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RADIOISOTOPE-POWERED CARDIAC PACEMAKER

REPORT TO:
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Quarterly Progress Report
for
Phase II
Radioisotope Powered
Cardiac Pacemaker Program
February 1, 1971 to April 30, 1971

May 1971

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TABLE OF CONTENTS

INTRODUCTION		<u>Page</u>
Task 1.0	Program Management, Control and Planning	2
Task 2.0	Reliability and Quality Assurance	16
Task 3.0	System Fabrication and Production Development	24
Task 4.0	System Testing	39
Task 5.0	Safety	42

LIST OF TABLES

<u>Table</u>	<u>Description</u>	<u>Page</u>
1	Experimental Model Life Test Data	41
2	Prototype Model Life Test Data	42
3	Compatibility of Bismuth Telluride (Bi ₂ Te ₃) with Various Capsule Materials at Cremation Temperatures	48

LIST OF FIGURES

<u>Figure</u>	<u>Description</u>	<u>Page</u>
1	Prototype Model Configuration	3
2	Radioisotope Powered Cardiac Pacemaker NU-4	4
3	System Design Review	5
4	Nuclear Battery Connection Combinations	6
5	Nuclear Battery Failure Summary	7
6	Circuit Failure Analysis	8
7	Nuclear Battery Life Test Experience	9
8	Comparative Reliability	10
9	Pilot Production Objectives	11
10	Pilot Production Guidelines	12
11	Process Flow Chart	14
12	Facility Revisions	15
13	Radiograph of Radioisotope Powered Cardiac Pacemaker No. P-5	17
14	Leak Testing of RPCP Nuclear Battery	22
15	Thermal Performance Tests Using Production Type Thermopile with Prototype and Production End Shields Assemblies	29
16 & 17	Radioisotope Powered Cardiac Pacemaker Exterior Case Weld	34
18	Pacer Unit XP-9 - 6 Tapes in Series	38
19	Maximum Cremation Temperatures Quoted or Measured by by Various Crematories	43
20	Maximum Cremation Temperatures Measured by Various Cremation Furnace Manufacturers	45

DRAWINGS

15-J-4189-1	RPCP Model NU-4, Ser. Nos. 1-100 Assembly
15-J-4189-2	RPCP Model NU-4, Ser. Nos. 1-100 Process Flow Chart

INTRODUCTION

This is the fifth Quarterly Progress Report of the Radioisotope Powered Cardiac Pacemaker Program Phase II. It describes the results of the work performed in the period from February 1, 1971 to April 30, 1971.

TASK 1.0 - PROGRAM MANAGEMENT, CONTROL AND PLANNING

The various preparations for pilot production of Radioisotope Powered Cardiac Pacemakers have continued during this report period. The details of these preparations are discussed under the various task headings in this report. These preparations are an estimated 80 to 85% complete. In view of this stage of events, it is appropriate to review the general nature of these preparations, the ground rules and, most importantly, the objectives of these preparations.

Figures 1 and 2 illustrate the Phase I and Phase II system designs, respectively, for reference purposes. Figure 3 summarizes the significant changes in the Phase II system which have been discussed in detail in previous reports. The most significant of these revisions are the redundant tape arrangement which substantially increases the reliability potential of the nuclear battery, and the heat source restraints that resulted in a significantly improved mechanical shock and vibration capability of the nuclear battery. The various possible nuclear battery tape redundant combinations are illustrated in Figure 4. Alternative C was selected for implementation in Phase II as the most reliable combination that could be constructed consistent with the other system constraints, including size.

During this period, an analysis of the fourth nuclear battery failure was performed. This was prototype model P-5. This latest unit, as with each of the previous nuclear battery failures all occurred in dogs and each exhibited gross internal mechanical damage as a result of the shock and vibration environment within the dogs. A summary of these battery failures is shown in Figure 5. At the end of April, the various nuclear batteries accumulated a total of 32.38 unit years of operation with a total of four failures. At this same time, the Phase I electronic circuits accumulated a total of 61.38 unit years of operation with 12 circuit failures. The electronic circuit in Unit E-17 failed during this period and it was removed from the dog. The failure mode was an open emitter in the output transistor Q3. Figure 6 is a summary of the circuit failure modes, whereas Figure 7 illustrates the longevity data for all of the nuclear batteries. The greatest nuclear battery longevity thusfar is approximately three years and three months.

The comparative reliability of (1) the program objective, (2) the postulated reliability of the Phase I units had they been connected in the Phase II redundant configuration, (3) the Phase I circuits, and (4) conventional battery powered pacemaker systems are illustrated in Figure 8. With this present status in mind, let us now examine the pilot production program. Figure 9 lists the objectives of the program while Figure 10 contains the general guidelines that have been employed.

PROTOTYPE MODEL CONFIGURATION

Figure 1

RADIOISOTOPE POWERED CARDIAC PACEMAKER NU-4

Figure 2

SYSTEM DESIGN REVIEW

- REDUNDANT TAPE ARRANGEMENT
- DIE DRAWN ELECTRONICS CASE
- FEEDTHROUGH INSIDE ELECTRONICS CASE
- CAPTIVE SET SCREW IN TERMINAL BLOCK
- THERMOCOUPLE TAPES WITH WIDER BORDERS
- SINGLE MEMBER SUPPORT BRACKET WITH CROSS BRACE
- IMPROVED GETTER BASKETS
- HYBRID INSULATION ON ENDS
- HEAT SOURCE RESTRAINT

NUCLEAR BATTERY CONNECTION COMBINATIONS

(11 YEAR LIFE)

<i>ALT.</i>	<i>GENERAL ARRANGEMENT</i>	<i>DESCRIPTION</i>	<i>END OF LIFE NOMINAL V_{OC}</i>	<i>R_L LOWER LIMIT</i>	<i>R_U UPPER LIMIT</i>	<i>NO. OF TAPES REQUIRED (MINIMUM)</i>
A.		6 TAPES IN SERIES	5.950	3.8010	98.9843	6
B.		3 SUBSETS OF 2 TAPES IN PARALLEL	2.975	55.8405	99.9991	3, 1 PER SET
C.		2 SUBSETS OF 3 TAPES IN PARALLEL	1.983	85.7166	99.9999	2, 1 PER SET
D.		6 TAPES IN PARALLEL	0.992	94.8949	99.9999	2

Figure 4

NUCLEAR BATTERY FAILURE SUMMARY

<i>DESIGN</i>	<i>TAB LOCATION</i>	<i>TAPE NO.</i>	<i>GROOVE NO.</i>	<i>WIRE</i>
EXPERIMENTAL MODEL E-14	HOT TAB	3	1	CUPRON
PROTOTYPE MODEL P-6	HOT TAB	2	1	TOPHEL
PROTOTYPE MODEL P-4	HOT TAB	3	1	TOPHEL
PROTOTYPE MODEL P-5	HOT TAB	3	27	CUPRON

Figure 5

CIRCUIT FAILURE ANALYSIS

<u>FAILED COMPONENT</u>	<u>FAILURE MODE</u>	<u>NO. OF CIRCUITS</u>
Q ₃ TRANSISTOR	OPEN EMITTER	4
Q ₃ TRANSISTOR	COLLECTOR-BASE LEAK	2
Q ₂ TRANSISTOR	OPEN COLLECTOR	1
VR ₁ (ZENER DIODE)	PARTIAL SHORT	1
Q ₂ TRANSISTOR	POSTULATED COLLECTOR-BASE LEAK	1
UNCERTAIN	LOSS OF OUTPUT SIGNAL	<u>3</u>
TOTAL		12

