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CONTRACT AT(30-1)-3979
ADVANCED HEAT PIPE
THERMIONIC TECHNOLOGY

MASTER

MID-TERM STATUS REPORT
FOR
TASK I
"DEVELOPMENT OF HIGH VOLTAGE MODULE"

PERIOD OF PERFORMANCE
MAY 1, 1968 THROUGH FEBRUARY 28, 1969

PREPARED FOR:
U. S. ATOMIC ENERGY COMMISSION
NEW YORK OPERATIONS OFFICE
NEW YORK, NEW YORK

BY
RCA ELECTRONIC COMPONENTS
POWER DEVICES OPERATION
LANCASTER, PENNSYLVANIA

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FOREWORD

This report was prepared by RCA, Lancaster, Pennsylvania under U. S. Atomic Energy Commission Contract AT(30-1)-3979 entitled, "Advanced Heat Pipe Thermionic Technology". The program of work, to date, has been monitored by Mr. Lester Price of the Space Nuclear Systems Division, Germantown, Maryland.

This Mid-Term Status Report covers the work performed since program inception, 1 May 1968 through 28 February 1969. The studies and accomplishments presented therein represents the efforts of the Special Power Devices Engineering Department. Mr. W. E. Harbaugh, Project Engineering Leader, provided technical direction for the program. Mr. R. W. Longsderff, Project Engineer for the program, directed a group of technical personnel in performance of the actual program of work.

ABSTRACT

The design of a heat pipe-thermionic module concept capable of output potentials as high as 28 volts has been investigated. Technologies required for this module design have been developed beyond the state-of-the-art. An advanced Al_2O_3 casting technique was developed for the fabrication of the key insulated tri-layer assembly. Arc suppression coatings have been developed for the prevention of voltage arcs in the module due to potentials above the ionization potential of cesium. Fabrication and assembly techniques necessary for the logical development of the high voltage module concept have also been investigated. Heat pipe designs capable of transferring the required thermal through-put for high voltage module concepts have also been investigated.

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TASK I - DEVELOPMENT OF HIGH VOLTAGE MODULE
(Responsible Person - R. W. Longsderff)

SECTION I

INTRODUCTION

The inherently low impedance of a single thermionic diode presents problems associated with high current devices, ie., high lead losses, increased system weight etc. although series connection and/or power conditioning can offset some of these problems, the advantages gained are often nullified by additional system losses and added system weight. Therefore, it is obvious that a higher voltage thermionic system which is capable of eliminating the need for power conditioning or external series connection of multiple units is of major importance. Efforts have been accelerated to develop a design approach which employs internally connected diodes to form a multi-converter module with one cesium reservoir which is capable of output voltages as high as 28 volts.

This design concept consists of basic diode assemblies mounted on a common heat pipe and internally series connected. Each basic converter section is electrically insulated from but thermally bonded to the common heat pipe heat source by cast alumina layers. The collector of each converter section employs a similar cast-alumina layer to insulate individual collectors from a common outer containment tubing. The respective converter units are internally connected by a spiral slotted interconnecting lead.

Two of the more complex problems that must be resolved before this type of system can be brought to reality are (1) proper arc suppression within the cesiated device (cesium has an ionization potential of 3.89 volts), and (2) maintenance of adequate inter-electrode spacing for a large number of converter sections.

SECTION II

PROGRAM ACCOMPLISHMENTS

A. Electrode Technology (Responsible Persons - R. W. Longsderff/S. W. Kessler)

The key component in the high voltage module concept is the insulated emitter-collector electrode assembly. Accordingly, considerable effort has been devoted to the task of developing technology which will enable insulated electrode assemblies to be fabricated on a repetitive basis. This effort is divided into tasks involving alumina casting, casting weld tests, interelectrode lead development, assembly techniques and finish machining techniques. To date, the major effort has been devoted to the development of advanced casting techniques and casting weld tests.

1. Casting Techniques

Initial casting technology employed during the program used an existing technique developed by RCA under contractual sponsorship of the U. S. Air Force. This technique employs a capillary type flow of alumina between two concentric molybdenum cylinders as shown in Figure 1. Although this method has proven satisfactory for the flow of alumina throughout the casting, the alumina exhibited a porous, spongy type structure as well as small void areas. A yield of approximately 20% was average and repeated thermal cycling was necessary to insure adequate filling. For these reasons, advanced casting techniques were initiated and explored.

