

AD759752



# IRCM LAMP DEVELOPMENT

## FINAL TECHNICAL REPORT

CONTRACT No. N00014-72-C-0256

February 1, 1972 to July 31, 1972

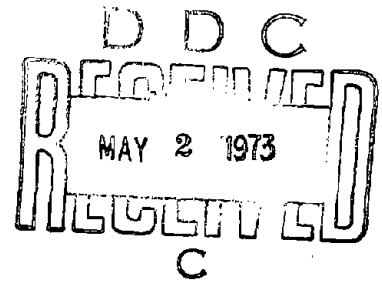
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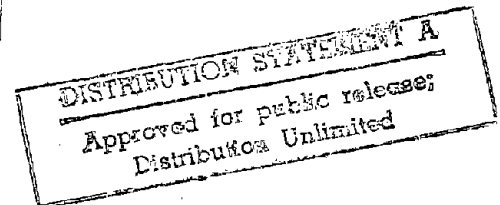
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DIVISION OF VARIAN

301 Industrial Way  
San Carlos, California



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## ABSTRACT

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The EIMAC IRCM source was patterned after the ADM-1 series E source. The lamp is of double envelop design. The inner (arc) envelope consists of a synthetic (cesium-filled) sapphire tube with refractory metal electrodes. The outer envelope, quartz/metal assembly is evacuated to protect the inner envelope from oxidation during operation. High temperature brazing alloys for sapphire/Cb-1Zr seals were evaluated and thermal cycling tests made on brazed seal structures. Techniques for cesium filling were investigated. Power tests were run with the sapphire inner envelope portion in a vacuum bell jar to verify the thermal design and determine basic design deficiencies.

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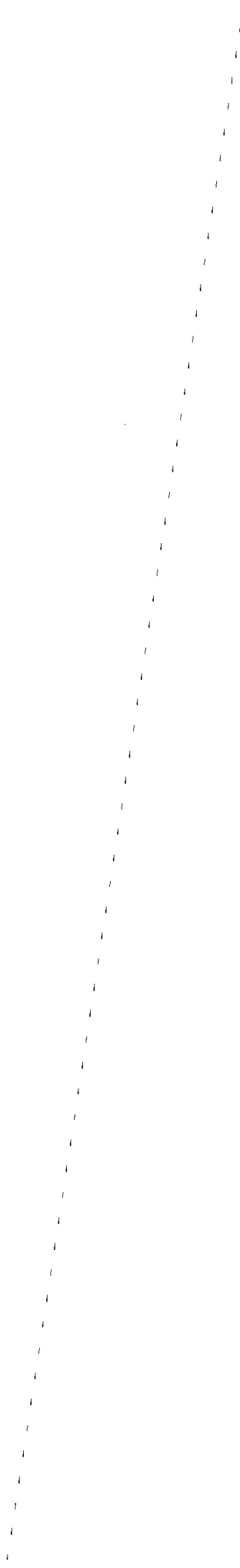


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## 1.0 INTRODUCTION

The purpose of this program was to design, develop and fabricate two prototype CASPAR/CAIR arc lamps for testing purposes. Ceramic-to-metal seal development and fabrication of prototype lamps was done on a previous contract, N00014-C-0044. The EIMAC IRCM source was patterned after the ADM-1 series E source.

The program was organized as follows:

1. Design at least two iterations to correct deficiencies in the thermal design of the lamp.
2. Seal Evaluation: Evaluate high temperature brazing alloys for sapphire/Cb-1Zr seals; conduct thermal cycle tests on brazed seals.
3. Cesium Filling: Evaluate reliability of and run proof tests on vacuum distillation technique for charging lamps with Cs.
4. Lamp testing: Run lamps through typical operational sequences; first tests with nude lamps (i.e., minus outer quartz envelope) in vacuum bell jar to verify thermal design, determine any basic design deficiencies with later results to be run on encapsulated lamps (with integral quartz jackets) in air.
5. Miscellaneous Technology: Perform experimental work as necessary to verify design concepts and solve problems encountered in processing and fabrication.

## 2.0 DESIGN & OPERATION

### Structural

A layout drawing of the X6236 lamp is shown in Figure 1. The lamp is a double envelope design. The inner envelope, a synthetic sapphire tube with massive refractory metal electrode mounts, contains the cesium arc. The outer envelope, a quartz/metal assembly, encloses a vacuum to protect the inner envelope from oxidation during operation. Details of the design are as follows:

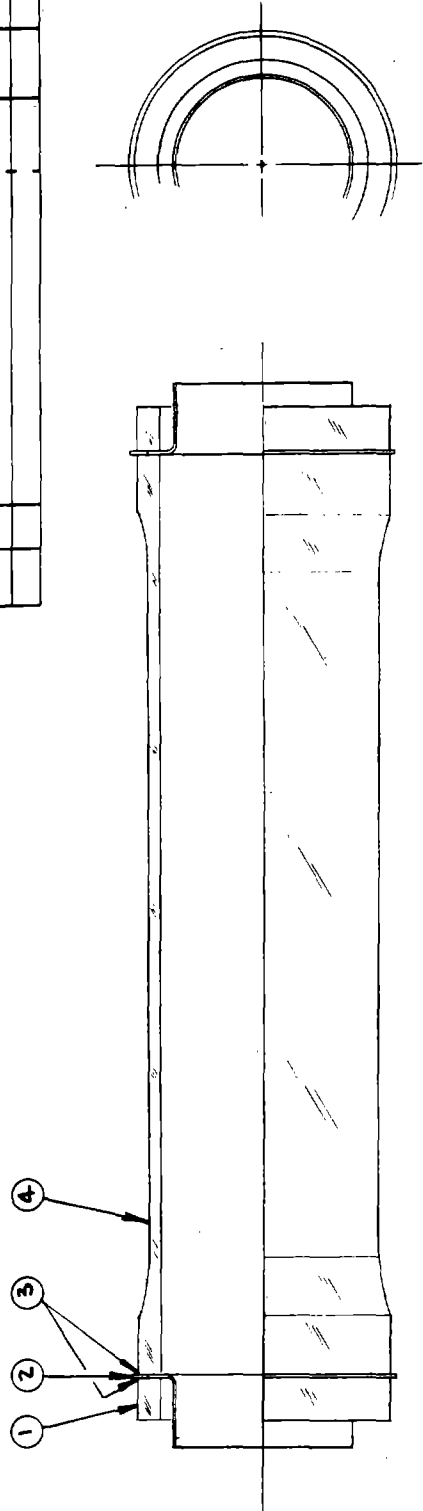
#### Arc Envelope Sub-Assembly

The arc envelope sub-assembly shown in Figure 2, consists of a synthetic sapphire tube 4 in. long x 0.9 in. bore x 0.050 in. wall, sealed at each end to Cb-1Zr eyelets. The sapphire/Cb-1Zr seals are brazed with Cb-17%Fe-1%Zr alloy. The sapphire tube is flared at each end to provide additional surface area on the tube ends for seal reliability.

The sapphire tubes are received from the vendor in essentially ready-to-use form. They are ground (by the vendor) from solid boules grown by the Czochralski technique. The tube axis is oriented at approximately 60° to the optical axis of the crystal. The O.D. of each tube is polished; ends and the I.D. are finish ground. After grinding, the tubes are annealed at high temperature for several days (the exact annealing schedule is vendor proprietary) to reduce damage, e.g., surface defects, introduced during grinding. A by-product of the anneal is



REVISIONS			
ZONE	LTR	DESCRIPTION	DATE
	A	REVISED & REDRAWN	10 APR 68



QTY	PART NUMBER	DESCRIPTION	CODE IDENT	ITEM
1	192090	ARC ENVELOPE		4
A/R		BRAZING POWDER		3
2	192098	EYELET		2
2	192092	BACKUP RING		1

**LIST OF MATERIALS**

CONTR NO. N00014-72-C-0156  
 DR **JD** DATE 16 APR 68  
 CH  
 APPD

UNLESS OTHERWISE SPECIFIED  
 DIMENSIONS IN INCHES  
 FRACTIONS ±1/64  
 DEC. ±.005, ANGLES ±1°  
 EIMAC GEN MFG SPEC  
 PMS82 APPLIES

MATERIAL  
**NOTED**

DESIGN ACTIVITY APPD  
 APPROVED

ARC ENVELOPE ASSY

SIZE B CODE IDENT 192156 REV A

SCALE 2x SHEET 2x OF

FIG. 2

PAGE 4

substantial improvement in optical finish of the ground surfaces. Significant cost savings are realized by using the ground and annealed tubes instead of tubes with polished I.D.'s.