Figure 6

NUCLEAR BATTERY LIFE TEST EXPERIENCE

TOTAL ACCUMULATED R. P. C. P. TEST HOURS 283,857

MODEL NO.	1966	1967	1968	1969	1970	1971	UNIT HRS.
UNIT 3							28,401
UNIT 4							27,949
UNIT 5							26,222
UNIT 9							19,641
UNIT 10							18,301
UNIT 12							19,070
UNIT 13							13,334
UNIT 14							11,701
UNIT 16							15,801
UNIT 17							16,885
UNIT 18							15,993
UNIT 20							12,300
UNIT P-1							12,684
UNIT P-2							11,821
UNIT P-3							12,637
UNIT P-4							6,742
UNIT P-5							11,437
UNIT P-6							2,938

Figure 7

COMPARATIVE RELIABILITY

(90% CONFIDENCE)

Figure 8

PILOT PRODUCTION OBJECTIVES

- DEMONSTRATE PRODUCTION TECHNIQUES FOR LARGE VOLUME PRODUCTION
- COMPETITIVE COST DEMONSTRATION
- INTERMEDIATE VOLUME PRODUCTION DEMONSTRATION
- PROVIDE SYSTEMS FOR RELIABILITY TESTING
- PROVIDE SYSTEMS FOR LABORATORY TESTING
- PROVIDE SYSTEMS FOR ANIMAL AND HUMAN IMPLANTATION

PILOT PRODUCTION GUIDELINES

(BASED ON PHASE I TECHNOLOGY)

- APPROXIMATELY 75 TO 100 UNITS.

SYSTEM MUST BE COST EFFECTIVE.

CONSISTANT MANUFACTURING PROCESSES.

FIXTURES.

PROCESS PARAMETERS.

MATERIALS.

MANUFACTURING PROCESS SUITABLE FOR VOLUME PRODUCTION.

REPRODUCIBLE MANUFACTURED COMPONENTS.

The sequential manufacturing process is summarized in Figure 11. This is an abbreviated version of the complete process flow chart appended to this report (Drawing 15-J-4189-1). Each process, as it is developed, will result in a written procedure, with well-defined Quality Assurance limits, including a designation of the equipment and fixtures that are required.

All of the facility revisions are complete. These are summarized in Figure 12.

During this period, a sub-contract for electronic circuit fabrication was initiated for the preparation of 250 circuits that will be furnished in three groups of 11 (pre-production), 39 (production qualification), and 200 (production).

During this same period, a trial tape brazing operation was initiated to evaluate the production fixtures and to uncover latent manufacturing limitations using the older style of thermocouple tape. It uncovered a requirement for additional tape assembly fixtures but was generally satisfactory.

Also of interest, is a broadened survey of crematoriums and crematory manufacturers discussed in Task 5 of the report. The results tend to confirm a conclusion that cremation occurs generally between 1800°F and 2300°F. Temperatures below 1300°F are below the auto-ignition temperature of carbon, whereas, 2600°F is the upper limit of the fire-brick lining. Our single measurement of a simulated cremation peaked between 2000°F and 2100°F.

Some welding difficulties have occurred at Mound Laboratory with the middle heat source encapsulation that is being examined jointly by NUMEC and Mound Laboratory. The details are discussed in Task 3 of this report.

PROCESS FLOW CHART

Figure 11

FACILITY REVISIONS

- CHEMICAL PROCESS

 - DEIONIZED WATER SYSTEM

 - DISTILLED WATER SYSTEM

- VENTILATION SYSTEMS

 - ELECTRICAL SYSTEMS FOR DESIZING TANKS, PLATING,

 - DEGREASING AND FEEDTHROUGH SYSTEM

15

- FABRICATION

 - LIQUID N₂ LINE TO CLEAN ROOM

 - ARGON DISTRIBUTION SYSTEM TO CLEAN ROOM

 - ELECTRICAL DISTRIBUTION SYSTEM TO CLEAN ROOM FOR TIG

 - WELDING, BRAZE CHAMBERS, EPOXY MOLDING SET UP AND

 - DEGASSING FURNACE

 - COOLING WATER DISTRIBUTION SYSTEM TO CLEAN ROOM

TASK 2.0 - RELIABILITY AND QUALITY ASSURANCE

Reliability Data

At the end of April, the various nuclear batteries have accumulated a total of 32.38 unit years of operation with four thermocouple tape failures, one in each of four nuclear batteries implanted in dogs at NHLI.

At the end of April, the Phase I circuits have accumulated a total of 61.38 unit years of operation with a total of 12 circuit failures.

Failure Analyses

National Heart and Lung Institute notified NUMEC that pacer unit P-5 had stopped pacing approximately 3/15/71. The unit had been implanted in a dog on 1/14/70 and operated satisfactorily for approximately 15 months. After failure, it was removed from the dog and returned to NUMEC on 3/24/71, at which time a failure analysis began. The unit was not pulsing and was first radiographed (Figure 13). The radiographs were similar to those taken of other units that had been in dogs, and suggested that P-5 had been exposed to severe repetitive shocks. This was indicated by the displacement of both getter baskets from the end of the fuel encapsulation to a position one-half way between the fuel encapsulation and the bottom of the case. The epoxy was machined away and the electronics case lid was removed. The voltage from the battery with the electronics connected was 0.67 volts. The electronics were then disconnected and removed from the battery. The open circuit voltage of the battery was 2.35 volts which indicated an open tape in the battery. The exterior case was punctured and tested to establish that a vacuum had been maintained. No gases were present within the precision of the measuring apparatus. The weld securing the lid to the exterior case was then machined away and the thermopile removed. The general condition of the thermopile was as follows:

- (1) Getter dust was observed at both ends of the module.
- (2) Getter baskets had shifted, as indicated by the radiographs.
- (3) Insulation tape was frayed and crushed in the area of the hot strap.
- (4) Three hot shoes are partially loose from the hot strap.
- (5) Cold shoe #3 was completely forced off the cold strap.

The individual tape resistance was measured and it was found that tape No. 3 was open. Examination of the thermopile revealed that the lock tab in the No. 4 tape

FRONT VIEW

END VIEW

RADIOGRAPH OF
RADIOISOTOPE POWERED CARDIAC PACEMAKER NO. P-5

Figure 13

position on the hot strap was bent in such a manner that it rubbed against a cupron wire in the No. 3 tape. The cupron wire broke approximately 1/8 inch from the ceramic and in the middle of the tape. Apparently the repetitive shocks caused the tab to rub against the wire resulting in a wire breakage. The locking tabs in several of the other areas were either broken or distorted.

The Phase II pacers are designed differently from P-5 in that the hot shoes will be spot welded to the hot strap instead of using the locking tabs and the thermopile assembly has been generally redesigned to withstand this severe shock and vibration environment.

During this report period dog implanted unit E-17 was removed. Preliminary measurements made by NHLI personnel indicated that the unit was producing a very weak output signal (in the millivolt range) but at the proper rate. This unit had been implanted on 9-10-69, was last found to be operating properly on 1-25-71, was found to be defective on 2-1-71 and was removed on 2-4-71.

The failure analysis performed at NUMEC showed that the electronic circuit (135A-28) had failed. The failure mode was verified to be an open emitter of the output transistor (Q_3). This is the same mode that has occurred in three previous circuit failures (135A-4, 135A-18 and 135A-22). The failure analysis also showed that the nuclear battery of E-17 after being implanted for about 17 months has not degraded and in fact has slightly improved.

Another failure has occurred in a Phase I circuit. The unit is 135A-8 which had failed on 7-14-70 in Experimental Unit E-10. The previous failure was a multivibrator transistor (Q_2) which was replaced externally. The new failure is in the output transistor (Q_3) whose emitter has opened. This same failure mode has occurred in four other circuits of which three were dog implants.

