ARL 67-0179
AUGUST 1967

Aerospace Research Laboratories

AN APPROACH TO RADIATION SOURCE DESIGN FOR MILITARY APPLICATIONS UTILIZING THE WALL-STABILIZED ARC AS AN EXAMPLE

P. W. SCHREIBER
K. R. BENEDETTO
THERMOMECHANICS RESEARCH LABORATORY

Project No. 7063

OFFICE OF AEROSPACE RESEARCH
United States Air Force

NOTICES

Agencies of the Department of Defense, qualified contractors and other government agencies may obtain copies from the

Defense Documentation Center
Cameron Station
Alexandria, Virginia 22314

This document has been released to the

CLEARINGHOUSE
U.S. Department of Commerce
Springfield, Virginia 22151

for sale to the public.

Copies of ARL Technical Documentary Reports should not be returned to Aerospace Research Laboratories unless return is required by security considerations, contractual obligations or notices on a specified document.

400 - October 1967 - CO455 - 12-241

ARL 67-0179

AN APPROACH TO RADIATION SOURCE DESIGN FOR MILITARY APPLICATIONS UTILIZING THE WALL-STABILIZED ARC AS AN EXAMPLE

P. W. SCHREIBER
K. R. BENEDETTO

THERMOMECHANICS RESEARCH LABORATORY

AUGUST 1967

Project No. 7063

AEROSPACE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

The work reported herein was performed at the Thermo-Mechanics Research Laboratory of the Aerospace Research Laboratories at Wright-Patterson Air Force Base, Ohio.

The authors wish to express their gratitude to the many people who helped in one way or another to bring this report to completion. Special thanks go to Mr. Paul Taylor and Mr. Marion Linder whose craftmanship and understanding have contributed greatly to the development of this investigation.

The authors also acknowledge the guidance of Mr. Erich E. Soehngen, Director of the Thermo-Mechanics Research Laboratory at ARL, for his leadership in support of this program.

ABSTRACT

An approach to the selection of radiation sources for military applications is presented. A logical breakdown of the various types of discharge sources and a list of parameters to be considered are given. As an example, an analytical and experimental study of the fully developed, laminar flow, argon electric arc discharge is included. A description of the arc facility and the diagnostic techniques used are presented. The analytical results are compared with experimental results.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Electric discharges with particular emphasis on energy exchange processes and diagnostic techniques have been under investigation by the Thermo-Mechanics Research Laboratory (ARN) of the Aerospace Research Laboratories (ARL) for a number of years. This research, directed by Mr. Erich E. Soehngen, has placed considerable emphasis on radiant power losses from arc heated plasmas. In-house efforts include high pressure radiation studies from a wall-stabilized arc, radiation studies using a convection stabilized arc, and long, high power arcs in laminar and vortex flow fields. These in-house efforts are supported by contractual work in plasma radiative properties, transport properties, diagnostic techniques, and analytical techniques for calculating the transport of radiative energy (1- through -13).

The above research was stimulated by the anticipated application of high power discharges for radiation sources. Possible military applications may include: Jamming optical equipment; battlefield illumination; aerial photography in selected spectral regions; optical radar; inducing temporary blindness; communications; radiation decoys; solar simulation; simulating aerodynamic heat loads; materials testing; invisible fences.

In this report, an approach to source design is suggested. The steps are: (1) Determine all requirements which a source must have; (2) use simple empirical data and analytical techniques to select the appropriate source;

(3) if possible, design the source using computer programs; and (4) back up the design with good plasma diagnostics. At present, however, it is difficult for an engineer to find the required information to make source selections. Thus, a good handbook would be desirable. As a step in this direction, the results obtained for a wall-stabilized argon arc operating at atmospheric pressure are discussed. The comparison of experimental with measured data shows that the properties of this type source may be calculated in great detail. Also, diagnostic tools are discussed. In particular, a simple technique for measuring plasma temperature distribution in less than a millisecond is given.

Hopefully, as a result of this report, better coordination between the engineer who has a need for a radiation source and ARN, will be achieved. This coordination will help ARN to direct its research toward satisfying these needs.

THEORY

Introduction. Because the design of a radiation source is governed by the particular application, such quantities as lumens, lumens per watt, or total power radiated are insufficient to evaluate available sources for a given application. If all the important requirements are known and fall within the present state of the art of source design, success may be assured. For the above reasons the approach to radiation source design suggested in this report is: (1) Identify the important quantitative attributes which the source must have for a particular application (this may require a research program); (2) survey all of the various radiation sources in terms of the requirements (a handbook should be made available); (3) evaluate acceptable sources to determine if any requirements extend beyond the state of the art (be certain the information is up-to-date); and (4) if the requirements can be met, simple analytical approximations and empirical data may be used for preliminary designs and, if available, the final designs may be accomplished with the aid of computer programs. The last step presupposes that the required source property data are available.

Radiation Sources. In order to illustrate the breadth of possible discharge radiation sources, a logical division is shown in Fig. 1. Although this division is not complete, it does show the large number of potential sources available and indicates the need for a good survey of radiation sources.

Source Attributes. For a particular application, important source attributes to consider are:

(1) Spectral distribution of radiation

(2) Total radiant power per watt input

(3) Maximum and minimum power levels

(4) Voltage, current characteristics

(5) Source efficiency for a particular application

(6) Source size and shape

(7) Operating time and reliability

(8) Starting techniques

(9) Electrodes

(10) Cooling water and gas requirements

(11) Source weight

(12) Window or tube transmission

(13) Data available on similar sources

(14) Property data available

(15) Adaptability to optical requirements

(16) Computer programs available

(17) Electrode power losses

(18) Plasma flow field.

In order to estimate the arc attributes, plasma property data should include thermal conductivity, electrical conductivity, total and spectral radiation as a function of temperature and pressure. If the velocity profile is important, viscosity and density as a function of temperature must be known.