The initial samples were fabricated using the capillary type method and checked with an ultrasonic flaw detection apparatus. The tests

FIGURE 1 CROSS-SECTIONAL DRAWING OF CAPILLARY CASTING

showed the samples to be completely filled and free of large voids. However, cross-sections of the samples indicate that small bubble-like voids existed throughout the casting. The results of these tests established two distinct problems with regards to the casting technique. First, complete filling of the casting with alumina is dependent upon an equal flow (down the capillary) around the entire circumference of the casting. If one side of the capillary is filled faster than the other, capillary force will cause circumferentially filling as well as sealing off large void areas. At liquid temperature, the viscosity and surface tension of Al_2O_3 are sufficient to cause the flow of the liquid into the casting to be random and inturn encapsulate gas pockets. Second, during casting the liberation of gas in the capillary area causes small bubble-like voids throughout the alumina layer. These two distinct problems appear to be dependent on a number of conditions and parameters.

The time-temperature relationship (during casting) appears to be extremely critical for proper flow of the Al_2O_3 into the casting since viscosity and surface temperature are temperature dependent. The time element allows for greater outgassing of the casting components. Purity of casting materials, such as the Al_2O_3 , molybdenum parts, and furnace atmosphere may all contribute to the formation of bubbles and voids. As a result of these conditions, several tests procedures were developed in an effort to gain control of the variables.

Four Al_2O_3 samples, each acquired from different processes and/or vendors, were placed in molybdenum cups and fired at schedules similar to those used for casting. The results showed evidence of gas bubbles in all four samples. The furnace schedules were altered to permit investigation of the time-temperature relationship during casting. In one

test, the rate of temperature change with respect to time was greatly increased. The bubble formations were more pronounced and greater in number. In another test, the rate of temperature change with respect to time was decreased. The bubble formations were not as pronounced as in the first test and the Al_2O_3 layer, which was very dense and transparent, showed no evidence of bubble formation. The first test was performed in a 100% helium atmosphere.

Several additional test samples were cast, using 100% helium atmosphere, to refine the furnace schedule and determine optimum helium flow rates. Samples from these tests revealed the presence of small patches of free molybdenum floating on top of the Al_2O_3 . The presence of this molybdenum indicated that the furnace atmosphere was not completely neutral, was oxidizing the furnace shields at a lower temperature, and that these oxides were being dissociated at the higher casting temperatures.

Tests were performed to determine the optimum ratio of helium to hydrogen in order to establish a completely neutral furnace atmosphere. A ratio of six to one (helium to hydrogen) flow rate to the furnace produced samples which were free of bubbles and molybdenum deposits on the Al_2O_3 .

The second area of concern, which involves the formation of gas pockets during casting, was investigated using a lucite model and glycerine as a casting fluid. Results of these tests show that the gas pockets were created by an uneven flow rate (from top to bottom) around the circumference of the tri-layer. As a result, the bottom of the sample is filled before all areas along the length of the sample are filled thereby forming gas pockets which are virtually impossible to eliminate due to the viscosity and surface tension of the Al_2O_3 .

Another test was performed in which the lucite model was tilted at a 60 degree angle and the glycerine added in the lower half of the top opening. This procedure established a method of positive gas displacement along the upper portion of the sample circumference. The results of this test proved that gas pockets can be eliminated. The casting was modified to incorporate a separate Al_2O_3 reservoir as shown in Figure 2. This reservoir was connected to the bottom of the casting assembly by 1/4 inch O. D. tubing. As a result, the Al_2O_3 flow pattern is from the bottom of the casting to the top, thereby permitting positive gas displacement out the top of the assembly. A picture of this assembly is shown in Figure 3. Adoption of this method also permitted use of a pure helium furnace atmosphere since dissociated residual molybdenum will float in the Al_2O_3 reservoir. Assemblies of this type were fabricated and casting tests performed. Analysis of these assemblies indicated that a reaction occurred between the molybdenum tubing and the Al_2O_3 . This reaction created a flow problem in the 1/4 inch O. D. tubing between the reservoir and the casting.

