization of four atmospheres without deformation or failure. The prototype will be similarly tested.
 3. Sterilization was previously covered.
 4. Shock - A test unit has shown the pacemaker design can meet the 3 foot fall requirement. Additional tests will be conducted on completed pacemakers.
 5. Shock, vibration, transportation and storage - Specific recommendations were previously submitted. The capability of the prototype RPCP to meet these recommendations must, of necessity, await the completion of prototype units. Sufficient testing has been conducted (vibration, shock, and drop tests) on assembled but unwelded nuclear batteries to

induce confidence in the ultimate results. The detailed results of this work was contained in an earlier monthly report and is repeated as follows.

Preliminary drop tests, vibration, and shock tests have been performed on a unit of the experimental design fabricated of old tapes and placed into case halves held together by a clamp. This unit was called DT-1. Only five active tapes (out of the six present) were connected in series and the unit resistance was 34,300 ohms. The method of performing the drop tests was to obtain a performance of the unit in vacuum, then after backfilling with an inert gas and stabilizing in air, the unit was dropped and resistances obtained after each drop by doing a load line with the low output voltage available in air. After the drop testing, the unit was again placed into a vacuum system and evaluated in terms of its thermal performance. The results are as follows:

Drop Test Results on DT-1*

In order of tests
 Performance in vacuum OCV = 4.71 volts
 Power = 163 μ W
 Resistance = 34,300 ohms

<u>Drop*</u>	<u>Internal Resistance After Each Drop</u>
Before	34,000 ohms
2 feet	33,000 ohms
2 feet	36,000 ohms
3 feet	29,000 ohms

Performance in vacuum OCV = 4.07 volts
 Power = 140 μ W
 Resistance = 29,900 ohms

<u>Drop*</u>	<u>Internal Resistance After Each Drop</u>
3 feet	-
3 feet	-

* - Drops to a two millimeter thick silastic pad on a granite laboratory table.

Performance in vacuum OCV = 4.64 volts
Power = 151 μ w
Resistance = 35,700 ohms

<u>Drop</u>	<u>Internal Resistance After Each Drop</u>
4 feet	-
4 feet	35,800 ohms

Performance in vacuum OCV = 4.86 volts
Power = 165 μ w
Resistance = 35,900 ohms

These qualitative results indicate that there should be no serious problem in meeting the design objectives of a 3 feet drop to a granite surface with the case enclosed in 2.0 millimeters of silastic. Also, examination of the unit after the test showed no serious deterioration internally that would induce any serious degradation of performance.

Using the same unit, DT-1, a series of vibration and shock tests was performed serving the dual purpose of evaluating certain design aspects of the pacer and establishing our ability to perform these tests in-house. The series of tests included:

1. Vibration testing on mutually perpendicular axes in air (not fueled).
2. The same tests in vacuum (fueled).
3. Modified shock tests consisting of short bursts of high g-level vibration tests, in vacuum (fueled).

The method used in vibration testing consisted of the following steps:

1. The resonance points of the platform were established by scanning from 17-500 Hz with no test unit mounted on the platform.
2. A load line was taken on test unit, stationary in vacuum.
3. The resonance points of the test unit were established by mounting the unit on the platform and scanning over the frequency range again and noting any resonance points which differed from previously established values for the platform alone.
4. The test unit was vibrated for 15 minutes at resonance at a 2-g force level.
5. The load line was repeated immediately after vibrating.

The method used in shock tests was as follows:

The recommended shock amplitudes for such tests are up to 20g in 5g steps with half-sine wave shock of 11 ± 1 millisecond duration.

The last requirement represents a frequency of 45 Hz. The vibrator was capable of a force level of 13g at 45 Hz; therefore, testing was done at 35 Hz up to 16g. To go higher than this would have introduced distortion into the vibration waveshape and given indeterminate results. The vibrator was used for these preliminary tests as an expedient, and the test is much more vigorous than required inasmuch as the unit was shocked 20 to 30 times instead of once. The vibrator was calibrated to establish power setting to give us 5, 10, 15, and maximum g levels. The test unit was mounted on the platform, a load line was taken, and the test unit was subjected to vibrations for approximately 1/2 second. Before increasing the force level, a load line was taken on the test unit.

Results of the Vibration Tests

Resonance points were found at 111 Hz and 118 Hz with the vibration displacement vector on the X and Y axes respectively and at 80.5 Hz along the Z axis (see below for axis definition). Testing for 15 minutes at 2g produced little or no change in unit performance. There was some shifting of thermopile and/or end shields that improved or degraded thermal performance in a random fashion. Some of this shifting was of a "relaxing" nature, i.e., the coiled thermopile was seeking a least stressed condition (reference Table F).

