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FINAL TECHNICAL REPORT

RESEARCH AND DEVELOPMENT
on
Compact Arc Near Infra-Red
Radiation Sources

August 9, 1965 - July 15, 1967

Contract No: DA 44-OC9-AMC-1049(T)
Requisition No: 42/E1215/65 (65-1075-C)

Submitted to: Research and Development Procurement Office
USAFERDL
Fort Belvoir, Va.

By: Duro-Test Corporation
North Bergen, New Jersey

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FINAL TECHNICAL REPORT

RESEARCH AND DEVELOPMENT ON COMPACT ARC NEAR INFRA-RED RADIATION SOURCES

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SUMMARY

This is the final technical report on the development of prototype compact arc radiation sources directed towards increasing the infra-red radiance in the 0.85 to 1.5 micron region over pure xenon lamps of equal wattage.

Included in this report are all design and fabrication techniques employed for the construction of synthetic sapphire envelope short arc lamps with cesium, rubidium, mercury, and xenon fills. Spectral irradiance curves have been measured for a 250 watt xenon lamp as well as for cesium-xenon, and cesium-mercury-xenon, and rubidium-xenon lamps operating at various partial pressures and wattages. Radiance data for a quartz envelope xenon lamp and sapphire envelope cesium-xenon and rubidium-xenon lamps are shown for the applicable spectral range. The expected power and energy increase in that spectral range was obtained with increasing cesium and rubidium pressures. The characteristically strong cathodic concentration and higher plasma temperature of the xenon discharge, however, result in lower radiance values for cesium-xenon, cesium-mercury-xenon, and rubidium-xenon discharges when equal arc areas are compared.

I. Introduction

A. Provisional Program for the Full Contract Period

The following tentative program was based on (1) USAERDL RFQ AMC(T)-44-009-65-1075-C, (2) plan of technical approach as detailed in the proposal for the RFQ by Duro-Test Corp., and (3) the present contract's Work and/or Services Schedule - Article I - Scope of Work. Following discussions and negotiations with Mr. S. B. Gibson and Dr. D. Fromm, USAERDL, Combat Surveillance, Night Vision and Target Acquisition Lab., Night Vision Lab., Fort Belvoir, Va.* the provisional program was amended to concentrate on a particular phase of development which will be described in detail under B. below.)

1. Experimental investigation and tests and fabrications of prototype samples, all directed toward substantial increases in the near infrared spectral radiance, within the region from 0.85 to 1.50 microns, of high intensity gaseous discharge sources. The general areas of investigation shall include, but not necessarily be limited to, the following:

*) The Contracting Officer's representatives for this Contract.

- a. Compilation, study, and analysis of excitation energies, ionization energies, dissociation energies, energies of resonance spectral lines, and vapor pressures of elements and compounds which are most promising for increased near infra-red spectral radiance in low wattage compact arc lamps.
- b. Experimental investigation to establish the interactions between carrier gases and additives which influence shifts in the spectral distribution toward the near infra-red region.
- c. Test measurements on selected plasma compositions to determine radiation, thermal, chemical, electrical, and mechanical requirements of lamps for proper operation and control.
- d. Fabricate, test and deliver experimental prototype lamps which demonstrate the feasibility of producing metallic-vapor arc sources of high intensity near infra-red radiance for military applications. The

experimental lamps shall have the following design goals:

- 1) Power ranges: 100 to 250 watts
250 to 350 watts
350 to 500 watts
- 2) Near infra-red radiation efficiency:
100% higher than a pure xenon lamp of equal wattage and equal visual security when viewed through an IR filter with a sharp cut-off at 0.85 microns.
- 3) Operating life: 25 hours (minimum)
- 4) Arc length: 3 millimeters (operating minimum)

2) In connection with, and as part of the work and services to be performed the following shall be furnished:

- a. A total of 9 experimental prototype arc lamps, including 3 in each of the power ranges specified under item IA 1d above. These nine lamps will be selected by the government as those exhibiting the most desirable operational and configuratory characteristics.
- b. All experimental and test materials, not

expended, and all experimental devices fabricated in connection with the work and services performed under this contract.

- c. One complete and reproducible set of detailed working drawings of all equipment, devices, assemblies, and subassemblies which may be developed in connection with the work and services of this contract. The drawings shall be sufficiently complete to allow reproducing the equipment, devices, etc., at the research and development level.
- d. Three Quarterly Technical Progress Reports in accordance with the requirements as specified in "Instructions for Preparation of Reports."
- e. One Final Technical Report in accordance with the requirements as specified in "Instructions for Preparation of Reports."

- 3. The areas of study listed under 1 above may be supplemented, to the extent applicable by Section II, "Plan of Technical Approach to Proposal by Duro-Test Corp. on RFQ AMC(T) - 44-009-65-1075-C. This proposal was dated February 8, 1965.

B. Amended Program for the Full Contract Period

Prior to the start of actual work on the contract it was thought that the program would essentially follow the "Plan of Technical Approach" outlined in the proposal of 8 Feb. 1965 and referred to under IA3 above. This meant that first priority was to be given to "Solution 1" — mercury vapor high pressure compact arc in quartz bulb with cesium as main additive and potassium, cadmium, zinc, and thallium as secondary additives; all additives to be introduced as iodides; xenon as a starting gas with limited contribution to IR emission — and "Solution 2" — xenon high pressure compact arc in quartz bulb with cesium and mercury as main additives and potassium, cadmium, zinc, thallium, as secondary additives; all additives, except mercury, introduced as iodides and xenon fill pressure lower than in pure xenon compact arc types.

Investigation and study of literature had revealed the significant shift in spectral distribution of the cesium-xenon discharge when the cesium pressure is increased from 30 to 540, and 1000 mm of mercury. These spectral data, shown in Fig. 1,

were thought to be highly applicable to the achievement of the contract objective because of the increasing energy output in the 0.9 to 1.5 micron region and decreasing energy output in the 0.8 to 0.9 region (where visual security is an important factor) with increasing cesium vapor pressure.

Fig. 2 indicates that partial pressures of these magnitudes would require 1200°C - 1300° if the cesium were introduced as an iodide compound. Quartz, however, is not capable of operating at these temperatures. Also, quartz is not able to chemically withstand elemental cesium which would obtain the required vapor pressure at only 650°C - 750°C .

The data shown in Figs. 1 and 2 made it obvious that cesium-xenon short arc lamps in alkali resistant synthetic sapphire bulbs would provide the most promising approach in order to attain the contract goals. Bulbs of synthetic sapphire were proposed in our "Plan of Technical Approach" under "Solution 3 and 4" in order to take advantage of the higher partial pressure of pure alkali additives; however, the exact nature of the spectral output as a function of pure alkali vapor pressure was not known at that time.

Based on A. and B. above, immediate priority was given to the fabrication of short arc synthetic sapphire lamps with cesium-xenon plasma. "Solution 3 and 4" of the "Plan of Technical Approach" were therefore substituted for "Solution 1 and 2" in order of importance and effort. This was approved by the Contracting Officer's representatives.

II. Investigation

A. Measurements of Quartz Envelope Xenon Lamps.

In order to establish a basis of comparison of spectral output in the 0.85 micron to 1.5 micron region between regular xenon lamps and sapphire infra-red emission sources, the spectral irradiance of a quartz xenon lamp, fabricated for this purpose, was measured at 250 watts. Instrumentation and measuring techniques are as described by L. Thorington, J. Parascondola, and G. Schiazzano¹. Fig. 3 shows the plotted spectral irradiance in watts/cm²-nm and lists the electrical, arc spacing, and operating pressure characteristics.

1. Chromaticity and Color Rendition of Light Sources from Fundamental Spectroradiometry. L. Thorington, J. Parascondola, and G. Schiazzano. Illuminating Engineering September 1964 page 607.

For radiance comparison measurements within specific arc areas a system shown schematically in Fig. 4 was constructed. The spectral transmittance of the type XK6 filter is plotted in Fig. 5. This filter transmits at 1.75 microns; consequently, a water cell with a 10 mm light path, which cuts off at 1.4 microns is inserted, ahead of the filter. The complete system is therefore capable of detecting in the desired 0.85 to 1.4 micron spectral range. The Eppley #4875 thermopile is calibrated at an intensity of 87×10^{-6} watts/cm² and generates 0.078 microvolts/microwatts/cm². The thermopile was found to maintain linear output up to 450×10^{-6} watts/cm². The image distance shown in Fig. 4 was chosen to stay within this value. Fig. 6 is a plot of radiance vs. detector output for the optical system described in Fig. 4. Fig. 7 shows detector outputs along the center line of the arc for the areas indicated of the quartz xenon lamp at 66.3 watts and 100 watts. The dashed lines represent the visible arc configuration. With the aid of Fig. 6 the individual area microvolt values can be converted to watts/steradian-cm² values. The 66 watt and

100 watt data points are shown in order to compare directly to similar wattage synthetic sapphire lamps with cesium and rubidium fills.

B. Fabrication and Processing Procedure for Compact Arc Sapphire Lamps.

1. First Experimental Prototypes

The use of synthetic sapphire bulbs in conjunction with an alkali high pressure plasma requires the fabrication of vacuum tight metal to sapphire seals with intermediate materials that resist chemical attack from the hot alkali metals. In order to establish basic construction and processing procedures, however, it was decided to first use the less expensive polycrystalline alumina as an envelope material. Accordingly, Fig. 8 to 13 show detailed initial lamp design, assembly, and processing techniques.

Based on the 650-750°C operating temperature requirement of the lamp, an envelope size of 3/4" long, 3/8" O. D. x 5/16" I. D. was chosen. A room temperature arc spacing of 3 mm was obtained with the tungsten anode and cathode as detailed in Fig. 8. A piece of columbium tubing 3/32" O. D. x .010" wall is prepared as shown in Fig. 9. The .031 diameter hole located 9/64" from one end serves to introduce the fill

gas and cesium vapor into the lamp. The shank end of the cathode is inserted into the exhaust tubing end near the exhaust hole so that the tubing end is located $1/8$ " beyond the cathode groove. The columbium is then rolled and titanium brazed into the groove for mechanical joining.

Fig. 10 shows the anode and cathode columbium cap designs. The anode cap (bottom of drawing) was purposely left as part of a columbium rod so that it serves as an induction generator susceptance during the titanium brazing of the anode shank into the columbium cup recess. After the brazing the cup-anode assembly is completed by cutting and machining the cup portion off the columbium rod.

Four components are now ready for lamp assembly with #1731 glass frit a) tungsten anode-cup assembly, b) polycrystalline alumina envelope, c) tungsten cathode - exhaust tube assembly, d) columbium cathode cup (Fig. 3, top portion). The frit mixed with a low burn-off vehicle such as butyl acetate is applied to the ends of the alumina tube and inside of cups as well as to the

area of the exhaust tubing adjacent to the cathode cup hole.

Fig.11 shows the arrangement employed in the process used to melt and flow the frit and thereby join the four components. The lamp assembly with the tubulation down is placed on a two part moly support with the free tubulation end resting on the lower moly support. As the cathode has been previously attached to the tubulation tubing and the anode-cup assembly sits on top of the envelope, the desired arc spacing is determined completely by the length of the exhaust tubing extending beyond the cathode cap and sitting on the lower moly support.

(Variations in arc spacings can, of course, be obtained by changing anode and cathode lengths).

A ceramic sleeve is placed around the lamp assembly to prevent any evaporation from the tungsten oven or moly supports to reach the lamp envelope.

After the tungsten oven is placed onto the assembly a vacuum jacket (not shown) is inserted over the lamp assembly-support structure and connected to a high vacuum system.

An induction generator is used to induction heat the tungsten oven which in turn radiates energy to the lamp assembly. All heating is done in vacuum at a maximum pressure of 10^{-4} mm of mercury. The temperature rise and fall time is controlled by the induction generator input power. Various time-temperature rates have been tried in order to obtain the glazed frit flow and blue-gray color appearance characteristics suggested by the Corning Glass Works (frit manufacturer).

Fig. 12 shows the detail of the assembled and fritted prototype short arc lamp ready for exhausting and cesium-xenon filling.

A pyrex glass appendage is prepared in which a cross arm holds a separately distilled capsule of cesium metal. A tungsten hammer is inserted, which during initial processing, may rest on the cesium capsule. The lamp columbium tubulation is joined to a columbium sealing glass, Corning Code #7280, to which are joined #7052 and #3320 glasses to complete the graded seal to #7740 pyrex. The lamp-glass appendage assembly is placed on the vacuum system. The lamp is baked by sliding

a quartz cylinder over the lamp, flushing argon through the cylinder while torching the outside of the cylinder. Heat is therefore conducted to the lamp through the quartz cylinder and argon gas. Xenon is filled in the conventional way by freezing. The appendage is then tipped off at the point indicated in Fig. 13. The tungsten hammer is forced against the cesium capsule, breaking it, and allowing cesium to enter the appendage when heat is applied. By carefully torching the glass appendage cesium is driven into the columbium exhaust tubulation. The lamp is then tipped off at the 7280 glass portion of the graded seal. The tipped off lamp is inserted into a quartz cylinder through which argon is flushed. The columbium tubulation is heated by induction heating, driving the cesium into the lamp. The lamp is kept in the liquid nitrogen dewar during this operation. The columbium exhaust tubing is pinched in several locations with pinch-off jaws equipped with tungsten carbide elements. The completed lamp is mounted into a support structure and sealed into an outer bulb. The lamp construction described above is listed in Table I and is designated as (a). Lamp number 16 through 25, 27, 28, 34, and 36 were fabricated in this way. (Lamps # 1 through 15 were

experimental processing units not meant to result in finished lamps.) The operating results can be summarized as follows:

- a. Columbium tubulation pinch-off not tight.
- b. Ignition at 1 atmosphere or less xenon fill occurred at inner edge of columbium tubulation instead of the tungsten cathode tip. The lower thermionic work function of columbium (3.96 eV) compared to tungsten (4.45 eV) is responsible for this.
- c. 4 atmospheres of xenon fill was required in order to achieve proper ignition.

2. Construction Changes to Eliminate Ignition Difficulties

Fig. 14 shows a design in which anode and cathode were lengthened. The length between the columbium exhaust tube edge and the cathode tip was, therefore, increased. It was thought that even with low xenon fill pressures and the lower work function of columbium with respect to tungsten the arc would strike at the cathode tip. This design also allowed the use of a 1 1/4" long envelope capable of dissipating a higher lamp wattage. Test results (see lamp #26 Table I) still indicated unreliable starting and operation. The arc was observed to switch randomly between cathode

tip, cathode chamfer, and columbium exhaust tubing.

The lamp design shown in Fig. 15 and represented by (c) in Table I, resulted in reliable ignition and operation even at low xenon fill pressures. The edge of the columbium exhaust tubing is completely shielded by the tungsten cathode step and there is no tendency for the arc to be "drawn" to the lower work function columbium tubing.

3. Temporary Solution for Columbium Tip-Off

The many columbium tip-off leaks obtained with construction (a) necessitated a temporary method of sealing the tubulation while a permanent method was being developed. Corning Code #7280 glass was found to bead to columbium tubing and also withstand attack of cesium metal and vapor. A lamp tip-off could, therefore, be effected in a conventional glass tip manner. Fig. 14 and Fig. 15 show these types of tip-offs.

At no time was it considered that the 7280 glass would be used in a finally developed lamp. The method, however, allowed lamps to be built and valuable data to be obtained until metal pinch-off method was established.

4. Design for Reducing Envelope Cracks.

As listed in Table I several sapphire and alumina lamps developed cracks near the end caps. These cracks were longitudinal in direction (protruding about $1/8$ " beyond the rim of the caps) and believed to be mechanical in origin due to the confining effect of the relatively massive caps and their consequent lack of sufficient flexibility with respect to the envelopes at elevated temperatures. Expansion coefficients of columbium and alumina at 1000°C are 7.88×10^{-6} cm/cm- $^{\circ}\text{C}$ and 8.5×10^{-6} cm/cm- $^{\circ}\text{C}$ respectively, which clearly requires flexibility in end cap design. This belief was further confirmed by the observation that all cracks, except one, occurred at the anode cap end. Because of the recessed construction this cap is more massive than the cathode cap.

Two additional design changes were, therefore, incorporated as per Fig. 16 and Fig. 17. Fig. 16 shows the reduction in end cap lips and fig. 17 shows the method employed to obtain the same end cap mass for the anode and cathode ends. Finished lamps are classified as (d) and (e) respectively in Table I.

5. Metal Tubulation Pinch-Off Developed Lamp Construction.

Fig. 18 shows the first attempt made to substitute a metal pinch-off method for the 7280 glass tip. A .015" wall thickness #52 alloy (52% Ni 48% Fe) sleeve was placed over the columbium exhaust tubing. The lamp was processed in the way described under B1. When the lamp was ready to be tipped off, the #52 alloy sleeve was pinched as shown in the drawing. Although there is no hermetic seal between the O.D. of the columbium tubing and the I. D. of the #52 alloy sleeve, the soft #52 material apparently "squeezed" into the columbium, thus sealing any cracks or tears which easily occur in that brittle material. Lamp number 62 and 63 (construction (f) in Table I) were made according to this method. Lamp number 63 burned 6 hours before a small leak was observed in the tubulation pinch-off. Fig. 19 and Fig. 20 show the final developed lamp construction and metal pinch-off method. This construction is designated as (g) in Table I. The lamp is prepared with columbium end caps and exhaust tubing as described under B1. Referring to Fig. 19, the columbium tubulation is then cut approximately 3/8" from the bottom of the lamp. A piece of 304 stainless steel tubing, 0.125" O.D. - .035" wall thickness, and a piece of Kovar tubing 0.125" O.D. - 0.010" wall

thickness are machined as shown. A 72% Titanium 28% nickel alloy wire is placed on the tubing joints to allow a vacuum braze to be made between the three different tubing segments. The Kovar end of the lamp is then spliced to Corning Code #7052 tubing which is sealed to Corning Code #3320 tubing and then joined to the Code #7740 pyrex appendage as described and shown in Fig. 13. Lamp filling techniques are maintained as specified under B1. Fig. 20 shows a completed pinched-off lamp.

Fig. 21 illustrates the mounting of alumina and sapphire lamps in an outer envelope of quartz. This has the purpose of preventing oxidation of the columbium parts. The outer envelope is filled with a xenon pressure equal to that existing inside the lamps. In this way the possibility of ignition between the external edges of the columbium caps is prevented.

Lamp number 67 (see Table I) was placed on life test. The lamp was burned at 96 watts for 19 hours after which a small leak appeared near the anode cap to alumina frit seal. This result indicates that the construction and pinch-off techniques

developed approach the contract objective of 25 hours life.

C. Radiance and Irradiance Measurements

Fig. 22 shows radiance values of a sapphire cesium-xenon lamp (see lamp #63 Table I.) for the indicated areas along the center line of the arc. The same detecting system is used here as previously described in A. The results can, therefore, be directly compared to those obtained in Fig. 7. The strong cathodic constriction, which is such a marked characteristic of the d.c. xenon arc discharge, is absent from the cesium-xenon discharge. This results in radiance values which are lower by an approximate factor of 3 in that region of the discharge. Although the cesium discharge shows higher radiance values near the anode, the average radiance along the arc center line for the xenon discharge at 65 watts and 100 watts is 38 percent and 54 percent higher, respectively, than for the cesium discharge.

In order to determine how the power of a cesium discharge distributes itself between 0.85 to 1.5 microns, spectral irradiance measurements were

made. Fig. 23 and 24 show results for a cesium-xenon discharge at indicated operating pressures and wattages. Fig. 25, 26, and 27 show data for a cesium-mercury-xenon discharge. (The reason for introducing mercury into the cesium-xenon discharge will be explained in the Discussion). The results of these measurements can be tabulated as follows:

<u>Figure Number</u>	<u>Discharge</u>	<u>Lamp Wattage Watts</u>	<u>Average Power 0.85 - 1.5 microns microwatts/cm²-mm</u>
23	Cs-Xe	42.5	9.73
24	Cs-Xe	72	20
25	Cs-Hg-Xe	73.6	18.55
26	Cs-Hg-Xe	80	23.2
27	Cs-Hg-Xe	93.5	27.9

The above measurements were made with alumina lamps according to the method described for the measurement of the quartz xenon lamp. The in-line transmission of polycrystalline alumina in the 0.85 - 1.15 micron range is 45 percent. The illumination of the entrance part on the integrating sphere attached to the radiometer entrance slit must therefore be corrected for the use of sapphire lamps with an in-line transmission of 90%. An experiment was conducted comparing the forward illumination of sapphire and alumina lamps, (see Table I lamp nos. 53 and 54), operating at the same wattage. Measurements were taken at various distances from a photocell.

In all cases the sapphire lamp produced a forward illumination which was greater by a factor of 2.08 to 2.12.

Applying this factor (2.10) to the above tabulation and comparing this to the xenon lamp measurement the following obtains:

Figure Number	Discharge	Lamp Wattage Watts	Average Power 0.85 - 1.5 microns microwatts/cm ² -mm
27	Cs-Hg-Xe	93.5	58.5
3	Xenon	100	37.3

The cesium-mercury-xenon discharge operating in a sapphire envelope, therefore, shows a 57% increase in spectral irradiance over a comparable wattage xenon discharge.

A further result of the measurements is that as the cesium pressure is increased by an increase in lamp wattage, reabsorption of the 8521Å and 8943Å resonance radiation causes a decrease in output in the 0.85 to 1.1 micron region. This is accompanied by a marked increase in output for the 1.2 to 1.5 micron region.

Although the contract objective called for an investigation from 0.85 to 1.5 microns, there was general agreement that a principal range of interest

was the 0.85 to 1.1 micron region. Present filter response (such as CS7-56 Corning filter with S-1 phototube) requires that I. R. Sources emit predominantly from 0.85 to 1.1 microns.

Based on the data obtained in Fig. 23-27 and discussions with the contracting officer's representative, rubidium was considered to meet these principal spectral requirements. The reabsorption of the broadened 7800Å and 7948Å rubidium resonance lines should result in high continuum output in the 1.0 micron region. Fig. 28 shows the vapor pressure curve for rubidium. The values are sufficiently close to cesium to allow the same lamp construction in order to obtain similar operating pressures at equal lamp wattages.

Accordingly, rubidium-xenon lamps were fabricated and tested (See Table I, lamp numbers 65, 68-71, 73-78). Radiance data are shown in Fig. 29. Results are similar to those obtained for cesium. The arc configuration matches that of cesium and the radiance values for each specified arc area are within 10% of those obtained for cesium.

Spectral irradiance data are shown in Fig. 30. The predicted increase in output in the 0.85 to 1.1

region over a cesium discharge operating at the same wattage has been achieved. As is shown the average power for the rubidium-xenon discharge is 29.9 microwatts/cm²-nm compared to 27.9 microwatts/cm²-nm for the cesium-mercury discharge as shown in Fig. 27.