The Czochralski grown sapphire was the only available sapphire material for arc envelopes in the sizes required, (i.e., 1 in. O.D.).

Cb-1Zr was chosen for the seal metal members for at least three reasons:

1. Cb provides the best thermal expansion match with sapphire, of the metals and alloys otherwise suitable for the application.

2. the nominal one percent Zirconium content is instrumental in improving alkali metal resistance of the entire lamp structure by tying up oxygen.

3. Cb is compatible with the high Cb-content brazing alloy used.

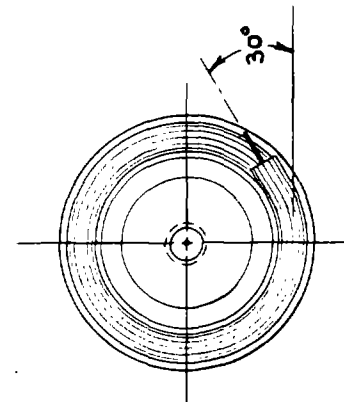
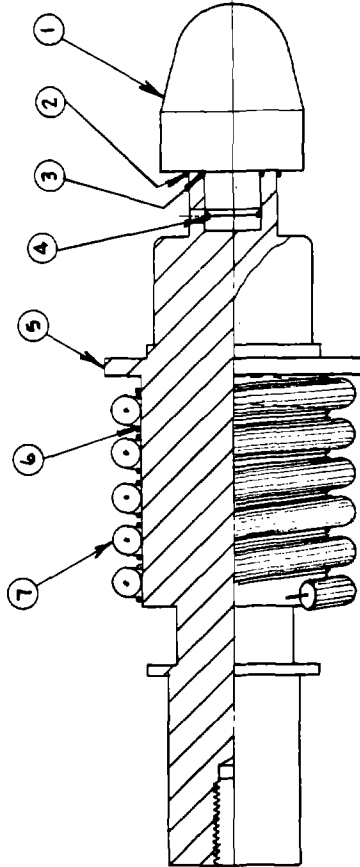
#### Electrode Sub-Assemblies

The anode and cathode assemblies are shown in Figure 3 and 4 respectively. They consist of machined molybdenum rods to which the pure tungsten electrodes and the wound heaters are attached by titanium brazing.

The cathode sub-assembly has additional parts which are joined during the same titanium brazing operation; namely, an expansion joint bellows, a fill tubulation and capweld adapter, and a threaded expansion joint connector.

The dimensions of the molybdenum mounts and the expansion

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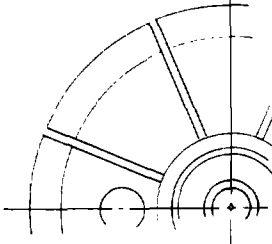
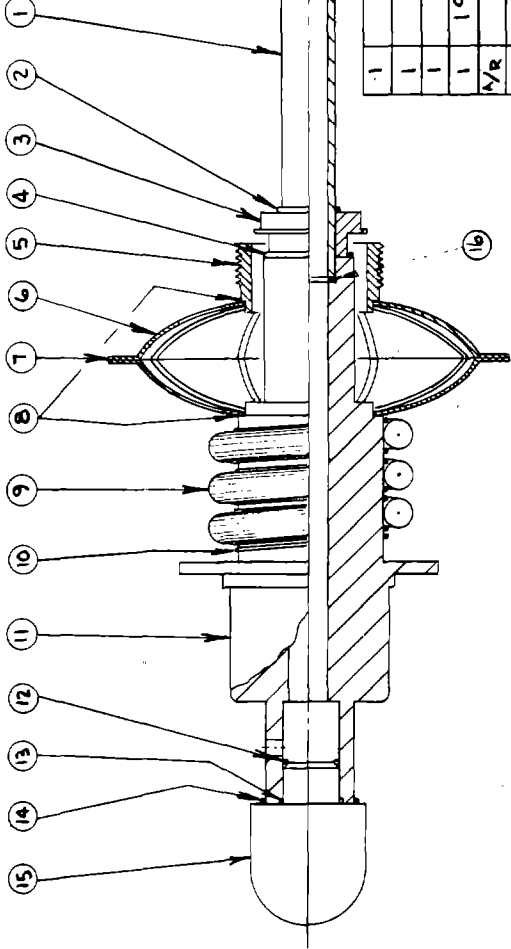
QTY	PART NUMBER	DESCRIPTION	CODE IDENT	ITEM
1		ANODE HEATER		7
M/R		BRZE WIRE Tl, .023DIA. WIRE x BRAND.		6
1	192114	ANODE MOUNT		5
1		BRZE RING, Tl, .023DIA. WIRE x .203 I.D.		4
1		BRZE RING, Tl, .023DIA. WIRE x .250 I.D.		3
1	192122	ANODE		2
1				1

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED	CONTR NO	DATE	DIV	EIMAC, Division of Varian 1000014-78-C-0256 For EIMAC, the material is subject to the restrictions of the EIMAC Material Control System. For other divisions, the material is subject to the restrictions of the applicable division.
DIMENSIONS IN INCHES	DR ID	DATE		
FRACTIONS ±1/64	CH			
DEC ±.005, ANGLES ±1°	APPD			
EIMAC GEN MFG SPEC PSM82 APPLIES				
MATERIAL				
NOTED				
1 X 6236	192154			
QTY	USED ON	NEXT ASSY	SIZE	REV
	APPLICATION		B	192155
			SCALE	2A
				SHEET 2A OF

FIG. 3

REVISIONS			
ZONE	LTR	DESCRIPTION	BY/APPD



1	192171	BRAZE RING, T1, .023 DIA. WIRE X .203 I.D.	16
1	192172	CATHODE	15

QTY	PART NUMBER	DESCRIPTION	CODE IDENT	ITEM
1	192123	CATHODE MOUNT		11
1	192108	SLOTTED BELLOWS		7
1	192109	CONNECTOR		6
1	192137	TUBULATION ADAPTER		3
1		TUBULATION		2
1		BRAZE RING, T1, .023 DIA. WIRE X .250 I.D.		1
1		BRAZE RING, T1, .023 DIA. WIRE X .375 I.D.		14
1		BRAZE RING, T1, .023 DIA. WIRE X .250 I.D.		13
1		BRAZE RING, T1, .023 DIA. WIRE X .203 I.D.		12
1		CATHODE HEATER		10
1		BRAZE WASHER, T1		9
2		BRAZE WASHER, T1		8
1		BRAZE WASHER, T1		7

LIST OF MATERIALS	
CONTR	DIV
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DR 3D	DATE 2/11/64
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DESIGN ACTIVITY APPD	
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UNLESS OTHERWISE SPECIFIED	
DIMENSIONS IN INCHES	
FRACTIONS ± 1/64	
DEC ± .005, ANGLES ± 1°	
EIMAC GEN MFG SPEC	
PSMS-82 APPLIES	
MATERIAL	
NOTED	
QTY	1
USED ON	192154
NEXT ASSY	
APPLICATION	

FIG. 4

CATHODE ASSY

DWG NO. 192157

SHEET 2 OF 2

SUPERSEDES

joint were determined by thermal impedance considerations.

A 1-1/8 in. diameter flange on the cathode and anode assemblies is provided for attachment of the heat shields.

The heaters are coaxial, 0.125 inch diameter tantalum sheath, MgO insulation, and a 24 gauge Ta center conductor wire.

The expansion joint on the cathode subassembly is designed to provide low resistance to axial motion and high resistance to radial motion. It consists of two domed members of 0.010" Ta with eight equiaxed slots in the periphery.

The fill tubulation is 0.25 inch diameter x 0.049 inch wall Cb-1Zr tubing. As a safety measure a cap is electron-beam welded over the pinch-off since pinch-offs are reported to be unreliable during lamp operation at elevated temperature.

#### Internal Mounting

A nickel extension provides electrical and thermal contacts and structural support for the lamp cathode.

Heater leads are of stranded nickel wire. Attachment to the coaxial heaters as well as to feedthrough pins is made by mechanically crimping special connector sleeves onto the heater leads.

#### Outer Envelope

A quartz/metal assembly consisting of an IR grade quartz cylinder, nominally 2 in. dia. x 4 1/2 in. long, attached with graded glass seals to thin wall stainless steel end members at each end constitutes the basic external shell of the source. The end caps are stainless steel with ceramic-metal feedthroughs

for heater leads. These are TIG welded to the outer envelope and the lamp mounts. The cathode end cap also has a 1/4 inch copper tubulation for final evacuation of the completed lamp assembly.