Analytical Methods. In principle, the best approach to source selection and design is to use simple analytical techniques and empirical data to determine the most promising conditions. At present, simple guidelines are being formulated at ARN for the design of wall stabilized sources (14). In addition, a versatile computer program for the developed, wall-stabilized, electric arc in a laminar gas flow field is near completion (15). This program will allow the designer to compute any desired physical quantity which depends on the temperature and velocity profiles. To facilitate the use of this program, a library of current transport and thermodynamic properties is planned. Thus, any detailed calculations may be completed for an engineer at ARN. Hopefully, additional programs for convection and vortex stabilized discharges will be completed in the near future.

For the wall-stabilized arc, good basic design techniques are developed for non-absorbing plasmas in developed laminar flow. For this type discharge, one solves the equations shown in Fig. 2. In Fig. 2, T is temperature, k(T) is thermal conductivity, $\sigma(\phi)$ is electrical conductivity, E is electrical field strength, $P(\phi)$ is power radiated per unit volume, p is static pressure, $\mu(\phi)$ is viscosity, V_z is axial velocity, and R is wall radius.

An analog and corresponding digital program (MIMIC) were developed to solve the equations (16). Input data include the electric field strength, total mass flow rate, arc radius, and the plasma properties. Output data include temperature distribution, velocity distribution, power radiated, and current, Calculated data were compared with measured data obtained by using the arc facility described in the next section.

TEST FACILITY

Arc Test Facility. A photograph of the arc test facility is shown in Fig. 3. This facility allows one to study vortex or wall-stabilized discharges at power levels up to one megawatt in quartz tubes or tubes constructed of insulated, segmented, copper sections of various diameters. The entire discharge assembly is mounted on a hydraulic scissor table which allows one to position any part of the arc column on the axis of various optical systems. In addition, the assembly may be moved in a single horizontal direction with a slide mechanism mounted on the scissor table. Thus, the discharge image may be traversed across optical slits to obtain lateral profiles. This arrangement allows one to map the discharge in the axial as well as the radial direction without moving any optical equipment.

A vortex generator, which holds the cathode assembly, is mounted on the slide mechanism as shown in Fig. 4. The strength of the vortex may be varied by changing the gas injection angle of four symmetrically placed cylindrical tubes having 0.015-inch diameter holes. In addition, gas may be injected through flow straighteners at the bottom of the chamber to provide axial flow in the arc column. In all cases, the generator is connected to the discharge tube through a converging nozzle. The total mass flow rate may be changed, and it is measured utilizing a system of sonic nozzles. The cathode consists of a 1/4-inch diameter thoriated tungsten rod, rounded at the emitting end and water cooled at the opposite end (200 to 1000 psi). The position of the cathode tip may be changed relative to the arc column in order to study its influence on the discharge stability. This type cathode was used throughout the testing program, and it gave satisfactory performance for currents up to 1600 amperes.

In order to extend the lifetime of the anode at currents in excess of 500 amperes, four anodes are used. Each anode is connected to a separate power supply as illustrated in Fig. 5. This arrangement allows the current flowing to each anode to be independently adjusted without having resistors in each anode circuit. The anode assembly is shown in Fig. 6. The discharge is started by withdrawing a tungsten electrode at reduced currents. An air driven piston retracts this electrode in a fraction of a second. In order to reduce the starting current, a water cooled resistor is connected in series with the starting electrode. As the starting electrode passes the anodes, the arc is transferred to one of them.

Power Supplies. A number of A. O. Smith, d-c power supplies, which may be connected in series - parallel arrangements, are part of the facility. Each supply is controlled by varying the coefficient of coupling between the primary and secondary windings of the three-phase input transformers. Because the reluctance of the three magnetic paths as well as the coefficients of coupling are not equal in each phase, a large 120-cycle per second ripple is observed in the output. An analysis showed that the system may be balanced at a given power setting by adjusting the coefficient of coupling independently. By this method, the 120-cycle per second ripple was reduced, and a 20 millihenry inductor in series with the arc almost eliminated the 360-cycle per second ripple for currents of the order of 1000 amperes. The total power available from this system is approximately one megawatt.

Control Console. The arc operation is controlled from a central console. At this console, the arc experiment is programed by means of a rotary cam controller which closes switches at preselected times. A typical sequence of programed events are:

(1) Starting power supplies are turned on

(2) Starting electrode gas supply is turned on and electrode is driven out

(3) Cameras are started, oscilloscope sweeps are started, etc.

(4) Additional power supplies are turned on

(5) Power supplies are turned off

(6) Starting electrode is returned.

Fifty Kilowatt Model. In addition to the basic discharge apparatus, a smaller model was designed to operate at 50 kilowatts and 400 amperes. This apparatus was constructed to make preliminary tests with an MHD generator, and it is shown in Fig. 7. For a 3/4-inch diameter quartz tube, the arc may be operated for approximately 4 seconds at 50 kilowatts. To increase the power level the tube length may be increased or the tube diameter increased. Increasing the tube diameter would require a greater current in order to operate at the maximum efficiency. The arc may be pulsed approximately every minute, and for longer operating times, it may be modified for vortex gas flow.

The anode consists of coiled copper tubing which is water cooled from a 250 psi supply. The self-magnetic field at the anode causes the anode spots to move which prolongs its lifetime. The cathode is similar to the one used on the basic test apparatus.

EXPERIMENTAL RESULTS

Introduction. For the 1-inch diameter, wall-stabilized arc, a number of measurements were completed. These measurements are illustrated in Fig. 4. Because it is necessary that the flow be laminar and time independent in order to make comparisons with analytical calculations, the arc was observed with a Fastax camera as well as photomultipliers. The results of this investigation may be found in Reference (17). For argon, a region of mass flow rate was found where the films indicated that the flow was laminar and independent of time for periods up to 0.8 sec. The computer programs, at present, are only applicable to this type flow.