Analysis of the tubing showed that powdered metallurgy tubing of questionable purity had been used for these tests. A grey sluggish compound formed in the tubing and inturn clogged the flow to the casting. Vacuum-arc-cast tubing was substituted and additional tests performed. Good results were attained on two consecutive assemblies after normal flow was established throughout the casting. No large gas pockets were detected in the casting, however, the Al_2O_3 did not appear to be of maximum density. It is theorized that the time-temperature schedule and furnace atmosphere may have contributed to this condition. However, subsequent tests, using varying furnace atmospheres and time-temperature schedules did not completely remove the small bubble formations

FIGURE 2 CROSS-SECTIONAL DRAWING OF GRAVITY/
CAPILLARY CASTING

FIGURE 3 PHOTOGRAPH OF CASTING EMPLOYING
EXTERNAL Al_2O_3 RESERVOIR

in the alumina layer. As a result, an improved casting method was pursued. Since the problem appeared to be the generation of gas within the melting Al_2O_3 or the entrapment and combining with other gases, a logical approach would be to create a vacuum in the capillary area prior to filling. Accordingly, these gases would then be removed and the liquid Al_2O_3 would then be forced into the capillary area. A cross-section view of this casting assembly is shown in Figure 4.

One assembly was fabricated with the liquid Al_2O_3 reservoir located at the top of the casting. The bottom of the casting was sealed to a 1/4 inch O. D. exhaust tubing. This 1/4 inch molybdenum tubing extended below the furnace hot zone and was connected to both a helium line for pressurization before the Al_2O_3 melted, and a vacuum system which evacuated the 1/4 inch tubing and capillary area after the Al_2O_3 melted. Thus, the Al_2O_3 was forced down the capillary and into the 1/4 inch tubing where solidification took place due to the reduction in temperature. The process was completed following closure of the 1/4 inch tubing. A block diagram of this system is shown in Figure 5. A picture of the casting assembly is shown in Figure 6.

Results of these tests indicated total filling of the capillary with solid Al_2O_3 . No voids or spongy areas were found throughout the sample. One section, 0.400 inches long, was cut from the sample and metallogically polished on both ends. A photomicrograph of the sample is shown in Figure 7. This sample had a cold resistance of 500,000 ohms in either direction. In addition, a high intensity lamp beam was projected into the Al_2O_3 layer and observed on the opposite side. The sample was leak-checked to determine the vacuum integrity of the alumina layer.

FIGURE 4 CROSS-SECTIONAL DRAWING OF VACUUM CASTING

FIGURE 5 SCHEMATIC DIAGRAM OF VACUUM CASTING TECHNIQUE

FIGURE 6 PHOTOGRAPH OF VACUUM CAST ASSEMBLY

FIGURE 7 PHOTOMICROGRAPH OF VACUUM CAST
ALUMINA TRI-LAYER (Magnification 138X)

This test indicated that the sample was not impervious to helium. A complete coherent seal was not anticipated since cracks do exist due to the difference in thermal expansion between the Al_2O_3 layer and the molybdenum sleeves.

Additional tests, employing the vacuum casting technique, were performed to further define casting parameters, ie., optimum temperature, back pressure, etc. Results of these tests indicate that quality of the casting is dependent upon temperature and Al_2O_3 viscosity. If, during casting, the temperature is above $2080^{\circ}C$ the viscosity is lowered to the point where it is difficult to hold the liquid level at the capillary entrance prior to evacuation. Thus, Al_2O_3 flows into the capillary prematurely, closing the vacuum appendage. Increasing the back pressure above the normal head pressure (approx. 3 lb/in^2) to the capillary produces a bubbling condition in the Al_2O_3 reservoir which induces voids. It is therefore necessary to maintain accurate temperature control as well as helium back pressure to the capillary.

All of the above mentioned tests were performed using a 6:1 helium to hydrogen furnace atmosphere. Tests employing a temperature above $2080^{\circ}C$ during casting showed that small bubble formations in the Al_2O_3 were formed. It can, therefore, be concluded that the furnace atmosphere was of a reducing type atmosphere and that these bubble formations are pronounced at higher temperatures. It is therefore desirable to change the furnace atmosphere to a more neutral or slightly oxidizing atmosphere and to complete the vacuum casting operation at temperatures just above the melting point of Al_2O_3 . Tests performed using optimized furnace atmospheres and temperatures produced sound, dense castings which

approach single crystal structure in the tri-layer area. Samples fabricated using this advanced casting technique will be thermally and electrically evaluated.