This failure has not been incorporated into the Phase I circuit reliability calculations since it occurred in a circuit that previously failed.

Tape Inspection and Procedures

Three fixtures have been completed for the inspection of insulation and thermocouple tape. The first fixture was used for incoming tape inspection and has been discussed in a previous report. The second fixture was used to measure the amount of coating placed on the thermocouple wires during the electroplating process. After the 65 inch lengths of tape (consisting of seven grit blasted areas spaced either 8.500 inches or 8.350 inches apart) have been plated in the grit blasted areas

and dried, they are then placed in the inspection fixture. The fixture is plexiglas and basically consists of a supported 70 inch plexiglas trough, a dial gauge (.0001 inch increments) located at the end of the trough and a tape wrapping mechanism. The tape is placed in the trough and the plated area of the tape is located between the gaging anvils. A 10 oz. weight is used to maintain a constant force on the anvils. After making the measurement, the tape is wound onto a spool. This spool is then placed on the tape assembly fixtures. The advantages of the fixture are: (1) it offers minimum handling and wrapping of the thermocouple tape, (2) it provides a process control for the electroplating operation.

In addition to measuring the plating thickness, the inspector performs a visual examination of the plated areas at 30X. At each section of tape (either 8.350 inches or 8.500 inches) the inspector sews a metal tag at the end of the tape. This metal tag has a number scribed on it and is a means of following that particular section of tape through the complete braze cycle. If any irregularities are discovered it is brought to the attention of the chemical processing group for correction.

Another fixture has been fabricated to inspect the assembled brazed thermocouple tape. This fixture is similar in design to the fixture used in Phase I. The new fixture differs in that the material is stainless steel instead of plexiglas and the new fixture will only measure the Phase II designed tape length. The previous fixture was adjustable to different tape lengths, but this capability lowered its degree of accuracy. The brazed thermocouple tapes are placed in the fixture and the inspector measures the total resistance, groove isolation and determines the polarity. A visual inspection of each tape is performed at 30X. At this point the metal tags are removed. The final report correlates all the serialized component parts used in the assembly of the brazed thermocouple tapes such as ceramics, hot and cold shoes and the sections of tophel and cupron tape. The quality of each braze can then be related to the quality of each component.

Evaluation of Incoming Thermocouple Tape and Insulation Tape

A total of 315 yards of thermocouple tape has been visually and dimensionally inspected. Under 30X magnification the tape was visually inspected for the following defects:

- (a) bent, pulled or broken wires
- (b) areas with missing fibers
- (c) number of wires
- (d) picks per inch (tightness of weave)

Quality Control rejected 55 yards of the thermocouple tape for the above listed defects. Dimensionally the tape was inspected for tape width, O.D. of the wire thickness of the tape, distance between wires and weight per square inch of tape. None of the tape was rejected for dimensional reasons.

In general the tape visually and dimensionally is of good quality and will be released for production. The areas rejected by Quality Control have been identified and will be removed when Production cuts the tape into 65 inch lengths prior to the grit blasting and plating operation.

A total of 550 yards of insulation tape was inspected and accepted for use in production.

Component Inspection and Traceability

All of the component pieces used in the assembly of a pacemaker are either 100% inspected or subjected to a sampling plan. In general the 100% inspection plan is required for the following items:

- (1) fuel capsule/plug components
- (2) coated ceramics used for the hot/cold shoes
- (3) plated 65 inch lengths of thermocouple tape
- (4) brazed thermocouple tapes
- (5) incoming thermocouple tape
- (6) case and lid assemblies

The 100% inspection plan implies in addition to a detailed inspection, that each component is assigned an inspection number which remains with that part through the final assembly of a pacemaker.

Certain components do not require 100% inspection in that they are machined in stock quantity or chemically milled in batch quantity. In this situation the batch or machined stock are assigned a lot number at inspection time. The stock or batch is then sampled according to a standard procedure and inspected. After a review of sampled data it is then determined if a 100% inspection is needed. If the data obtained from the samples is acceptable, the stock or batch is released for production.

Components which are not accepted by Quality Control are then tagged, "QC Hold". An Internal Deficiency Report is prepared by the QC engineer who sends copies of the report to the Q.A. Manager, Program and Project Managers. A review is then conducted by the above mentioned persons. If the decision is made that the

deviations will not impair the intended use or reflect in the degradation of the overall system, components may then be released for production. If the components are released for production the specific drawings will be changed (for example, increase tolerances) to reflect the decision. However, if after a review it is decided not to use the components in question then the Quality Control Department will label and scrap the components.

It is possible with either the 100% inspection plan or the sampling plan to trace a particular component at any stage of production to any previous production step and finally to a material purchase order with material certification. Therefore after final assembly of a pacer it will be possible to trace its components to production data, inspection data and material purchase orders.

Leak Testing

Subsequent to an internal review of the recommendation for the purchase of a specific helium leak detector to fulfill the leak testing requirements for RPCP components, final recommendations for the purchase of this unit were formulated and submitted to the AEC for approval. The unit selected was a VEECO Instruments Inc. Model MS-12-ABR-5 leak detector which has a sensitivity level of 5×10^{-12} atm-cc/sec. Approval was received from the AEC and the purchase order placed for its procurement. This helium leak detector was received and has been installed. Preliminary performance capabilities have been demonstrated in preparation for mock-up tests of fixture components used during the final assembly operations on the RPCP units.

The conceptual design and general layout design drawings have been prepared for some of the fixtures which will be used during pilot production leak testing. One of these fixtures would provide the capability for leak testing the final nuclear battery subassembly just prior to the electron beam weld sealing of the weld closure plug. Shown in Figure 14 is a schematic sketch of this leak test fixture which is to be coupled to the VEECO MS-12 leak detector. The nuclear battery subassembly is comprised of the battery case, case lid and electronics case subsequent to the TIG welding of each of these three components, as shown. In addition, both a ceramic-to-metal feedthrough and a weld closure plug have been brazed to the nuclear battery case lid which is depicted in the exploded view of Figure 14. In order to insure hermeticity of the nuclear battery subassembly at these brazed and welded joints and in the battery case wall, this nuclear battery subassembly test was devised. Note that a double "O" ring seal is provided in the fixture which surrounds the weld closure plug and a differential pumpdown

LEAK TESTING OF RPCP NUCLEAR BATTERY

Figure 14

with the use of an auxiliary rough pump assists in preventing the flow of helium through the "O" rings directly to the leak detector. A helium environment surrounds the outside of the subassembly while the leak detector is coupled to the inside of the nuclear battery so as to simulate the pressure differential direction during normal system operation.

TASK 3.0 - SYSTEM FABRICATION AND PRODUCTION DEVELOPMENT

Electronics

The subcontract between NUMEC and the selected Phase II electronics circuit vendor has been approved and work has started. The contract calls for the following delivery schedule:

- 11 preproduction circuits - July 23, 1971
- 39 qualification circuits - September 1, 1971
- 200 production circuits - October 15, 1971

Welding of Middle Capsules for Fueled and Safety RPCP Heat Sources

Production welding of the middle capsule components is being performed for the fueled and also unfueled safety RPCP heat sources at Mound Laboratory. A welding problem has been encountered during the course of the production runs on fueled heat sources while welding the Hastelloy C-276 middle encapsulations. During the welding of 26 Phase II middle capsule components for fueled heat sources performed in June and December 1970, three capsules did not meet the leak test specification. In addition, an alumina stringer or inclusion problem was detected by Mound on some of the weld verification samples. Apparently, some of the heats of Hastelloy "C" from which previous prototype fuel capsules had been fabricated, had relatively low (approximately 0.05%) aluminum compositions while some of the newer Hastelloy C-276 material had 0.24% aluminum.