Results of Shock Tests

Thermal performance was not affected greatly in the horizontal positions at any g level. When the unit was opened for inspection, however, it was noted that at least one hot shoe had come loose from the hot strap. A few end shields shifted slightly. In the vertical position an open circuit occurred due to a broken wire in the body at Tape #6. (Reference Tables G, H, and I.)

Although the shock and vibration test results thus far are of a preliminary nature, they do confirm that the prototype design, which will use the same T/C tapes, connections, and support technique as the experimental model, can meet the design objectives. It should be noted that the unit did not degrade in performance, develop a significant increase in internal resistance or an open circuit during the vibration tests. Also, the shock test failures occurred after a much more severe shock test than the unit is required to meet.

6. Safety - The capability of the prototype heat source to contain the helium pressure buildup under credible fire conditions is described in Section IV of the System Design Description. An analysis of the credible accident categories and corresponding credible accident definitions is contained within NUMEC report 3731-9.

This report also contains a description of the level and mode of testing that is planned for a series of unfueled prototype "heat sources" when these "heat sources" become available. The experimental work conducted thus far has been performed with the experimental model inner encapsulation configuration under the conditions of 50 years of helium buildup during exposure to the maximum credible fire temperature of 1900⁰F for 2.6 hours. Three test pieces successfully met this testing. A detailed summary of these tests was previously furnished as an attachment to the monthly progress letter for January 1969. This data is also furnished as Table J attached to this report. Since the prototype capsule design is superior to the experimental model design, similar or better results should be obtained from the prototype capsule testing.

15. Reliability and Quality Assurance

The detailed plans for system qualification testing will be included in the Phase II Program Plan.

16. Packaging and Packing

The packaging and ^{C/}packing design details should await completion of the prototype design approval. This is not a critical item since the pacer heat source is designed to exceed the current transportation shipping

container requirements. The pacer itself will meet the shock and vibration requirements required by the application (which exceed normal shipping requirements), and the sterilization capability can be readily achieved by packaging similar to that presently employed by conventional pacemaker manufacturers. Drawing ESK-103-D is an example of such a design which may be modified if necessary after the prototype design is approved. A shock indicator is included so that if the package is subjected to a shock greater than the equivalent of 5g at 11 milliseconds, the pacer can be evaluated for change.