#### Thermal

As with the ADM-1 lamps, the X6236 lamp cathode is heat choked to some extent, the expansion joint serving this function. Because the inner lamp runs in a vacuum (unlike most other IRCM lamps) the operating temperatures tend to be high - over 900°C at the seals and at the electrode bases.

Thermal impedance of the ADM-1 and EIMAC X6236 lamps were calculated for anode and cathode conduction paths. Room temperature thermal conductivities were used in the calculations. The resulting curves for the cathode path are shown in Figure 5.

The cathode impedance for both lamps is on the order of 25°C/watt. Anode end thermal impedance is a much lower, 1.9°C/watt in both cases.

On the basis of these calculated thermal impedances one expects only a small fraction (perhaps 300 watts) of the input power to be conducted to the supports through anode (primarily) and cathode heat paths.

The remainder of the input power must be radiated as useful pulse IR or as background radiation.

#### Arc Envelope Sub-Assembly Braze

The arc envelope sub-assembly is brazed in a special molybdenum and alumina fixture with Cb-17Fe-1Zr alloy powder, -325 mesh. The alloy powder is mixed with a lacquer and applied

CATHODE ENDS OF EIMAC & ADM-1 LAMPS

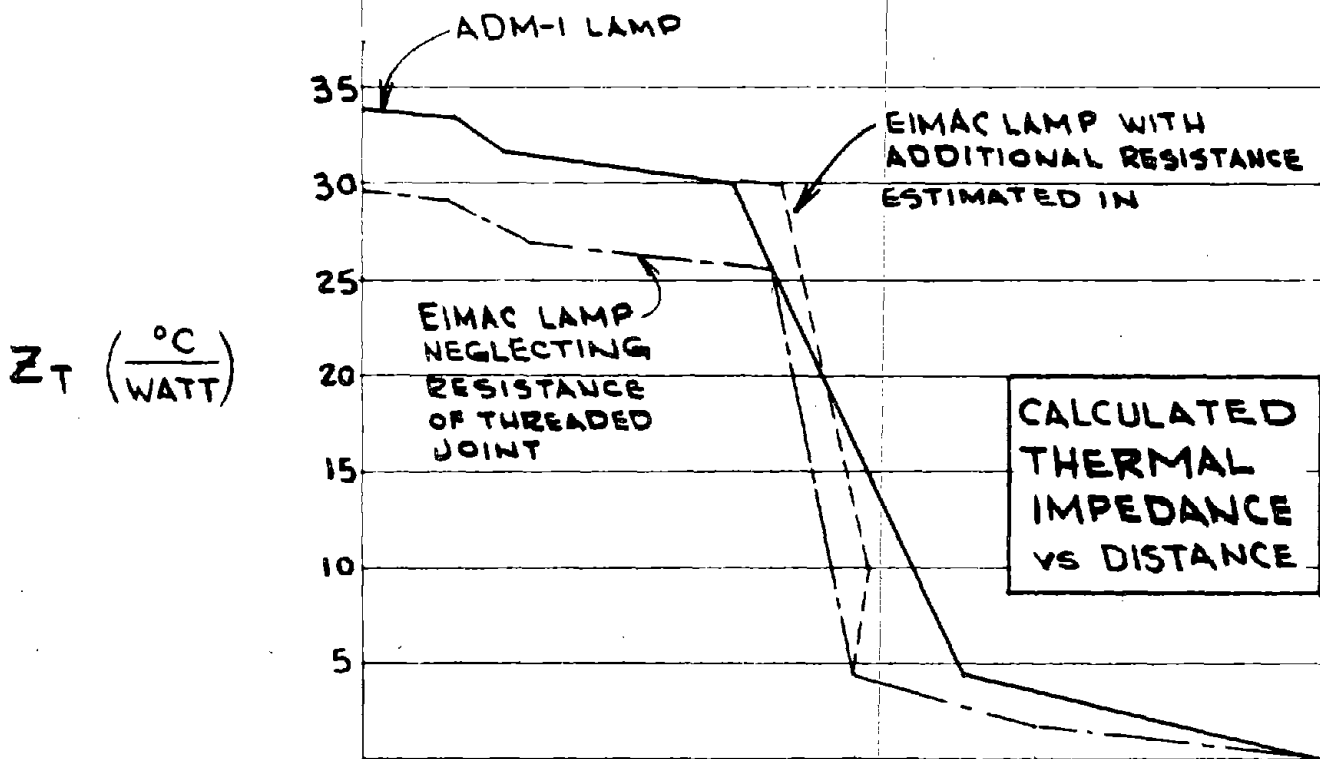
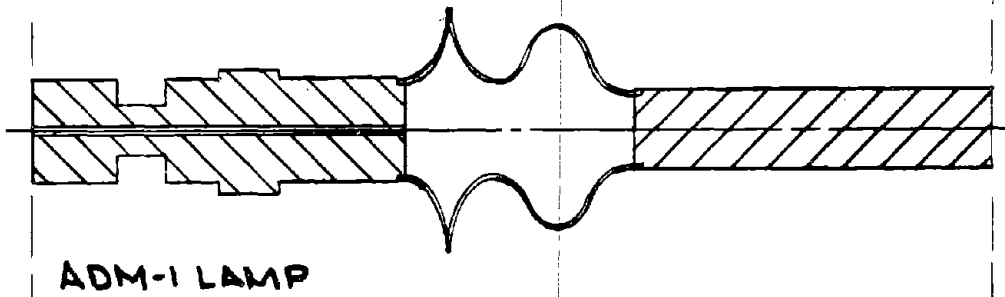
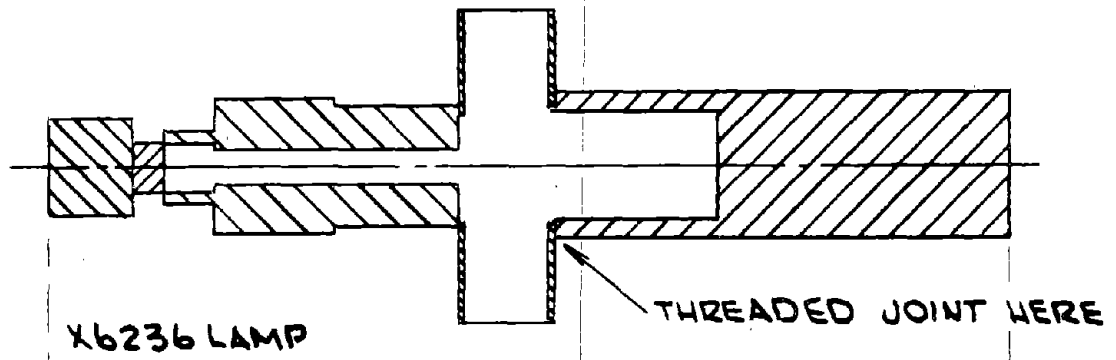


FIG. 5

to each end of the arc tube and to the seal surface of the back-up rings by a dipping technique. The parts are placed together so that the lacquer/powder mixture "squeezes" out of the joints, forming small fillets.

A special note: The arc tube and back-up rings are oriented to give crystallographic continuity using a cross polarized light prior to assembly. This substantially reduces the anisotropy stresses that develop at the joints.

The brazing is done in vacuum at 1720°C for about 3 min. The brazed assemblies are then leak checked on a He mass spectrometer leak checker.

#### Cathode & Anode Subassembly Brazes

Heater wires are prewound on mandrels and then placed on anode and cathode mounts. The electrodes and other parts are also assembled. The arrangements on both assemblies provide self-jigging.

The expansion joint bellows are spot-welded together with titanium brazing shim sandwiched between the flange surfaces and finally copious quantities of titanium wire are wrapped over the areas to be brazed. Both assemblies are brazed in vacuum at slightly above titanium melting point.

A nickel electroplate was deposited on critical seal surfaces, i.e., electrode braze area, tubulation braze on cathode subassembly, to improve bonding of the titanium braze to the molybdenum. There is definite evidence that bonding is not adequate without this step.

The cathode subassembly is leak checked after brazing to confirm vacuum tightness of the tubulation joints.

#### Lamp Assembly Braze

This operation is done in two steps. First the cathode subassembly is vacuum-brazed to the arc envelope assembly with the cathode pointing down to allow placement of brazing powder at the joint without danger of particles dropping out. After the first braze the anode sub-assembly is put in place, is inverted, and the second braze is made.