2. Electrode Fabrication

Electrode assemblies are fabricated using one quarter inch sections cut from the 3 inch length casting. This cutting process must be performed using methods which will not crack or pull-out the alumina layer. Several types of abrasive cutting wheels were employed for this process. The Allison No. GC120 and Beuhler No. 4110 have proven to be superior. A clean 1/8 inch cut, with no chipping or breaking out of the alumina layer, can be made using either of these cutting wheels.

The machining of the tri-layer assembly, shown in Figure 8, is complicated by the presence of the alumina layer. Machining tests indicated that the machinability of assemblies without damage to the alumina layer is dependent upon the quality of the alumina layer plus good refractory metal machining practices. Assemblies which were porous and/or spongy broke-out readily when machined, while assemblies which displayed solid alumina layers were machined with little or no damage to the alumina layer. A photograph of a machined electrode assembly is shown in Figure 9. The importance of the machined end areas of the tri-layer has been demonstrated in tests performed for the U.S. Air Force in which voltages up to 50 volts DC were applied across tri-layer assemblies at 1500° C. In most samples, voltage break-down occurred in these chipped-out end areas. Closure of these end areas with a high voltage coating is discussed in the following paragraphs.

FIGURE 8 CROSS-SECTIONAL DRAWING OF EMITTER/COLLECTOR
TRI-LAYER ELECTRODE ASSEMBLY

FIGURE 9 PHOTOGRAPH OF EMITTER/COLLECTOR
TRI-LAYER ELECTRODE ASSEMBLY

The electron beam welding of electrodes to the interelectrode lead is another technology necessary in the fabrication of electrode assemblies. Sound mechanical joints are necessary to insure low impedance from an electrical point of view. Welding criteria must produce accurate alignment between electrodes without damaging the cast alumina layer.

The electrode assembly technique involves the welding of the emitter-lead-collector assembly prior to the slotting of the lead. A weld fixture was designed in which concentricity of emitter-collector surfaces are maintained following electron beam welding. Therefore, electrode alignment is positive on the inner heat pipe tubing. Slotting of the interelectrode lead is detailed in subsequent paragraphs. A drawing of this welding fixture is shown in Figure 10. The fixture utilizes 1/8 inch diameter sapphire balls as bearing surfaces in the alignment of the emitter and collector tri-layer assemblies. These bearings provide very accurate (less than 0.002 inch tolerance) method of electrode alignment and easy removal of the sub-assembly after welding by removal of the sapphire balls.

Several weld tests have been conducted primarily to determine if damage to the alumina tri-layer occurs during normal electron beam welding. Assemblies were welded using an electron beam welding schedule of 65 kilovolts at 6 milliamperes and at a part rotation of 20 rpm. This schedule produced more local heating than the normal schedule of 70 kilovolts at 6 milliamperes and part rotation of 30 rpm. However, no damage to the cast alumina layer was observed. These tests did reveal that changes to the welding fixture were necessary. Spring tension, established by the weld fixture on the welded assembly, caused the interelectrode lead to buckle during welding. This spring has been changed to allow axial movement of the assembly during welding.

FIGURE 10 CROSS-SECTIONAL DRAWING OF ELECTRON BEAM WELDING
FIXTURE FOR ELECTRODE SUB-ASSEMBLY FABRICATION

Additional weld tests will be performed to establish the mechanical strength of the weld and evaluate the completed sub-assembly with respect to end use application.

The interelectrode lead previously mentioned forms the series connection between collector and preceding emitter assembly. Therefore, it is necessary that this lead be designed with an area to length ratio which will prohibit excessive electrical losses and excessive thermal losses from emitter to collector. An optimization of the lead area to length ratio can be established by slotting the lead as shown in Figure 11. By varying the number of slots, slot length and slot thickness, a optimized area/length relationship can be established.

The lead for 1450° C emitter temperature, used in the initial module design, was optimized by employing 0.005 inch thick molybdenum having six 0.85 inch slots, 0.015 inch wide. These slots are spiraled and over-lap each other by approximately 50% as shown in Figure 11. The width between slots is approximately 0.100 inch. Slotting tests, using the electrical discharge cutting technique, have been made. This method has proven successful in that accuracy can be maintained without experiencing severe mechanical stress.

Following successful welding and slotting of the electrode assembly, post weld, slot machining is performed as required to insure concentricity of electrode surfaces as dictated by subsequent assembly procedures. Successfully fabricated assemblies are thermal cycled to insure thermal stability.