Voltage and Current. Total arc voltage was measured from the cathode to each anode using voltage dividers and four scope sweeps. Arc current was determined from the voltage across a calibrated shunt. This voltage was recorded on an independent scope sweep. As shown in Fig. 8, the main current and voltage of the arc are constant for approximately 0.5 sec (arc current 1500 amp). The changes in current and voltage were traced to the introduction of wall impurities such as Na and Si. To illustrate this point, the relative intensity of the Si line at 3905.5 Å is shown in Fig. 9. Notice that the line intensity increases rapidly at the same time the voltages and current deviate from their constant values. At this time, the total radiation, shown in Fig. 8 also shows a large change. Thus, it is the impurity level which limits the length of the constant radiation pulse.

Voltage Gradients. In order to compare the arc characteristics with calculated values, the voltage gradient was measured in the developed region of the arc. Measurements were achieved by using two small tungsten probes cemented in the wall of the tube and separated by an axial distance of 1.27 cm. The probe diameters were 0.08 cm. The probe signal was determined by using a differential amplifier and the output measured on a scope sweep. A sample output is shown in Fig. 8. Notice the deviation from the approximate constant value when impurities enter the plasma. Occasionally water vapor condensed on parts of the arc between runs. The effect of water on the arc characteristics was drastic. Thus, several preliminary runs were made before recording data. If one observed this rule carefully, then consistent results were obtained. The measured voltages were made with a high impedance input. Thus, the probe current was in the order of 10 microamps. Large probe currents gave poor response times. The reason for this result is not known. However, surface contamination may play an important role.

Total Radiation. Total radiation per cm of arc length in the developed region was measured for the 1-inch diameter as well as the 3/4-inch diameter argon arc. A vacuum thermopile having a CaF_2 window and a time response of 0.01 sec was used for these measurements. The thermopile was calibrated and the data analyzed (no absorption) as outlined in Reference (18). The output voltage was amplified with a Preston d-c amplifier and displayed on a scope sweep. A sample output is shown in Fig. 8.

Plasma Temperature Measurements. Due to the short time duration of the pulsed arc discharge, time resolved arc column temperature profiles had to be determined. To do this an optical image scanning system was built which was used to obtain lateral continuum radiation profiles in a selected narrow wavelength band as shown in Fig. 10. The absolute continuum intensity of the arc plasma was determined by comparing the arc radiation output with the output of a tungsten ribbon standard lamp. An Abel inversion was used to reduce the lateral column scans to radial point by point continuum intensities. Published data for argon continuum intensity as a function of temperature was used to convert the radial intensity distributions to temperature distributions.

A narrow band interference filter system was used to select a wavelength region in which to determine continuum intensity. This filter had peak second order transmission at 5464 Å with a half width of 8 Å. Radiation was detected using an end window photomultiplier tube located behind the filters.

The signal output from the photomultiplier was fed directly to a calibrated multiple trace oscilloscope. The sensitivity of each trace was set to display on the screen a relative signal range of 2.5 orders of magnitude. A delayed trigger system was devised to allow profiles to be taken at any time during the arc's duration.

To calibrate the system the image of the arc column was replaced by an image of a calibrated standard lamp.

The observed voltage output from the arc scan can be represented by

$$V_A = K_i G_A \int_{\lambda_1}^{\lambda_2} \mathcal{R}(\lambda)\, \tau(\lambda)\, I_A(\lambda,T)\, d\lambda$$

where

V_A is voltage output,

K_i is an instrument constant,

G_A is amplifier gain,

$\lambda_2 - \lambda_1$ is the wavelength interval,

$\mathcal{R}(\lambda)$ is photomultiplier response,

$\tau(\lambda)$ is filter transmission function, and

$I_A(\lambda,T)$ is arc continuum radiation intensity as a function of wavelength and temperature.

Over the small wavelength interval $(\lambda_2 - \lambda_1)$, $\mathcal{R}(\lambda)$, and $I_A(\lambda, T)$ can be considered constant and removed from the integral.

Thus,

$$V_A = K_i G_A \mathcal{R}(\bar{\lambda})\, I_A(\bar{\lambda},T) \int_{\lambda_1}^{\lambda_2} \tau(\lambda)\, d\lambda .$$

In a similar way, the voltage output from the calibration standard can be represented by

$$V_L = K_i G_L \mathcal{R}(\bar{\lambda})\, I_L(\bar{\lambda},T) \int_{\lambda_1}^{\lambda_2} \tau(\lambda$$

Taking the ratio of these voltages and canceling yields

$$\frac{V_A}{V_L} = \frac{G_A\ I_A(\lambda,T)}{G_L\ I_L(\lambda,T)}$$

or

$$I_A(\lambda,T) = \frac{V_A\, G_L\, I_L(\lambda,T)}{V_L\, G_A}$$

This corresponds to the lateral continuum intensity of the arc column at the selected wavelength region.

The lateral intensity over the arc column diameter was converted to radial intensity points by using a solution of the Abel inversion equation as devised by Nestor and Olsen (19). The computer output expressed in $\left[\frac{Watt}{St-\mu-cm^3}\right]$ as a function of radius was correlated with temperature by using data published by Olsen for argon at 1.1 atmospheres corrected to 1.0 atmospheres (20). The resulting temperature profile is compared with calculated values in Fig. 11.

A report is being prepared for publication by ARN describing in greater detail the technique used to determine plasma temperature by this filter method (20).

Heat Flux Measurements. Total heat flux to the wall of the tube was determined by measuring the temperature rise of a solid copper ring section of known mass and dimension. The quartz tube was cut, and a one-inch long copper ring was inserted between the two lengths of quartz. The copper ring was not cooled and was instrumented with a thermocouple on its outside surface. The thermocouple output was connected directly to an electrically floating, oscilloscope differential amplifier.

From the basic equation for heat content in calories

$$\Delta Q = m C_p \Delta T$$

where

ΔQ = change in caloric heat content,

m = mass of copper ring section,

C_p = specific heat of copper, and

ΔT = change in ring section temperature.

The change in ring section temperature was determined directly from the thermocouple output voltage.