III. Discussion

A. Mercury Addition to the Cesium-Xenon Discharge

The study of various gas and vapor compositions and their influence on the spectral output of I.R. sources was within the scope of this contract. Experiments were limited to xenon and mercury additions to cesium and rubidium discharges.

Xenon serves as a starting gas and also allows the lamps to operate at a high internal pressure for cleaner operation. Spectral irradiance data show that the strong xenon emission in 0.82 to 0.99 micron region is completely absent in the cesium-xenon discharges. This is due to the lower excitation levels of cesium and the partial pressure of each element existing in the lamps fabricated and measured. Also, data in Table I (see lamp number 34, 35, 37 and 38) show that, for the xenon pressure range investigated,

the voltage gradient, and consequently the lamp voltage is determined only by the cesium vapor pressure. This is explained by the low atomic cross section for electron interaction of xenon compared to cesium at the existing plasma temperature (equivalent to 0.5 - 1.0 eV).

Mercury addition, also, does not influence the spectral content when added to the cesium-xenon discharge due to the low excitation levels of cesium when compared to mercury. As is evident from Table I, however, the discharge voltage gradient, and therefore the lamp voltage, increases. This is due to the fact that the cross-section of the mercury atom for interaction with electrons is similar to those of cesium and the other alkali metals for the average electron energy of approximately 0.5 to 1 eV which prevails in the arc plasma. The addition of mercury, therefore, considerably reduces the mobility of the electrons in the plasma and thus increases the gradient, according to:

$$G = \frac{j}{e n_e b_e}$$

(G: Gradient; j: current density; e: electronic charge; n_e : electron density; b_e : electron mobility).

Mercury addition, therefore, allowed lamp wattage to be increased without increasing the lamp currents. This has the advantage in that a less massive anode

and cathode can be used. Also, lamp efficacy will be higher as the electrode losses are a smaller part of the total lamp voltage.

B. Spectral Irradiance and Radiance Results.

The increase in spectral output coupled with the decrease in radiance for equal arc areas of sapphire cesium and rubidium lamps as compared to xenon lamps must be evaluated in terms of their application in optical systems.

Arc concentration is, of course, a required source attribute for high beam characteristics. The lack of concentration and constriction of the cesium and rubidium discharges considerably reduces their usefulness where good optical control is a requirement. The increased spectral output in the 0.65 to 1.5 micron range can be used to advantage only if a method of constricting the cesium or rubidium discharge can be found.

The addition of hydrogen, which was previously studied with pure xenon lamps¹, and which showed a strong arc contraction may provide similar results with cesium

1. Xenon Compact Arcs with Increased Brightness through Addition of Hydrogen, W. E. Thouret, H. S. Strauss, Illuminating Engineering, Vol. LVIII, No. 5, Page 371.

and rubidium discharges. Hydrogen, as a molecular gas, is predominantly dissociated into atoms within the arc discharge and predominantly in the molecular state in the non-radiating gas volume between arc and lamp envelope. Therefore, a substantial amount of energy is carried away from the arc through diffusion of dissociated hydrogen atoms into the cooler surrounding gas volume, where they release their dissociation energy in the process of recombining into molecules. This loss of dissociation energy from the arc is equivalent to a marked increase of thermal conductivity in the surrounding gas. Calculations of the thermal conductivity of hydrogen as a function of temperature and pressure which include the effect of dissociation energy transfer reveal a pronounced maximum in the temperature range of 3,000 - 4,000°K. This temperature exists at the edge of the xenon radiating arc. A steep drop of temperature further inside the arc occurs which is the cause of the strong contraction resulting in a higher axial temperature, brightness, and radiance.

Temperature profile measurements of alkali discharges are described in the literature and values of 4,000 - 4,500°K in the arc center have been reported¹. Temperatures near the edge of the radiating arc have been measured at 1500°K. The addition of hydrogen may, therefore, cause an arc contraction near the arc center in cesium and rubidium lamps with a consequent increase in radiance.

1. Parameters of the High Pressure Sodium Discharge Column.
K. Schmidt, General Electric Co., Nela Park, Cleveland, Ohio.
(Available from author.)

IV. Conclusions

A technique has been established, and made available to the government, for fabricating sapphire envelope lamps operating with cesium-xenon, cesium-mercury-xenon, and rubidium-xenon electrode stabilized arc discharges. As detailed in Table I, performance reliability must be improved. Mechanical design changes, involving anode and cathode end-caps can accomplish this by increasing their flexibility. Thus, the thermal expansion and contraction characteristics of synthetic sapphire will not lead to occasional cracking of envelopes as encountered even during the later stages of the contract work.

Nine sapphire lamps were delivered under the contract to the Night Vision Lab., Fort Belvoir, Va. 3 lamps were filled with cesium-xenon and 6 lamps were filled with rubidium-xenon. Table I lists their operating data.

As stated in the report, a significant increase in spectral output (based on irradiance measurements) for cesium and rubidium lamps over pure xenon lamps at equal wattage was achieved in the 0.85 to 1.5 micron region. Individual arc area radiance measurements, however, showed considerably lower values than for pure xenon lamps of equal wattage.

V. Financial Statement

At the end of the completed contract period, July 15, 1967 the total fixed contract price of \$42,392.00 has been spent.

The Accounting Department of Duro-Test Corp. will render a detailed statement.

Herbert S. Strauss

Herbert S. Strauss
Manager
Vapor and Xenon Lamp Engineering

S. F. Cortorillo

S. F. Cortorillo
Engineer in Charge of Lamp Design
and Processing

H. Kee

H. Kee
Engineer in Charge of Mechanical
and Tool Design

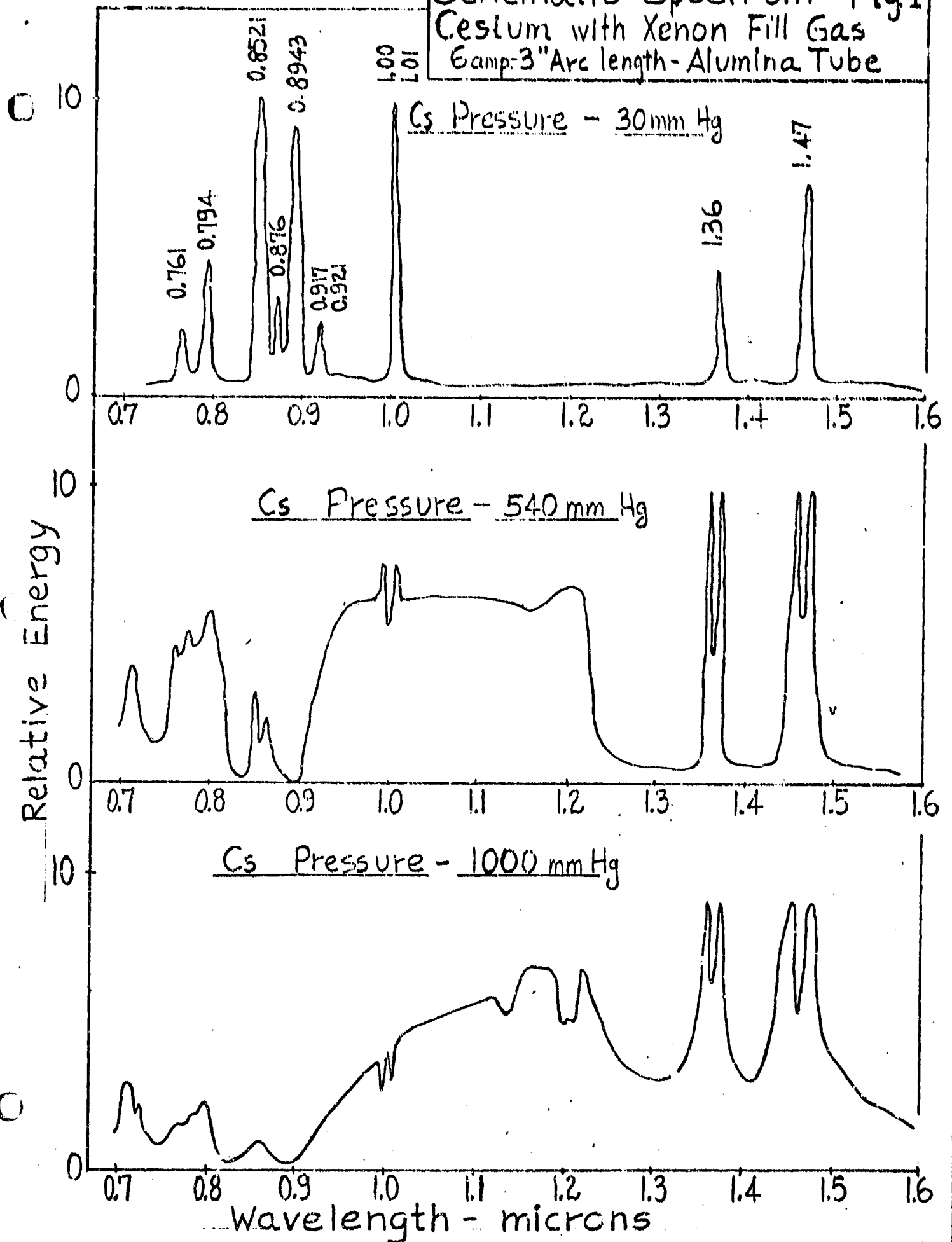
A. H. Olsen

A. H. Olsen
Engineer working with Mr. Cortorillo
on Lamp Processing During Last
Stages of Contract

W. E. Thouret

Approved:
W. E. Thouret
Associate Director, Engineering

Schematic Spectrum - Fig 1 Cesium with Xenon Fill Gas Camp-3" Arc length - Alumina Tube



VAPOR PRESSURE vs. TEMPERATURE

CESIUM and CESIUM IODIDE

Vapor Pressure - mm Hg

1000

100

10

1

0.1

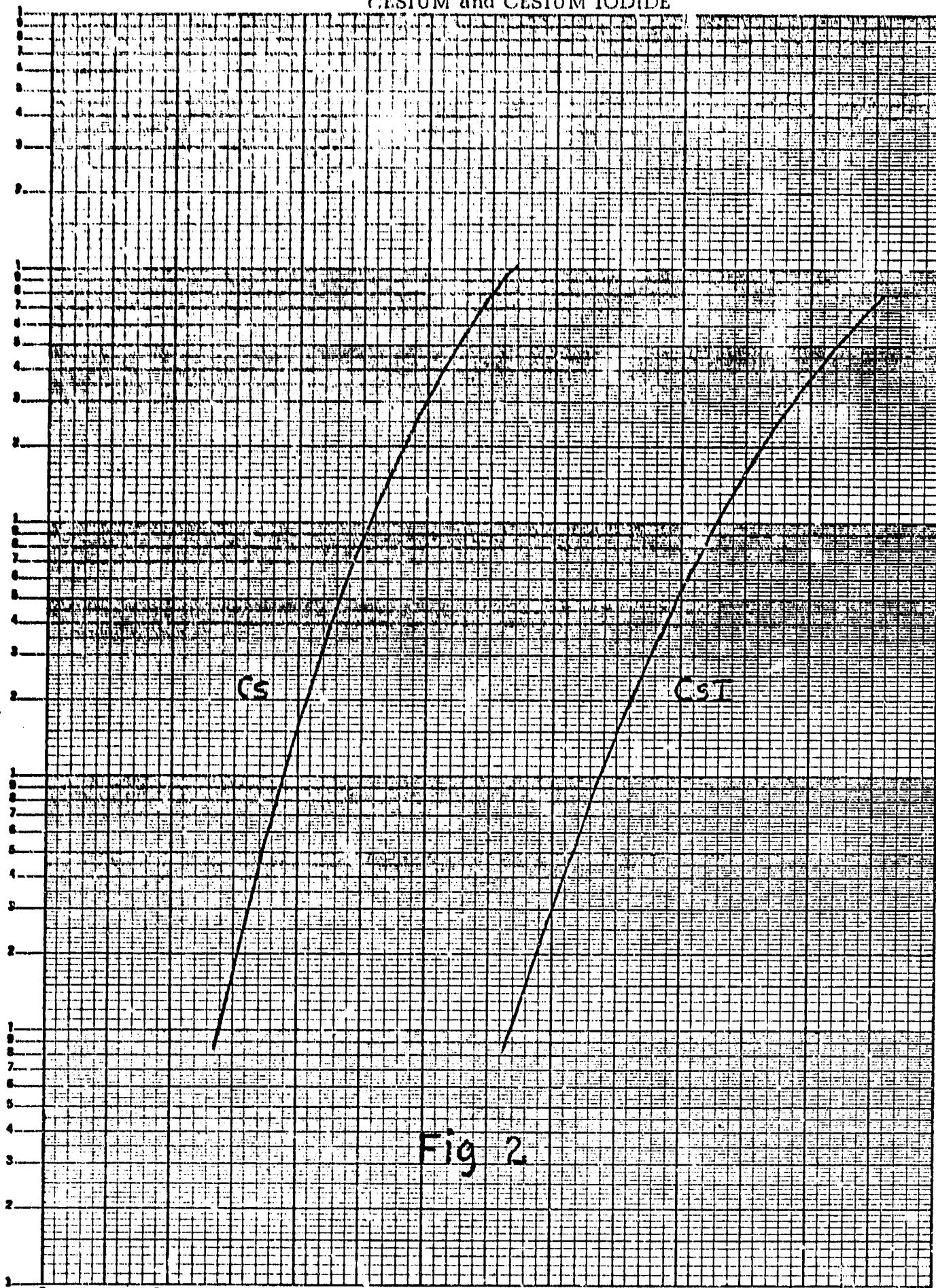
CS

CS₂I

Fig 2

Temperature - °C

K&E
SEMI-LOGARITHMIC 359-91
KEUFFEL & ESSER CO. MADE IN U.S.A.
5 CYCLES X 70 DIVISIONS



NO. 2332A CENTIMETERS

FIBRASCOP ALLENDALE
CALIFORNIA

DESIGNED BY
PATENTED AND REGISTERED
78 10. FOURTH ST. GAITHER, PA.

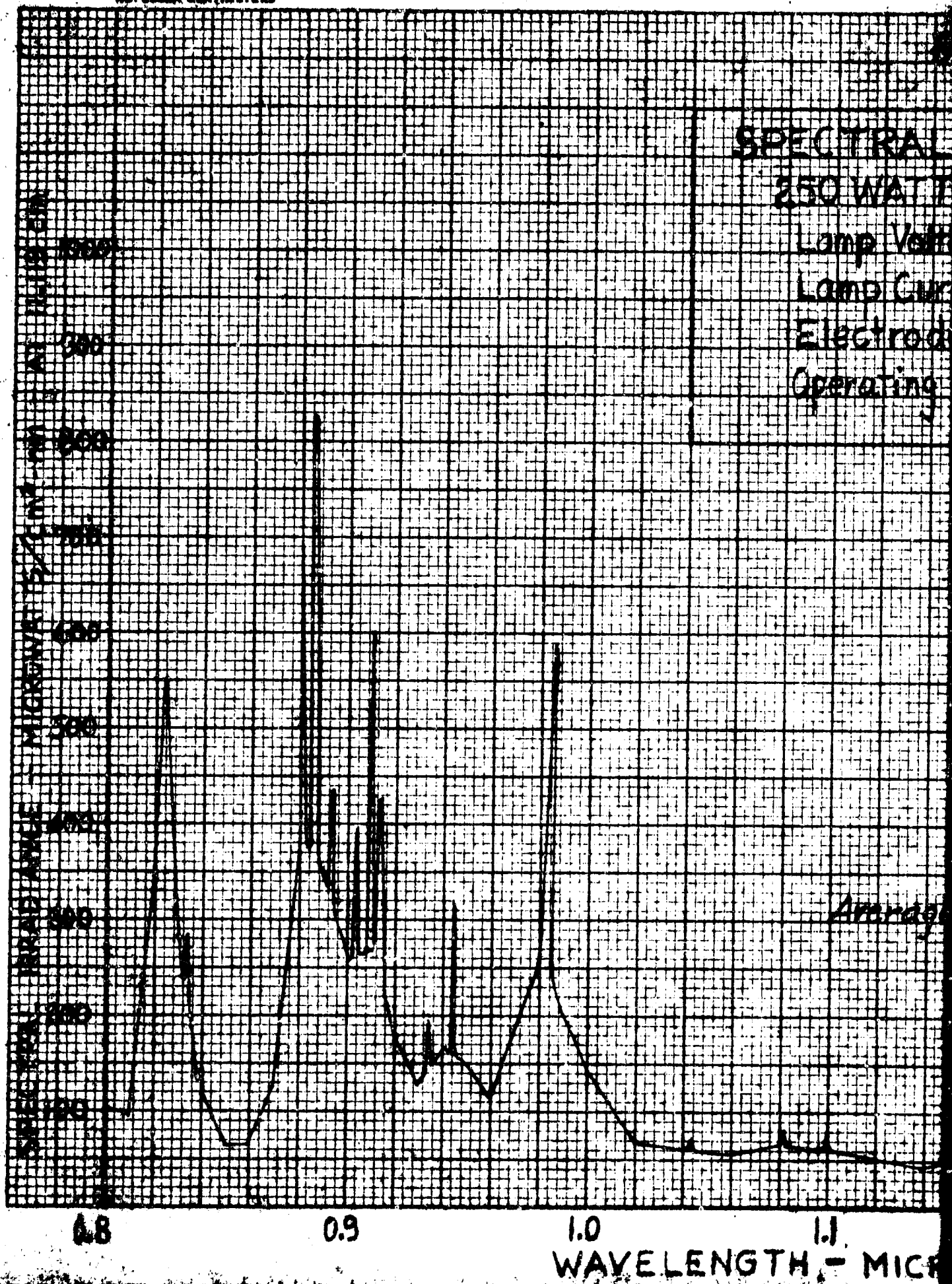


Fig. 3

CENTRAL IRRADIANCE
50 WATT XENON LAMP

Lamp Voltage - 250 volts

Lamp Current - 10.0 amps.

Electrode Spacing - 3.4 mm.

Operating Pressure - 30 atm.

Average $_{0.85-1.3\mu}$ = 93.20 microwatts/cm²-nm

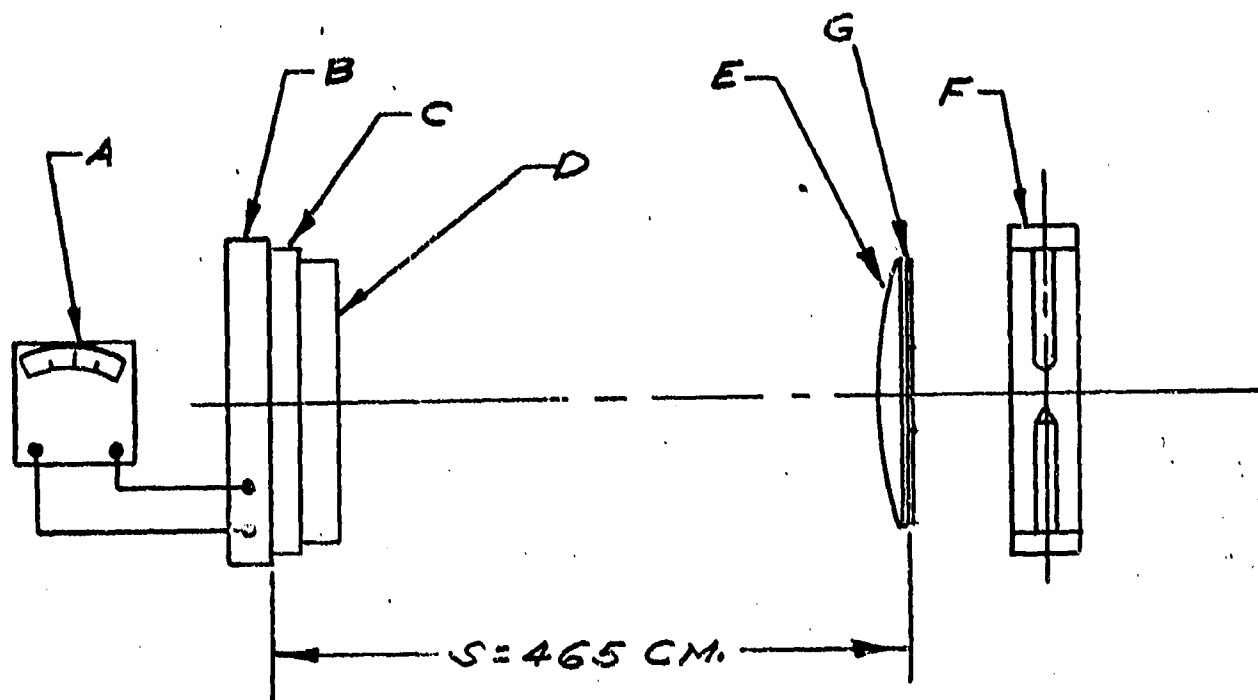
1.1 MICRONS

1.2

1.3

1.4

FEB 1966



$$T_{C+D} = 0.304$$

$$T_E = 0.86$$

- A. Keithley Instruments Model 150A Microvoltmeter
- B. Eppley Laboratory Bismuth Silver (16 Junction) Thermopile
- C. Baird-Atomic, Inc., Type XK6 Optical Interference Filter
- D. Water Cell (10 mm Light Path)
- E. 6" focal length quartz lens
- F. Lamp
- G. 1" Dia. Stop

<u>FIG. 4</u>		DURO-TEST CORP. NO. BERGEN, N.J.	
DWN: H. KEE		DIAGRAM-RADIANCE MEASURING SYSTEM, 0.85-1.4 MICRONS	
DATE: 6-30-67			