Brazing is done with 56Zr-29V-16Ti alloy powder at 1250°C in vacuum.

#### Filling

The lamp is attached, tubulation up, to the fill manifold via a swagelock fitting. Prior to attachment a glass ampoule pre-filled with the desired cesium charge and wrapped with tungsten cloth is inserted in the tubulation. The lamp is baked at 280°C for 1 hour with vacuums of  $2 \times 10^{-7}$  torr. Then it is valved off and the ampoule broken by partly squeezing the tubulation from the exterior. The tubulation and manifold, up to the closed valve, is heated to 300°C or higher, driving the cesium by vapor transport into the cool lamp.

120 torr of neon is backfilled into the lamp. It is then pinched off.

A Cb-1Zr cap is electron-beam welded over the pinch-off.

### Encapsulation in Outer Envelope

First a weld adapter part of Kovar is brazed to the anode mount with Cusil. This braze is made by localized RF induction heating in a hydrogen purged bell jar.

Radiation shields are attached by spot welding to the flanges on anode and cathode mounts.

Heater leads are attached with special sleeve connectors using a mechanical crimping tool.

The inner lamp assembly is positioned within the outer envelope with end caps in place prior to final heater lead to feedthrough connection. After the final heater lead crimp is made the closure welds on the end cap are made by TIG welding.

The completed lamp assembly is evacuated after which the heaters are operated to at least rated power for out-gassing. In addition the lamp can be run at lower D.C. power to facilitate degassing of the exterior of the inner envelope and mounts prior to pinch-off.

### Seal Studies

At the start of this program the brazing alloys developed on the prior contract, Cb-17Fe powder mix and Cb-15Ni powder mix, after extensive trials, were found to be unsatisfactory for sapphire/Cb-1Zr joints although they appeared to work well with Lucalox and Vistal.

Obtaining reliable joints to sapphire with these brazing powders required premetallization of the sapphire seal surface with  $W-4.7\%Al_2O_3 - 0.1\%Y_2O_3$  at  $1825^\circ C$ , an inconvenient additional

step. Furthermore, the Cb-17Fe braze even with premetallization of the sapphire was of marginal utility for two reasons:

1. during initial melting iron-rich liquid "soaked" into the porous metallizing layer, leaving Cb particles behind so that the higher temperature melting behavior of the Cb-17Fe braze system was altered.

2. the same iron rich-liquid phases tended to blush over the Cb-1Zr metal parts causing it to stick to the brazing jig.

The Cb-15Ni system, although more well behaved, has the deficiency of forming a liquid phase at 1350°C or so, that tended to erode the metallizing and destroy bonding to the ceramic. Since seals in lamp service do not exceed 1000°C in temperature this may not in fact be detrimental. Nevertheless, we decided to try for more temperature margin.

Prealloyed Cb-17Fe-1Zr powder, originally formed by arc melting and comminuted to -325 mesh powder under purified argon was tried in a metallized sapphire/Cb-1Zr joint configuration and gave encouraging results, i.e., well filleted vacuum tight braze. The joint specimen was cycled in vacuum to 1200°C five times and remained vacuum tight.

There was some doubt about the melting behavior of the alloy. According to the Cb-Fe constitutional diagram the 17%Fe composition corresponds to a 1670°C eutectic. Thus brazing at 1700°C and above should give complete melting yet the brazed joints did not reflect this.

Melting tests were conducted with small dabs of the powder placed on sapphire discs to as high as 1750°C. There was still incomplete melting. We suspected either of two factors as the cause:

1. Original alloy composition too low in iron
2. Iron lost by volatilization during vacuum brazing.

A thermal-cycle test capsule with metallized sapphire was brazed with the Cb-17Fe-1Zr at 1720°C. Cb-1Zr end caps were electron-beam welded to the sapphire/seal cup assembly. The first welds were leakers. An attempted reweld caused the sapphire tube to crack. Only a small point of the weldment leaked however. This specimen was cycled to 1350°C three times and to 1500°C and 1600°C. No leaks developed in the seals or in the sapphire tube. After these cycles the specimen was sectioned and examined. There was evidence of extensive erosion of the metal member and substantial Cb particulate phase, certainly unlike the classic eutectic micro-structure.

Two new thermal cycle capsules were brazed with Cb-17Fe-1Zr; one with and one without metallizing. Electron-beam welds of the end caps were successful allowing these specimens to be cycled with He pressurization so that leakage at high temperature could be detected. The end cap/tubulation joint was brazed with Cb-33Fe powder mix.

The metallized specimen was cycled\* to 1200°C 25 times and 1300°C 25 times without detectable leakage. The unmetallized specimen was cycled to 1300°C 50 times and to 1400°C 3 times without detectable leakage in situ. However, subsequent leak check of this capsule on leak checker indicated a very small leak.

On the basis of the encouraging results new lots of alloy were procured from the vendor. Cb-17Fe-1Zr-100 mesh powder and Cb-13Fe-1Zr-100 mesh powder were obtained.

Melt tests on the new powders showed them not to form nearly as much liquid phase at a given temperature, e.g., 1690°C, as the original Cb-17Fe-1Zr -325 mesh powder. This was particularly surprising in the case of the new Cb-17Fe-1Zr powder since it had been made in the same fashion as the original powder, except of course for the larger particle size.

Wet chemical analysis, performed by the vendor, of the new powders indicated their composition to be reasonably close to specification.

The original powder was analyzed by wet chemistry and was found to be close to specified composition.

We concluded therefore that melting behaviour was being influenced by the particle size as well as by volatilization of Fe. The -100 mesh Cb-17Fe-1Zr powder was returned to the

Heating rate of more than 100°C/min., soak at temp., natural cool down, next cycle starts when specimen down to 180°C. See Final Report on N00014-69-C-0044 for description of test setup.

vendor for additional comminution to -325 mesh so that, hopefully, it would behave in the same fashion as the reasonably successful original alloy.

A 50g lot of -100 mesh Cb-20Fe-1Zr powder was also procured with the idea that the additional Fe would compensate for loss by volatilization.

Controlled melting experiments had been done to estimate the weight loss (presumably by Fe volatilization) of powder during brazing and results indicated a loss of 5-6% based on total sample weight. If the initial composition is 20% Fe, we reasoned, volatilization would drive the Fe composition towards 17% and complete melting would occur at 1670 °C, thus eliminating the need for 1720°C brazing and perhaps reducing overall Fe loss.

Some work was also done on a backup approach for brazed sapphire/Cb-1Zr seals. Other manufacturers (AVCO, Sanders) have had success with Ni-Ti in equiatomic proportions. This corresponds with compound NiTi which is claimed to be ductile. The melting point of this material is about 1250°C.

A trial braze of sapphire/Cb-1Zr joint was made with 0.0012" Ni washer (crudely fashioned by hand) sandwiched between two 0.001" Ti washers (also crudely fashioned), and was brazed at 1250°C. Result: Very good looking completely filleted joint which unfortunately leaked (small but real leak).

### Fill Technique Experiments

The original fill scheme involved high temperature distillation of cesium from a storage reservoir into a calibrated volume (so as to obtain a desired charge) and subsequently into the cool lamp. This scheme required the use of high temperature bellow valves to contain the cesium in the calibrated volume whose temperature is in the 600°C range. (See First Quarterly Report on N00014-69-C-0044 for details).

A series of experiments were run with this fill scheme to determine the degree of accuracy and reproducibility obtainable in the cesium change. The results indicated that accuracy and reproducibility were very inadequate. Evidence indicated that the valves tended to leak cesium vapor at high temperature.

As a result of these findings we opted for an alternate fill scheme which involved filling small bore glass ampoules with a controlled amount of cesium (as indicated by cesium column height within the ampoules) and nipping them off. The prefilled ampoule was then inserted into a metal appendage on the fill manifold or into the lamp tubulation, and broken after pumpdown of the manifold by partially crushing the metal tube around said ampoule. The cesium was then driven into the lamp by heating the manifold to 300°C or so.

Several trials were conducted on four variations of this basic scheme which were:

1. with cesium ampoule in auxiliary appendage, valve off

manifold under vacuum, crush ampoule, and drive cesium into lamp by heating manifold, then back fill lamp with neon and pinch-off.

2. with cesium ampoule in auxiliary appendage back-fill manifold with neon (starting gas) pinch-off manifold, crush ampoule, drive cesium into lamp, pinch-off lamp.