Due to the pulsed mode of arc operation and the effects of the initial low current starting sequence, two separate thermocouple readings had to be taken to determine heat flux to the wall during the high current pulse. A short pulse and a long pulse reading was taken. The difference in measured heat load to the section could then be attributed to the high current operation. In order to compare and check these measurements with the known electrical power put into the developed arc column per inch length, the arc electrical power was converted to calories per second and multiplied by the time difference between the short and long pulse. Since the ring section receives both radiated and conducted energy from the column, the value of Q obtained from the ring section measurement should equal the value of Q obtained from the measured electrical power put into the arc. By subtracting the measured value of radiated energy from the total energy received by the ring section, we may then obtain total heat energy to the wall by conduction.

An example of data obtained by this method follows (see Fig. 8):

Mass, M, of copper section = 456 grams per inch,

C_p of copper = .093 cal/gram °C,

ΔT as measured from thermocouple = 14.7 °C,

Δt as measured from current traces = .125 seconds.

Typical results obtained from these data are:

Heat energy into the arc column = (23 kw per inch) (.24 calories per second per kw) (.125 seconds) = 690 calories per inch, heat energy measured from ring section = (456 grams per inch) (.093 calories per gram per °C) (14.7 °C) = 624 calories per inch, measured radiation loss = 269 calories per inch. Errors in these measurements can be attributed to the following:

(1) The starting conditions of the arc may vary somewhat from run to run;

(2) All of the radiation from the column was not collected by the ring section (some was reflected);

(3) Due to the mass of the ring section, approximately 10 seconds was required after the end of the pulse before the section reached its maximum temperature at the location of the thermocouple. During this time, some of the heat energy is convected away from the section to its surroundings, thereby reducing the measured temperature rise (effect was reduced by insulated guard rings on each side of the section).

Measured Lumen Output. The lumen output per unit length of arc column was measured for the 3/4-inch diameter argon arc operating at approximately 50 kilowatts. This measurement was achieved by using a selenium photocell and wratten filter number 57. The combined response of this system is compared with the standard eye response in Fig. 12. Part of the error associated with the mismatch of the response curves tends to cancel out because the system was calibrated by using a standard candle power source. The lumen output per unit length as a function of current is compared with calculated values in Fig. 13. Neglecting electrode losses, one obtains approximately 40 lumens/watt in the developed region. Because the arc length may be made long (if one has a high voltage source) this efficiency may be achieved. For the test arc (22 cm long) one obtains approximately 25 lumens/watt. At 50 kilowatts, this gives a total output of 1.25×10^6 lumens. The calculated value of lumen output does not include contributions due to line radiation. Thus, as shown in Reference (22) for total radiation, their contribution to lumen output may be as great as the continuum contribution. In order to make more realistic calculations, spectral radiation data as a function of temperature including lines are required and these data should be measured.

CONCLUSIONS

Before one selects a radiation source, all important requirements for a given application must be determined. From an analysis of these requirements, approximate source characteristics are determined. If the requirements are beyond the present state of the art, additional source research is justified. In order to accomplish these objectives, a handbook of simple analytical techniques, plasma properties, and pertinent empirical data for the various sources is required. For the final design, computer programs should be used if they are available.

Simple analytical methods are available for the wall stabilized arc. In addition, detailed computer programs are available for a final design. These calculations have been compared with measurements for argon plasmas using Emmons' transport property data (23), and Morris' spectral continuum data (22), and excellent agreement was obtained (see Fig. 11 and Fig. 13). However, additional data on spectral radiation as a function of temperature including line radiation are required.

Radiation source design should be supplemented by excellent diagnostic techniques. Total and spectral radiation standards should be available for use with radiometers and spectrometers. A handbook of simple diagnostic techniques would be helpful to the engineer.

Diagnostic techniques were developed to measure arc voltage gradient, current, heat flux to the wall, total radiation, lumen output, and temperature distributions for pulse lengths greater than 100 milliseconds. A very simple method for measuring temperature distributions is less than a millisecond using an interference filter system was innovated and compared with standard techniques. The simplicity of this system makes it an excellent diagnostic tool for engineering measurements.

The argon wall stabilized arc operating at atmospheric pressure may be used as a radiation source, and the design and diagnostic techniques applicable to this source are excellent. However, there are disadvantages as well as advantages. The advantages are:

(1) The source may be designed for very efficient total radiation (greater than 70 per cent of the power input).

(2) The lumen output per watt is comparable to other sources.

(3) Transport and thermodynamic properties are well known.

(4) The arc may be adapted to high voltage or high current power supplies.

(5) Arc apparatus can be designed to be very light in weight.

(6) The arc is simple to construct, modify, and repair.

(7) The arc may be operated in the megawatt regime.

(8) Reliability of all parts except the anode is excellent.

(9) Does not require high voltage starting techniques.

(10) Computer programs are available for arc design.

The major disadvantages are:

(1) Arc shape is restricted to a long cylinder.

(2) Argon is exhausted to atmosphere. Thus, larger gas supply is required.

(3) Pulse duration times are limited to several seconds (can be extended with vortex flow).

(4) Requires water cooled electrodes.

(5) Anode design needs improvement.

(6) Requires a starting electrode which doubles the length of apparatus.

Hopefully, the information given in this paper will help the engineer to more realistically design radiation sources for military purposes. If the source described in this report meets the desired requirements, ARN can design and supply the source within several months. If long operating times are required, long vortex stabilized arcs can be designed by empirical and simple analytical techniques.

REFERENCES

1. Soehngen, E. E., "Energy Exchange Phenomena in Electric Arcs and Their Application to Aerospace Technology", ARL 63-173, October 1963.

2. Morris, J. C., Bach, G. R., Yos, J. M., "Research on Radiation from Arc Heated Plasma", ARL 64-180, October 1964.

3. Morris, J. C., Krey, R. U., Liebermann, R. W., "Research on Radiation from Arc Heated Plasma", ARL 65-164, August 1965.