Fig. 5

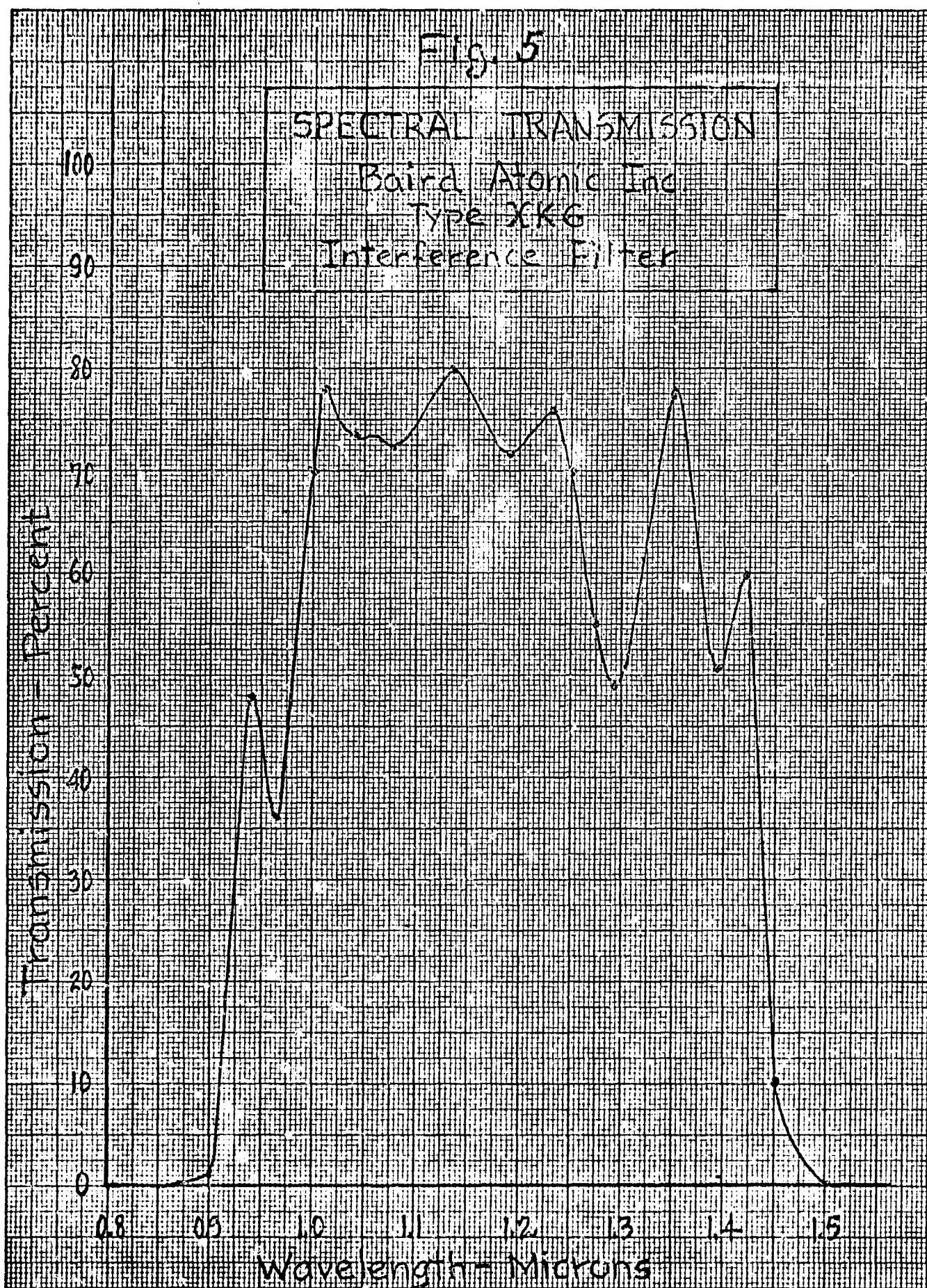


FIG. 6

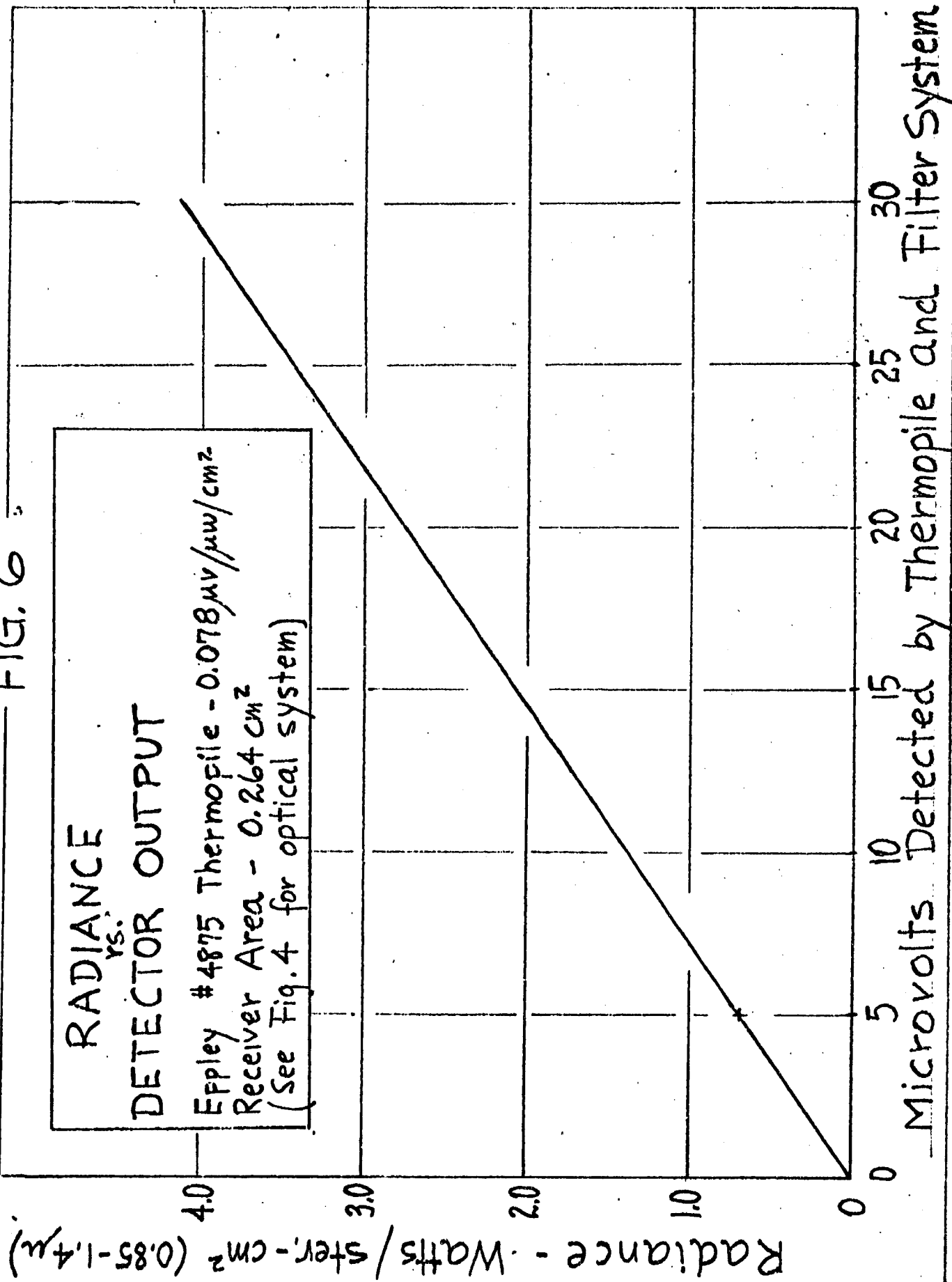
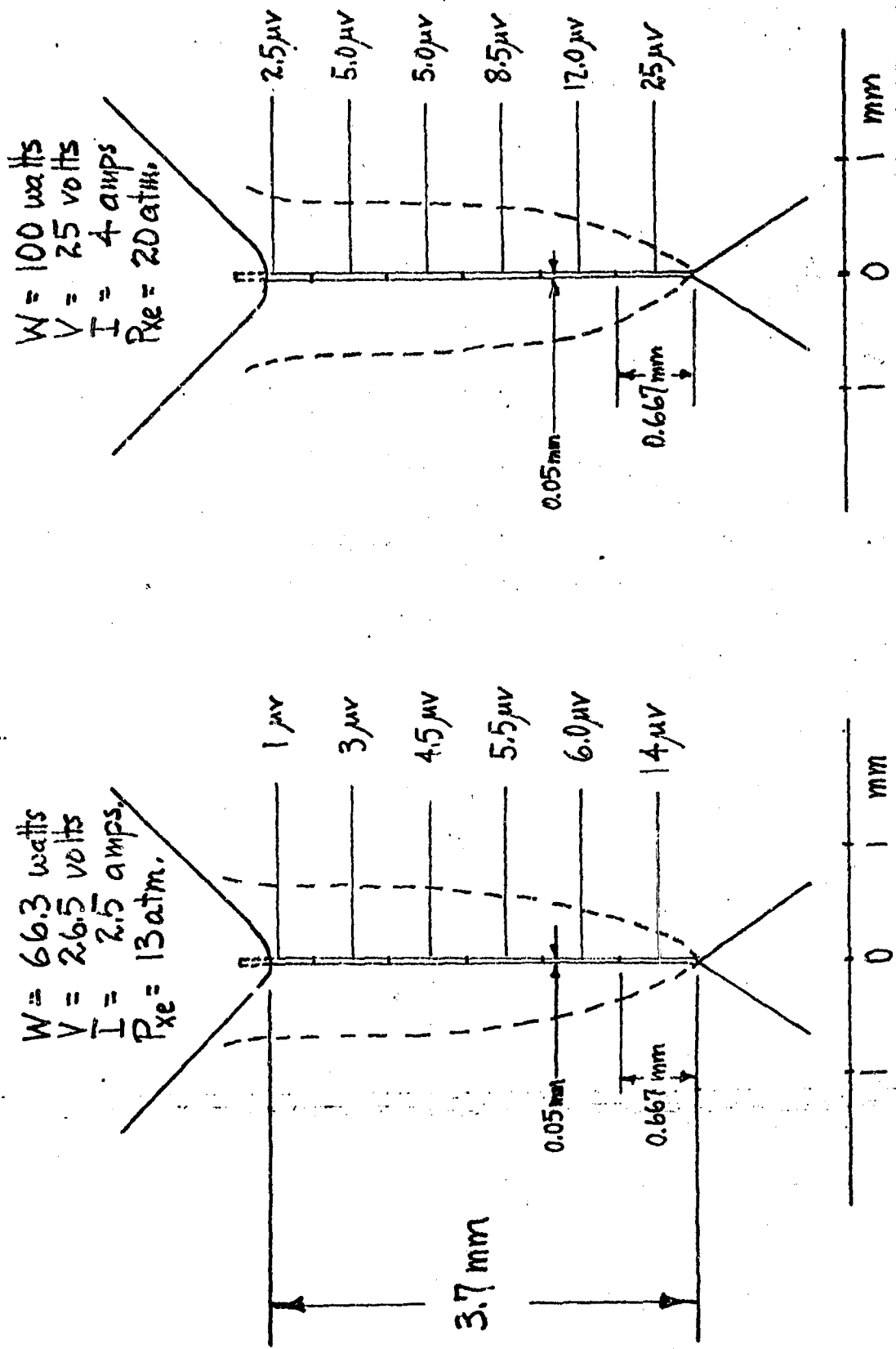
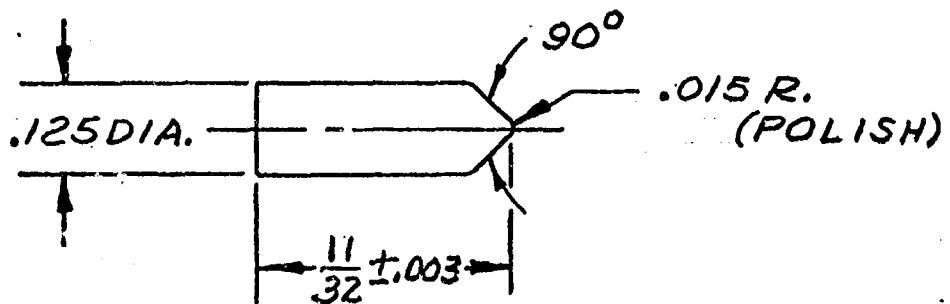


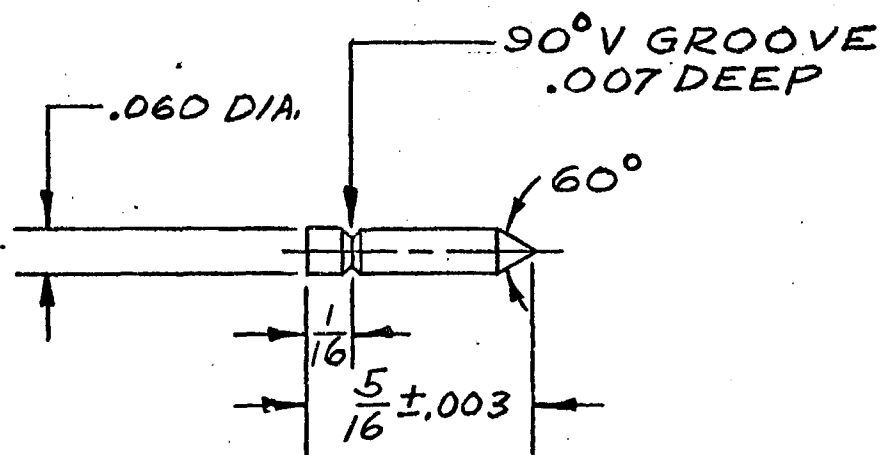
FIG. 7 RADIANCE ALONG ARC CENTER LINE FOR
QUARTZ XENON LAMP
(See Fig. 6 for microvolt to radiance conversion)





MAT'L: SWAGED TUNGSTEN

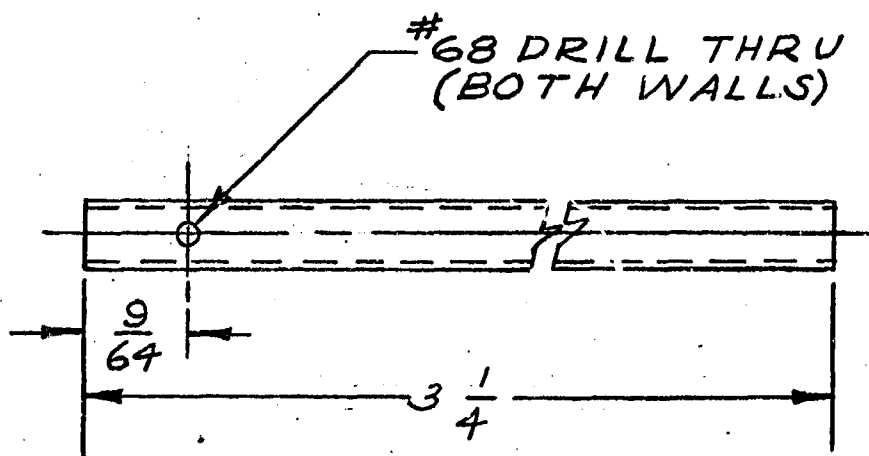
NAME: ELECTRODE, ANODE



MAT'L: SWAGED TUNGSTEN

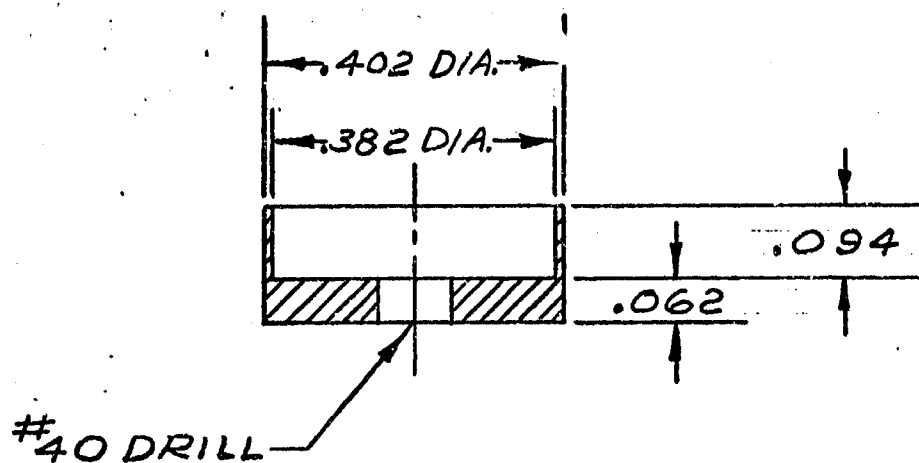
NAME: ELECTRODE, CATHODE

Fig. 8		DURO-TEST CORP. NO. BERGEN, N.J.	
		ELECTRODES	
USED ON: J65-6		DWG. NO: J65-8	
DWN: Hke	APP:		
SCALE 4/1	DATE: 3/2/66		



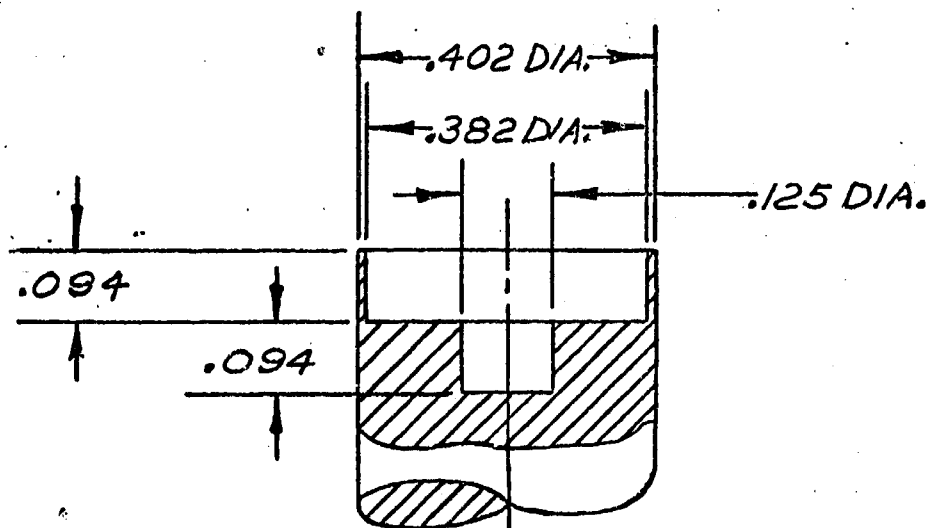
MAT'L: SEAMLESS COLUMBIUM TUBING,
STRESS RELIEVED TEMPER,
.094 O.D. X .010 WALL

Fig. 9		DURO-TEST CORP. NO. BERGEN, N.J.	
USED ON: J65-6		TUBULATION	
DWN: KEE	APP:		
SCALE 4/1	DATE: 3/2/66	DWG. NO: J65-9	



MAT'L: COLUMBIUM

NAME: CATHODE CAP



MAT'L: COLUMBIUM

NAME: ANODE CAP

Fig. 10		DURO-TEST CORP. NO. BERGEN, N.J.	
USED ON: J65-6		CAPS, ELECTRODE	
DWN: Hke	APP:		
SCALE 4/1	DATE: 3/1/66	DWG. NO: J65-7	

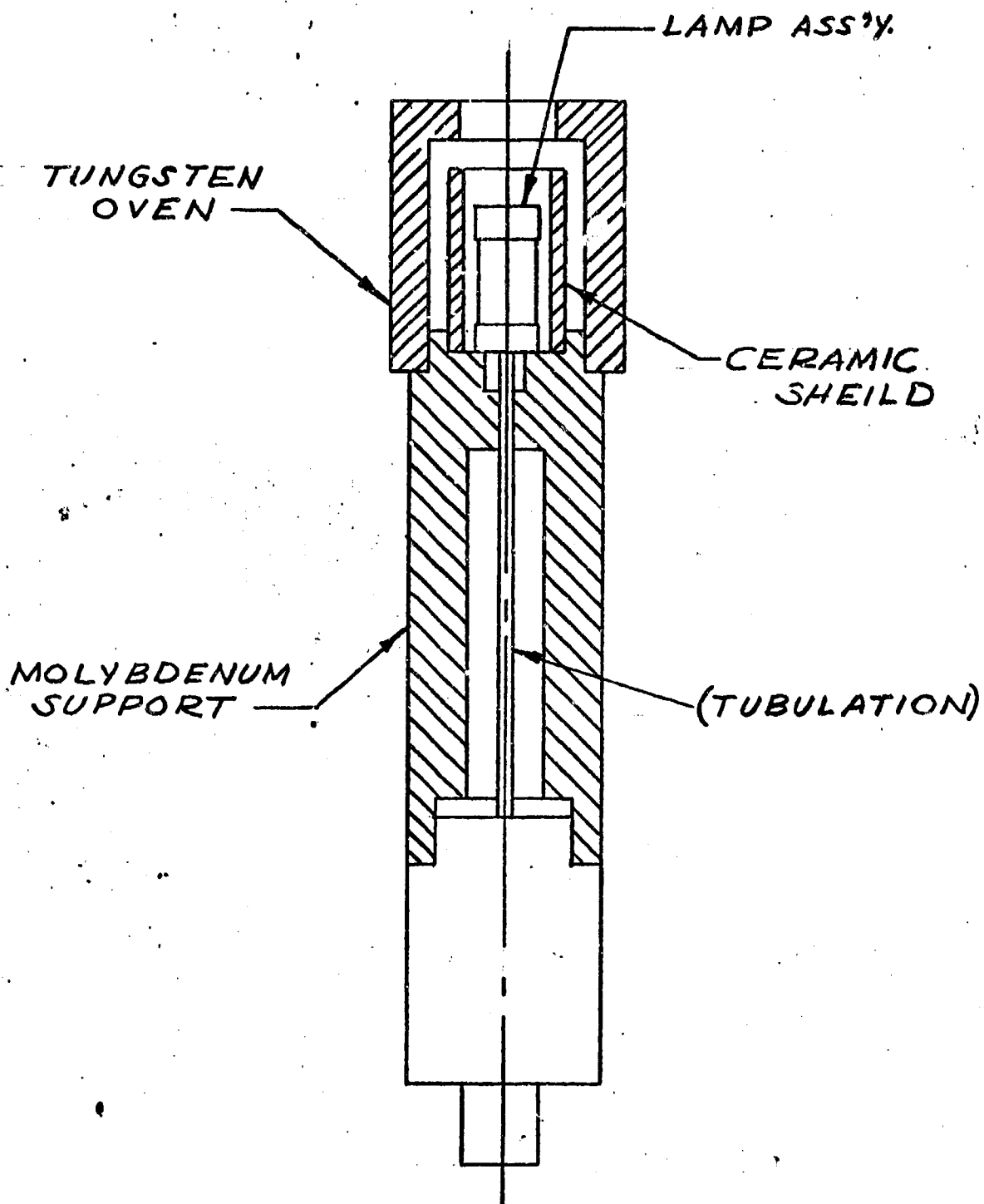


Fig. 11

DWN: Hke SCALE 1/1		DURO-TEST CORP. NO. BERGEN, N.J.
		LAMP FRIT SEAL OVEN & SUPPORT ASS'Y. (WITH LAMP IN PLACE)
APP:	DATE: 3/2/66	DWG NO: J65-10