LOADING EFFECTS ON PROTOTYPE PACER COMPONENTS

AT (30-1)-3731
 RADIOISOTOPE POWERED CARDIAC PACEMAKER
 6-12-69 I S E C. 501

APPLIED FORCE, GRAMS

Figure A

EFFECT OF THE NUMBER OF END SHIELDS ON OUTPUT POWER

T.C. UNIT NO.5 11.5" TAPES, CONTINUOUS FOIL SIDE SHIELDS
FUEL I-C-4, $Q = 0.13722$ WATTS, TITANIUM END SHIELDS

EFFECT OF THE NUMBER OF END SHIELDS ON OPEN CIRCUIT VOLTAGE

T.C. UNIT NO.5 11.5" TAPES, CONTINUOUS FOIL SIDE SHIELDS

FUEL I-C-4, $Q = 0.13722$ WATTS, TITANIUM END SHIELDS

RELATIVE END SHIELD PERFORMANCE

PERFORMANCE RESULTS WITH 5 & 6 TAPES

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 RADIOISOTOPE POWERED CARDIAC PACEMAKER
 4-20-69 GM EC 497

Figure E

THERMAL PERFORMANCE DOUBLE FUEL GEOMETRY

THERMAL PERFORMANCE SEALED AND UNSEALED UNITS

CARDIAC PACEMAKER CIRCUIT SCHEMATIC

38

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 RADIOISOTOPE POWERED CARDIAC PACEMAKER
 GM / KC 9/18/68 EC 393

Figure H

TABLE A
DESIGN OBJECTIVES

1. NPC 250-1 (NASA), dated July, 1963	Reliability Program Provisions for Space System Contractors
2. Mil-Q-9858A, dated December 16, 1963	Military Specification: Quality Program Requirements
3. MLM 1270, pages 31-59 (C-RD), dated June 7, 1965	Plutonium-238 Isotopic Power Source: A Summary Report
4. Rev. 2, pages 1-22b, dated November 15, 1965	Plutonium-238 Fuel Data Sheets
5. Contractor Drawing 15-D-174, dated March 16, 1966	Cardiac Pacemaker Radioisotope Power System
6. Size: Approximately 6 x 5 x 2.8 centimeters, with all corners having a radius greater than 0.5 centimeters, except for the lead fittings.
 7. Weight: Approximately 100 grams; and Specific Gravity approximately 1.4.
 8. Design Life: 10 year minimum operating life for human model and 5 year minimum operating life for animal model.
 9. Reliability: 0.95 reliability at 0.90 confidence.
 10. External Radiation: Maximum allowable dose rate is 0.3 mrad/hour at 5 cm. from the surface of the unit and 5.0 mrad/hour at the surface. Of this, the neutron dose rate shall not exceed 0.1 mrad/hour at 5 cm. from the surface and 1.5 mrad/hour at the surface.
 11. Sterilization: The system is to be shipped presterilized, and is to be capable of resterilization under hospital conditions.
 12. System Electrical Output: Shall be a pulse of the following characteristics:
 - A. Current: 4.0 milliamperes minimum, 7.0 milliamperes maximum into a load consisting of a resistor which may vary between 300 and 700 ohms paralleled by a series resistor-capacitor branch of 0.25 microfarad and 1,000 ohms.
 - B. Shape: 1.5 to 2.0 millisecond rectangular current pulse with full recovery between pulses, i.e., no direct current. The pulse must achieve full current output within 0.10 millisecond.

- C. Rate: Human* model -70 ± 5 pulses per minute
 Animal* model -120 ± 5 pulses per minute

*Basic design is to be predicated upon 70 ± 5 pulses per minute; design alternatives shall be capable of operation at 120 ± 5 pulses per minute.

- D. Power Output: At the radioisotope thermoelectric generator feedthrough pacemaker electronics interface shall be approximately 160 microwatt(e).

13. Component Characteristics:

- A. Fuel: Shall be Pu-238 in accordance with MLM 1270, pages 31-59. As an objective the design should be capable of being adapted to alternate plutonium fuel forms.
- B. Radioisotope thermoelectric generator: Shall be based on wire thermoelectric couples woven into tapes.
- C. Container: Shall be a hermetically sealed, titanium container(s) which completely encloses the radioisotope thermoelectric generator and pacemaker electronics. The container shall serve as system anode and shall be designed to prevent electrolytic destruction over operating lifetime.
- D. Pacemaker electronics: Shall be based on Cordis model Ventricor or commercial equivalent.
- E. Cathode electrode: In a monopolar configuration shall be "Chardack" electrode with 50 cm Chardack spiral Elgiloy electrode wire.

14. Environmental Conditions - Operation: The system shall be capable of operating during and after exposure to the following conditions:

- A. In-Vivo in humans at ambient temperature of 97°F - 106°F and in animals. The surface of the pacemaker shall not exceed ambient by more than 3°F .
- B. In-Vitro in 100% humidity, Ringer's solution at 106°F and under pressure from one-half to four atmospheres.
- C. Sterilization under hospital conditions.
- D. Shock: After 3-foot drop on a graphite surface with the system encased in 2 mm. Silastic for test purposes.
- E. Shock, Vibration, Transportation and Storage: Contractor to recommend design specifications for Commission approval.

- F. Safety: The fuel capsule shall provide for absolute containment of the radioisotope fuel. The fuel shipping cask and system shipping container may be considered for containment purposes.
15. Reliability and Quality Assurance: The reliability and quality of the system shall be assured by programs approved by the Contracting Officer established and conducted generally in accordance with NPC 250-1 and Mil-Q-9858A. Detailed plans for system qualification testing shall be prepared as required by the Contracting Officer. This shall include but not be limited to the following:
- A. Safety qualification testing
 - B. In-Vitro qualification testing
 - C. In-Vivo in animal qualification testing
 - D. In-Vivo in human qualification testing
 - E. Acceptance test for all deliverable items
16. Packaging and Packing: Preservation, packaging and packing of the system shall provide protection against the hazards encountered during handling, transportation and storage from the time of sterilization to the time of implantation. The package shall include provisions for handling and storage and for assuring sterilization as long as package integrity is not violated. The package shall be packed in a shipping container constructed so as to assure acceptance for transportation by common or other carriers. Packing and exterior shipping containers shall provide the package protection against handling, storage and transportation hazards.