Before Slotting

After Slotting For
Lead Correction

FIGURE 11 CROSS-SECTIONAL DRAWING OF INTER-ELECTRODE LEAD

B. Cast Alumina Technology (Responsible Persons - R. W. Longsderff/S. W. Kessler)

The cast alumina tri-layer technology is the key to the high voltage module concept. Cast alumina has been used to insulate the emitters of multi-converter modules from the central heat source. Although the tri-layer was exposed to cesium there was no voltage impressed across it during these tests. In other tests, tri-layer elements have held off 30 volts in vacuum at 1600° C while conducting thermionic input heat fluxes greater than 30 watts per square centimeter. Further evaluation of the tri-layer is necessary to determine the voltage hold-off capabilities in a cesiated atmosphere over the range of temperatures to be employed in the high voltage module concept.

A test vehicle has been designed and fabricated for tri-layer assembly testing. A cross-section of the test vehicle is shown in Figure 12. This test vehicle, which utilizes a heat pipe to supply the heat input to the tri-layer assembly, is designed to permit calorimetric measurements of heat flux through the tri-layer assembly. A large sapphire viewing port permits visual observance during test. Cesium pressure can be varied over the entire range of thermionic pressure by use of an external liquid cesium reservoir. True hohlraums have been included in both sides of the alumina tri-layer as well as the heat pipe to enable measurement of the complete temperature profile across the thermal path. Voltage can be applied across the alumina layer since the heat pipe and calorimeter are separated by a ceramic insulator.

The assembly to be tested will also be coated at both ends with an arc suppression coating to prevent cesium from entering the alumina layer and to extend the insulating path beyond the 0.005 inch thickness of the alumina

FIGURE 12 CROSS-SECTIONAL DRAWING OF CAST ALUMINA TEST VEHICLE

layer. The composition and method of application of this coating is described in subsequent paragraphs.

Design goals for the test assembly are: (1) voltage hold-off up to 30 VDC minimum, and (2) 30 watts per square centimeter heat flux transferred thru the alumina layer. Both conditions will be achieved at a temperature of 1450° C and 4 mm Hg cesium pressure. Assemblies meeting these design objectives will be life tested for 1000 hours at the above stated conditions.

C. Ceramic Spacer Technology (Responsible Person - R. W. Longsdorff)

The design criteria of the high voltage module concept necessitates use of high strength alumina rings for spacing of electrode assemblies. These rings also aid in the shielding of adjacent areas having a difference in potential.

A study of materials which qualify for the established design criteria shows that only high purity alumina and yttria ceramics can be considered as candidates for this application.

The use of single crystal Al_2O_3 or Y_2O_3 has been eliminated because of the difficulty and cost of fabrication with respect to the advantages over alumina or yttria. The ability to fabricate high purity alumina ceramics in varying geometries has been demonstrated in previous ceramic work for fossil-fuel fired thermionic systems. Alumina, therefore was selected as the material for evaluation.

The ceramic spacer design and application is shown in Figure 13. The ceramic spacer is located between two adjacent emitter assemblies during assembly of the module components on the common heat pipe. Ceramic spacer

FIGURE 13 CROSS-SECTIONAL DRAWING OF MODULE
CERAMIC SPACER/COLLECTOR CLOSURE

tolerances must be adequate to accomodate the inherent difference in thermal expansion between the molybdenum heat pipe and emitter section versus the alumina spacer.

Tests will be performed in which ceramic spacers will be located to simulate end use conditions.

D. High Voltage Coating Technology (Responsible Person - R. W. Longsdorff)

The high voltage module concept provides that certain internal portions of the module be at maximum output potential difference while exposed to cesium vapor at elevated temperatures. Therefore, it is necessary to prevent arcs from occurring between these sections by coating them with a layer of insulation.

The module concepts' predominant use of molybdenum dictates the development of a suitable coating which uses molybdenum as a base metal. However, other base materials, (Ta, Cb, and TZM molybdenum alloy) have been used in the initial coating tests to provide a more versatile design approach if required. Coating materials selected for initial evaluation included Al_2O_3 , Y_2O_3 and a combination of both. Boron nitride and silicon nitride were also considered but not tested since they had deficiencies which were not tolerable for the application.