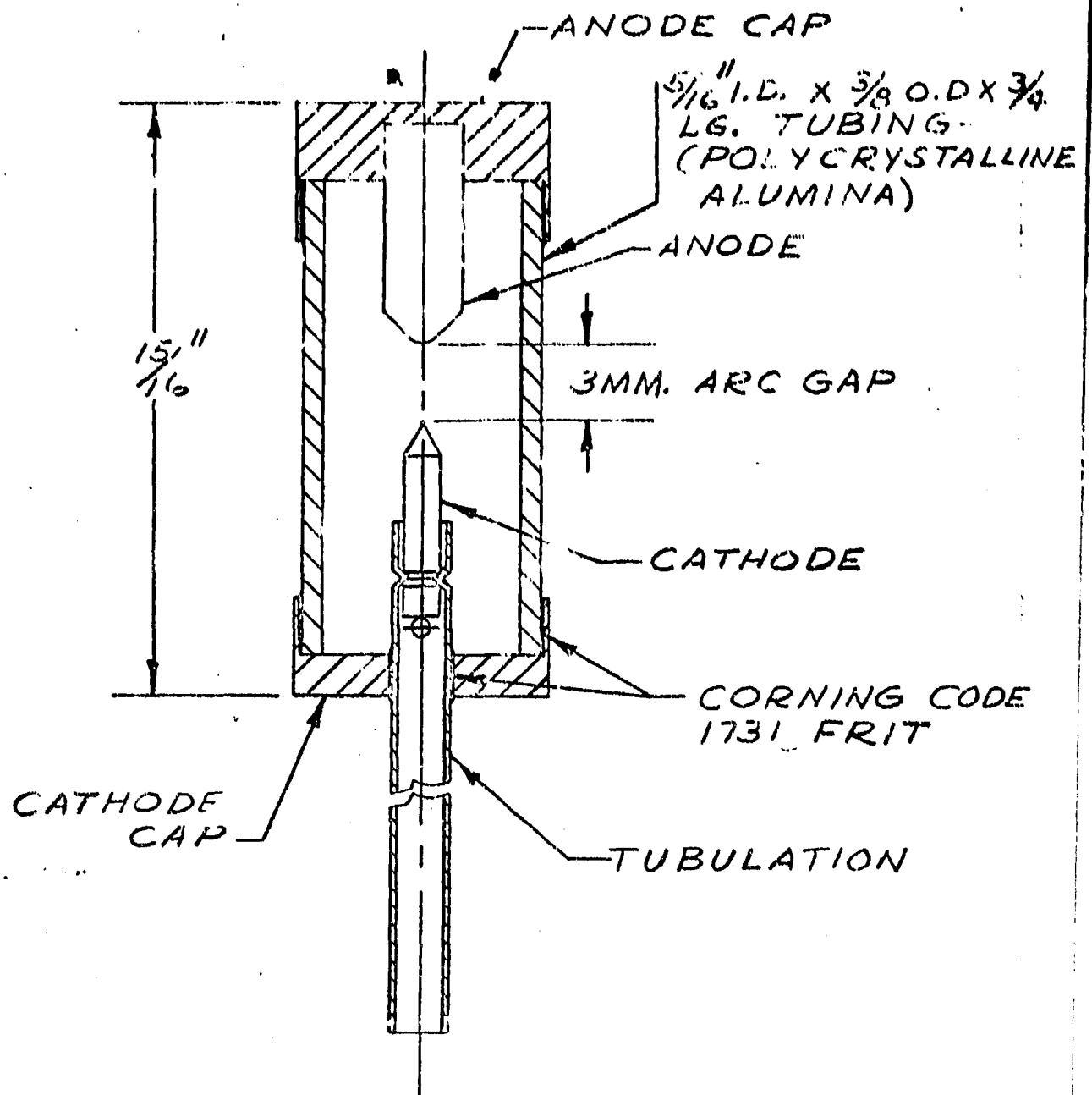


Fig. 12		DURO-TEST CORP. NO. BERGEN, N.J.	
		LAMP ASS'Y., NEAR INFRA-RED	
DWN: Kce		DATE: 3/1/66	DWG. NO: J65-6
SCALE 4/1			

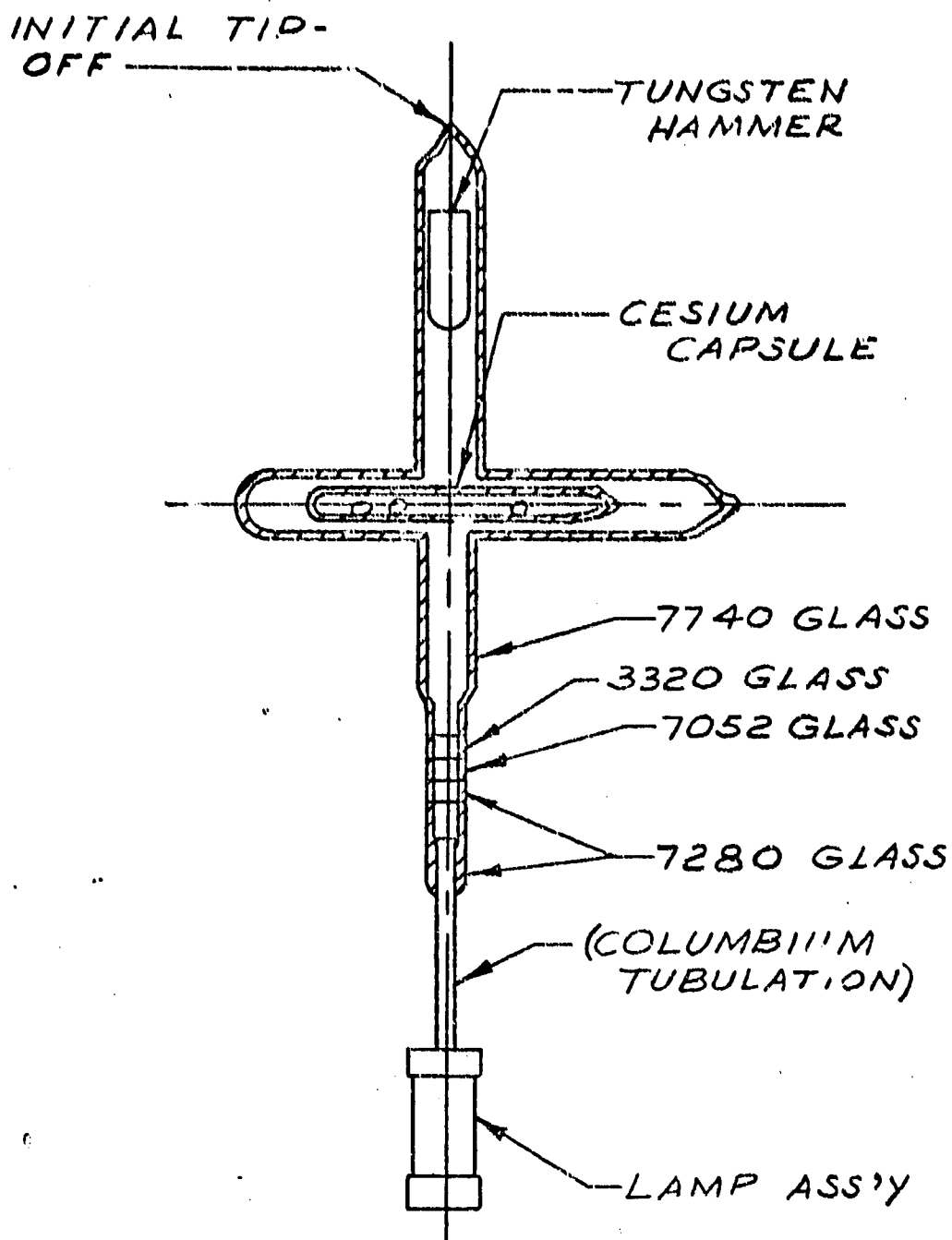


Fig. 13

Fig. 13		DURO-TEST CORP. NO. BERGEN, N.J.	
		LAMP EXHAUST & FILL APPARATUS (CERAMIC LAMP)	
DWN: Hke	APP:	DWG. NO: J65-11	
SCALE 1/1	DATE: 3/8/66		

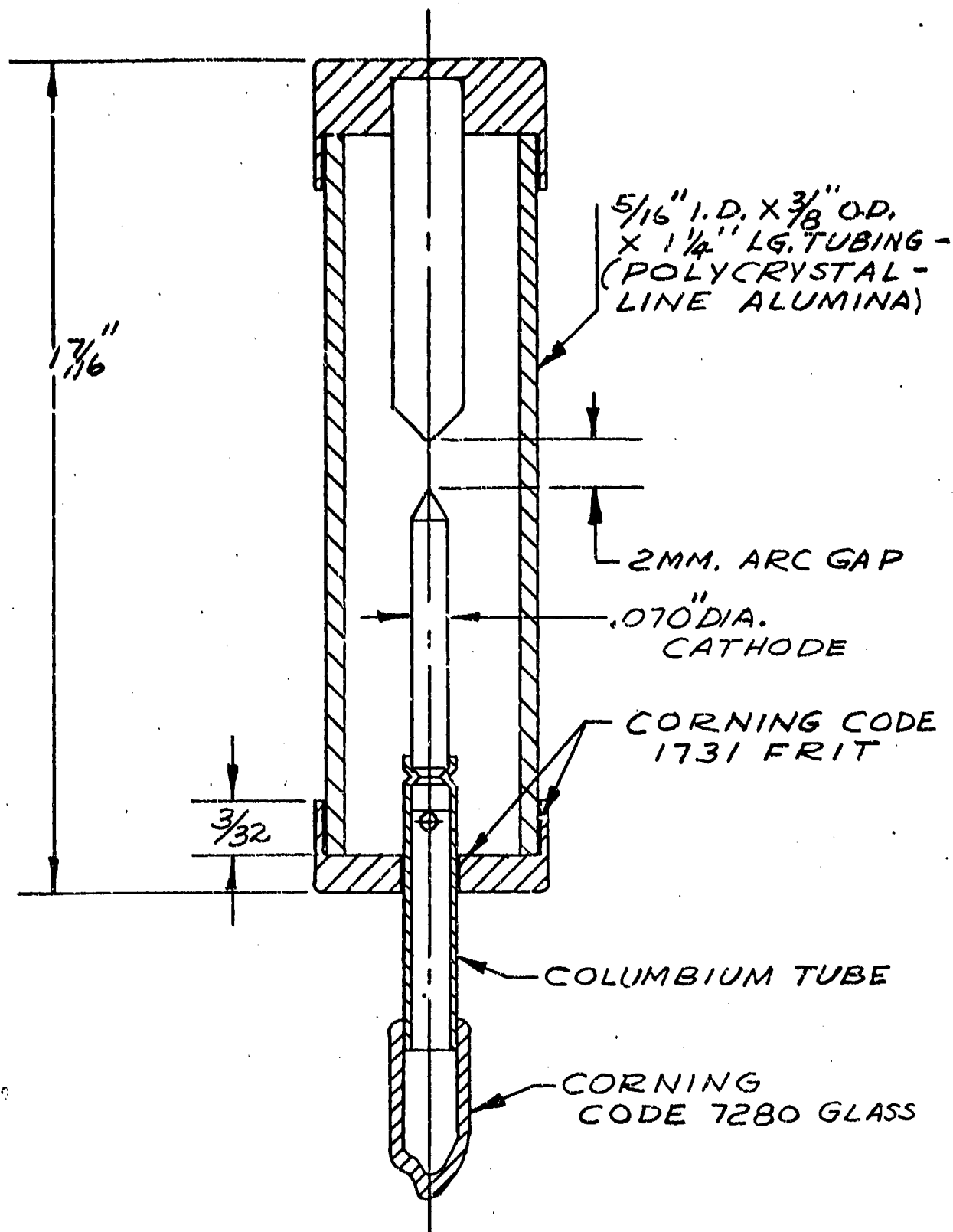


FIG. 14		DURO-TEST CORP. NO. BERGEN, N.J.	
		LAMP ASSEMBLY, NEAR INFRA-RED	
DWN: HKEE		DWG. NO: J65-12	
SCALE: 4/1	DATE: 5/24/66		

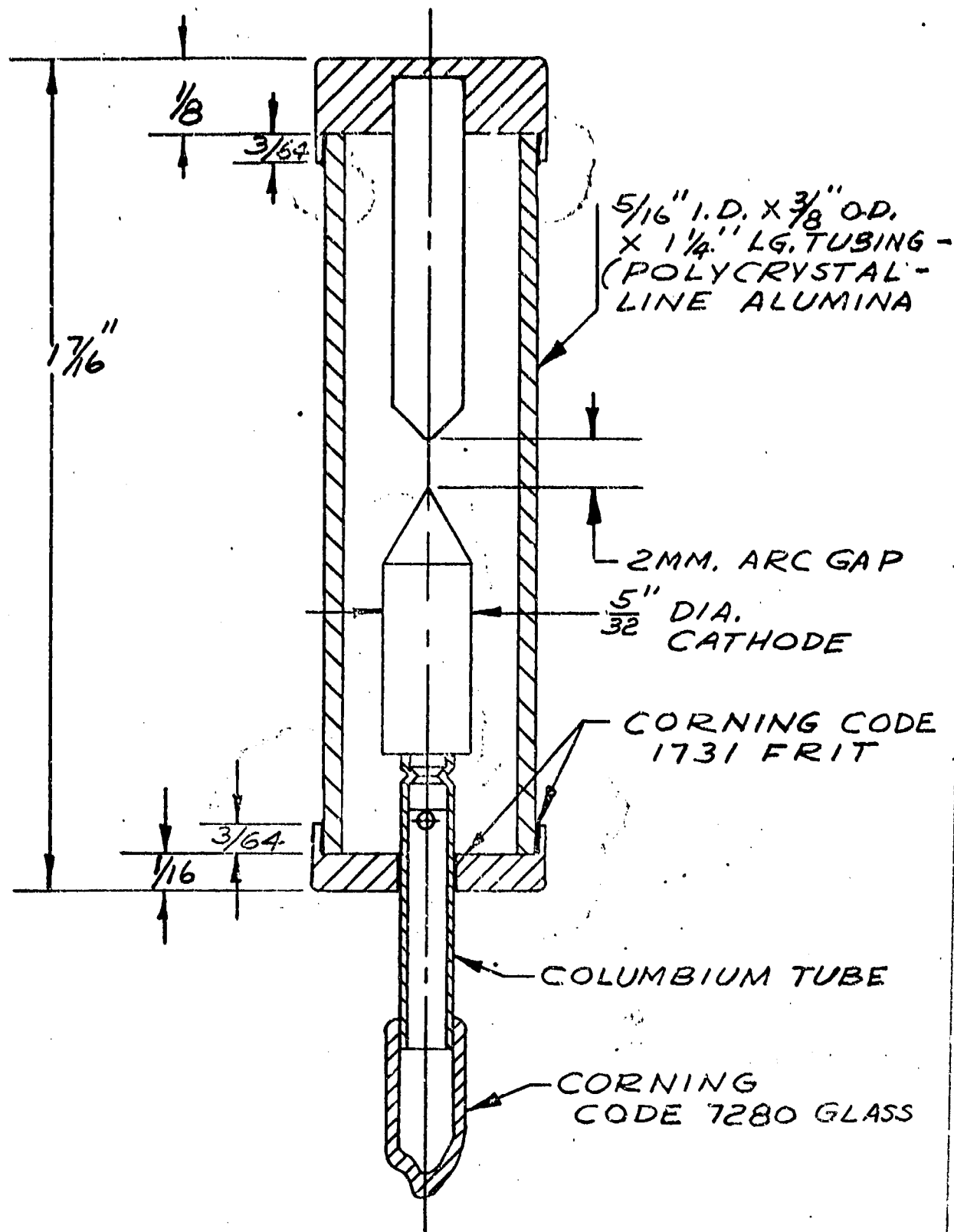


FIG. 15		DURO-TEST CORP. NO. BERGEN, N.J.	
DWN: HKEE		LAMP ASSEMBLY, NEAR INFRA-RED	
SCALE: 4/1	DATE: 5/26/66	DWG. NO: J65-14	

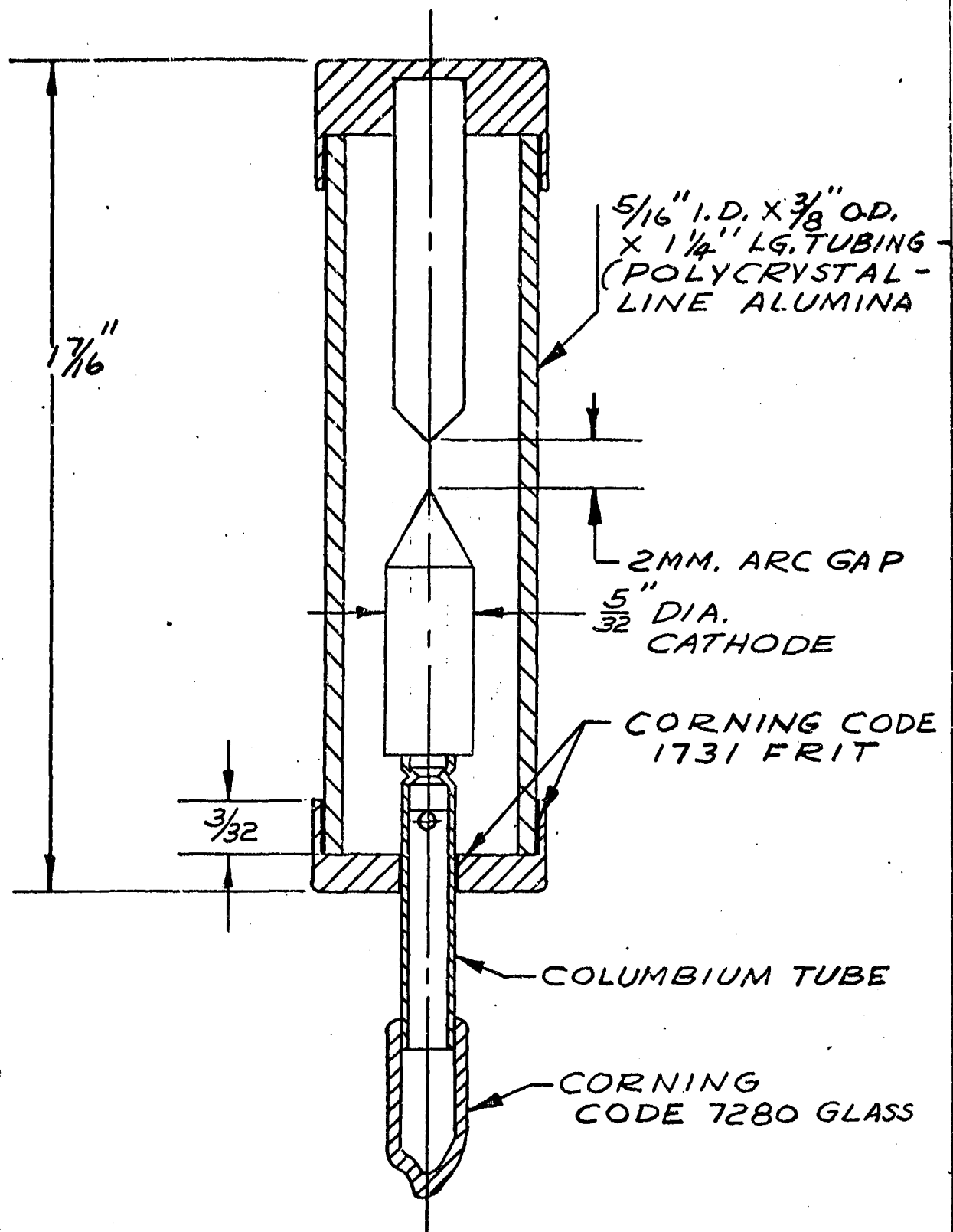


FIG. 16		DURO-TEST CORP. NO. BERGEN, N.J.	
		LAMP ASSEMBLY, NEAR INFRA-RED	
DWN: HKEE			
SCALE: 4/1	DATE: 5/26/66	DWG. NO: J65-13	

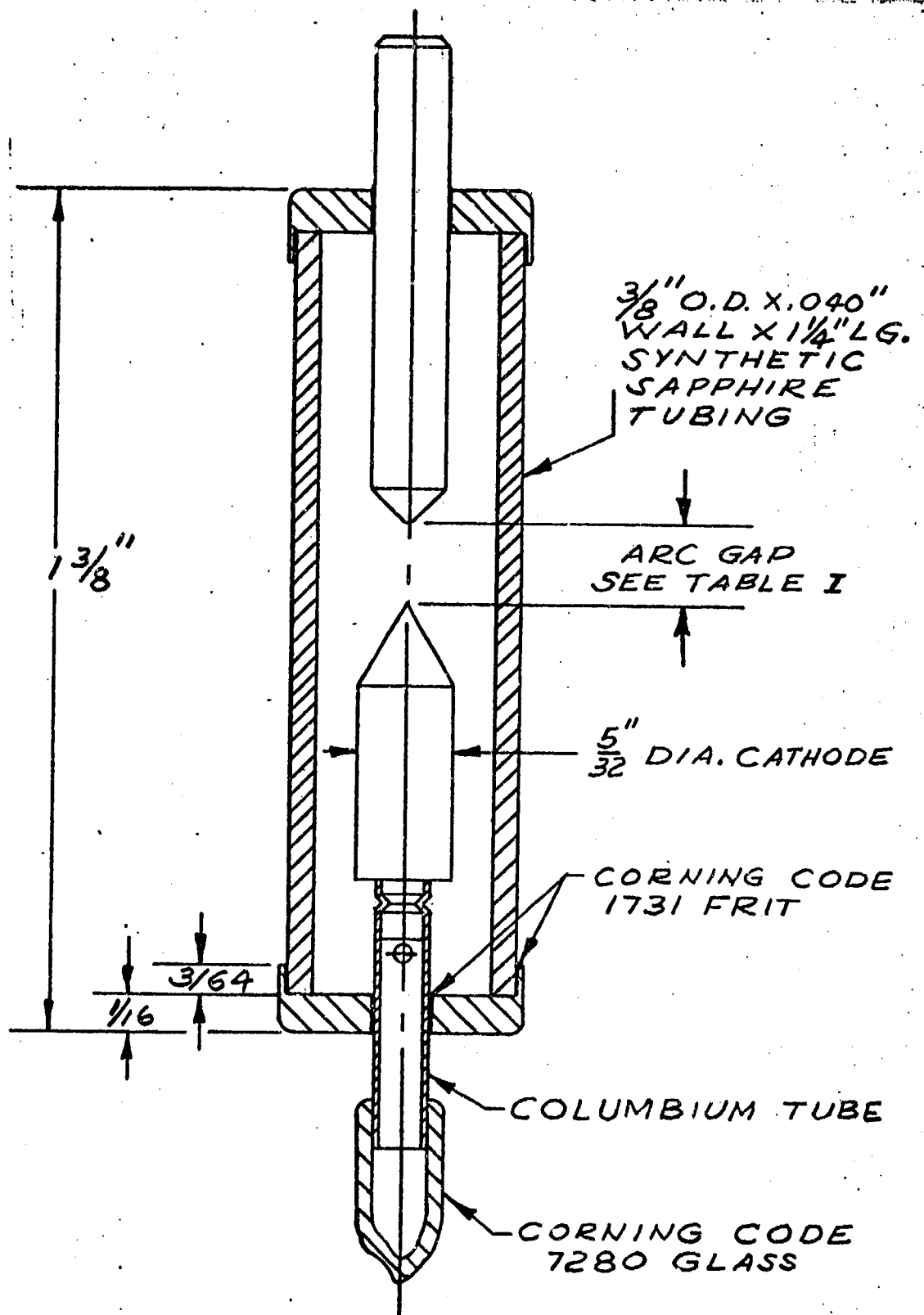


FIG. 17

DURO-TEST CORP.
NO. BERGEN, N.J.