Table B

TABULATION OF TAPE LENGTH AND NUMBERS ON PERFORMANCE
(High Fuel Experimental Model Design)

6 TAPE TESTS

<u>Perimeter (inches)</u>	<u>Tape Length (inches)</u>	<u>Date</u>	<u>Power In (watts)</u>	<u>ΔT (°C)</u>	<u>Minimum Fuel</u>		<u>Nominal Fuel</u>	
					<u>Voc (Volts)</u>	<u>Power (μ watts)</u>	<u>Voc (Volts)</u>	<u>Power (μ watts)</u>
3.720	7	3-22-69	0.121	94	4.90	162 (129) *	5.35	190 (139)
4.050	7	3-24-69	0.236	146	5.35	146 (138)	5.80	172 (149)
	9	3-13-69	0.121	99				
4.320	9	3-14-69	0.241	160	6.15	152 (159)	7.8	186 (172)
	11.5	4-23-69	0.121	120				
	11.5	4-22-69	0.236	183				

5 TAPE TESTS

3.275	7	4-07-69	0.121	103	4.38	153.5 (137)	4.71	176.5 (146)
3.695	7	4-10-69	0.236	153	4.95	150 (152)	5.38	178 (164)
	9	2-26-69	0.121	110				
	9	2-27-69	0.236	174				
3.99	11.5	4-17-69	0.121	123	5.22	130 (159)	5.72	157 (173)
	11.5	4-15-69	0.236	183				

* - The number in parenthesis is the temperature difference across the thermocouple tape used to determine the open circuit voltage and peak power.

TABLE C

9-INCH TAPE PREDICTED E.O.L. PERFORMANCE

D.F. used = 0.919
 TC = 43°C

		<u>Maximum Fuel</u>		<u>Nominal Fuel</u>		<u>Minimum Fuel</u>	
		<u>B.O.L.</u>	<u>E.O.L.</u>	<u>B.O.L.</u>	<u>E.O.L.</u>	<u>B.O.L.</u>	<u>E.O.L.</u>
Best Estimate	ΔT	188	177	175	165	162	152.5
Output							
	voltage, volts	7.5	7.0	6.95	6.5	6.4	6.0
	power, μ watts	287	253	246	217	208	182
Minimum	ΔT	173	164	162	153	150	142
Output							
	voltage, volts	6.85	6.5	6.4	6.0	5.9	5.5
	power, μ watts	240	214	208	184	175	156

Table D
 PREDICTED PROTOTYPE PERFORMANCE
FUEL - 0.238 + 0.024 WATTS

(0.95 inactive tape factor used on all data)

$T_c = 43^\circ\text{C}$
 D.F. = 0.919

		<u>Maximum Fuel</u>		<u>Nominal Fuel</u>		<u>Minimum Fuel</u>	
		<u>B.O.L.</u>	<u>E.O.L.</u>	<u>B.O.L.</u>	<u>E.O.L.</u>	<u>B.O.L.</u>	<u>E.O.L.</u>
Best Estimate	Voltage, Volts	7.1	6.65	6.6	6.2	6.1	5.7
	Power	273	240	234	206	198	173
Minimum Expected	Voltage, Volts	6.5	6.2	6.1	5.7	5.6	5.2
	Power	228	203	198	175	166	148

Nominal Resistance - 47,900 ohms

Resistance Range - 44,550 to 48,860

Tapes - Number - 6
 Length - 8.5 inches tophel
 -.35 inches, cupron

TABLE E
PROTOTYPE RPCP WEIGHT TABULATION

	<u>Weight (grams)</u>	<u>Weighed</u>	<u>Calculated</u>
Fuel and Ta Tubing	1.158		X
Inner Capsule and Plug	8.856	X	
Middle Capsule and Plug	2.734	X	
Platinum	0.471		X
Outer Capsule and Plug	2.912	X	
	(16.131)		
<u>Heat Source</u>			
Hot Strap	1.215	X	
Thermocouple Tape (6) Sub-Assembly	14.238	X	
Insulation Tapes (24)	8.900	X	
Cold Strap	1.819	X	
	(26.172)		
<u>Thermopile</u>			
Beryllium Copper Heat Sink and Thermopile Holder	3.860		X
Titanium Support Brackets	1.975		X
Titanium Lid	3.057	X	
Titanium Outer Case	19.127	X	
Feedthroughs	0.513	X	
End Shields (including getter basket)	1.597	X	
.005 inch End Plates	0.776		X
Getters (6)	0.300	X	
Epoxy Holder	0.750	X	
Titanium Brackets	0.184		X
	(32.139)		
<u>Hermetic Case and Support Structure</u>			
Electronics Package	6.358	X	
Electronics Case	7.064		X
080 Screws (2)	0.139	X	
Feedthrough (wire included - 2)	1.026	X	
RIV	1.097		X
	(15.684)		