Methods of application which have been considered include: chemical vapor deposition, ion sputtering, spray - sintering and plasma spraying. The proven stability of alumina in similar applications make this a desirable material for evaluation. Methods were developed for applying Al_2O_3 on molybdenum. Samples were coated using a vapor deposition process. These coatings were extremely thin (800-1600 microns) and demonstrated little voltage-hold-off

characteristics, a minimum coating thickness of 0.005 inch was necessary to insure a non-porous surface coating which is due largely to the particle size of the Al_2O_3 powder used. Difficulty was experienced in spraying the smaller particle size necessary to achieve good coverage at a reduced thickness.

Ion sputtering techniques were also considered. However, the lengthy rate of application for the required coverage plus the lack of thermal stability on heavier coatings makes this method of application undesirable.

Another method of application involves a spraying sintering process. A mixture of the insulating powder used plus a suspension liquid for spraying purposes and a binding liquid for holding the insulating powder in place before sintering is sprayed onto the test sample. This coating is prepared, by mixing an ink which consist of the particular insulative oxide (Al_2O_3 , Y_2O_3 , Al_2O_3/Y_2O_3) ethyl cellulose and butyl carbitol acetate as the binder and toluene as the spraying vehicle. The oxide particle size is less than one micron as mixed with the binder and vehicle. This ink is then ball-milled in an Al_2O_3 jar having Al_2O_3 balls to break up the conglomerates formed by the mixture. Initial coating efforts were made without the ball-milling process and found to be porous due to the unbroken conglomerates. Samples of molybdenum, columbium, tantalum and TZM molybdenum alloy were coated using this technique.

Initial tests were made by spraying samples until a continuous surface covering was achieved. Thickness of these coatings was approximately 2-3 mils prior to firing. Samples were then fired to 1800° C in either a vacuum or hydrogen atmosphere for sintering. Some degree of porosity was experienced following

firing. This procedure has been modified to include a single coating of 0.5 to 1 mil which is immediately sintered. This process is repeated until no porosity is evident. This condition usually occurs after three coatings and firings. A coating thickness of 2-3 mils results from this process. The particular results depend upon the base metal, furnace atmosphere used for sintering and the oxide/base metal combination. A summary of the coating techniques is shown in Table I. Of the coating/metal combinations tried, molybdenum-alumina, TZM molybdenum alloy-alumina and molybdenum-alumina/yttria produced the most favorable results. Samples of the more favorable combinations were prepared for test in the test vehicle shown in Figure 14. The initial tests were of little value from a voltage-hold off standpoint. Voltage arcs were experienced between the non-coated edges of the sample holder and the ground point of the test vehicle. However, the samples were thermally cycled in a cesiated atmosphere to a temperature of 1450° C. All samples proved to be thermally adequate.

The test vehicle has been modified to correct the voltage arc problem and additional samples have been prepared for test. Figure 15 is a photograph of this test vehicle.

Another area of coating development to which considerable effort has been devoted is the coating of the end-areas of the tri-layer assemblies. In most tri-layer assemblies small radial cracks, which are due to the thermal mismatch of molybdenum and alumina, leave these end areas subject to cesium penetration and voltage arcing within the tri-layer. If these end areas can be sealed by an additional coating, cesium penetration can be prevented. In addition, as can be seen from Figure 16, at typical thermionic cesium pressure, a distance of approximately 0.4 centimeters is required for voltage