The fabricators of the Hastelloy "C" and C-276 materials were contacted to assist in the solution of the alumina stringer welding problem. They indicated that aluminum is added to the heats of material as a deoxidizing agent. The Stellite Division has quoted aluminum compositions ranging from 0.01% up to 0.32%. Normally, the percentage of aluminum is not listed in the chemical analysis certification on the heat supplied by Stellite even though this analysis was made and reported internally. It has also been determined that the average aluminum content for 30 heats of Hastelloy "C" was 0.23% while that for 53 heats of Hastelloy C-276 was 0.21%. In addition, there was a wider distribution for the Hastelloy "C" than the C-276. Hastelloy C-276 therefore represents a more controlled homogenous material since it is double melted and has a lower and more desirable carbon content.

In order to assist in an analysis of the middle capsule components which have been welded at Mound Laboratory, information on the material certifications and compositions was obtained. This data was prepared for each of the heats of Hastelloy C-276 and Hastelloy "C" materials which were used in the fabrication

of prototype middle capsules for the pacemaker program. Some middle capsule components were also welded at NUMEC in the hope of inducing cracks in the capsules during welding. These were fabricated from the same heat of Hastelloy C-276 material that produced welding problems at Mound. Although no leaky capsules resulted, detailed investigations of the metallographic sections seemed to indicate a potential for inclusions or stringer; however, these were subsequently identified as normal carbide precipitates.

Further efforts have been performed by both NUMEC and Mound Laboratory. The evidence thusfar suggests that this welding problem is caused by alumina (Al_2O_3) stringers or inclusions in the weld bead of the middle capsules. Two separate meetings were held with Mound Laboratory personnel to review the results of their assessment of this problem as well as to provide assistance in evaluating the results. The following conclusions were derived from these meetings.

Data were presented which indicated that there was a previously undetermined problem in alumina concentration in Hastelloy C-276. Apparently, this material can result in stringers or inclusions in the weld bead of the pacemaker middle capsule. They had previously reviewed their results on welding parameters and techniques for the middle capsule and ascertained that all of these were identical since the weld development work of April 1969. They had noticed, however, some drossy (slag) appearances in the weld region which were somewhat different from those of prior welds. In addition, it was determined that there were not as many dispersed carbides in the new material, which is consistent with the Hastelloy C-276 composition as compared with Hastelloy "C". It was considered possible that the aluminum concentration (or stringer or inclusions) resulted in leaks in three out of 26 middle capsule welds. However, this effect had not been positively established at that time by the direct metallographic sectioning results on the middle capsules which could not pass the leak test. Further test data and an actual correlation of a capsule which could not pass the leak test with a stringer inclusion at the crack region was required prior to concluding that the aluminum concentration in the base material is the primary and only cause of the problem.

It was decided that the production welding of 20 safety test middle capsules would be performed by Mound Laboratory as soon as possible. The inner capsules for these simulated heat sources were already fabricated and ready for assembly. The results of these welds were to provide more data for a broader based analysis. In addition, if one or more capsules from this series of 20 middle capsule welds

did not pass the helium leak test requirement, the precise location of the leak in the capsule could be determined. Also, a thorough and meticulous metallographic sectioning at these welded regions could be performed to assist in confirming or denying the actual cause for the leak. Therefore, it was expected that if the problem presented itself once again, further clarification for the source of the welding problem could be made.

In order to be prepared for alternatives, some additional work was pursued. It was determined that aluminum is added so as to improve the hot working capabilities of the material. If a lower aluminum or aluminum oxide content in the Hastelloy C-276 was required, the availability of such material was of interest. It was also agreed that the fabrication of fueled heat sources should be continued as soon as possible. A new problem of functional fit inside the outer capsules was observed to occur in the December 1970 production run as a result of weld bead spillover. This problem was not encountered in the June 1970 fabrication series. It is believed that this is probably not related to the alumina stringer problem.

With NUMEC's concurrence, Mound Laboratory personnel then proceeded with welding the middle encapsulations for the safety test capsules. Five of these twenty welds would not pass the leak test specification. Subsequently, a second meeting was held to review these new results on the welding problem and to assist in evaluating the data. Recommendations were made on the methods to investigate the cracks and the alumina stringer inclusions.

The drossy appearance of a typical capsule which did not pass the leak test was discussed and examined as well as the procedures and test data taken during welding. Detailed metallographic sectioning results on two of the leaky middle capsules were reviewed. Initially, the crack region was located by Mound personnel using a pressurized argon-acetone bubble test. After cutting off the bottom of the capsule, a fluorescent penetrant test was performed and the location where the crack emerged on the outside surface was reconfirmed. A series of seven sequential polishes of approximately 0.002" in depth were performed on one of the mounts. By this series of polishes, a three dimensional sketch of the alumina stringer or crack in the capsule weld was deduced. This crack occurred in the weld bead, about two to four mils away from the heat affected zone. In this and four other capsules, the crack angled toward the trepan region while in one case, the crack emerged on the top of the capsule. The three dimensional travel of this crack was through a 0.017" width (wall thickness in a radial direction), a 0.002" height (in the axial direction) and a 0.012" length (in a circumferential direction).

Two additional mounts of these two capsules were prepared and diamond polished for electron microprobe x-ray analyses. The detailed microprobe analysis of these mounts was performed during a visit to Mound Laboratory. Analyser current images, x-ray images and x-ray line analyses positively confirmed the presence of aluminum along the complete stringer or crack regions investigated. Depressions (lack of composition) for nickel and chrome were also observed at these regions. Similar results were obtained on the second capsule mount. It was concluded that aluminum or alumina stringer inclusions may be the primary cause for the cracks during welding of these two middle capsules.

Requests for quotation were made on the availability, cost and delivery schedules of low aluminum Hastelloy "C" or C-276, including both normal and vacuum remelted material. In addition, the material must continue to fulfill the Aerospace Material Specifications, AMS-5750A, previously required. As a result, Hastelloy "C" and C-276 rods were purchased from available off-the shelf stock material. This included one sample of Hastelloy C-276 and two samples of different heats of Hastelloy "C" material. One of the Hastelloy "C" samples has an aluminum composition of 0.01%. The objective of purchasing these samples of material is to permit a more thorough evaluation in attempting to eliminate the welding problem. Further evaluations on this material are being made.

Extensive metallographic, aluminum and oxygen analyses have been performed on some samples of previous and new heats of Hastelloy "C" and C-276. These analyses are a continuation of the efforts to deliver middle capsule and plug components which will not exhibit the alumina stringer problem during welding. Two separate heats of Hastelloy C-276 material (number 2760-7-3013 and number 2760-7-3014) were utilized to fabricate the Phase II middle capsule components N-2-1 through 135 and middle plug components N-5-1 through 135. Heat number 2760-7-3013 presented the alumina stringer weld problem at Mound Laboratory. It is not known whether heat number 2760-7-3014 will present a similar alumina stringer weld problem. As a result, middle capsule plugs are currently being fabricated to further evaluate the welding problem.

Additional Hastelloy "C" and C-276 material has been received for evaluation and possible capsule and plug fabrication. Capsule components are being fabricated from two of these heats of "C" and C-276 material for weld development purposes. Further efforts are being pursued in resolving some of the unknown aspects so as to determine which is the best material for fabricating middle capsules.

Thermal Performance Tests with a Production Type Module - XP-16

A module was fabricated using the new thermoelectric tapes with the wider border. This wider border will give the outside wires of the tapes extra protection and facilitate sewing of insulation to the tapes. The module had insulation tapes that were woven with starch oil binder, which gives a stronger and tighter woven insulation. Also, nine foils on each end were made with Rodney foils. In some previous tests with rolled foils, Rodney foils had poorer performance than the Hamilton foils usually used. However, a very long delivery date and a much higher cost made it desirable to re-evaluate Rodney foil with the new glass and foil sandwich insulation.