TABLE E - continued

	<u>Weight (grams)</u>	<u>Weighed</u>	<u>Calculated</u>
<u>Hermetic Electronics Package</u>			
Titanium Terminal Block (including set screw)	0.818		X
Epoxy	15.000 (15.818)		X
Heart Lead Support			
Total Weight	105.944 grams		

TABLE F
SUMMARY OF THERMAL PERFORMANCE VIBRATION TESTS

<u>Test</u>	<u>OCV Volts</u>	<u>Corrected OCV</u>	<u>Calc. Resistance Ohms</u>	<u>Peak Power μ Watts</u>	<u>$\frac{\Delta T}{^\circ C}$</u>
Before Vib. X-axis	4.737	6.629	36,097	155.34	168
After Vib X-axis	4.500	6.389	36,370	139.81	163
Before Vib. Y-axis	5.110	7.083	37,028	176.29	178
After Vib. Y-axis	5.164	7.508	34,892	191.07	188
Before Vib. Z-axis	4.905	6.674	37,607	159.87	169
After Vib. Z-axis	5.160	7.296	36,084	184.47	180

TABLE G
SUMMARY OF THERMAL PERFORMANCE SHOCK TEST ON X-AXIS

<u>Test</u>	<u>OCV Actual</u>	<u>Corrected OCV</u>	<u>Calc. Resistench Ohms</u>	<u>Peak Power μ Watts</u>	<u>$\frac{\Delta T}{^\circ C}$</u>
Initial	5.255	7.292	37,528	191.77	183
After 5-g	5.200	7.416	34,143	189.8	186
After 10-g	5.24	7.582	37,429	183.4	200
After 15-g	5.29	7.441	37,786	189.12	189
After 16-g	3.08	7.317	26,517	108.19	184

Note: Low voltage after 16-g test was due to output lead of tape 2 shorting to input lead to tape 1, effectively removing these tapes from the circuit. This represents a "valid" failure. Condition was repaired and testing continued.

TABLE H
SUMMARY OF THERMAL PERFORMANCE SHOCK TEST ON Y-AXIS

<u>Test</u>	<u>OCV Actual</u>	<u>Corrected OCV</u>	<u>Calc. Resistance Ohms</u>	<u>Peak Power μ Watts</u>	<u>ΔT °C</u>
Initial	4.90	7.448	33,561	178.85	187
After 5-g	4.880	7.345	33,903	175.75	185
After 10-g	4.785	7.308	33,454	171.03	184
After 15-g	4.898	7.231	34,493	173.88	182
After 16-g	4.956	7.211	35,149	174.70	181

Note: Only four tapes active (two inactive) due to broken lead during repair of condition in note to Table .

TABLE I
SUMMARY OF THERMAL PERFORMANCE SHOCK TEST ON Z-AXIS

<u>Test</u>	<u>OCV Actual</u>	<u>Corrected OCV</u>	<u>Calc. Resistance Ohms</u>	<u>Peak Power μ Watts</u>	<u>ΔT °C</u>
Initial	4.152	6.929	30,440	141.58	174
After 5-g	4.14	6.909	30,441	140.76	174
After 10-g	Unit failure - open tape				

TABLE J
SPECIFICATIONS FOR PROTOTYPE SYSTEMS

Thermopile

Thermocouple Tapes	Redundancy - none
	Wire Size -
	Cupron Special - 0.0020 inch
	Tophel Special - 0.0025 inch
	Tape Thickness - 0.0045 inch
	Length
	Cupron Special - 8.35 inches
	Tophel Special - 8.5 inches
	Number of Couples per Tape - 88
	Manufacturer - Prodesco or Carolina Narrow
	Number of Tapes - 6

Insulation Tapes	Width - cut on taper from 1.5 to 2.0 inches
	Length - ~9.0 inches
	Thickness - 0.0015 inch
	Manufacturer - Prodesco
	Number of Insulation Tapes - 24

End Shields

Material - titanium
Number - 15 on each end

Side Shields

None

Heat Source

Pu-238 - triple encapsulation, 0.238 ± 0.024 watts
Support - end shields and thermopile assembly

Getter

Material - Ceralloy 400
Size - 0.132 inch diameter, 0.056 inch thick
Number - 6

Case

Material - titanium
Thickness - 0.025 inch
Outside dimensions - 6 x 4.8 x 3.10 cm.

Feedthrough

Braze - gold-titanium (Ref. design) Act. Nickle-titanium
Wire - platinum
Ceramic - aluminum oxide

Electronics

Cordis Corporation

Estimated Output Power - minimum

160 watt End of Life

Estimated Weight

106 grams