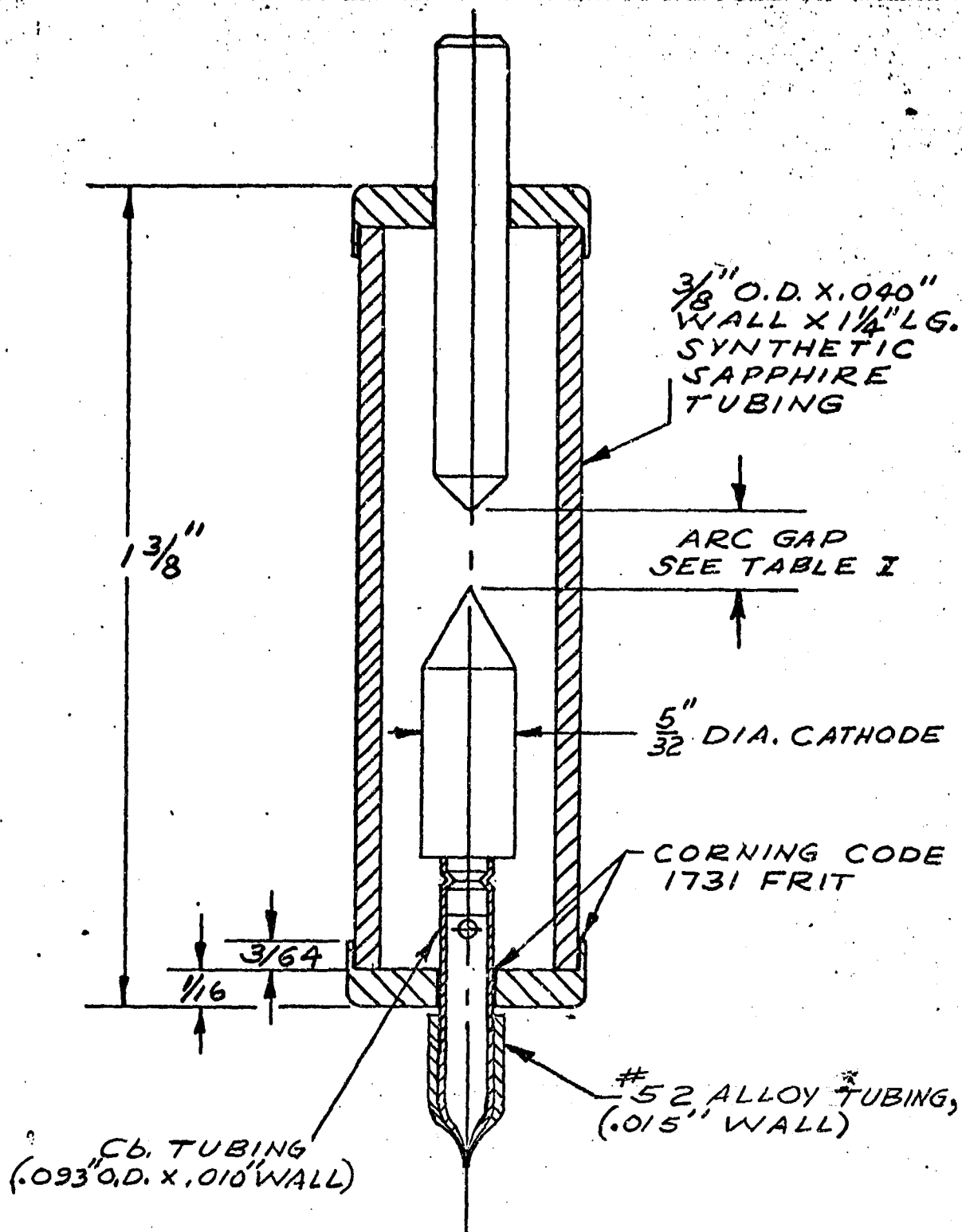
LAMP ASSEMBLY-
NEAR INFRARED

DWN: HKEE

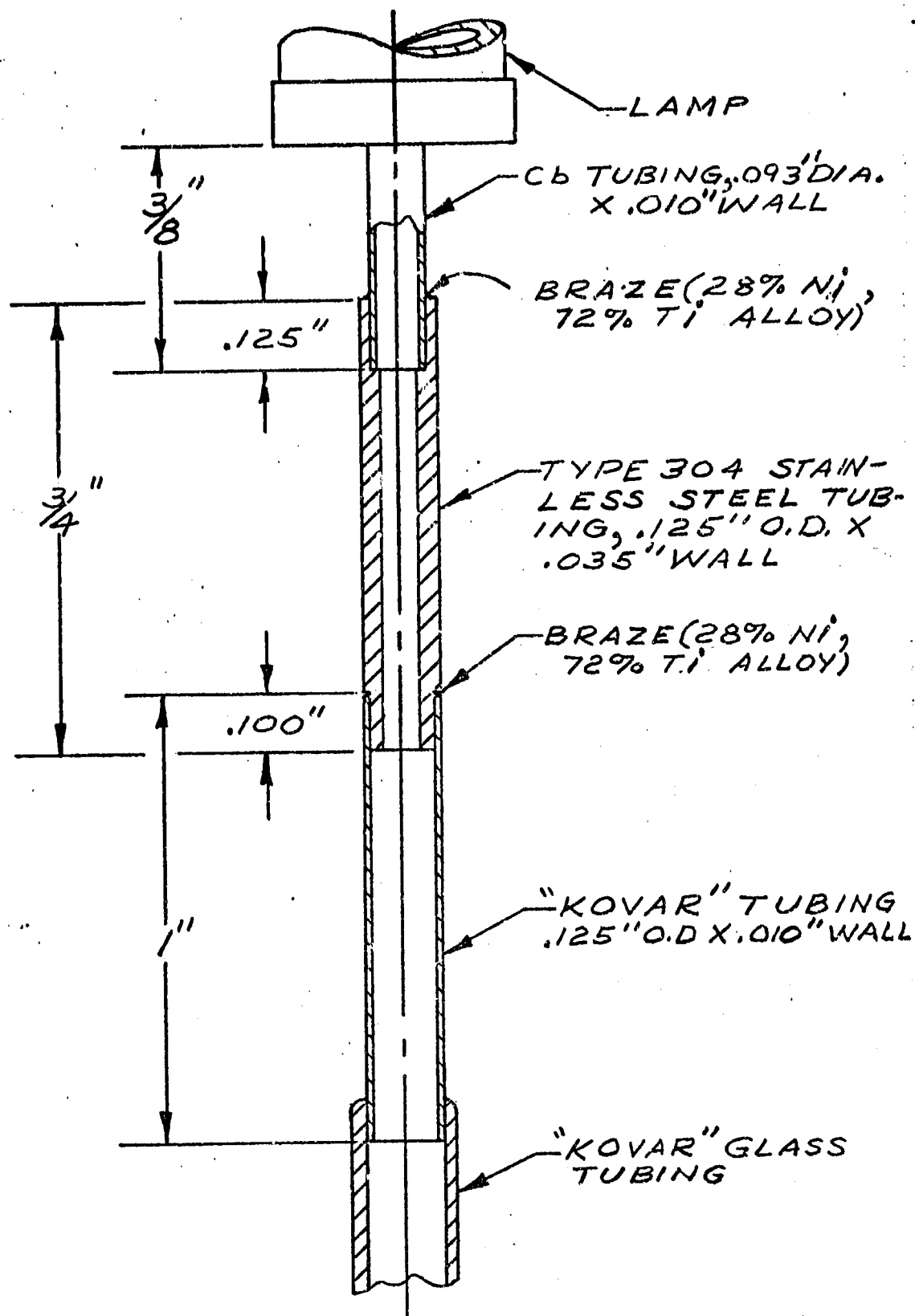
SCALE: 4/1

DATE: 6.30.67

DWG. NO.



<u>FIG. 18</u>		DURO-TEST CORP. NO. BERGEN, N.J.	
		LAMP ASSEMBLY- NEAR INFRARED	
DWN: HEE		DWG. NO.	
SCALE: 4/1	DATE: 6/28/67		



<u>FIG. 19</u>		DURO-TEST CORP. NO. BERGEN, N.J.
		LAMP PREPARATION FOR METAL PINCH-OFF
DWN: HEE		
SCALE: 4/1	DATE: 6/28/67	DWG. NO.

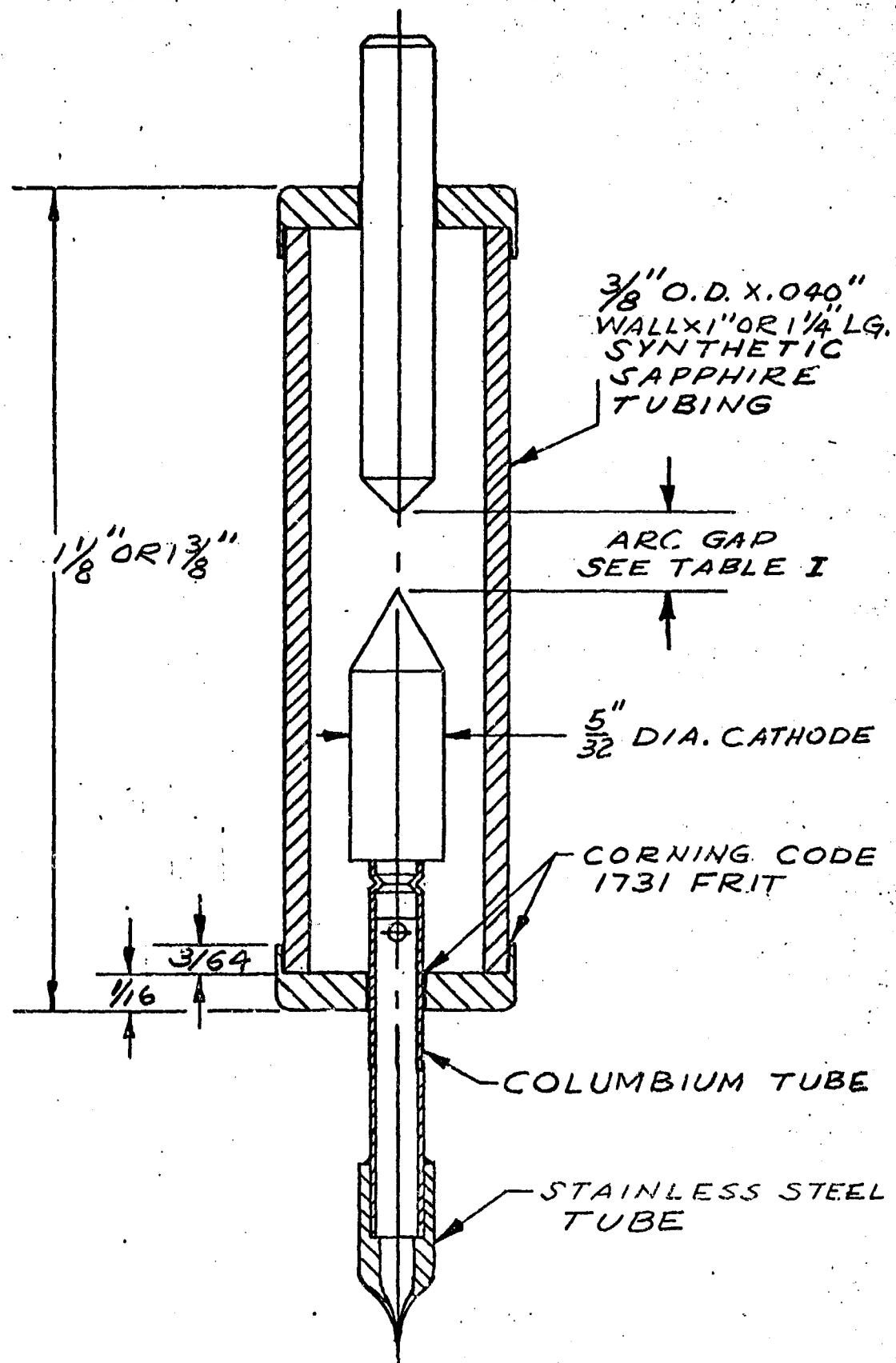


FIG. 20

DURO-TEST CORP.
NO. BERGEN, N.J.

LAMP ASSEMBLY-
NEAR INFRARED

DWN: HEE

SCALE: 4/1

DATE: 6.30.67

DWG. NO.

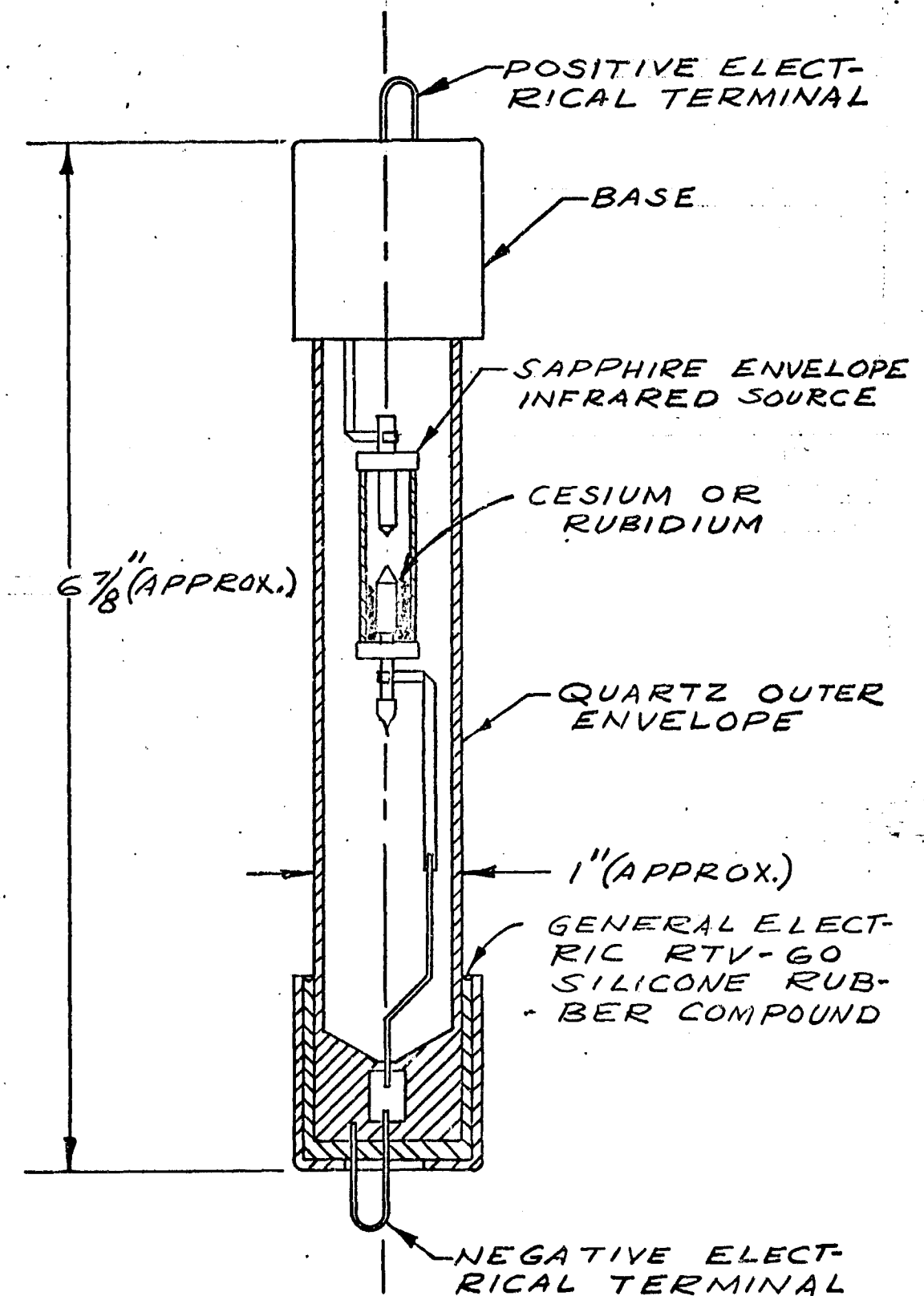


FIG. 21

DURO-TEST CORP.
NO. BERGEN, N.J.

INFRARED RADIATION
SOURCE MOUNTED IN
OUTER ENVELOPE

DWN: HKEE

SCALE: $\frac{1}{4}$

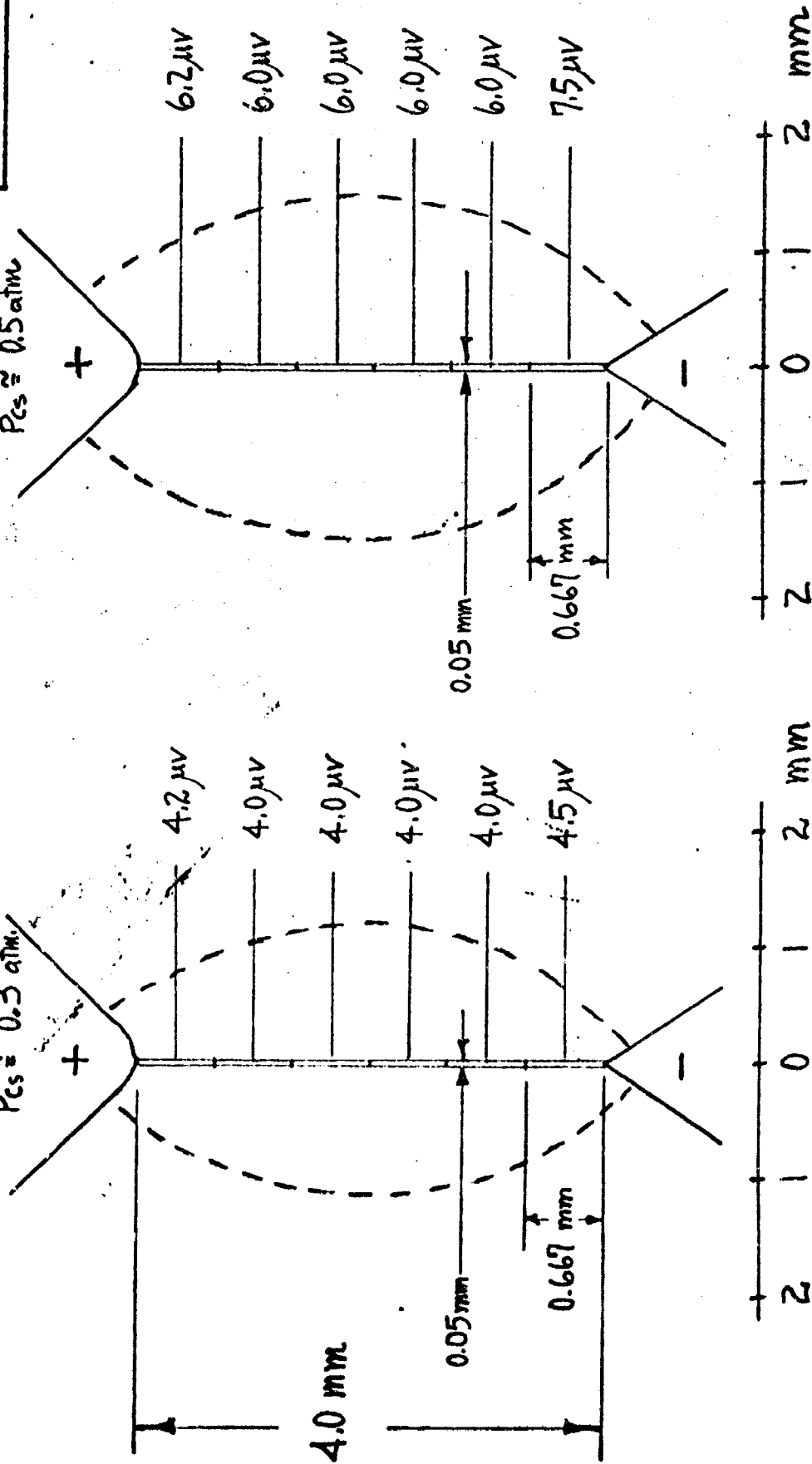
DATE: 6-30-67

FIG. 22 RADIANCE ALONG ARC CENTERLINE FOR
SAPPHIRE CESIUM-XENON LAMP. (See Fig 6

for micro-
volt to
radiance
conversion

$W = 94.5$ watts
 $V = 13.5$ volts
 $I = 7.0$ amps
 $P_{Xe} = 3$ atm
 $P_{Cs} \approx 0.5$ atm

$W = 65$ watts
 $V = 13$ volts
 $I = 5$ amps
 $P_{Xe} = 2$ atm
 $P_{Cs} \approx 0.3$ atm



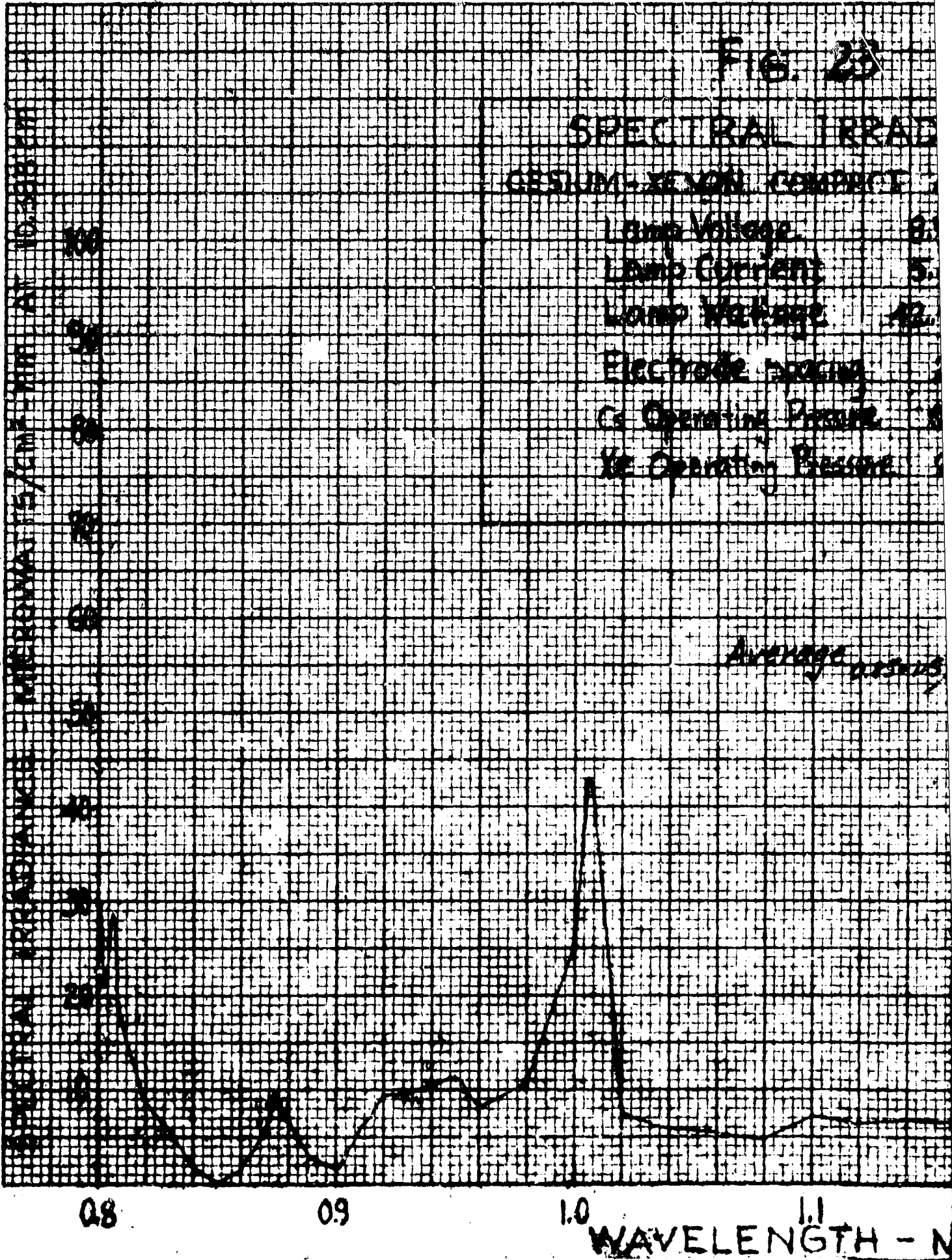
NO. 2890A CENTIMETERS

FIG. 23

SPECTRAL IRRADIANCE
CESIUM-XENON COMBUST

Lamp Voltage 81
Lamp Current 5
Lamp Voltage 42
Electrode spacing
Cs Operating Pressure
Xe Operating Pressure

Average curve



LIBRASCRIPT
GLENDALE
CALIFORNIA

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DAVENPORT AND RESEARCH
70 NO. ROBERTS ST. EASTON, PA.