4. Wechsler, A. E., "Characteristics of Metal Vapors", ARL 66-0004, January 1966.

5. Skifstad, J. G., "Review of Theoretical Analysis of Arc Heating in a Tube", ARL 65-207, October 1965.

6. Cremers, C. J., "The Spectrometric Measurement of the Temperature Field in an Arc with a Transpiration-Cooled Anode", ARL 65-117, June 1965.

7. Olsen, C. D., and Maldenado, C. D., "New Method for Obtaining Emission Coefficients from Emitted Spectral Intensities, Part II. Asymmetrical Sources", ARL 67-0035, February 1967.

8. Lamb, J. D., and Schreiber, P. W., "The Application of a Differential Interferometer to an Axially Symmetric Arc Heated Plasma", ARL 66-0222, November 1966.

9. Uhlenbusch, J., "Theory and Calculation of Stationary and Quasi-Stationary Cylindrical Arcs", ARL 65-109, May 1965.

10. Wechsler, A. E., Glaser, P. E., and Jasperse, J., "Characteristics of Metal Vapors", ARL 65-53, March 1965.

11. Morris, J. C., and Garrison, "Nitrogen Recombination Continuum in the Vacuum Ultraviolet", J. Quant. Spectrosc, 6, p. 899, (1966).

12. Marlotte, G. L., and Lemm, P. D., "Basic Research on Gas Flows Through Electric Arcs", ARL 65-231, November 1965.

13. Vidya Staff, "A Survey of Plasma Diagnostic Techniques, ARL 64-80, May 1964.

14. Bauder, U., Private Communication.

15. Skifstad, J. G., Private Communication.

16. Schreiber, P. W., and Schreiber, E., "Analog Computer Solution for the Developed Laminar Electric Arc Column", ARL 66-0212, October 1966.

17. Skifstad, J. G., Andrada, T., and Schreiber, P. W., "Fastax Films Showing the Development of a Pulsed, High Current Arc in a Tube", AIAA Paper No. 66-731, 1966.

18. Schreiber, P. W., "Radiation from an Alternating Current Arc", Proceedings of the First Plasma Arc Seminar of the Thermo-Mechanics Research Laboratory, ARL 63-151, September 1963.

19. Olsen, H. N., and Nestor, O. H., "Numerical Methods for Reducing Line and Surface Probe Data", SIAM Rev., 2, p. 200, 1960.

20. Olsen, H. N., "Partition Function and Lowering of the Ionization Potential in an Argon Plasma", Phys. Rev., 124, p. 1703, (1961).