To obtain data as soon as possible, the module was tested in an open fixture using measurements from two tapes. Also, some tests were performed in a case with the production support bracket. The results of the tests showed:

1. At the nominal end shield spacing (1.965 inch) the performance was poor (≈ 15 percent low on open circuit voltage). However, by opening the spacing to 1.990 inch the performance was equal to that in previous tests (See Figure 15).
2. It was found that the getter baskets were too deep for the hot strap. By going to 0.070 inch getter baskets instead of 0.080 inch the performance was only ≈ 3 percent low on open circuit voltage at the nominal spacing.
3. With the same spacing and getter baskets, all Rodney foil end shield assembly performance was not significantly ($< \text{one percent}$) lower than with the unit using 16 Hamilton and 9 Rodney foils.

These results have the following effect upon the production unit design:

1. The wider boarder tapes can be used with no degradation of performance.
2. Similarly the starch oil binder insulation tapes can be used.
3. The possibility of degrading performance by having too tight a spacing will be corrected using 0.070 inch getter baskets instead of 0.080 inch, and taking 0.010 inch from each support bracket. To have more adjustment in tightness one extra rolled foil will be used at each end. This extra foil can be removed if a unit is too tight at final assembly.
4. Rodney foils can be used to complete the end shield assemblies for the pilot production units and can be used for all foils in future units.

THERMAL PERFORMANCE TESTS USING PRODUCTION TYPE THERMOPILE WITH PROTOTYPE AND PRODUCTION END SHIELDS ASSEMBLIES

Figure 15

Mechanical Production Preparations

All the facilities changes needed for mechanical fabrication have been completed and include:

1. Ultrahigh purity argon bank in clean room.
2. Liquid N₂ line installed in clean room and chemistry processing.
3. New parts degassing furnace installed.
4. Additional vacuum pump exhaust lines were installed in the clean room. (brazing chamber, weld box, potting chamber).
5. Additional recirculating process water lines were installed in the clean room. (brazing chamber, degassing furnace).
6. New TIG welder power supply and welding chamber installed in the clean room.
7. New epoxy molding chamber installed in the clean room.
8. Additional power lines were installed in the clean room to supply the necessary power for the new equipment.
9. New buffer for case polishing has been installed in the model shop.

In addition to the fixtures reported completed in the last quarterly the following fixtures have been fabricated:

1. Thermocouple tape degassing fixture.
2. Thermopile wrapping fixture.
3. Thermopile degassing fixture.
4. Tape brazing fixture.
5. Support bracket bending and forming die.
6. Epoxy molding fixture (non spring loaded).
7. Thermocouple tape measuring fixture.
8. Thermocouple tape electroplating fixture.
9. Epoxy machining fixture.
10. Modified thermocouple tape plating thickness measuring fixture.

Near the end of this report period a preliminary evaluation of the tape brazing fixtures and procedures was made. The results were as follows:

1. The brazing with no filler and no rebrase was excellent, with essentially zero tape rejects because of the braze.
2. Length was somewhat of a problem and will be fixed by proper gaging of the assembly fixture.
3. A production rate of 2 to 3 tapes per day, per man was obtained.
4. It was found that additional braze stations were needed based upon 3 men

assembling tapes and 1 checking and brazing. Five more braze stations were ordered, and to minimize down time 12 extra heaters were also ordered.

Chemical Processing Production Facilities

Areas designated as CP-I, CP-II and Dark Room have been completed as to their respective water, electrical and ventilation requirements. A summary of these preparations follows:

CP-I

Feedthrough brazing and annealing vacuum system complete with cooling water, exhaust vent and electrical supply.

Al_2O_3 coating drying oven for insulation tapes.

Rinsing sink with city and deionized water outlets.

CP-II

Thermocouple tape plating system complete with venting hoods, electrical supply and a hot deionized water outlet. A special cyanide waste disposal unit was also installed.

Vapor degreasing unit complete with cooling water, electrical supply and venting hood.

Desizing system complete with hot deionized water outlets, distilled water outlets and electrical heating units.

Grit blasting equipment complete with electrical supply and dust arrester.

Dark Room

Ventilation system for fumes evolved during photo-resist applications.

Resist drying oven.

Chemical Processing Production

Photofabrication Processes

Finalized photo-etch procedures have been utilized to produce twenty-five titanium hot shoes in two man-hours and twenty-five copper cold shoes in two man-hours. These man-hours represent the total process time.

A spray-etcher has been ordered which will significantly increase the speed and ease of operation. The etcher will be able to increase the surface area contact of etchant, thus promoting a rapid uniform etch.

Thermocouple Tape and Component Processes

The total ceramic tab procedure was employed to complete one hundred finished elements in one and a half man-days. This procedure includes titanium coating by the fusion salt process, copper and silver coatings and a preheating in a vacuum system to form the eutectoid.

Testing of the fixtures for electroplating braze alloy on thermocouple tapes is in progress to establish production techniques and quality assurance specifications and controls.

Some difficulties in the tape plating technique were encountered during the first few trial runs, but adjustments are being made to improve the quality of the electroplated braze coatings.

The most serious problems encountered are the following:

Non-uniform electroplate on wires and lack of plating on a few wires in any given section. This was determined to be a marginal cathode connection made by a piece of 5 mil aluminum foil at each tape plating location. Substituting a more ductile one mil foil and adding an additional connection at the ends of each tape eliminated the problem.

A grainy or dendritic plating of copper which did not adhere well to the wires caused coatings which were not acceptable for brazing into tabs. This problem was resolved by insuring a constant composition of the plating solution which, because it is heated, has a tendency to evaporate. Cleaning of the anodes after each tape run also minimized this problem.

By overcoming these difficulties and modifying the fixture slightly; using swing-away handles, thus making tape loading easier; it is now possible to produce 1 set (2 tapes) in one man-hour. This includes grit blasting, copper-silver plating, post cleaning and drying.

The quality assurance results at this time indicate that the plating thickness in the brazing areas have been running between 1.0 and 1.5 mils, with 1.5 mils as optimum, over 95% of the measured areas. The 1.0 to 1.5 mil range appears to be a favorable condition for the repeatability of the tape to ceramic tab braze operation.

Epoxy Molding

The small vacuum box for the epoxy molding operation has been received and installed. The epoxy molding fixture has been made. The final molding procedure is now being finalized.

TIG Welding

Preliminary TIG welds of the exterior case, exterior case lid, and electronic case have been made using the TIG welding argon box and cam welding fixture. The welds to date have produced a blue oxide in the weld area, showing that the argon box is not completely free of oxygen and moisture. The box has been checked and no leaks have been detected. The argon gas is presently being recirculated to attain a better inert atmosphere in the glove box. When a good inert atmosphere is obtained, the welds will have a silver color with no blue oxide present. A photograph of the cross sectional area of one of the preliminary welds is shown in Figures 16 and 17. The weld penetration thickness of this sample is satisfactory. In these particular sections the weld rollover has been controlled to the inside of the device by adjusting the outer chill position. This provides an additional mechanical anchor for the epoxy.

Final Degas Fixture

The fixture to degas the pacemaker just prior to final closure is complete. The heaters, thermocouples, and metering will be checked out as soon as the necessary modifications are made to the EB chamber to accept this fixture. All of the controls to run the degassing operation are presently being installed in a cabinet.

EB Closure Plug Weld

The final degas fixture also serves the purpose of protecting the pacemaker from the electron beam during the electron beam welding of the final closure plug. An optical viewing system has been installed to position the electron beam for the final closure weld. Trial closure welds using this method have been successful.