23

IRRADIANCE

IMPACT ARC LAMP

8.5 Volts

5.0 AMPS

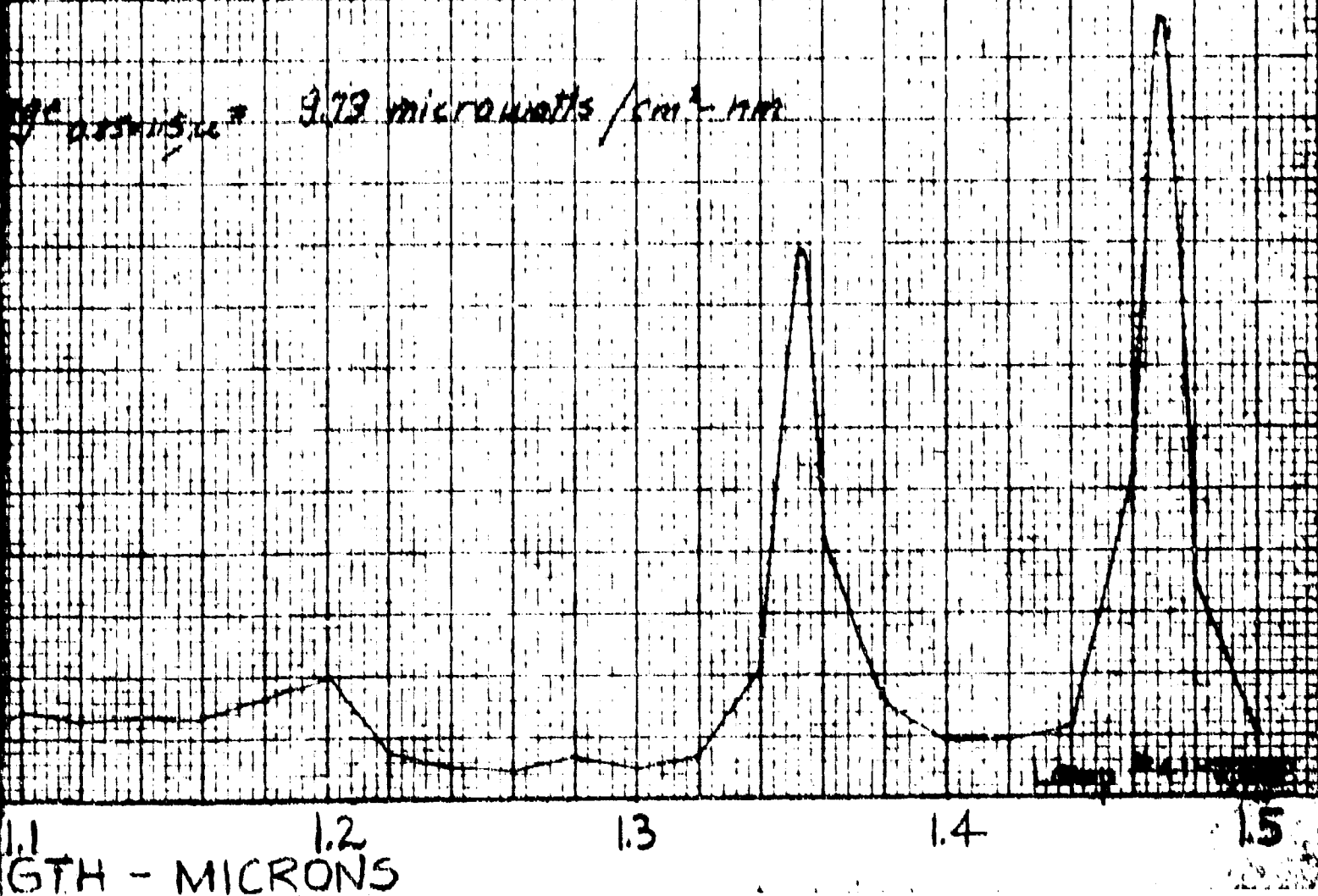
42.5 Watts

2 mm

0.10 atm (appr.)

0.5 atm (appr.)

$9.73 \text{ microwatts/cm}^2\text{-nm}$



NO. 2550A CENTIMETERS

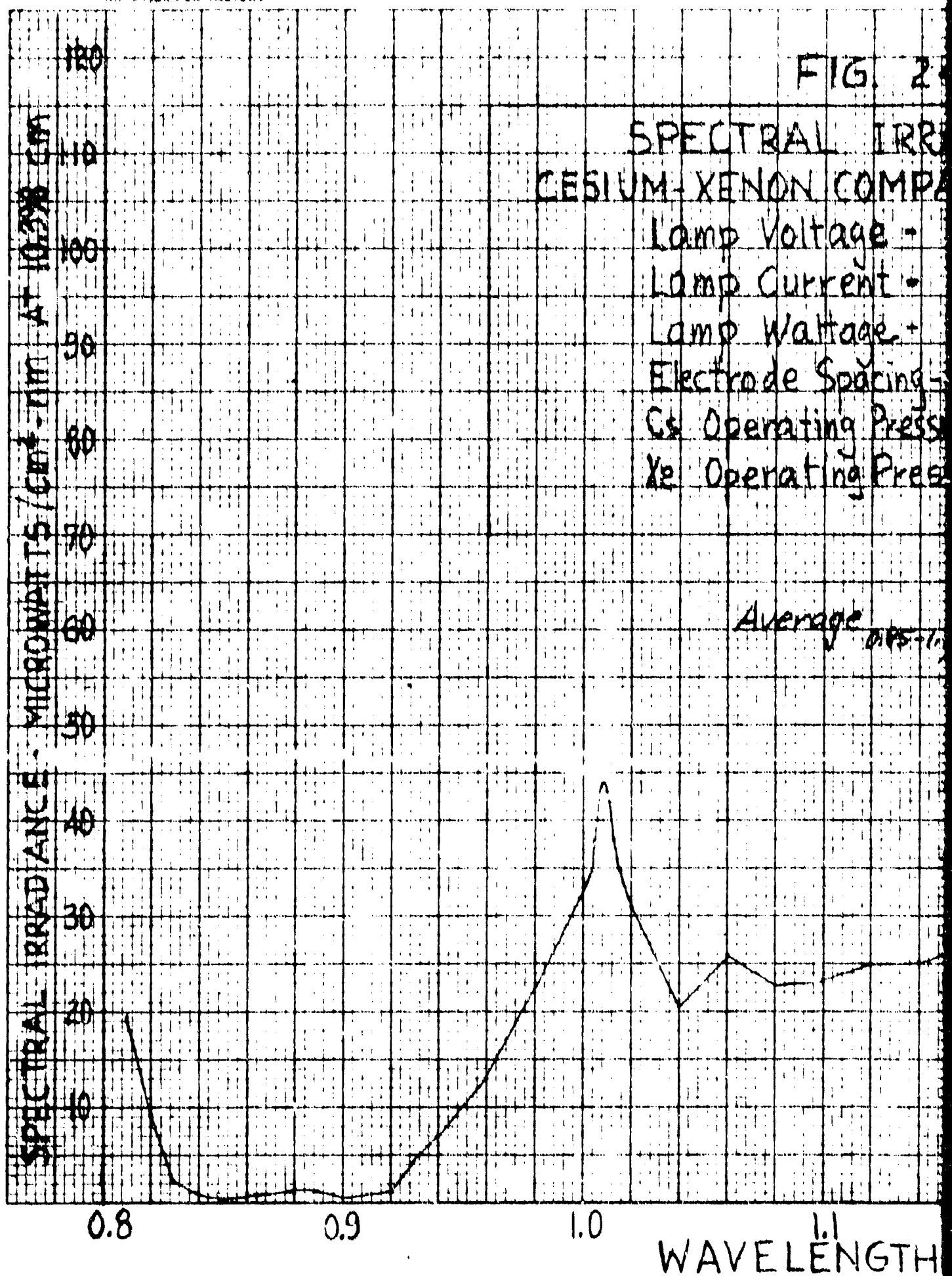


FIG. 24

AL IRRADIANCE
IN COMPACT ARC LAMP

Voltage - 14.4 Volts

Current - 5.0 Amps

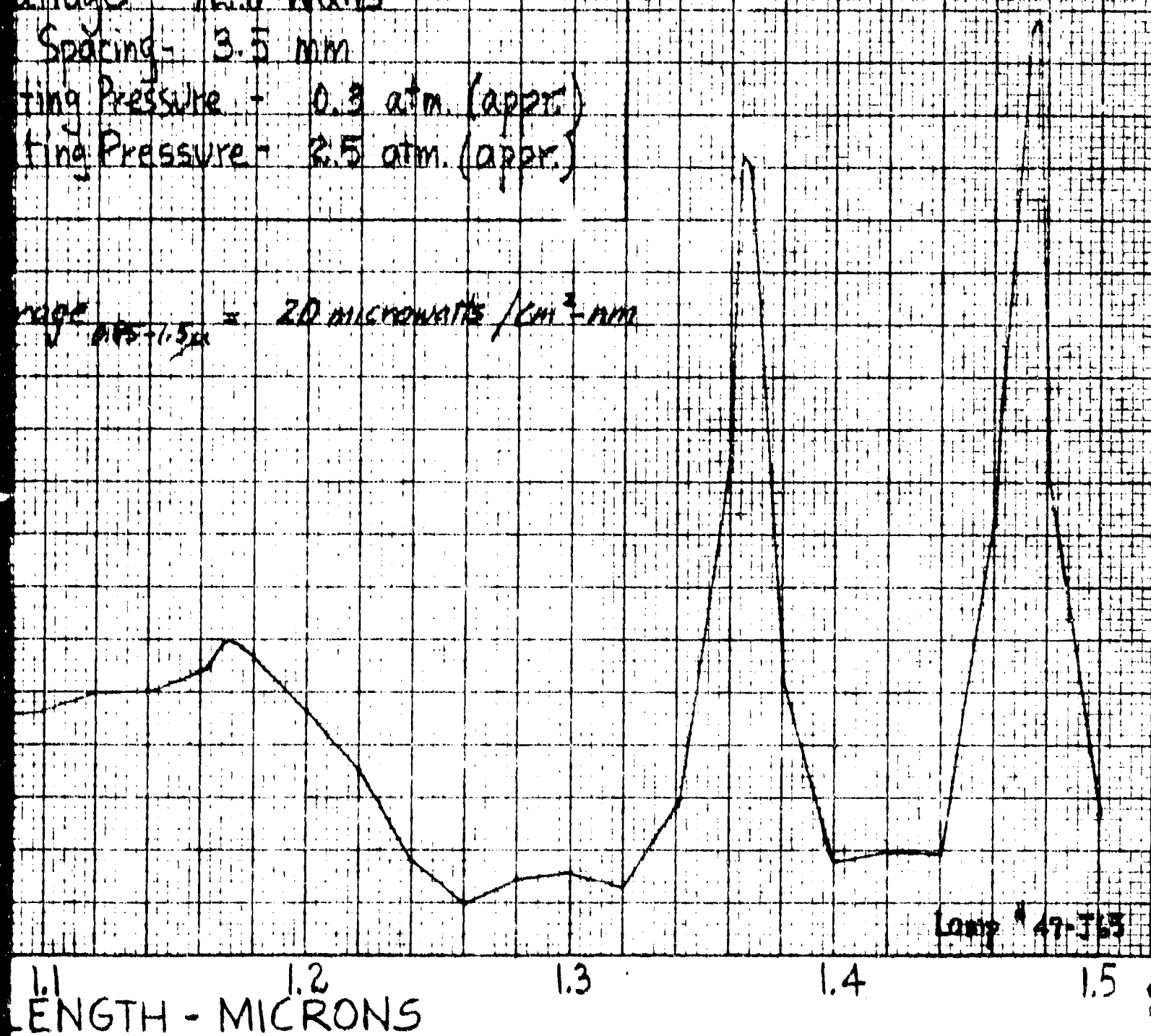
Power - 72.0 Watts

Spacing - 3.5 mm

Operating Pressure - 0.3 atm. (approx.)

Operating Pressure - 2.5 atm. (approx.)

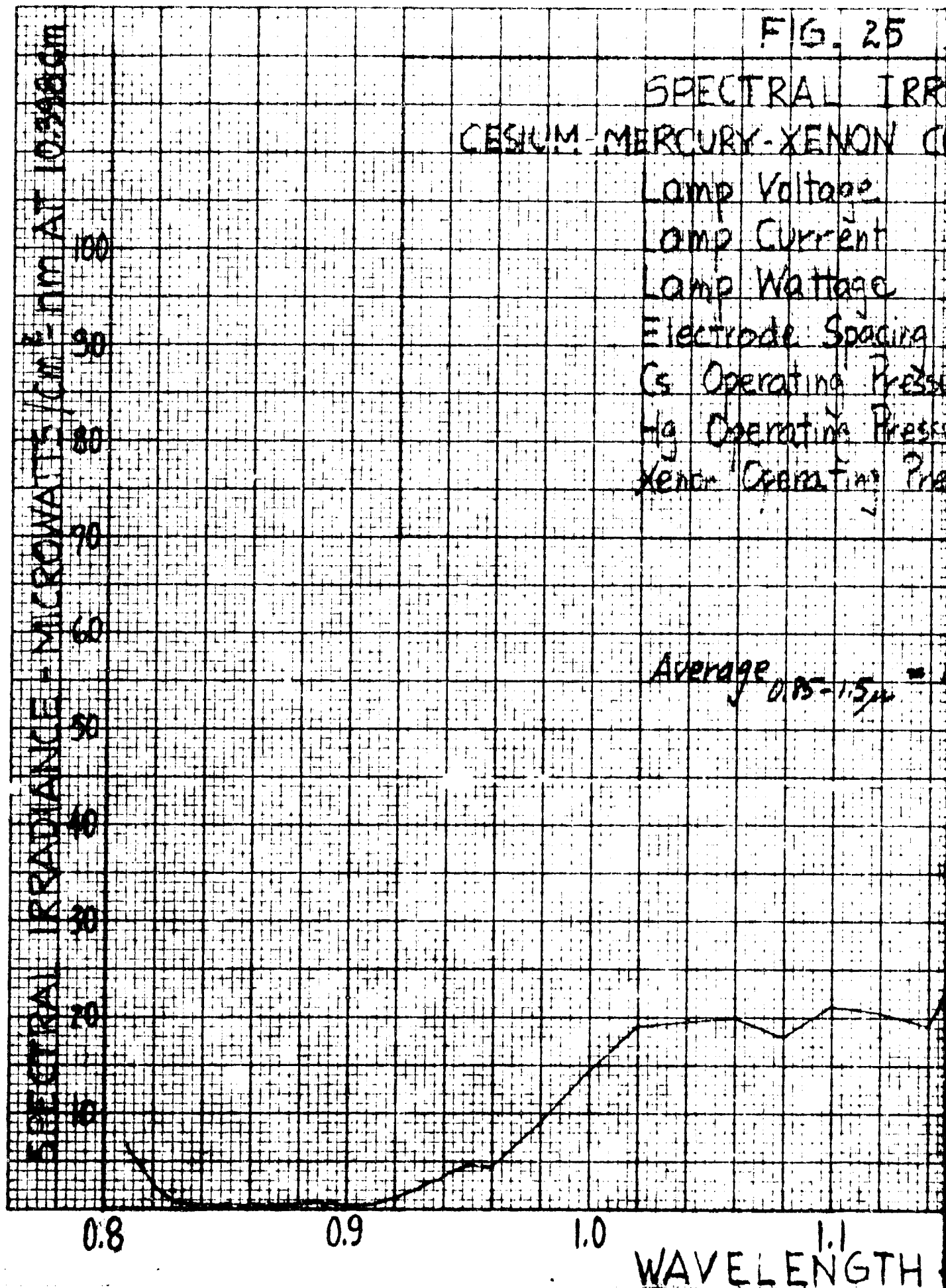
Average $\lambda = 1.5 \mu$ = 20 microwatts/cm²-mm



Lamp # 47-J63

LIBRASCOPE, GLENDALE, CALIFORNIA

DAVIDSON AND HIS ASSOCIATES
78 NO. FOURTH ST., LA JOLLA, CA.

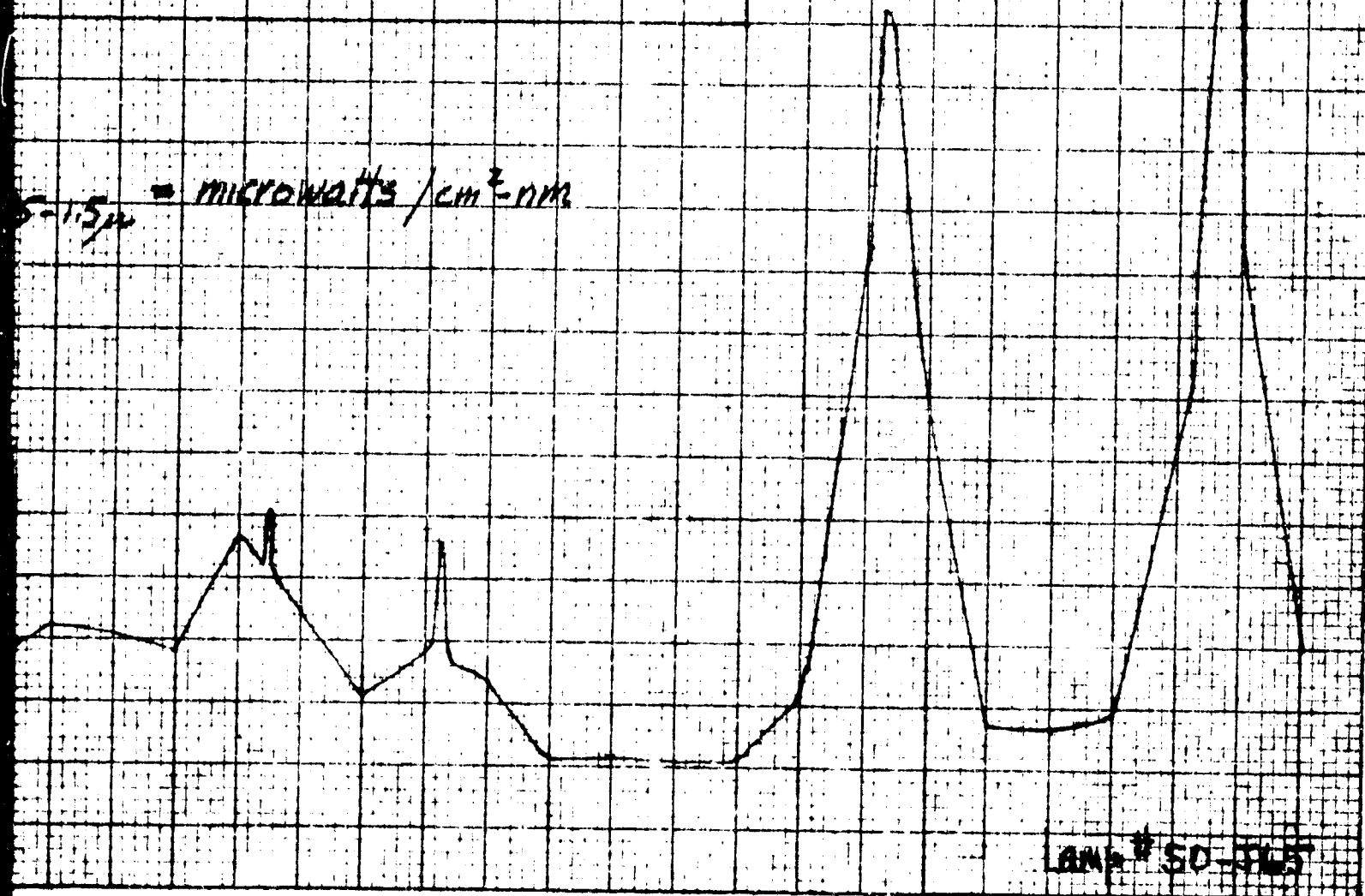


G. 25

AL IRRADIANCE XENON COMPACT ARC LAMP

Voltage 16.0 volts
Current 4.6 amps
Power 73.6 watts
Spacing 3.5 mm
Gun Pressure 0.33 atm. (appr.)
Fill Pressure 2 atm. (appr.)
Anode Pressure 25 atm. (appr.)