21. Schreiber, P. W., and Benedetto, K., ARL Report in Preparation.

22. Morris, J. G., "Research on Radiation from Arc Heated Plasmas", Quarterly Progress Report No. 4, 10 June 1966.

23. Emmons, H. W., "The Arc Measurement of High Temperature Gas Transport Properties", NSF 23, December 1965.

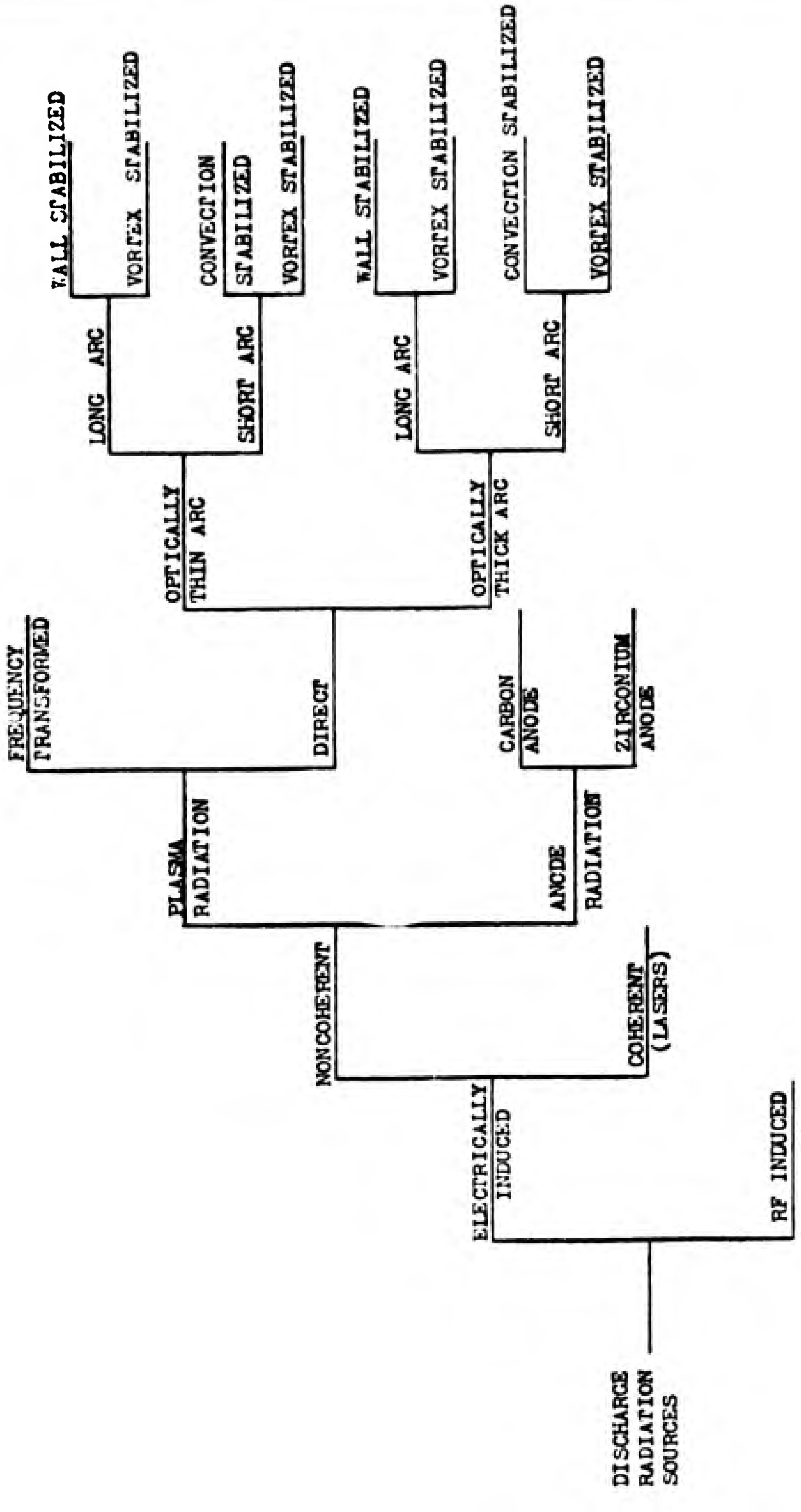


FIG. I. DIVISION OF DISCHARGE RADIATION SOURCES

BASIC EQUATIONS

A. **ENERGY EQUATION**

$$\frac{d^2\Phi}{dr^2} + \frac{1}{r}\frac{d\Phi}{dr} + \sigma(\Phi)E^2 - P_r(\Phi) = 0$$

$$\Phi = \int_{T_w}^{T} k(T)\,dT$$

B. **MOMENTUM EQUATION**

$$\frac{1}{r}\frac{d}{dr}\left[\mu(\Phi)\,\frac{dV_z}{dr}\right] - \frac{dP}{dz} = 0$$

C. **CONTINUITY EQUATION**

$$\dot{m} = 2\pi\int_0^R \rho V_z\,r\,dr$$

D. **OHM'S LAW**

$$I = 2\pi E\int_0^R \sigma\,r\,dr$$

ASSUMPTIONS

1. L.T.E.
2. FULLY DEVELOPED
3. NO STRESS POWER
4. LAMINAR FLOW
5. NO MAGNETIC FIELD
6. OPTICALLY THIN

INPUT DATA

$P_r(\Phi)$, $\sigma(\Phi)$, $\mu(\Phi)$, $\rho(\Phi)$

E, R, $\dot{m}$

OUTPUT DATA

$\Phi(r)$, $T(r)$, $V_z(r)$

$\frac{dP}{dZ}$, $j(r)$, $P_r(r)$

I, P_T, etc.

FIG. 2. EQUATIONS USED TO CALCULATE ARC QUANTITIES FOR DEVELOPED, LAMINAR FLOW.