3. same as 1. except cesium ampoule in lamp tubulation, pinch-off made between ampoule and lamp body.

4. same as 2. except cesium ampoule on lamp tubulation.

Results of the trials (in which glass or copper tube volumes simulated the lamp) indicated that the basic scheme was very sensitive to several variables including:

1) pressure in manifold; cesium distilled rather slowly with 120 torr of neon present.

2) time of distillation.

3) path length from ampoule to lamp.

4) temperature of manifold

The best approach appeared to be the third one. The cesium transferred rapidly because no neon was present to impede flow, the path length was short and the time required for transfer was reasonable. Temperature remained a critical variable for the following reason:

At too low a temperature (e.g., less than 275°C) the vapor pressure of Cs was too low to allow transfer in reasonable times. On the other hand too high a temperature caused the liquid cesium to react with the 7052 ampoule glass such that a significant

fraction of cesium was lost (typically 7 mg out of 30-35mg total weight).

#### Other Problem Areas

1) Ti brazing. Ti brazements appear not to bond well to moly members. Many tests using only plaques to which Ti or Cb tabs are brazed with Ti indicated poor bonding, i.e., tabs readily pulled away from moly at braze-moly interface.

Electroplating the moly with Ni had beneficial effect if a Ni plating thickness of 0.0001 to 0.0002 inch was used. However, thinner plated coatings did not give any apparent improvement. Unfortunately Ni plate tended to form a liquid phase with Mo which flowed on the surface of plated parts into inside corners or coagulated in globs or spatters.

2) Heater leads. Tantalum conductor wire embrittled and eroded during Titanium brazing, apparently because Ti reduced adjacent MgO insulation leaving free Mg which attacked the Ta. The solution was to leave an extra length of heater which can subsequently be cut off.

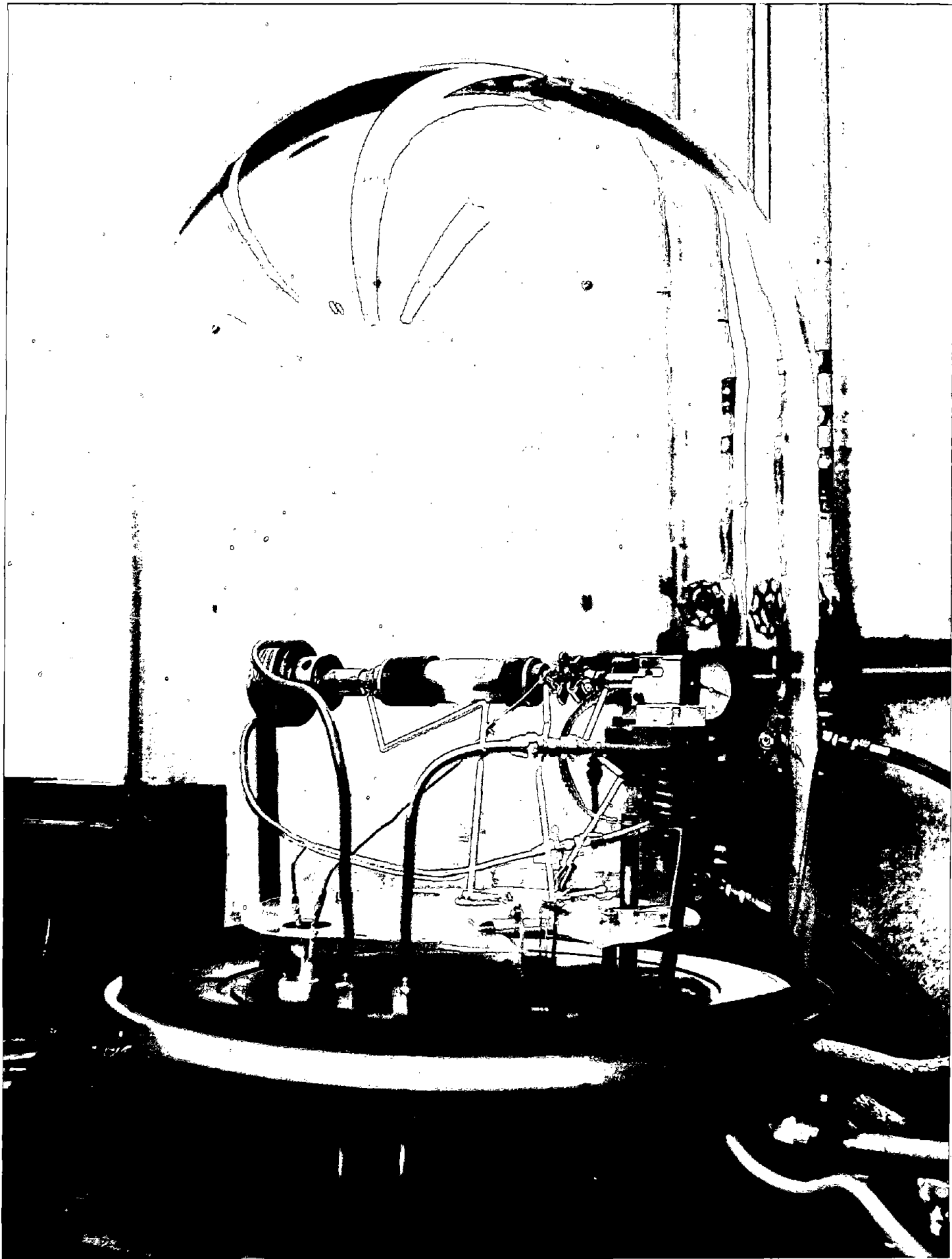
We also noted that MgO was darkened after Ti braze, further indication of reduction. It is not electrically conductive however.

#### Operation of 60Hz Modulator

X6236A, Serial No.1

#### Installation

This lamp, without the quartz outer envelope, was installed in the bell jar test vehicle as shown in Figure 6. Thermocouples were attached to the anode and cathode.



The thermocouples were made of 30 gage Chromel-Alumel wire. The T.C. beads were welded to molybdenum ribbon which was twisted tightly around the lamp elements with the bead sandwiched between lamp and ribbon. This attachment method gave good, reproducible readings.

The points of attachment of thermocouples were as follows:

T. C. Attachment:

1. Anode terminal adjacent to heat sink
2. Anode, over heater adjacent to heat shield flange
3. Cathode, next to heat shield flange
4. Cold side of expansion joint
5. Cathode terminal next to heat sink

The anode terminal was clamped into a water-cooled copper block with an intermediate copper shim. The fit of the clamp on the anode terminal was poor and the temperature of the terminal ranged between 400 to 500 degrees centigrade during arc modulation tests.

Arc Electrical Characteristics - Monitoring

The lamp voltage and currents were monitored during modulation tests on a Tektronix Type 547 oscilloscope with a Type A Dual-Trace Preamplifier.

The arc voltage was measured by adding the voltage on the anode terminal (touching thermocouple number 2) to the inverted cathode voltage (touching thermocouple number 3) in the preamplifier. 10X voltage probes were used for isolation.

After photographing the arc voltage trace, a second exposure on the same film was made of the arc current from a 1:100 transformer in the modulator.

The arc energy and rms current were obtained by integration of the instantaneous current and voltage product and the current squared at 20 microsecond intervals, using Simpson's rule, in a computer program written for the purpose.

It was found that the rms current was related to the peak current by:

$$I_{rms} = 0.07 i_{peak}$$

and the energy was approximately:

$$\text{arc} = 10^{-4} (e_{i \text{ peak}} i_{\text{peak}})$$

The results of the first and second test series are shown in Table I following. In the first sequence, the anode heater was not energized and the maximum arc power was 924 watts (shown in the 5th row and the 5th column) at a capacitor bank voltage of 261 volts. The cathode temperature (T3) reached 796°C at maximum power. The stored energy at 261 volts was 20.4 joules; the total power was 1411 watts. The total power shown in the table includes a contribution from the resistance of the electrodes, 0.0008ohms, which is attributable to the resistance of the expansion joint and is approximately 2 percent of the arc power.