$5-1.5\mu$ = microwatts/cm²-nm



LAMP # 50-105

WAVELENGTH - MICRONS

1.5 2

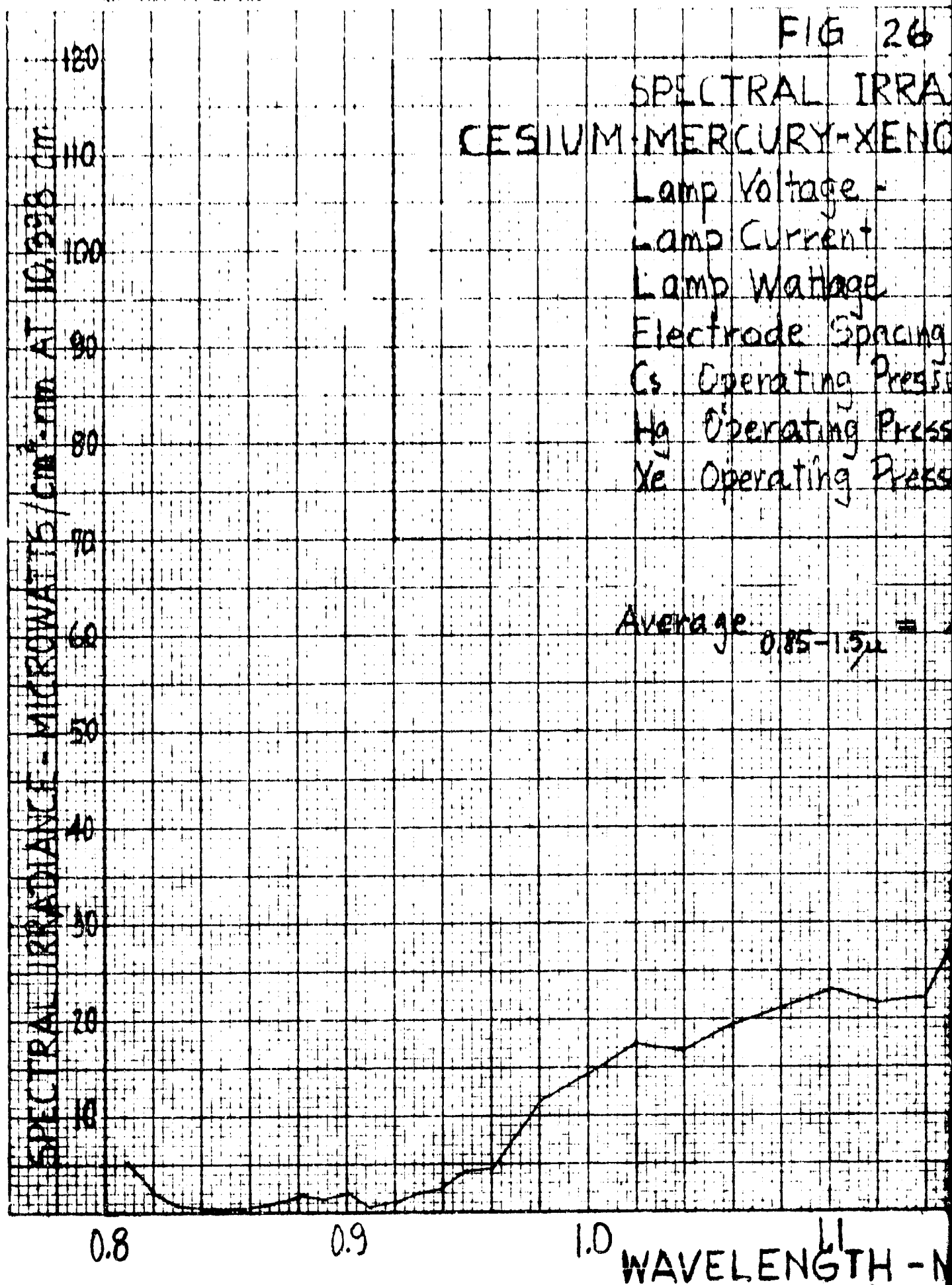
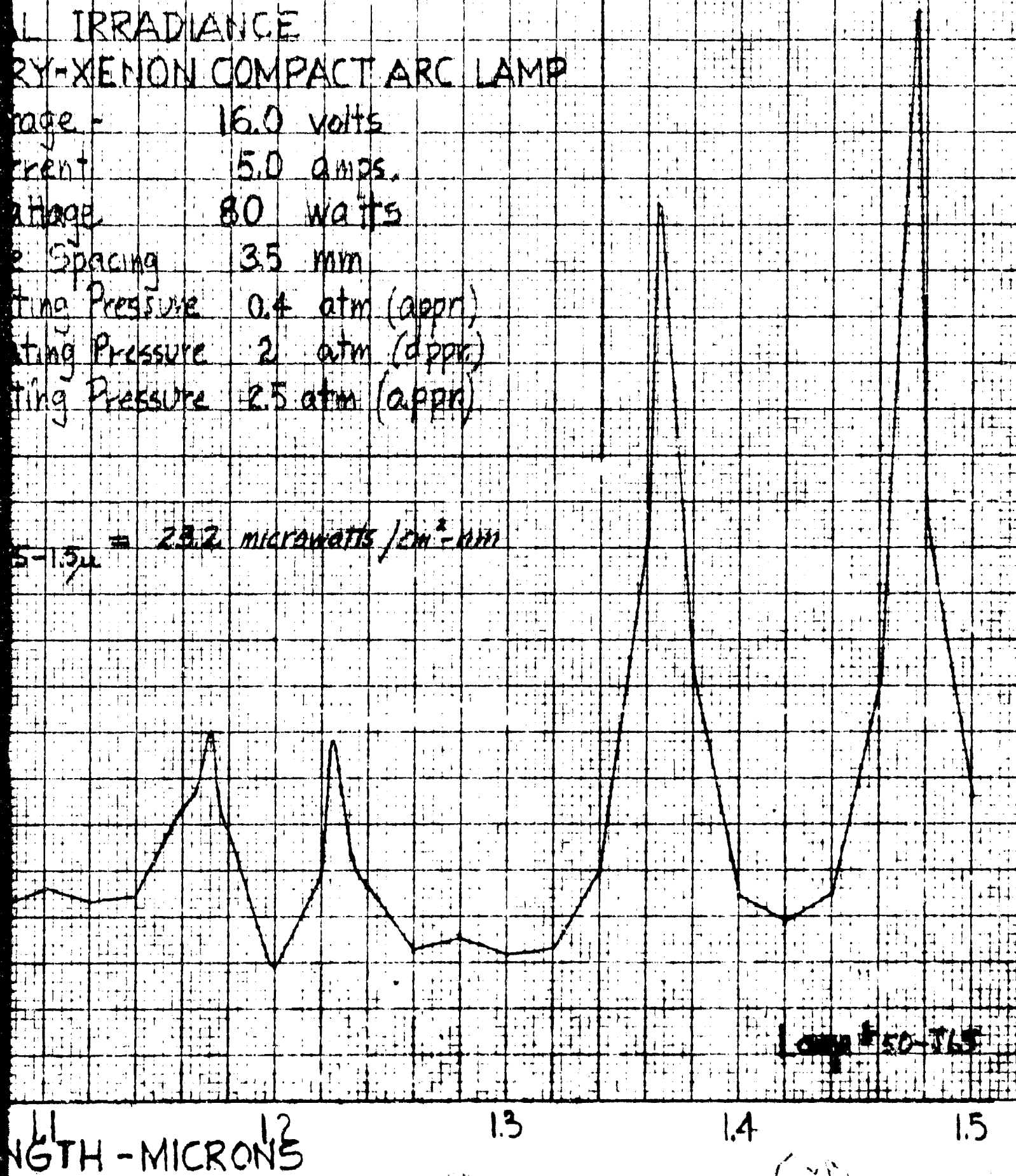


FIG 26

AL IRRADIANCE
RY-XENON COMPACT ARC LAMP

age - 16.0 volts
rent 5.0 amps.
age 80 watts
e Spacing 3.5 mm
ting Pressure 0.4 atm (appr)
ting Pressure 2 atm (appr)
ting Pressure 2.5 atm (appr)

$5-1.5\mu = 23.2 \text{ microwatts/cm}^2\text{-nm}$



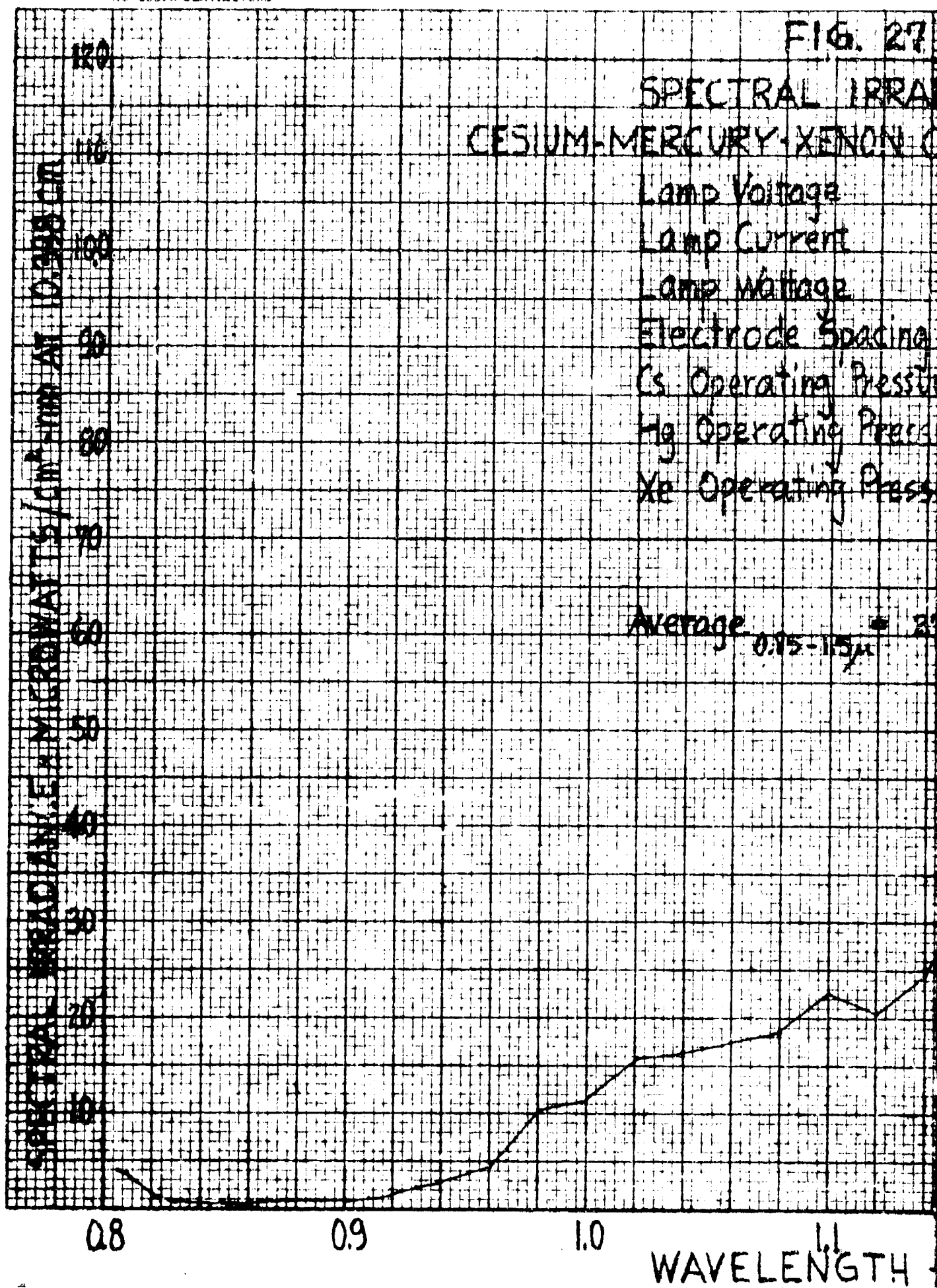
Long #50-165

FIG. 27

SPECTRAL IRRADIANCE CESIUM-MERCURY-XENON C

Lamp Voltage
Lamp Current
Lamp Wavelength
Electrode Spacing
Cs Operating Pressure
Hg Operating Pressure
Xe Operating Pressure

Average $0.15-1.15 \mu$ = 2.1



FIBRASCOPES GLENDALE CALIFORNIA

SAVONIAN AND COMPANY
7010 10th Ave. N. - Seattle, WA

FIG. 27

UL IRRADIANCE

XENON COMPACT ARC LAMP

age 17.0 volts

rent 5.5 Amps.

age 93.5 Watts

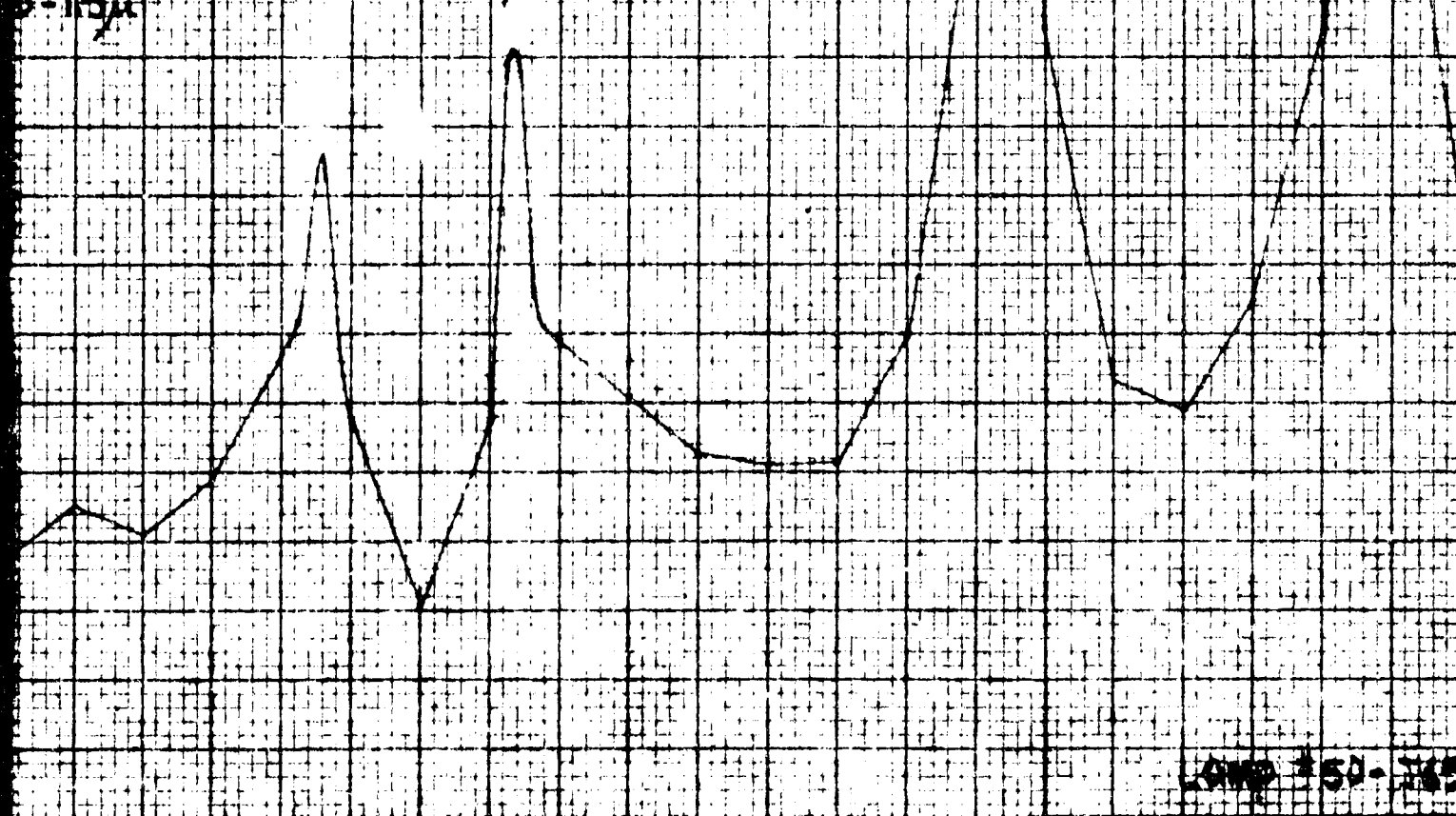
Spacing 3.5 mm

ing Pressure = 0.5 atm. (appr.)

ing Pressure = 2.0 atm. (appr.)

ing Pressure = 2.5 atm. (appr.)

$\lambda = 27.9 \text{ microwatts/cm}^2\text{-nm}$



WAVELENGTH - MICRONS

LAMP 150-745

VAPOR PRESSURE vs. TEMPERATURE
RUBIDIUM and RUBIDIUM OXIDE

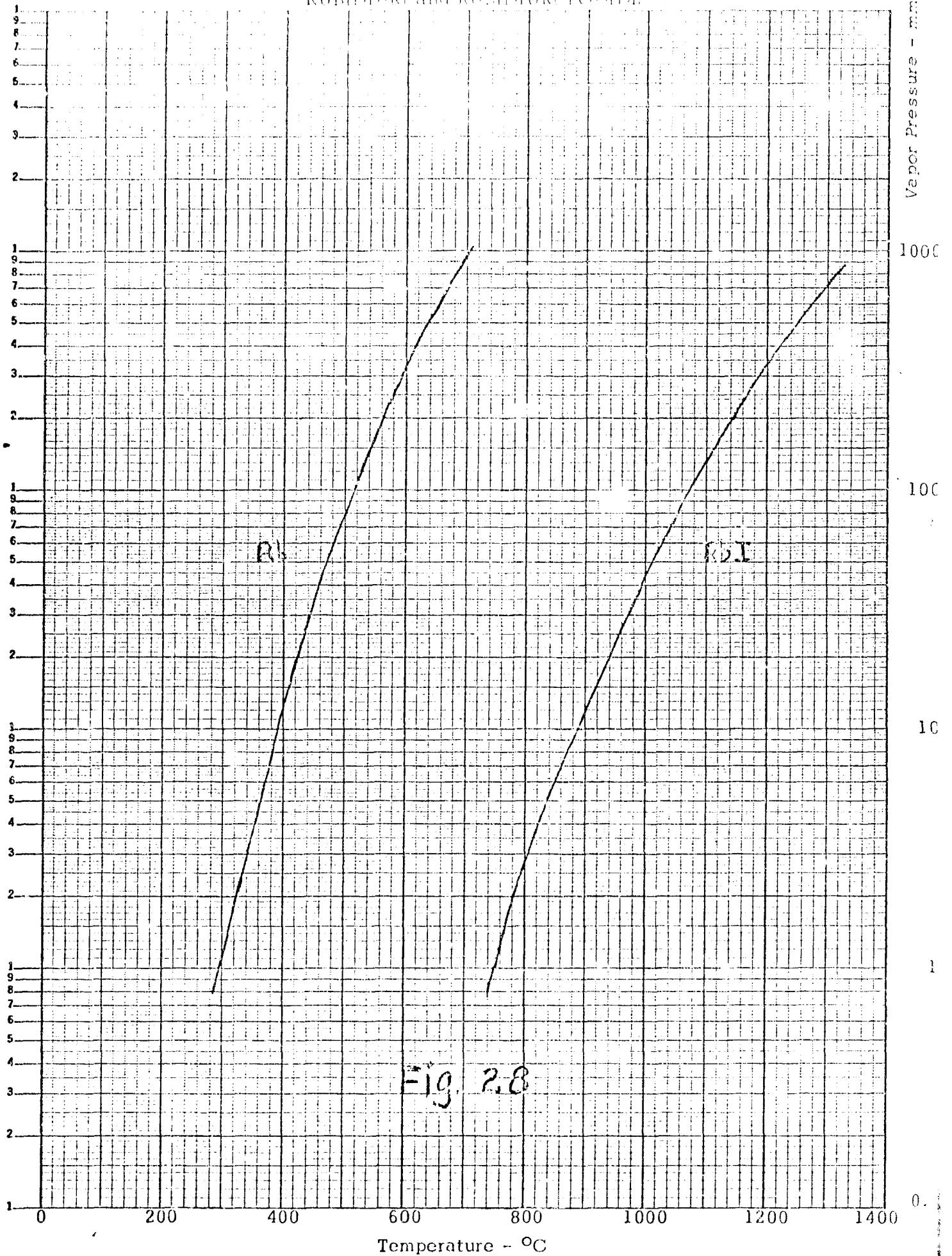


Fig. 2.8

FIG. 29 RADIANCE ALONG ARC CENTERLINE FOR
SAPPHIRE RUBIDIUM-XENON LAMP (See Fig 6.

for micro-
volt to
radiance
conversion)

$W = 55 \text{ watts}$
 $V = 11 \text{ volts}$
 $I = 5 \text{ amps}$
 $P_{Xe} = 2.1 \text{ atm}$
 $P_{Rb} \approx 0.3 \text{ atm}$

$W = 100 \text{ watts}$
 $V = 12.5 \text{ volts}$
 $I = 8 \text{ amps}$
 $P_{Xe} = 3 \text{ atm}$
 $P_{Rb} \approx 0.5 \text{ atm}$