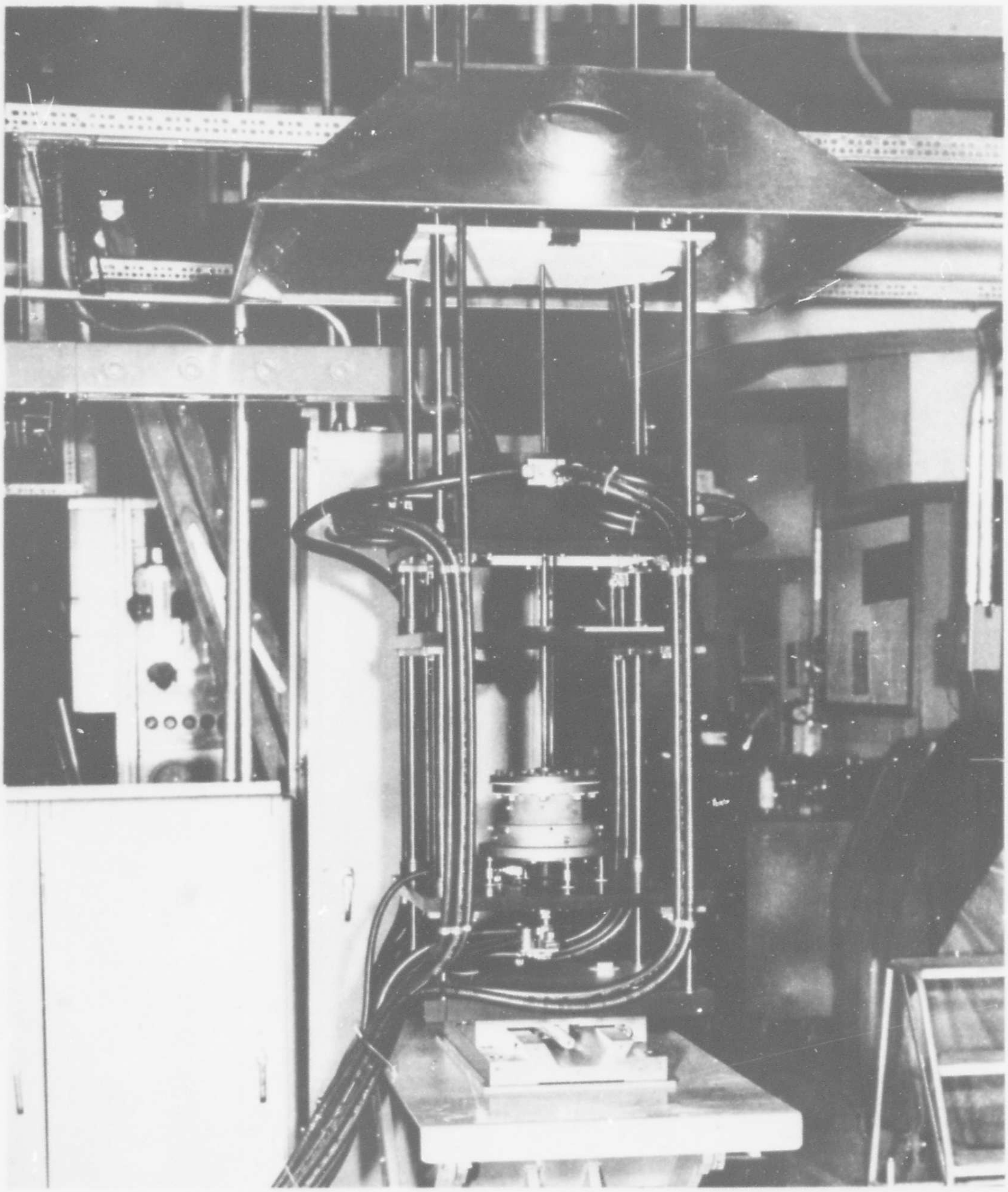


FIG. 3 ARC TEST FACILITY

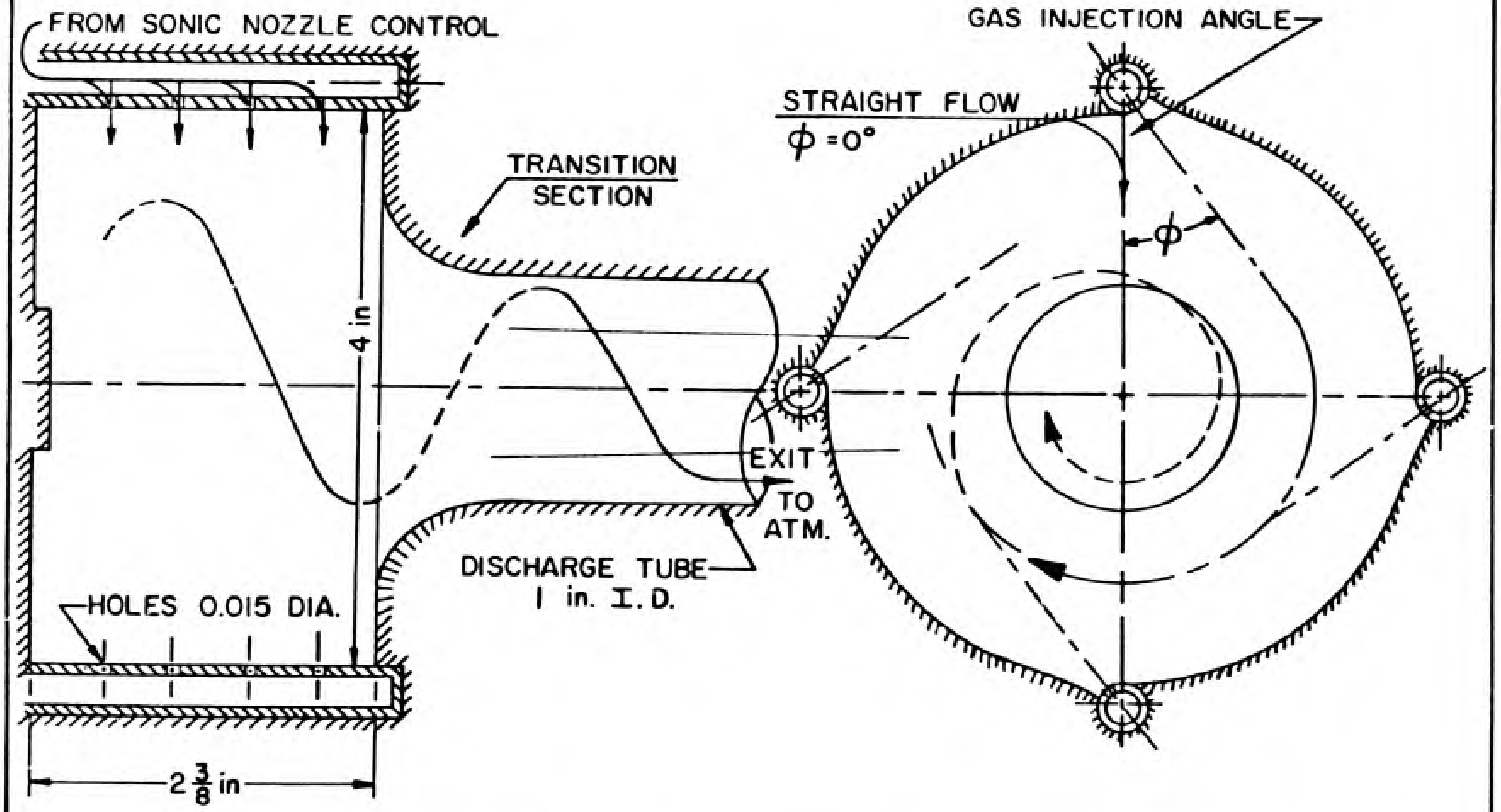


Figure 4 Vortex Generator