The anode temperature (T2) was 250°C to 300°C lower than the cathode temperature. Because this large temperature difference might contribute to excessive thermal gradients in the sapphire bore tube, the next test series was run with anode heater power

TABLE I  
X6236A-1 60HZ OPERATION

Series	Heater Anode	Pwr. Cathode	Keep-alive E <sub>ka</sub>	P <sub>ka</sub>	Arc Power	Total Power	Bank Volts	T <sub>1</sub> °C	T <sub>2</sub> °C	T <sub>3</sub> °C	T <sub>4</sub> °C	T <sub>5</sub> °C	Arc Variables		Heat H <sub>2</sub> O	
													W	W		Irms
Unit	W	W	V	W	W	W	V	°C	°C	°C	°C	°C	Amps	Amps	Ohms	W
1	0	81	--	--	--	81	--	41	47	514	133	68	--	--	--	32
	"	75	13	78	--	153	--	112	142	590	159	83	--	--	--	72
	"	66	38	228	434	734	184	328	449	745	234	115	88	1260	.039	210
	"	66	59	295	671	1042	220	361	500	771	248	123	110	1570	.041	--
	"	66	82	410	924	1411	261	392	552	796	264	130	119	1700	.048	--
2	60	79	0	0	0	139	0	160	198	517	140	72	--	--	--	82
	96	78	18	90	"	264	"	204	251	524	142	75	--	--	--	115
	88	66	70	350	450	954	184	401	548	730	217	107	62	880	--	234
	88	66	85	425	640	1219	220	430	594	761	234	114	77	1100	--	234
	0	0	66	330	650	980	220	376	516	683	211	106	105	1500	--	--
	0	0	82	410	974	1400	260	402	564	705	227	113	125	1800	.048	258
	0	0	90	450	1156	1626	300	438	618	745	255	125	140	2020	.044	--
	0	0	90	450	1455	1933	330	471	661	767	278	135	166	2400	.040	--
	0	0	90	450	1637	2121	360	459	679	793	302	144	184	2700	.037	343

applied at low arc power levels and during warmup, and both heaters were de-energized at the 220 volt (Bank) level. The results of the second test series are also shown in Table I. The bank voltage was raised in 30 to 40 volt steps to a maximum of 360 volts, at which point the total power input was over 2100 watts with 1637 watts of arc power. Now, with no heater power applied, the difference between anode and cathode temperatures was about 110 degrees centigrade, with a maximum temperature of 793 degrees recorded for the cathode.

The expansion joint in the cathode support line was very effective as a thermal isolator - there was 470 to 490 degrees temperature gradient between T.C. Number 3 and T.C. number 4 (adjacent to expansion joint on the cold side) with the cathode heater off. The calculated thermal resistance of the expansion joint and cathode body was 25 degrees C/watt, implying a heat flow of 19 watts to the cathode terminal. This agrees very well with a flow of 16 to 22 watts calculated from the temperature difference between T.C. number 4 and T.C. number 5 (cathode terminal) and the calculated thermal resistance of 6.5°C per watt for this section of the path.

The last column of the table shows the heat removed by the water cooled terminals, calculated from temperature rise and flow rate. Keeping in mind the heat flow of 16 to 22 watts in the cathode terminal, we see that the majority of the heat in the water comes from the anode cooling block. This is 15 to 17 percent of the total lamp power input.

A rough calculation of the radiation loss from the anode and cathode surfaces at 2100 watts input indicates that about 160 watts would be radiated. Thus some 500 watts or 24 percent of the total power input is lost by conduction to the supports or radiated to the environment.

The series 2 electrode temperatures are shown as a function of total power input in Figure 7. Note the extremely high temperature rise in the cathode temperature in the early part of the cycle, indicating that a lower thermal resistance is desirable in the expansion joint. The dashed portion of the curves indicates operation with the heaters off.

In the third series, the lamp was operated briefly at 300 volts bank voltage (1600 watts input). After shutoff, streaks and yellowish spots were visible on the inside of the sapphire bore tube but there had been no noticeable change in operating characteristics.

In the fourth to eighth series, the lamp was cycled through heater warmup, d.c. keep-alive arc, and three levels of arc power (bank voltages of 190, 220, and 260 volts) in a more or less methodical fashion at least 5 minutes in each of the first five conditions and 15 minutes minimum at 260 volts.

During these runs, the lamp impedance decreased steadily. Figure 8 shows the peak arc current for each operating condition and each test series; peak currents increased 33 percent to 45 percent between the first series and the last series. Figure 9 shows the instantaneous voltage - current characteristic for the

ELECTRODE TEMPERATURES  
 EIMAC X6236A SERIAL NO. 1  
 IN 60 HZ. MODULATOR  
 SERIES 2

TUBE NO. \_\_\_\_\_ PLOTTED BY \_\_\_\_\_ DATE \_\_\_\_\_  
 COORDINATE: EIMAC TX-10 8-17-54

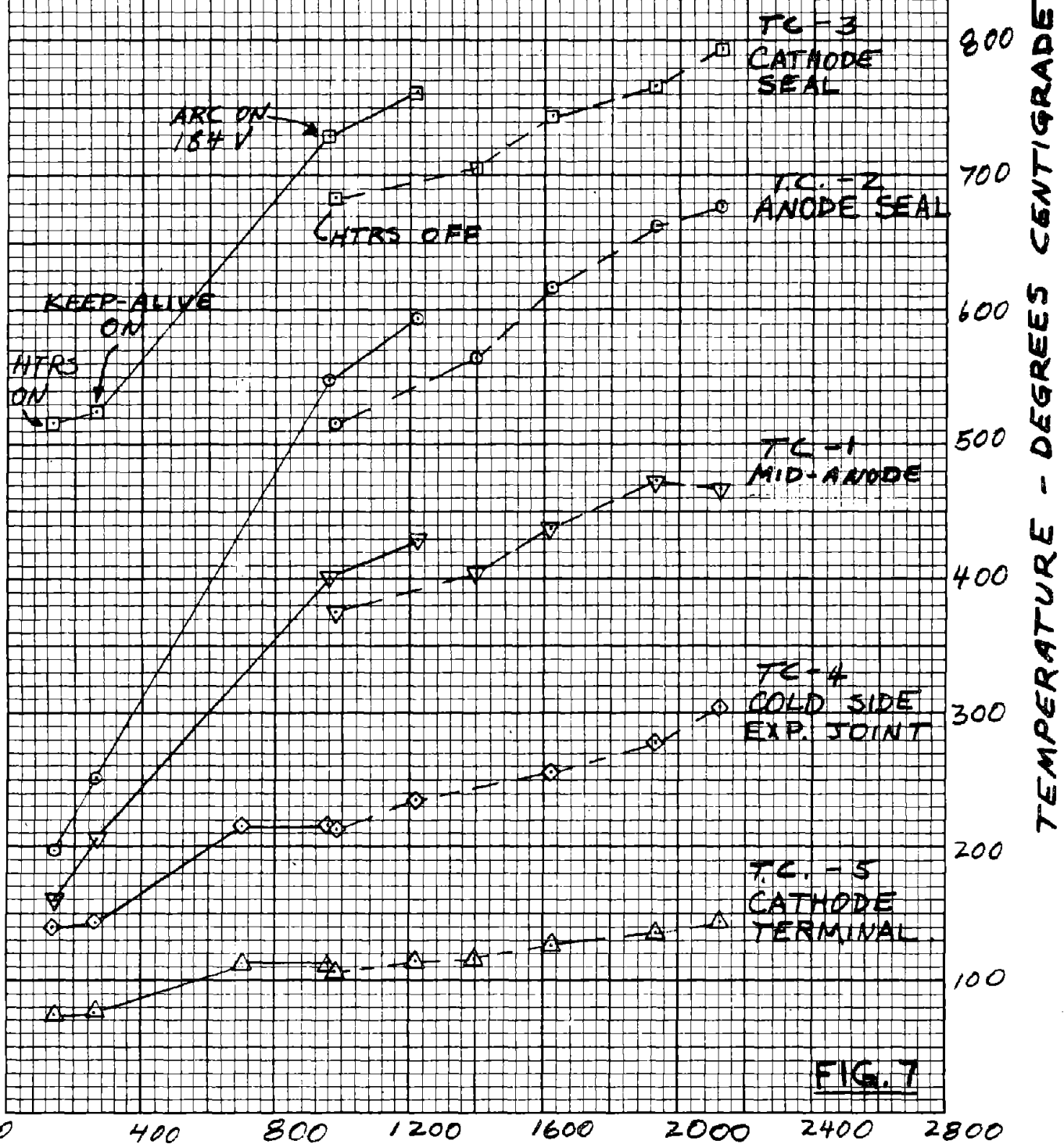


FIGURE 7. TOTAL POWER INPUT-WATTS

CASPAR LAMP

X 6236A

SERIAL NO 1.