Outer Case Dies

The vendor who is supplying the drawn titanium outer case components is presently making a production run of 150 of each of the four components. The problem of the interference fit between the exterior case lid and electronic case and between the electronic case and electronic case lid seems to have been corrected by reworking the dies.

EXTERIOR CASE
EXTERIOR CASE LID
ELECTRONICS CASE

Figure 16

Figure 17
EXTERIOR CASE LID
ELECTRONICS CASE
EXTERIOR CASE

RADIOISOTOPE POWERED CARDIAC PACEMAKER
EXTERIOR CASE WELD

During this report period, three outer cases and lids were hermetically sealed under vacuum to simulate the actual vacuum inside a completed pacemaker battery. These three cases were then externally pressurized to four atmospheres and their size remeasured to check the ability of the outer case to withstand four atmospheres of external pressure. The maximum dimensional change in height, length, and width was two thousandths. This small change should not affect the operation of completed units in any way. The three units were then externally pressurized to five atmospheres with negligible additional dimensional change. The test showed the outer case can easily withstand four atmospheres of external pressure with no sufficient change in dimensions. The ability of completed units to withstand four atmospheres will be demonstrated during the testing stage of the Phase II pacemakers.

Fixture Design

The following drawings for fixtures have been completed during the month of February.

15-A-4189-5	End Brace Template - Details
15-B-4189-110	Prototype Model - Cam Driven Welding Fixture Shaft Details
15-B-4189-111	Fixture for Assembly of Electronics Case, Lid, & Outer Case Filler Plate Detail
15-C-4189-119	Grit Blast Chamber - Work Station
15-D-4189-120	Electronics Case & Feedthrough Leak Detector Fixture Details
15-D-4189-187	Nuclear Battery Leak Detector Fixture Assembly
15-D-4189-188	Nuclear Battery Leak Detector Fixture - Detail
15-D-4189-189	Nuclear Battery Leak Detector Fixture Details
15-D-4189-190	Adjustable Stand for TIG Welding Electrode Assembly
15-D-4189-191	Adjustable Stand for TIG Welding Electrode - Details
15-D-4189-192	Termination Block TIG Welding & Epoxy Cut-Off Fixtures - Assembly
15-D-4189-193	Termination Block TIG Welding & Epoxy Cut-Off Fixtures - Details
15-D-4189-194	Termination Block TIG Welding & Epoxy Cut-Off Fixtures - Details
15-D-4189-195	Termination Block TIG Welding & Epoxy Cut-Off Fixtures - Details
15-D-4189-196	24" EB Vacuum Welding System Modified Optical Viewing System Assy.
15-D-4189-197	24" EB Vacuum Welding System Modified Optical Viewing System Assy.
15-D-4189-198	Cardiac Pacemaker Epoxy Molding Fixture
15-D-4189-199	Cardiac Pacemaker Epoxy Molding Fixture - Details
15-D-4189-200	Cardiac Pacemaker Epoxy Molding Fixture - Details

The following drawings for fixtures have been completed during the month of March.

15-D-4189-201	Outgassing and Closure Plug Welding Fixture - Positioning Fixture Assy.
15-D-4189-202	Outgassing and Closure Plug Welding Fixture - Positioning Fixture Details
15-D-4189-203	Inert Atmosphere Chamber Stand Details
15-D-4189-204	Multiple Outgassing and Closure Plug Welding Fixture Details
15-D-4189-205	Thermocouple Tape Plating Gage Fixture - Details
15-D-4189-206	Grit Blasting Chamber Tray Details
15-D-4189-207	Multiple Outgassing and Closure Plug Welding Fixture Electronics Cabinet Panel Detail
15-D-4189-208	Multiple Outgassing and Closure Plug Welding Fixture Electronics Cabinet - Assembly
15-D-4189-209	Epoxy Mold Vacuum Chamber

The following drawings for fixtures have been completed during the month of April.

15-C-4189-121	Cam Driven Welding Fixture, Detail
15-D-4189-210	Cam Driven Welding Fixture Assembly (Front View)
15-D-4189-211	Cam Driven Welding Fixture Assembly (Top View)
15-D-4189-212	Cam Driven Welding Fixture Slide Details
15-D-4189-213	Cam Driven Welding Fixture Slide Details
15-D-4189-214	Cam Driven Welding Fixture External Case Cam Details
15-D-4189-215	Cam Driven Welding Fixture Electronics Case Cam Details

Thermocouple Tape and Insulation Tape

The Phase II thermocouple tape and insulation tape has been received. These tapes are now being evaluated by Quality Control.

Mechanical Components Completed

1. 100 Terminal Blocks have been machined.
2. 125 Support Brackets have been remachined to accommodate the new longer spacing of the thermopile, which was concluded necessary after the thermal performance tests made with XP-16.

Gas Pressure Test on Prototype Unit XP-9

In order to determine the actual affect of gas pressure in an assembled pacer on output power, tests were made with nitrogen and helium from the micron range to one atmosphere pressure. The tests were conducted on the unsealed unit XP-9. This

pacers were sealed in a glass vacuum system in which pressures could be monitored with a mercury McLeod gauge, thermocouple gauge or mercury monometer. Voltage, resistance and case temperature measurements were made through glass-to-metal electrical feedthroughs. For each particular measurement gas was introduced to a predetermined pressure and measurements made until a constant open circuit voltage was reached. This time period was about 8-12 hours. The resistance of the thermopile remained the same throughout the tests ($\sim 47,300 \Omega$). Open circuit voltage under high vacuum was consistently about 5.92 volts.

Helium is a gas with very high thermal conductivity (360×10^{-6} cal/sec cm^2 $^{\circ}\text{C}/\text{cm}$) and was used to compare results with nitrogen which has a thermal conductivity (62.4×10^{-6} cal/sec cm^2 $^{\circ}\text{C}/\text{cm}$) comparable to the gases that might accumulate in a pacer.

The results of these tests are shown in Figure 18 which indicate that performance is severely affected in the 30 to 1000 μ range of pressure but is roughly independent of the thermal conductivity of the gas.

The performance becomes independent of pressure above a few mm of mercury and does show the effect of large differences in thermal conductivity.

PACER UNIT XP-9 6 TAPES IN SERIES

Figure 18

TASK 4.0 - SYSTEM TESTING

Table 1 contains the status of all the experimental models on life test. Unit E-3 which had shown a very slow rate of degradation before the last report period has remained essentially constant 72.7 ¹¹⁰ to 72.9 ¹¹⁰ over the last six months. None of the units has shown any degradation.

Data for prototype units is shown in Table 2. The three prototype units still running have not shown any degradation.

Table 1
Experimental Model Life Test Data
 4-31-71

			<u>Present Data</u>		<u>B.O.L. Data</u>	
			<u>Output*</u>	<u>Pulses/minute</u>	<u>Pulses/minute</u>	<u>Output*</u>
E-3 (1) (2)	28,401		72.9 μ W			84.8 μ W
E-4	27,949		2.6ma	77.5	78.6	2.9ma
E-5	26,222		3.8ma	94.0	95.7	4.4ma
E-9 (2)	19,641		82.1 μ W			82.3 μ W
E-10 (5)	18,301		73.4 μ W			77.5 μ W
E-12 (4) (3)	19,070		255.8 μ W			230.0 μ W
E-13BB	13,334		7.5ma	130.4	123.0	8.0ma
E-14 (4) (6)	11,701					
E-16	15,801		6.6ma	131.6	130.0	7.6ma
E-17 (4)	16,885					
E-18	15,993		7.1ma	128.2	125.2	8.0ma
E-20 (7)	12,300		260.9 μ W			260.5 μ W
TOTAL	225,598					

- (1) Battery unit.
- (2) Stopped pulsing 4-9-70 and could not be restarted. Electronics removed and load line obtained.
- (3) Had stopped in dog test. Electronics failed - removed 6-30-70.
- (4) Implanted in dog.
- (5) Not pulsing 7-14-70. Disconnected and removed electronics 7-16-70.
- (6) Returned 7-23-70. Not pulsing. Hours shown to 7-23-70. Module and electronics failed.
- (7) Disconnected and removed electronics 7-10-70.