TABLE I
ARC SUPPRESSION COATING SUMMARY

Sample Number	Substrate	Coating	Sintering Atmosphere and Temp.	RESULTS				Comments
				Hardness	Elect. Resis.	Density	Thermal Stability	
1	TZM	Al ₂ O ₃	Vac, 1800° C	G	F	F	G	Single Coat, .002 inch thickness. Pores Open Due to Shrinkage.
2	TZM	Al ₂ O ₃	Vac, 1850° C	G	F	F	G	Same As No. 1.
3	TZM	Al ₂ O ₃	H ₂ , 1800° C	G	F	F	G	Same as No. 1 Except Fewer Voids.
4	TZM	Al ₂ O ₃	H ₂ , 1850° C	G	F	F	G	Same as No. 3.
5	TZM	Al ₂ O ₃ /Y ₂ O ₃	Vac, 1900° C	G	P	P	P	Coating Melted and Balled up on Surface, Could Not Sinter.
6	TZM	Al ₂ O ₃ /Y ₂ O ₃	H ₂ , 1800° C	G	G	G	G	Three Coats, Three Sintering Firings, No Voids.
7	Molybdenum*	Al ₂ O ₃	H ₂ , 1800° C	F	F	F	F	Same as No. 1.
8	Molybdenum*	Al ₂ O ₃	H ₂ , 1825° C	G	F	F	G	Same as No. 3.
9	Molybdenum*	Al ₂ O ₃	H ₂ , 1825° C	G	G	G	G	Same as No. 6.
10	Molybdenum	Al ₂ O ₃ /Y ₂ O ₃	H ₂ , 1800° C	F	F	P	F	Surface Very Porous, Coated Single Cont, Single Sintering.
11	Molybdenum	Al ₂ O ₃ /Y ₂ O ₃	H ₂ , 1825° C	G	F	F	G	Same as No. 3.
12	Molybdenum	Al ₂ O ₃ /Y ₂ O ₃	H ₂ , 1825° C	G	G	G	G	Same as No. 6.
13	Tantalum	Al ₂ O ₃	Vac, 1800° C	P	F	P	P	Coated One Time, Fired Once, Soft and Spongy.
14	Tantalum	Y ₂ O ₃	Vac, 1800° C	P	F	P	P	Same as No. 13.
15	Tantalum	Al ₂ O ₃ /Y ₂ O ₃	Vac, 1800° C	P	F	P	P	Same as No. 13.
16	Columbium	Al ₂ O ₃	Vac, 1800° C	P	F	F	P	Same as No. 13.
17	Columbium	Y ₂ O ₃	Vac, 1800° C	P	F	F	P	Same as No. 13.
18	Columbium	Y ₂ O ₃	Vac, 1900° C	F	F	F	F	Same as No. 13.
19	Columbium	Al ₂ O ₃ /Y ₂ O ₃	Vac, 1900° C	F	F	F	P	Same as No. 13.
20	Columbium	Al ₂ O ₃ /Y ₂ O ₃	Vac, 2000° C	P	P	P	P	Oxides Reduced

Note: All coatings applied by the spray/sinter technique.

* Samples surface treated with titanium hydride before coating.

FIGURE 14 CROSS-SECTIONAL DRAWING OF ARC SUPPRESSION TEST VEHICLE

FIGURE 15 PHOTOGRAPH OF ARC SUPPRESSION
TEST VEHICLE

FIGURE 16 VOLTAGE-SPACING RELATIONSHIP FOR CESIUM

hold off up to 30 volts. Since the alumina layer is only 0.013 centimeters thick, it is obvious that an additional distance must be achieved by coating the tri-layer end-area. The total assembly end-area thickness is approximately 0.7 centimeters for both the emitter and collector tri-layer. Therefore, a complete end-area coating would provide adequate standoff for voltages to 30 volts. Other components which may need arc prevention coatings have also been tested coated. Continued effort will be made to complete the evaluation of this coating technique using various geometries and typical module operating parameters.

E. High Voltage Module Assembly Techniques (Responsible Person-R. W. Longsdorff)

One of the greatest deterrents to the use of a high voltage module concept has been the complexity of fabrication and assembly. The use of the insulated, interconnected emitter-collector tri-layer assembly and complete sub-assemblies which can be post weld/braze machined for close tolerance accuracy eliminates much of this complexity.

The basic assembly technique being developed makes use of complete sub-assemblies which can be machined after electron beam welding or brazing to close tolerance and assembled onto the heat pipe. All closures will be made by electron beam welding except the ceramic-to-metal seal sub-assembly.

The major sub-assemblies and their order of assembly is shown in Figure 17. These sub-assemblies include the upper and lower end cap sub-assemblies, shown in Figures 18 and 19 and the integral emitter-collector tri-layer assembly. Each of these sub-assemblies will be tested for thermal stability under actual module temperature conditions.