60 Hz MODULATED TEST

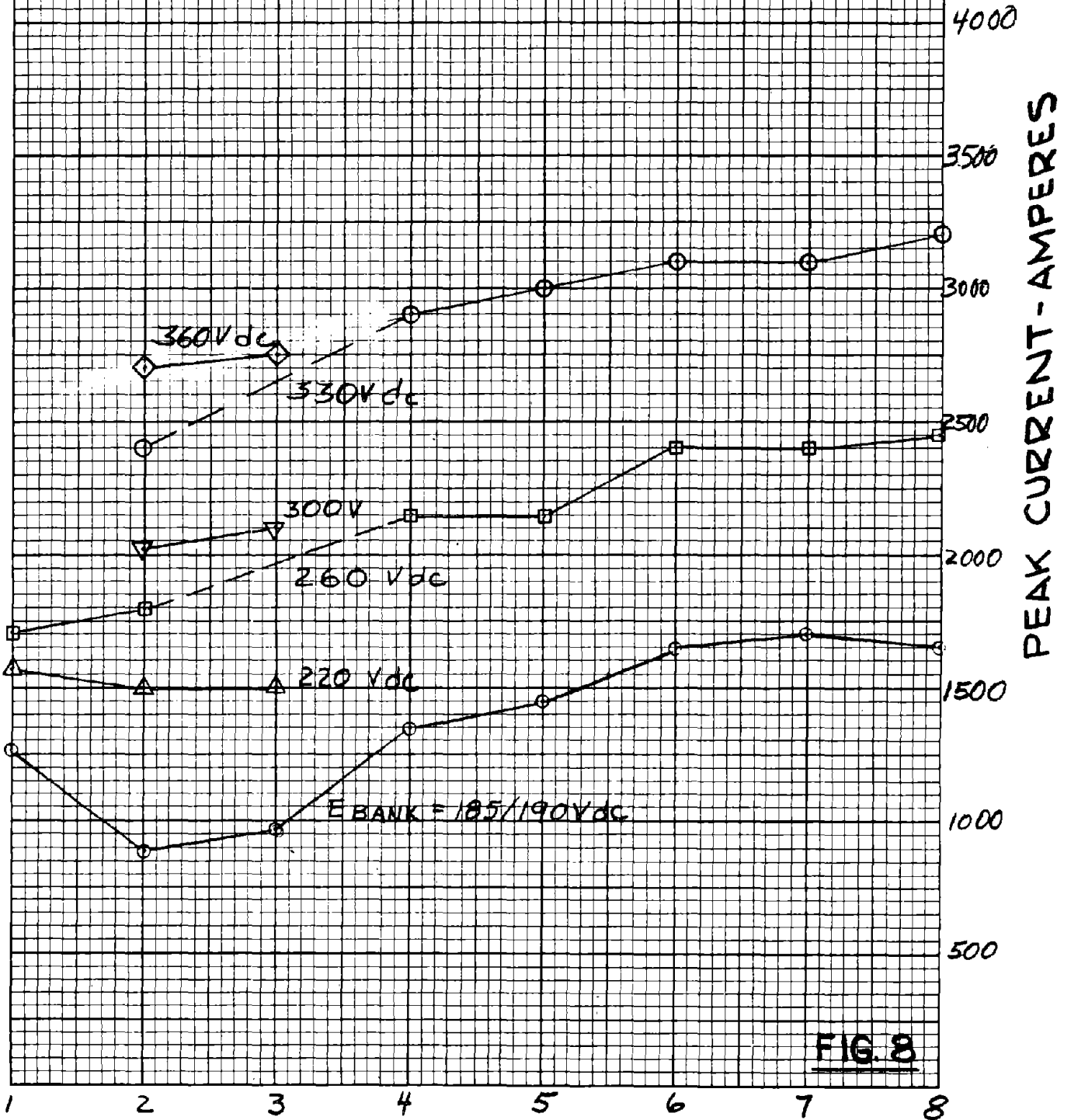
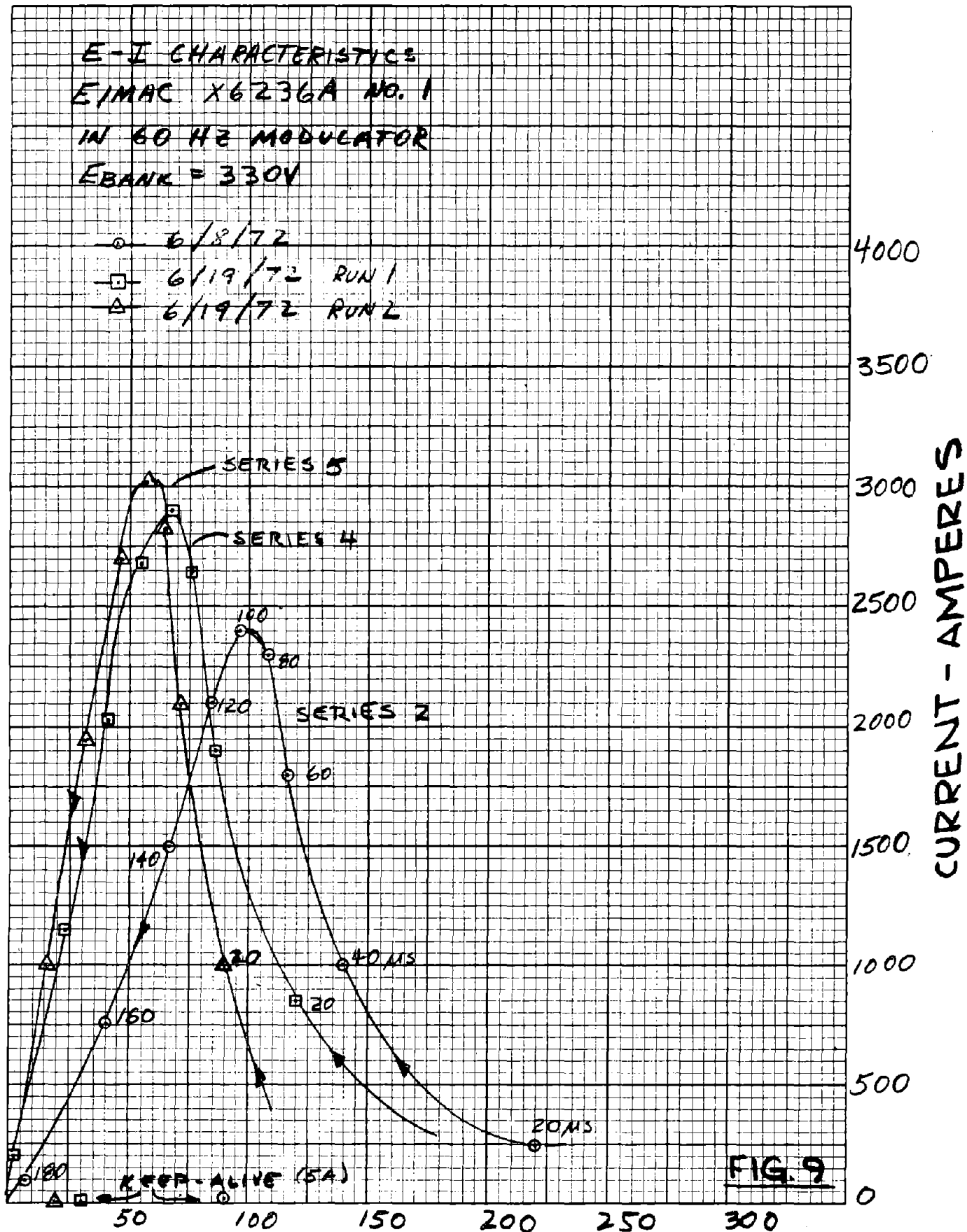


FIGURE 8.

SERIES SEQUENCE NUMBER

E-I CHARACTERISTICS  
 EIMAC X6236A NO. 1  
 IN 60 HZ MODULATOR  
 EBANK = 330V

- 6/8/72
- 6/19/72 RUN 1
- △ 6/19/72 RUN 2



TUBE NO. \_\_\_\_\_ PLOTTED BY \_\_\_\_\_ DATE \_\_\_\_\_  
 COORDINATES: EIMAC 7 X 10 9-17-36

FIGURE 9.

ARC VOLTAGE - VOLTS

pulsed arc for series 2, 4 and 5. The points plotted were read from waveform photographs at 20 microsecond intervals over the 180 microsecond pulse length.

From these data, we concluded that the lamp developed a leak between the third and fourth test and, furthermore, that the modulator efficiency was approximately 80 percent. That is, the arc energy was 78 to 82 percent of the stored energy in the modulator capacitors.