*Peak power is given in microwatts if unit had no electronics on 4-31-71. For units with electronics, values are pulse height in milliamperes.

Table 2

Prototype Model Life Test Data

4-31-71

<u>Unit</u>	<u>Hours</u>	<u>Present Data</u>		<u>B.O.L. Data</u>	
		<u>Output</u>	<u>Pulse/minute</u>	<u>Pulse/minute</u>	<u>Output</u>
P-1 (2) (1)	12,684	6.1 ma	126.5	125.3	5.5 ma
P-2	11,821	6.3 ma	130.4	126.9	5.7 ma
P-3 (2) (5)	12,637	203.9			231.9 μ W
P-4 (2) (6)	6,742				
P-5 (2) (10)	11,437				
P-6 (2) (3)	2,938				
TOTAL	58,259				
XP-10 (4) (7)	1,344				
XP-14 (8)	560				
XP-15 (9)	540				

- (1) Returned from dog implant and has restarted, electronics was opened to get load line.
- (2) Dog implants.
- (3) 5-15-70 unit not running - observed at NHI. Returned 5-26-70 to NUMEC. Hours shown to 5-15-70.
- (4) Sealed 7-22-70 @ 1255.
- (5) Returned from NHI not pulsing 10-15-70. Re-started this date with external battery. Opened electronics case to get load line.
- (6) Unit returned 8-27-70 not pulsing. Case punctured and opened 8-28-70. Hours shown to 8-28-70.
- (7) Unit failed 9-15-70, while being tested to destruction during drop testing.
- (8) Sealed 10-13-70. Unit shock tested to destruction. Opened 11-5-70.
- (9) Sealed 10-28-70. Opened 11-20-70.
- (10) P-5 failed 3-15-71.

TASK 5.0 - SAFETY

Safety Analyses of Possible Cremation Conditions

Additional results have been developed on the assessment of possible cremation conditions for a Radioisotope Powered Cardiac Pacemaker which has been accidentally left in a body prior to cremation. This study was conducted to determine the expected temperature versus time conditions during such a cremation exposure. After initial investigations, one actual measurement of the cremation temperature as a function of time was performed in order to provide preliminary information for design purposes. These results were reported previously. In order to obtain a better estimate of the maximum temperature during cremation, various crematories and cremation furnace manufacturers throughout the United States were contacted. The inquiries were made in such a manner as to provide a representative sampling across the country.

All crematories contacted were asked three basic questions: 1) What was the maximum temperature reached in their cremation furnace and if the quoted temperature was substantiated by thermocouple measurements; 2) What was the duration of the cremation cycle; and 3) What type of burner was used, whether it be gas or oil, and the name of the furnace manufacturer. Similar questions were posed to the furnace manufacturers. Additional comments were usually made by the personnel contacted and some of these were related to the melting of different types of jewelry or tooth fillings. Accordingly, melting points of various jewelry alloys and pure metals were tabulated for comparison purposes. Since some of the results quoted were qualitative and/or inconsistent and not supported by experimental data, various crematories throughout each state were designated by a letter within that state.

Shown in Figure 19 are the maximum cremation temperatures quoted or measured by various crematories throughout the United States. Of the total of 29 crematories contacted, 18 of these provided measured or quoted maximum temperatures. In some cases, a temperature range was specified. In others, the data was recorded even though it might possibly be inaccurate based on other information transmitted. In Figure 19, the maximum measured cremation temperatures range from 1800 to 2300°F, as specified by six of these eighteen crematories. Other quoted temperatures and temperature ranges which were not supported by thermocouple measurements fell between 1000 and 2300°F and this information was provided by eight other crematories. Since the standard minimum temperature to effect cremation

MAXIMUM CREMATION TEMPERATURES QUOTED OR MEASURED BY VARIOUS CREMATORIES

43

Figure 19

is in the range of 1300 to 1350°F (in order to obtain the autoignition of the free carbon) quoted temperatures below 1300°F are considered to be possibly inaccurate.

In addition, some high temperatures quoted from four other crematories were deemed as possibly inaccurate. These high temperatures ranged from 2400 to 3000°F. Primary reasons for considering that these quoted temperatures may be inaccurate were: a) due to the inconsistency of a high maximum temperature with an extremely long time for cremation; b) due to inconsistencies of the high maximum temperature with the quoted degree of melting of various jewelry and tooth filling alloys; c) the fact that the upper limit temperature for the firebrick lining of most furnaces is about 2600°F, and that above this temperature the firebrick begins to flow; and/or d) a wide temperature range was quoted, detracting from the credibility of the temperatures.

Figure 20 presents the results obtained on the maximum cremation temperatures measured by various cremation furnace manufacturers. Five manufacturers were contacted and their maximum temperatures ranged nominally from 1400°F to 2200°F. In addition, as noted in the figure, the Industrial Equipment and Engineering Company in Florida stated that they have one type of furnace which has the capability of achieving temperatures of 2500°F but this is only after five to six hours of continuous operation. For the Jones Incinerator Company cremation furnace, a maximum of 2800°F was observed in the first ten minutes as measured at the top of the furnace and not near the body. In this first ten minutes, very little of the body has been burned during cremation. Shortly thereafter, the maximum temperature decreases to 2400°F for the next 20 to 30 minutes of operation.

Safety Testing

Fuel simulants were prepared and delivered to Mound Laboratory for loading within the Phase II safety test capsules. A total of 58 pins having a 0.049" diameter and 0.520" length were fabricated from tantalum wire to simulate the weight and size of the RPCP prototype capsule plutonium metal fuel. Three of these pins are to be used for each simulated heat source and a total of 17 safety test capsules require a fuel simulant.

Cremation Tests on Compatibility of Bismuth Telluride with Various Capsule Materials

Simulated cremation tests were performed on small quantities of bismuth telluride in contact with various fuel capsule materials. These tests were done to: a) evaluate the compatibility of bismuth telluride thermoelectric module materials with various capsule materials in a cremation environment, and b) compare the new data with earlier results made on the cupron tophel special thermoelectric

MAXIMUM CREMATION TEMPERATURES MEASURED BY VARIOUS CREMATION FURNACE MANUFACTURERS

CREMATION FURNACE MANUFACTURERS

FLORIDA - INDUSTRIAL EQUIPMENT
& ENGINEERING CO.

2.

CALIFORNIA-ALL-INDUSTRIAL
FURNACE CO.

CALIFORNIA-SMITH ENGINEERING CO.

ILLINOIS- JONES INCINERATOR CO.

NEW YORK-MORSE BOULGER CO.

LEGEND

— TEMPERATURE RANGE

● MEASURED TEMPERATURES

Figure 20

conversion material of the existing RPCP design. The tests were conducted to a maximum cremation temperature of 2100°F in both oxidizing and vacuum environments to correspond to the circumstance of the outer system (pacemaker) housing being either breached or unbreached, as a result of the cremation exposure. During each of these tests, samples of the Bi_2Te_3 were placed in contact with pieces of titanium, Hastelloy "C", tantalum and platinum as potential radioisotope heat source outer encapsulating materials. The first group of tests were performed in an oxidizing environment in a muffle furnace in which the temperature was programmed to a maximum of 2110°F over a 1-1/2 hour time interval. The encapsulation material being tested was formed as a small boat in which the bismuth telluride material was placed. After five minutes of operation, the temperature in the furnace was 1780°F and some gaseous fumes (Bi_2Te_3) evolved.