FIGURE 17 CROSS-SECTIONAL DRAWING OF TENTATIVE MODULE ASSEMBLY DESIGN

FIGURE 18 CROSS-SECTIONAL DRAWING OF UPPER
END-CAP SUB-ASSEMBLY

FIGURE 19 CROSS-SECTIONAL DRAWING OF LOWER END-CAP SUB-ASSEMBLY

Thermal bonding of the emitter tri-layer assembly to the heat pipe is currently being tested. This bonding technique must conform to the assembly technique to be used for module fabrication. Ideally, the tolerance between the heat pipe and emitter sleeve should permit the emitter sleeve to be moved along the heat pipe to the required location and still be adequately thermal bonded to prevent excessive temperature drop across the bond. The use of an intermediate material such as nickel, vanadium, palladium, etc. could be used to promote "wetting" and intimate contact between the two surface. However, caution must be exercised in the use of these materials to insure that no continued intermetallic diffusion exists at the temperature of interest. A test, in which three sample emitter sleeves were fitted to a heat pipe with varying degree of tolerance was completed. Temperature drop versus tolerance was measured to determine the degree of tolerance necessary to prohibit excessive thermal losses. The results of this test show that a maximum tolerance of 0.002-0.003 is required to limit thermal drop through the bond to less than 20°. A cross-sectional drawing of the test is shown in Figure 20. A photograph of the test assembly is shown in Figure 21.

The same degree of concern must be exhibited for the bond of the collector sleeve to the outer containment tubing since thermal losses across this bond will prohibit the adequate removal of waste heat from the collector assemblies. This bond can be eliminated by the use of individual closure sleeves welded between adjacent collector assemblies as shown in Figure 22. However, careful consideration must be given to this anticipated design change to insure that no sacrifice will be made in the establishment of accurate interelectrode spacing. An alternate design employing a collector containment tubing is shown in Figure 23.

FIGURE 20 CROSS-SECTIONAL DRAWING OF EMITTER-HEAT PIPE BOND
TEST VEHICLE

FIGURE 21 PHOTOGRAPH OF BOND TEST ASSEMBLY

FIGURE 22 CROSS-SECTIONAL DRAWING OF MODULE
CERAMIC SPACER/COLLECTOR CLOSURE

FIGURE 23 CROSS-SECTIONAL DRAWING OF TENTATIVE MODULE DESIGN
WITH COLLECTOR CONTAINMENT TUBING

F. Heat Pipe Development (Responsible Person - R. W. Longsderff)

A preliminary heat pipe design has been established and used as the basis for sizing other module elements. This design is based on a 14 volt, 800 watt module system. While a 28 volt module system is the ultimate design goal, an interim design seems desirable in order to develop technology necessary for a 28 volt system. Components sized for the 14 volt system design do not necessitate use of abnormally sized materials. Material and fabrication costs can thus be held to more reasonable levels while achieving an even greater amount of technology development.

The heat pipe design for a 14 volt module system has a geometry of 0.860 diameter x 26 inch overall length. The required gross heat through-put is approximately 12 kilowatts based on the preliminary module design described in paragraph G.

The heat pipe to be used for initial system feasibility evaluation will be the same diameter as that required for the 14 volt module system but, will be shorter in length to accomodate a 5 volt module system. A cross-sectional drawing of this heat pipe is shown in Figure 24. All components have been sized about this diameter for adequate system versatility. The heat pipe envelope is TZM molybdenum alloy and a molybdenum mesh for the capillary structure. A lithium working fluid will be used. The processing technique to be used will be the high temperature distillation process developed by RCA, Lancaster.

Other heat pipe designs have been investigated, using computer analysis, to determine heat pipe diameters and length required for transfer of adequate power for a 28 volt module system. The minimum diameter for transfer of adequate heat flux for a 28 volt, 2 kilowatt module is approximately 1.400 inches.

FIGURE 24 CROSS-SECTIONAL DRAWING OF TENTATIVE HEAT PIPE DESIGN

The length of the heat pipe would be approximately 48 inches. This 28 volt design will be reviewed and modified as technology becomes more defined for the smaller system.

G. Module Design (Responsible Person - R. W. Longsderff)

A preliminary module design has been established based on the heat pipe design described in paragraph F above. The initial module includes 10 converter sections, each having an emitter area of 5 cm^2 . The predicted module performance is expected to be 250 watts at an output potential of 5 volts. By varying the load impedance, voltages as high as 8 volts can be attained. This voltage level, which is considerably above the 3.89 volts ionization potential of cesium, will suffice as a practical demonstration to prove the feasibility of the high voltage approach.

Ten converter sections are also adequate for the evaluation of the electrode alignment and inter-cell connection techniques. All component elements to be used for the various technology developments will be based on this preliminary design. A cross-sectional drawing of this module concept is shown in Figure 25.

FIGURE 25 CROSS-SECTIONAL DRAWING OF TENTATIVE MODULE DESIGN WITHOUT COLLECTOR CONTAINMENT TUBING