#### Tests and Test Results

Eight series of tests were run, spread out over a period of two weeks. The last five were limited to three arc power levels and were designed to indicate thermal cycling capability. Table II shows the time/level schedule followed.

TABLE II

TIME (Minutes) at INDICATED LEVEL  
EIMAC X6236A, Serial No.1

Level: Series	Preheat	Preheat & Keep-alive	Modulator Bank Voltage					
			190	220	260	300	330	360
1	29	36	40	10	25	--	--	--
2	35	15	5	10	22	10	13	27
3	65	10	10	10	--	7	--	--
4	30	21	6	--	8	--	30	--
5	11	13	5	--	20	--	26	--
6	7	11	12	--	7	--	15	--
7	5	5	6	--	6	--	18	--
8	30	6	7	--	9	--	22	--

NOTES:       (1)               (2)               (3)

- (1) In preheat mode, 6 volts at 13 amperes was applied to the cathode heater; 9 volts at 12 amperes was applied to the anode heater. Total power input was approximately 200 watts.
- (2) Keep-alive current was maintained at 5 amperes. Total power input approximately 260-280 watts.
- (3) Storage capacitance in modulator capacitor bank was 6 microfarads. Bank-to-arc efficiency was 76 to 86 percent in analyzed test runs.

### 3.0 General Discussion and Recommendations

In this section various problem areas, some related to the EIMAC lamp and some to CASPAR type lamps in general, are discussed.

#### Operating Temperatures

From an analysis of thermal impedances of components in standard CASPAR lamps it is apparent that conduction cooling plays a relatively small role in dissipation of waste heat during lamp operation. Nevertheless, some minimum conduction cooling capability is essential as evidenced by the premature failure of the EIMAC sapphire lamp during full power pulsed operation due, at least partly, to faulty thermal design.

If thermal impedance at the cathode end of the lamp is too high the cathode subassembly runs at excessive temperatures approaching the limit of brazed joints.

Tests to evaluate new designs were run in a bell jar with thermocouples at critical nodes. Accurate simulation of operating conditions requires that a sleeve be positioned over the cathode end comparable in reflectivity and size with the reflector socket and that the lamp be modulated so that the high RMS current and the higher arc radiating efficiency are operative.

#### Ceramic-Metal Seal

Although the Cb-17% Fe braze composition tested out well (to 1100°C) in Lucalox/Cb-1Zr thermal cycle assemblies it is somewhat difficult to use because little liquid forms during brazing thus, capillary filleting, in the conventional sense, does not occur. Strong joints are made only when the powder

is packed properly into the ceramic-metal corner of the joint so that the brazing material bonds to the side wall of the ceramic. Frequently the brazing material sags away from the wall leaving an unfilleted end joint which is sensitive to peel crack failure.

Brazing compositions were tried containing more iron so that the increased liquid would promote filleting. This has additional value in brazes to tungsten metallized sapphire where Cb-17Fe works marginally because the tungsten coating absorbs the brazing liquid leaving Cb particulate phase behind. Results indicated a considerable improvement in "brazeability" with the increased iron content.

Good success was achieved with Cb-Ni brazes to metallized sapphire. These brazes are probably marginal at 1200°C but may be very adequate in a properly designed lamp.

There is some indication that the reliability of metallized-brazed seals may be influenced by surface roughness of the sapphire and residual mechanical stresses within the sapphire.

The use of flared tubes such as used by EOS was also considered since the increased seal area probably results in stronger, more reliable seals. According to Insaco such shapes increase cost of polished sapphire tubes by about 10% and tubes with ground finishes not at all.

#### Other High Temperature Seals

EB welding is an effective alternative to brazing. In many cases weld joint design is critical. E.B. weld joint designs in the lamps were mocked up for trial runs so that problems such as thin

wall burnback, misalignment of components, poor fixturing, and thermal shocks of seals or ceramic could be discovered and eliminated prior to lamp fabrication.

#### Mechanical Design and Assembly

Although the mechanical design and particularly the assembly sequence for the EIMAC lamp, represents an improvement over the ADM-1 lamp, there is need for further improvement. Some technique for attaching subassembly modules other than brazing, (e.g., welding) is highly desirable for ease of assembly. Such attachment techniques must be consistent with thermal design requirements.

The present EIMAC expansion joint appears to be adequate although it could be "beefed up" somewhat to reduce thermal impedance or axial vibration of lamp. Upon cooling, stress reversal could impose high tensile stress on envelope and seals.

Connection of solid wire heater leads during lamp assembly has been risky and tedious. Flexible braided lead wire were substituted.

#### Outer Envelope

Unreliability of present graded quartz-to-metal seals in outer envelopes was a problem that had several possible solutions:

- 1) Find better vendor for graded quartz assemblies, e.g., Misco Scientific, Berkeley, California.
- 2) Moly cup/quartz assemblies.
- 3) Sapphire outer envelope.

Options 1 and 2 were pursued with hopes that significant improvement in reliability would result.

Option 3 can be used with high expected reliability; to keep cost down sapphire tube must be small diameter, e.g. 1-1/4 inch, which puts constraints on general lamp design. Option 3 provides integral means of dissipating radiant heat from lamp now reflected by radiation shields.

#### Cathode Degradation

Cathode tip degradation was noted on lamps that were operated for several hours. This is believed to be associated with pulse heating induced thermal fatigue. The phenomenon is well known in the tube industry in situations of high pulse loading of collectors (anodes). Several references in the literature can be consulted for information on ways of quantitatively characterizing the problem and suggestions on improved designs.

Some general techniques for reducing the problem are as follows:

1. Reduce thermal flux by utilizing larger tip area.
2. Reduce cyclic stress in surface by utilizing cathode material of increased thermal diffusivity and lower expansion coefficient.
3. Reduce stress by cutting grooves in surface.

There is a good possibility that mechanisms more complex than simple pulse heating thermal fatigue are involved in the cathode degradation process. There is also a good possibility

that there is no "problem" at all; the cracking may have no adverse effect on lamp performance.

Use of tungsten as the cathode material may be beneficial in reducing sputtering (or evaporation) of cathode material on to the tube walls.

#### Deposits on Lamp Wall

There is some belief that metallic deposits on inner wall of the arc envelope are caused by sputtering of cathode material during start-up. It is also possible that evaporation of cathode material, particularly during the peak pulse temperature period, or at the localized hot spot during the neon arc, causes the deposition.

#### Subassembly Testing

A frustrating problem in construction of lamps was the failure of some small components after the entire lamp was assembled. To avoid this problem subassemblies should be given rigorous in process acceptance tests. For example:

1. heaters, wound and brazed on cathode and anode sub-assemblies, should be run to full rated power in vacuum prior to attachment to arc envelope assembly.
2. the lamp module (arc envelope with anode and cathode subassemblies brazed or welded on) should be heat cycled to, say, 1200°C and leak checked. This will reveal any damage done during the previous brazing or welding operation that was not immediately detectable, e.g., by leak testing.

3. the outer envelope should be closely inspected under a polariscope for visible defects. An acceptance specification detailing requirements for this component should be developed.

#### Lamp Testing

##### Thermal Design Tests

Lamp (without outer envelope) was mounted on water cooled fixture in bell jar. Thermo couples were attached at strategic locations (e.g., arc tube, C/M seal, end cap, both sides of expansion joint, radiation shield). Lamps were operated to full power following standard sequence for a simmer, half power, and full power operation while temperatures and keep-alive voltages were monitored.

The thermal design tests provided information on thermal impedances of components and joints, and operating temperatures throughout the lamp.

##### Annealing of Sapphire

There is some belief that work damage is done to sapphire tubes during cutting and grinding. An annealing schedule of 4 hours at 1850°C is recommended for improving reliability of tubes.

##### Analysis of Lamp Deposits

Apparently material from the cathode is sputtered or evaporated onto the envelope. As the deposit thickens it absorbs radiant energy and causes high thermal stresses locally, ultimately resulting in cracking.

### Evaluation of As-ground Finish of Sapphire

Polishing of sapphire, particularly the I.D., is the most expensive step in tube fabrication. Very possibly an as-ground and annealed finish would be satisfactory for cesium lamps. Optically the tubes would behave no worse than Lucalox and probably better, especially if annealed.

Some reduction in strength is possible due to micro-flaws in the ground finish. Annealing would probably be of help here. Also thermal tensile stress would develop on the outside surface. This surface can be polished inexpensively so no compromise in strength would occur.