After 30 minutes of testing, when the temperature reached 2025°F, a significant oxide and/or nitride scale was evident on the titanium boat material and the Bi_2Te_3 residue was contained in the corner of the boat. On the Hastelloy "C" sample, a fuzzy buildup on the surface was evident. The tantalum boat was severely oxidized by this time and the bismuth telluride residue was located in the corner of the boat. The bulk of the bismuth telluride material had vaporized. It is not certain whether any intermetallic attack between the Bi_2Te_3 module material and the above three encapsulating materials occurred; however, if such attack occurred, it was a limited affect.

Both 0.002" and 0.020" thickness of platinum boats were fabricated, and a small sample of Bi_2Te_3 material placed in the boat for testing in an oxidizing atmosphere. In both of these samples, the molten bismuth telluride wetted the upper wall surfaces, attacked the platinum simulated capsule wall material and produced a hole in the bottom of the boat. Table 3 summarizes the above data as well as the results in a vacuum environment. Thus, it was concluded that it is not desirable to use a bismuth telluride module material in a system design in which the melted bismuth telluride material can come in contact with a platinum capsule wall in an oxidizing environment during cremation or other similar fire exposures. The system that is the subject of this program does not use bismuth telluride at all.

Similar testing was performed with these four encapsulating materials in contact with molten bismuth telluride in a vacuum environment. Ribbons or pins of titanium, Hastelloy "C", tantalum, and platinum were assembled within vicor tubing with pellets of bismuth telluride. After pumpdown and sealing of these tubes, the entire assembly was programmed along a simulated cremation cycle to a maximum temperature of 2050°F for approximately one hour and twenty minutes.

COMPATIBILITY OF BISMUTH TELLURIDE (Bi_2Te_3) WITH
VARIOUS CAPSULE MATERIALS AT CREMATION TEMPERATURES

Tests performed for 1.5 hours along a simulated cremation curve to a maximum temperature of 2110°T in air and vacuum environments

<u>Bi_2Te_3 in Direct Contact with a Fuel Capsule Material Of:</u>	<u>Size of Sample</u>	Results From Tests In:		
		<u>An Oxidizing Atmosphere (Air) Environment</u>	<u>Size of Sample</u>	<u>Vacuum Environment</u>
Titanium (Ti)	0.013" thick boat	Formation of oxide and nitride scale on Ti; no significant attack by Bi_2Te_3 on Ti	0.013" thick ribbon	Significant wetting of Ti by Bi_2Te_3 ; no significant attack by Bi_2Te_3 on Ti observed
Hastelloy "C"	0.025" disc	Formation of fuzzy scale on surface of Hastelloy "C"; no significant attack by Bi_2Te_3	0.125" dia. rod	Partial alloying of Bi_2Te_3 with Hastelloy "C"
Tantalum (Ta)	0.010" thick boat	Severe oxidation of Ta; no observed Bi_2Te_3 attack	0.010" thick ribbon	Significant wetting of Ta by Bi_2Te_3 ; no observed Bi_2Te_3 attack
Platinum (Pt)	0.020' and 0.002" thick boats	Severe corrosive attack by Bi_2Te_3 on Pt; produced a hole through both the 0.002" and 0.020" thick material	4 ribbons, 0.002" thick	Significant alloying and melt down of Pt occurred

Table 3

Subsequent to the completion of the tests, the ribbons or pins of encapsulating material were removed from the vicor tubes. Results on the titanium and tantalum ribbons were very similar in that general wetting and possible but relatively shallow intermetallic attack occurred. However, no corrosive holes were generated completely through either the 0.013" titanium or the 0.010" tantalum.

In the case of the Hastelloy "C" pin placed in a vacuum environment with the bismuth telluride, some alloying of the Hastelloy with Bi_2Te_3 occurred. The platinum ribbons enclosed in a vacuum environment with a pellet of bismuth telluride showed significant alloying and melt-down of the platinum. Again, this data for vacuum environment cremation conditions are summarized in Table 3.

From the above results, it was ascertained that, on a preliminary investigational basis, the application of platinum as an outer fuel encapsulating material is not desirable if bismuth telluride material can come in direct contact with that encapsulation. If a Bi_2Te_3 material does come into direct contact with a platinum encapsulating material and the material is subjected to a cremation or other high fire temperature in either an oxidizing or vacuum environment, failure of that encapsulating material will most likely occur. Hastelloy "C" exhibits some alloying but from the limited testing performed it is uncertain if a capsule of Hastelloy "C" would or would not fail.

Tantalum is also a poor choice for direct contact with bismuth telluride but primarily on the basis that if tantalum is the outer encapsulation, it could become readily oxidized as a result of the possible exposure to oxygen if the outer system case is breached. Titanium appears to be the best choice of the materials tested from a compatibility point of view with bismuth telluride.

Since previous cremation testing of Cupron Special-Tophel Special with a titanium outer fuel encapsulation produced no attack on titanium, titanium appears to be the best choice as an outer fuel encapsulation material for this application. Moreover, it should be recognized that a complete determination of the suitability of a given encapsulation system relative to fire and cremation conditions must be demonstrated by system tests in addition to bare capsule tests since the sensitivity of the fuel encapsulation to all of the materials contained within the system design requires demonstration.

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GENERAL NOTES:

1. ALL PIECES AND ASS'Y OF SUCH TO MEET NPS-15A SPECIFICATIONS.
2. SILASTIC MATERIAL TO BE INSERTED BY DOCTOR AT IMPLANTATION.

FOR DESCRIPTION OF CALLOUTS SEE BILL OF MAT'L'S
DWG. #15-D-4189-2
FOR SUB-ASS'Y SEE DWG #15-D-4189-3

REF. DWGS.										TOLERANCES UNLESS OTHERWISE SPECIFIED		NUMEC							
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15-D-4189-3	CASE, LID AND ELECTRONICS CASE SUB-ASS'Y	15-D-4189-12	THERMOPILE SUPPORT BRACKET TEMPLATE DETAILS	15-D-4189-21	COLD STRAP - DETAILS	15-A-4189-2	GETTER PELLET - DETAIL			DECIMALS	±	APOLLO, PA. U.S.A.							
15-D-4189-4	NUCLEAR BATTERY AND LID - SUB-ASS'Y	15-D-4189-13	CASE LID, ELECTRONICS CLOSURE + LID DIE BLANK - DETS	15-D-4189-22	FUEL ENCAPSULATION ASS'Y AND DETAILS	15-A-4189-3	SET SCREW - DETAIL			ANGLES	± 1/2°	RPCP MODEL NU-4 SERIAL NOS. 1 THRU 100							
15-D-4189-5	NUCLEAR BATTERY - SUB ASS'Y	15-D-4189-14	HOT STRAP, HOT & COLD TABS - DETAILS	15-D-4189-23	HEART LEAD ASS'Y AND DETAILS	15-A-4189-4	THERMOPILE SUPPORT BRACKET BLANK			SURFACE FINISH	✓	ASSEMBLY							
15-D-4189-6	THERMOPILE - ASS'Y	15-D-4189-28	TERMINATION BLOCK AND GETTER BASKET - ASS'Y	15-D-4189-24	INSULATION & THERMOPILE TAPE - ASS'Y	15-A-4189-5	SUPPORT BRACKET END BRACE - TEMPLATE			SCALE 4" = 1"		DRAWN 4-22-70 CHECKED 11-15-70 APPROVED 12-1-70	DWG NO. 15-D-4189-1	OF	2				
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