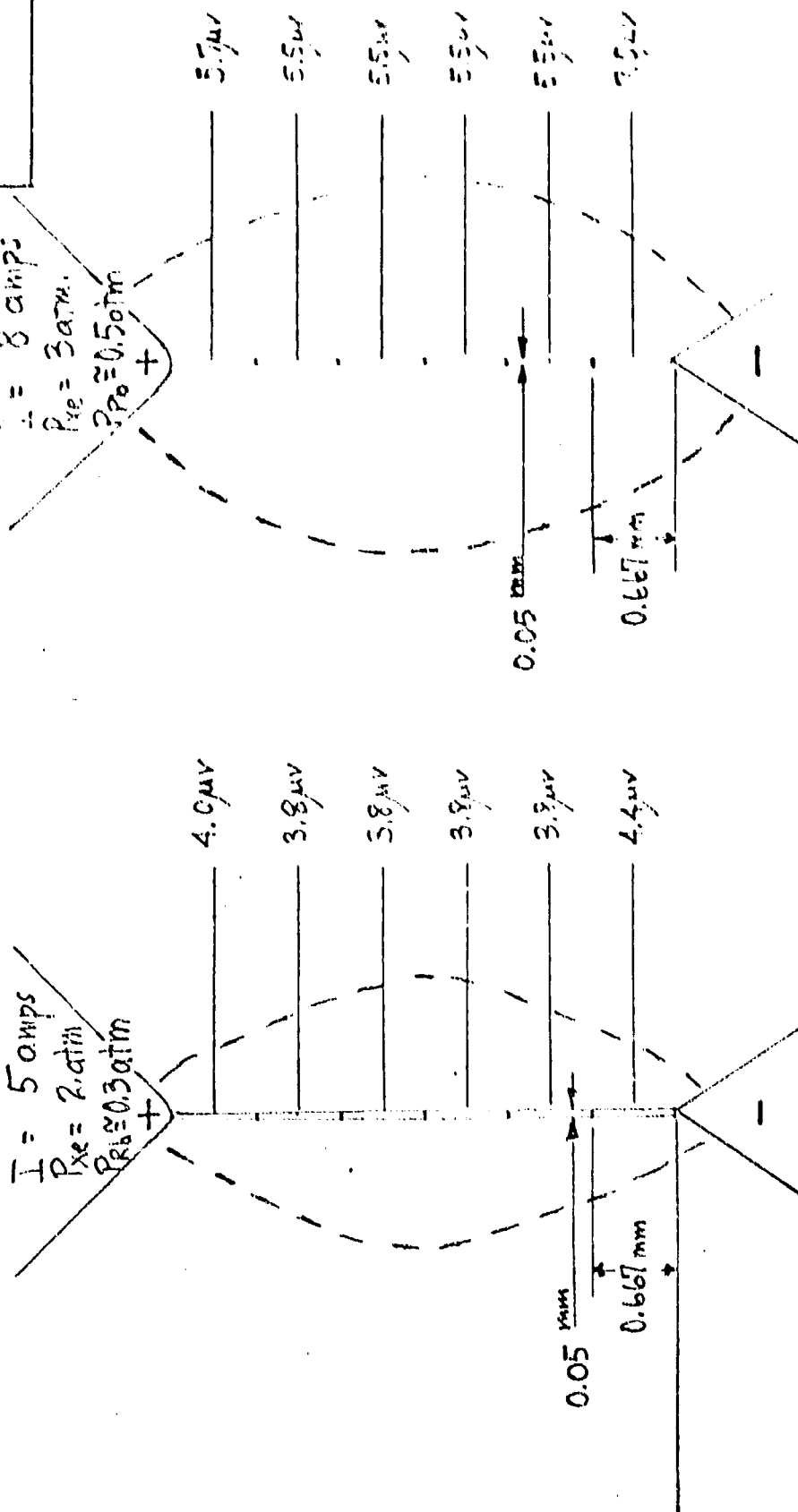
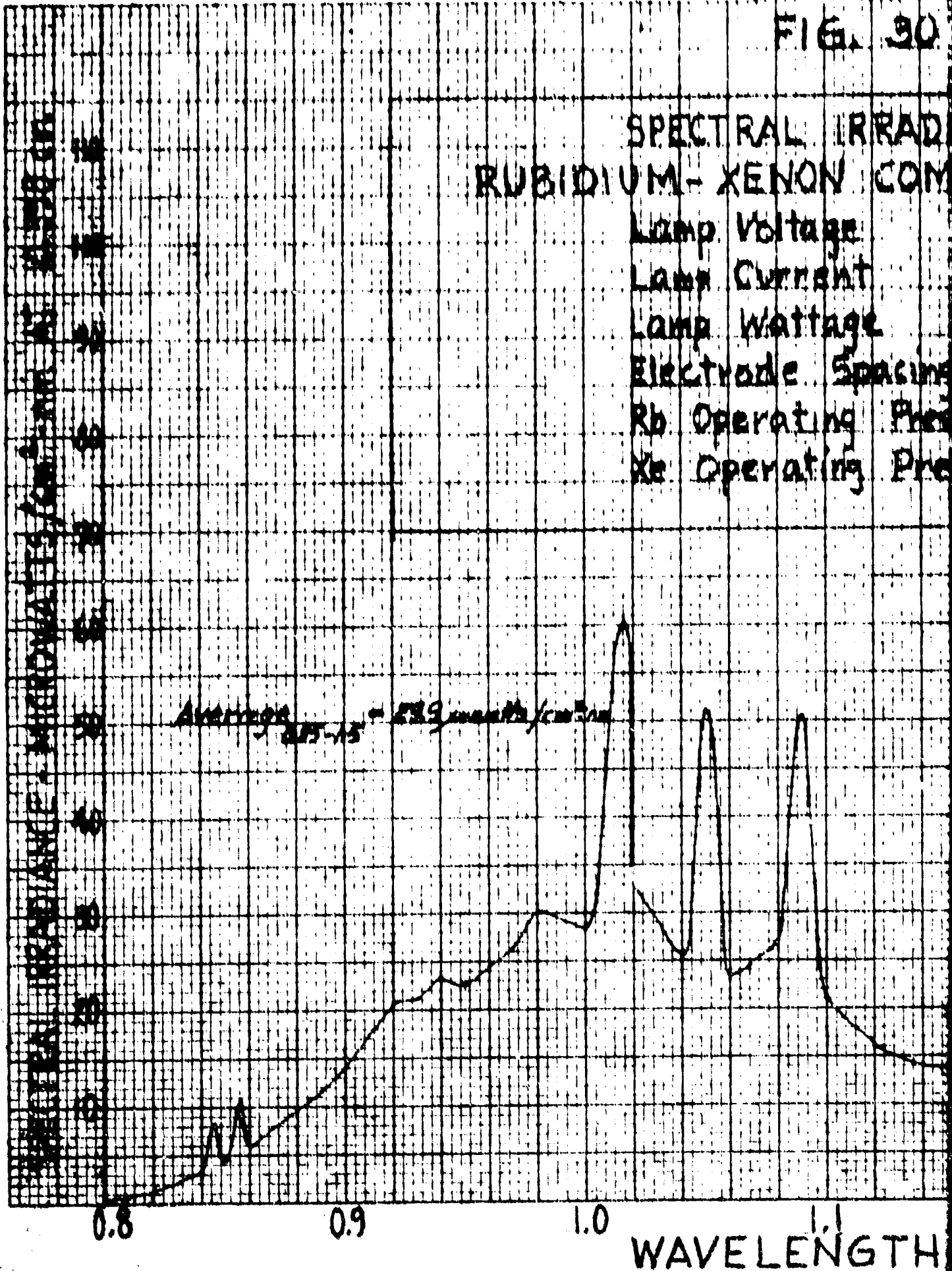


FIG. 30

SPECTRAL IRRADIANCE
RUBIDIUM-XENON COM

Lamp Voltage
Lamp Current
Lamp Wattage
Electrode Spacing
Rb Operating Pressure
Xe Operating Pressure



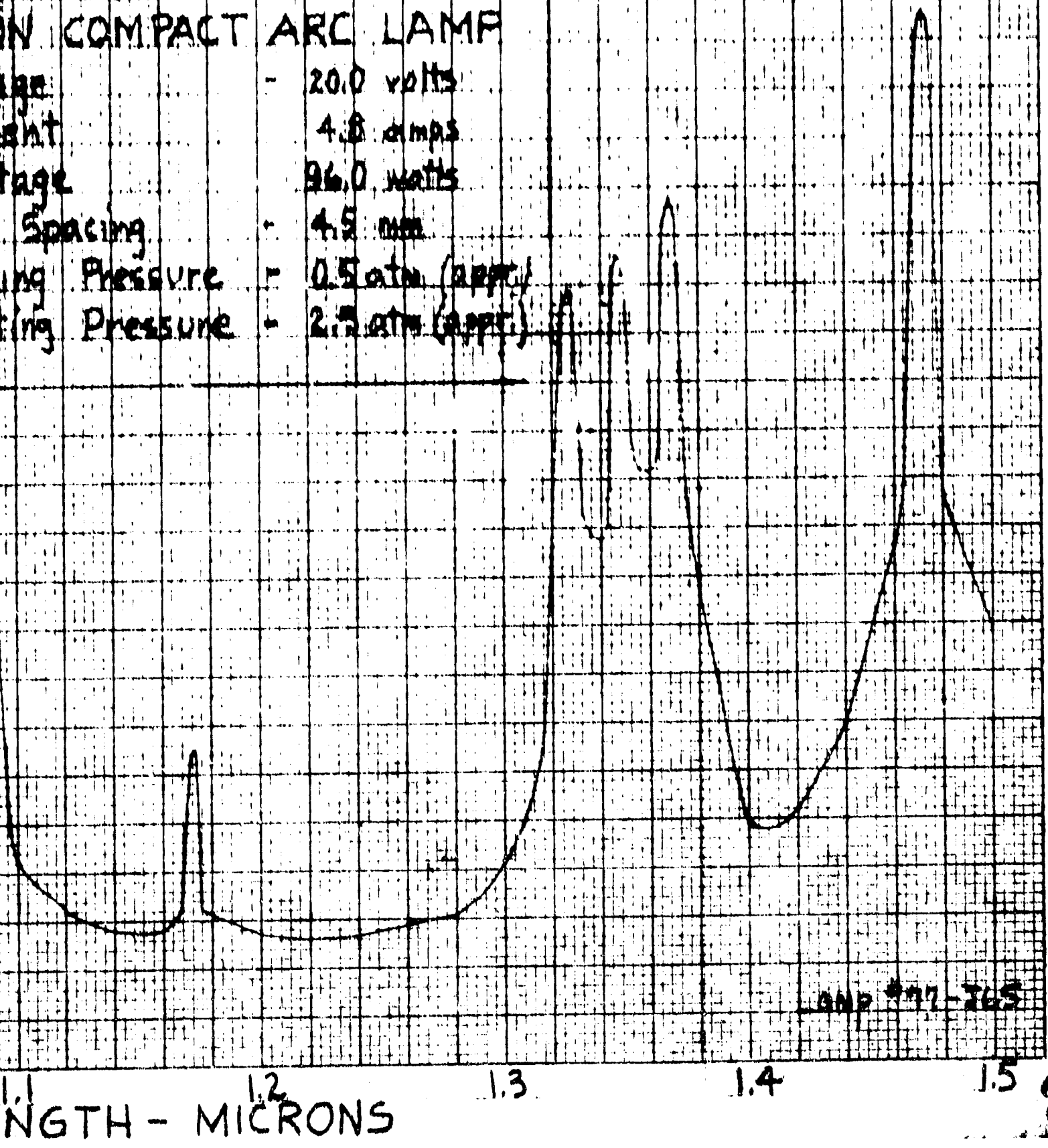
Quanticon

REPRODUCED BY
QUANTICON AND INSTRUMENTS
DIVISION OF SPECTRA, INC.

Fig. 30

IRRADIANCE ON COMPACT ARC LAMP

Operating Voltage - 20.0 volts
Operating Current - 4.8 amps
Power - 96.0 watts
Electrode Spacing - 4.5 mm
Operating Pressure - 0.5 atm (approx)
Filling Pressure - 2.5 atm (approx)



LAMP #77-765

TABLE 1

Lamp Number	Arc Spacing Rm. Temp. °M	Cesium or Rubidium Fill Mg.	Xenon Fill Atm	Mercury Fill Mg.	Lamp Voltage Volts	Lamp Current Amps	Lamp Wattage Watts	Envelope Dimensions Inches		Remarks
								O. D.	Length	
16(a)	3	49(Cs)	Vacuum	-	-	-	-	3/8	3/4	Ignition on edge of columbium ex- haust tubing. Lamp blackened within a few minutes
17(a)	3	-	1	-	-	-	-	3/8	3/4	Ignition again on edge of columbium exhaust tubing.
18(a)	3	-	4	-	18	3.5	63	3/8	3/4	Normal ignition between electrode tips.
19(a)	-	-	-	-	-	-	-	-	-	Failure in initial processing
20(a)	1.5	74(Cs)	4	-	-	-	-	-	-	Columbium pinch off attempted but not made.
21(a)	1.5	136(Cs)	4	-	8.6	2.7	23.2	3/8	3/4	Columbium pinch off failed after 15 minutes of operation.
22(a)	3	106(Cs)	4	-	-	-	-	3/8	3/4	Alumina etched during processing

TABLE 1 (CONT)

Lamp Number	Arc Spacing Rm. Temp. MM.	Cesium or Rubidium Fill Mg.	Xenon Fill Atm	Mercury Fill Mg.	Lamp Voltage Volts	Lamp Current Amperes	Lamp Wattage Watts	Envelope Dimensions Inches O. D. Length	Remarks
23(a)	3	-	-	-	-	-	-	3/8 3/4	Induction heater control experiment.
24(a)	3	-	-	-	-	-	-	3/8 3/4	Induction heater control experiment.
25(a)	3	-	-	-	-	-	-	3/8 3/4	Induction heater control experiment.
26(b)	2	-	1	-	16.2	3.0	48.6	3/8 1 1/4	Lamp ignition test. Arc switches from cathode tip to tubulation.
27(a)	2	-	4	-	19.2	2.4	46	3/8 3/4	Sapphire envelope. Tubulation leaked after 1 hour of operation. Lamp burned.
28(a)	2	-	-	-	-	-	-	-	Leak at columbium - sapphire seal.
29(c)	2	-	1	-	16.0	3.0	48	3/8 1 1/4	Lamp ignition test to test starting reliability. Lamp in operation condition.

TABLE 1 (CONT)

Lamp Number	Arc Spacing Rm. Temp. MM	Cesium or Rubidium Fill Mg.	Xenon Fill Atm.	Mercury Fill Mg.	Lamp Voltage Volts	Lamp Current Amps	Lamp Wattage Watts	Envelope Dimensions Inches	Remarks
30(c)	2	189(Cs)	1	-	8.4	4.5	37.6	3/8 1 1/4	After 15 min. of burning, leak developed between columbium cap and alumina envelope causing cesium to vaporize in the outer envelope I. D.
31(c)	2	-	-	-	-	-	-	-	Radiation pyrometer experiment.
32(c)	2	19(Cs)	1	-	16.0	3.0	48.0	3/8 1 1/4	Low cesium emission from discharge lamp in operating condition.
33(c)	2	-	-	-	-	-	-	-	Crack in columbium anode cap.
34(a)	3	153(Cs)	4	-	10.0	2.0	20	3/8 3/4	Sapphire envelope. Lamp delivered to USAERDL for further testing and evaluation.

TABLE 1 (CON'T)

Lamp Number	Arc Spacing Rm. Temp. MM	Cesium or Rubidium Fill Mg.	Xenon Fill Atm	Mercury Fill Mg.	Lamp Voltage Volts	Lamp Current Amps	Lamp Wattage Watts	Envelope Dimensions Inches D. D. Length	Remarks
35(d)	2	92(Cs)	4	-	8.0	3.0	24	3/8 3/4	Sapphire envelope. After 15 minutes of operation 7280 glass tip separated from columbium exhaust tubulation.
36(a)	3	-	-	-	-	-	-	3/8 3/4	Sapphire cracked at anode cap during sealing process.
37(d)	2	80(Cs)	1	-	7.0	3.0	21	3/8 1 1/4	Lamp in operating condition.
38(d)	2	273(Cs)	1	-	9.5	5.5	52.3	3/8 1 1/4	Lamp delivered to USAERDL for further testing and evaluation.
39(d)	2	-	-	-	-	-	-	3/8 1 1/4	7280 glass tubulation cracked during processing.
40(d)	2	124(Cs)	1	-	7.0	2.5	17.5	3/8 1 1/4	Lamp in operating condition.

TABLE 1 (CONT)

Lamp Number	Arc Spacing Rm. Temp. °F	Cesium or Rubidium Fill Mg.	Xenon Fill Atm	Mercury Fill Mg.	Lamp Voltage Volts	Lamp Current Amps	Lamp Wattage Watts	Envelope Dimensions O. D. Inches	Remarks
41(d)	2	112(Cs)	1	-	9.0	4.5	40.5	3/8 1 1/4	Lamp measured for spectral irradiance. Lamp burned for 3 hours. Lamp in oper condition.
42(d)	2	139(Cs)	1	-	8.4	4.0	33.6	3/8 1 1/4	Lamp in operating condition.
43(d)	2	240(Cs)	1	-	8.7	6.0	52.2	3/8 1 1/4	Lamp in operating condition.
44(e)	2	-	-	-	-	-	-	-	Experimental tungsten columbium brazing to test construction modification.
45(e)	2	202(Cs)	1	-	-	-	-	3/8 1 1/4	Lamp was dropped.
46(e)	2	188(Cs)	1	-	-	-	-	3/8 1 1/4	7280 glass tubing cracked during outer envelope processing.
47(e)	3.5	165(Cs)	1	-	14.4	5.0	72	3/8 1 1/4	Alumina envelope, lamp used for gradient and electrode losses determination. Lamp measured for spectral irradiance. Lamp in oper. condition.

TABLE 1 (CON'T)

Lamp Number	Arc Spacing Rm. Temp. MM	Cesium or Rubidium Fill Mg.	Xenon Fill Atm	Mercury Fill Mg.	Lamp Voltage Volts	Lamp Current Amps	Lamp Wattage Watts	Envelope Dimensions Inches O.D. Length	Remarks
48(e)	3.5	220(Cs)	1	13	18.2	5.0	92.5	3/8 1 1/4	Alumina envelope, lamp used for gradient and electrode losses determination.
49(e)	3.5	110(Cs)	1	13	17.5	5.0	87.5	3/8 1 1/4	Alumina envelope, 7280 glass tubulation cracked after 1 hour of operation.
50(e)	3.5	110(Cs)	1	13	Lamp measured for spectral irradiance. See Fig. 25, 26, 27. Lamp in operating condition.				
51(e)	3.3	138(Cs)	1	13.5	-	-	-	-	Sapphire envelope, Sapphire not sufficiently transparent after processing.
52(e)	3.4	220(Cs)	1	13	19.2	3.8	73	3/8 1 1/4	Sapphire envelope. Lamp in operating condition. Transparency is fair.
53(e)	5.1	-	1	-	19.2	4.0	76.8	3/8 1 1/4	Alumina envelope. Lamp required for "in-line" transmission comparison with sapphire envelopes.

TABLE 1 (CON'T)

Lamp Number	Arc Spacing mm.	Cesium or Rubidium Fill MG.	Xenon Fill Atm	Mercury Fill MG.	Lamp Voltage Volts	Lamp Current Amperes	Lamp Wattage Watts	Envelope Dimensions Inches O.D. Length	Remarks
54(e)	5.0	-	1	-	19.6	3.92	76.8	3/8 1 1/4	<u>Sapphire envelope.</u> Lamp required for "in-line" transmission comparison with alumina envelopes.
55(e)	3.5	91(Cs)	1	13	20	4	80	3/8 1 1/4	Alumina envelope. Lamp in operating condition.
56(e)	3.5	87(Cs)	1	13	19	5	95	3/8 1 1/4	<u>Sapphire envelope.</u> Transparency not sufficiently good for radiance measurements.
57(e)	3.5	77(Cs)	1	-	18.5	5	92.5	3/8 1 1/4	<u>Sapphire envelope.</u> Transparency not sufficiently good for radiance measure- ments. Lamp in operating condition.
58(e)	3.0	20(Cs)	4	-	18	5	90	3/8 1 1/4	<u>Sapphire Envelope.</u> Lamp measured for radiance. Results recorded in engineering notebook. Lamp delivered to USAERDL.

TABLE 1 (CON'T)

Lamp Number	Spacing Rm. Temp. MM	Cesium or Rubidium Fill Mg.	Xenon Fill Atm	Mercury Fill Mg.	Lamp Voltage Volts	Lamp Current Amps	Lamp Wattage Watts	Envelope Dimensions Inches O.D. Length	Remarks.
59(e)	3.0	30(CS)	4	-	13.5	2.5	33.8	3/8 1 1/4	Sapphire Envelope. Lamp measured for radiance. Results recorded in engineering notebook. Lamp delivered to USAERDL.
60(e)	3.0	35(CS)	1	-	10	5	50	3/8 1 1/4	Sapphire Envelope. Lamp delivered to USAERDL.
61(e)	3.0	20(CS)	4	-	-	-	-	-	Sapphire Envelope. Env. cracked at cathode cap during processing.
62(f)	3.0	50(CS)	4	-	10	6	60	3/8 1 1/4	Alumina envelope. Experimental Cb plus #52 alloy exhaust tubing for pinch-off test.
63(f)	4.2	20(CS)	1	-	Lamp measured for radiance. See Fig. 22 Lamp tubulation tip-off leaked after 6 hours of operation.				

TABLE 1 (CON'T)

Lamp Number	Arc Spacing Rm. Temp. MM	Cesium or Rubidium Fill MG.	Xenon Fill Atm	Mercury Fill MG.	Lamp Voltage Volts	Lamp Current Amps	Lamp Wattage Watts	Envelope Dimensions Inches O.D. Length	Remarks
64(e)	4.2	12(Cs)	1	-	16	5	80	1 1/4	Sapphire Envelope. Envelope darkened after 3 hours of operation.
65(e)	4.0	89(Rb)	1	-	15	3	45	1 1/4	7280 glass tubulation cracked after 20 minutes operation.
66(g)	3.5	-	1	-	Alumina Envelope cracked during 1st 2 minutes of operation.				
67(g)	3.5	153(Cs)	1	-	16	6	96	1 1/4	Alumina envelope with stainless steel tubing pinch off. Lamp burned for 19 hours. Leak at anode cap-alumina frit seal.
68(g)	3.5	199(Rb)	1	-	-	-	-	-	Leak at stainless steel to columbium braze.

TABLE 1 (CON'T)

Lamp Number	Arc Spacing Rm. Temp. MM	Cesium or Rubidium Fill Mg.	Xenon Fill Atm	Mercury Fill Mg.	Lamp Voltage Volts	Lamp Current Amps	Lamp Wattage Watts	Envelope Dimensions Inches		Remarks
								O. D.	Length	
69(g)	3.5	120(Rb)	1	-	19	5	95	3/8	1 1/4	Sapphire envelope with stainless steel tubing pinched off. Lamp burned for 2 hours. Lamp measured for radiance. Lamp developed crack in sapphire envelope.
70(g)	4.2	150(Rb)	1	-	19	5	95	3/8	1 1/4	Sapphire envelope. Lamp delivered to USAFPA.
71(g)	4.2	130(Rb)	1	-	18	5.3	95.4	3/8	1 1/4	Sapphire envelope. Lamp delivered to USAFPA.
73(g)	4.0	102(Rb)	1	-	-	-	-	-	-	Sapphire envelope. Sapphire cracked during test.
74(g)	3.9	105(Rb)	1	-	18	5.4	97.2	3/8	1	Sapphire envelope. Lamp delivered to USAFPA.
75(g)	3.8	106(Rb)	1	-	16.5	6	99	3/8	1	Sapphire envelope. Lamp delivered to USAFPA.

TABLE 1 (CONT.)

Lamp Number	Arc Spacing Rm. Temp. MM	Cesium or Rubidium Fill Mg.	Xenon Fill Atm	Mercury Fill Mg.	Lamp Voltage Volts	Lamp Current Amps	Lamp Wattage Watts	Envelope Dimensions Inches O.D. Length	Remarks
76(g)	3.5	86(Rb)	1	-	16	6.2	99.2	3/8 1	Sapphire envelope. Lamp delivered to USAERDL.
77(g)	5.1	67(Rb)	1	-	20	5	100	3/8 1 1/4	Alumina envelope. Lamp measured for spectral irradiance. Lamp in operating condition.
78(g)	4.5	131(Rb)	1	-	20	5	100	3/8 1 1/4	Sapphire envelope. Lamp delivered to USAERDL.

Construction (a) See Fig. 12
 Construction (b) See Fig. 14
 Construction (c) See Fig. 15
 Construction (d) See Fig. 16
 Construction (e) See Fig. 17
 Construction (f) See Fig. 18
 Construction (g) See Fig. 19 and 20

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