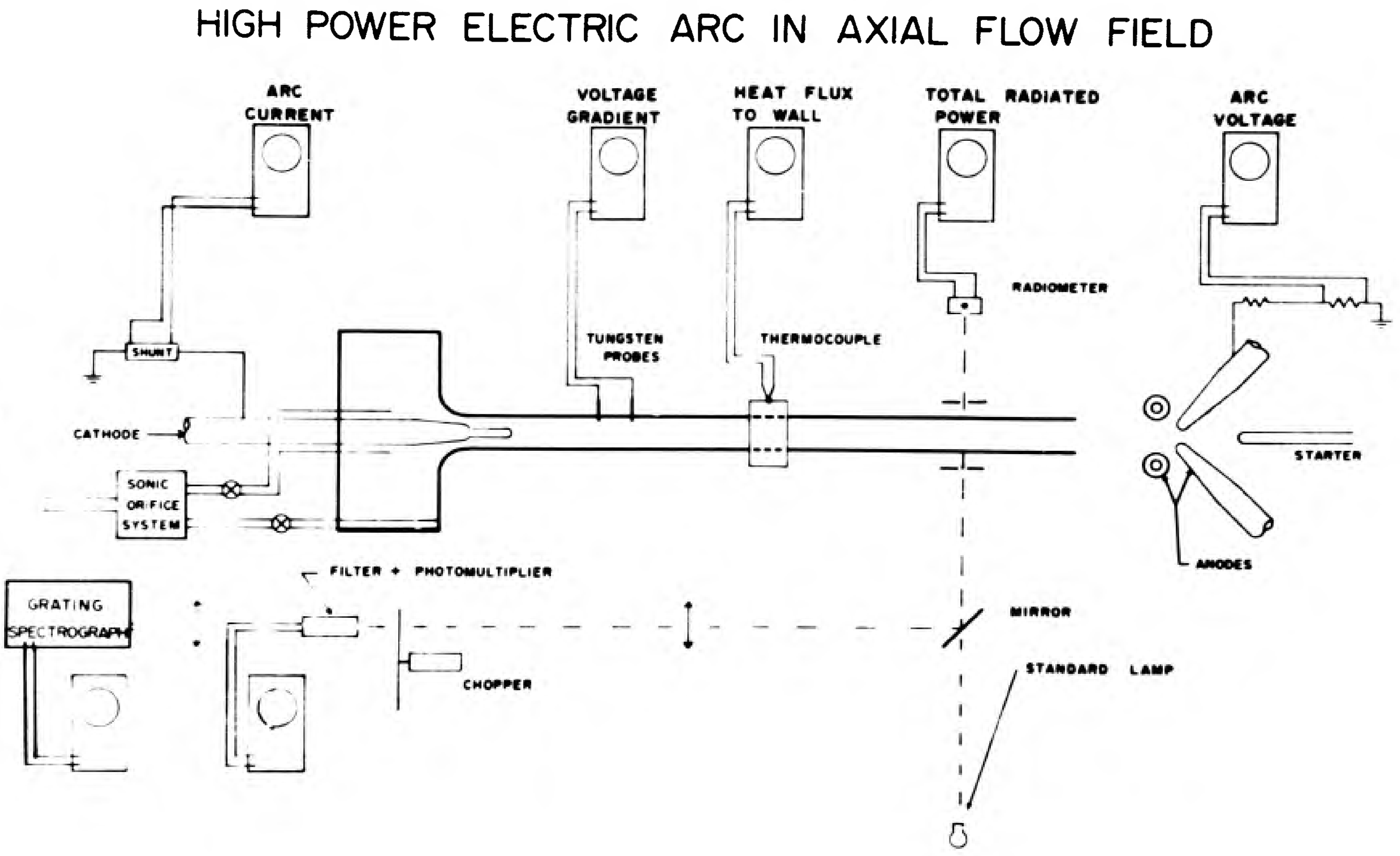


FIG. 5. ILLUSTRATION OF ARC DIAGNOSTIC MEASUREMENTS

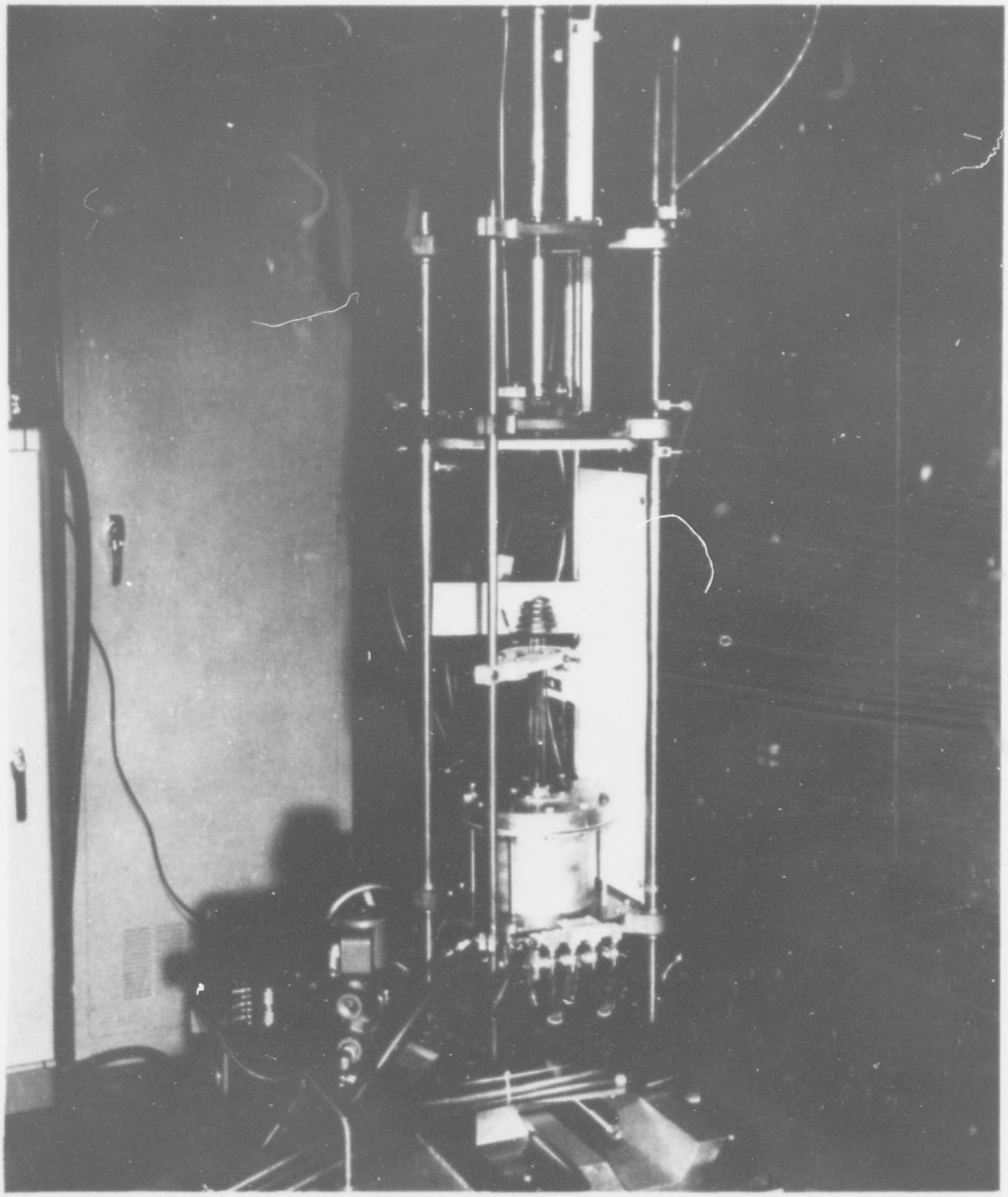


FIG. 7 WALL STABILIZED ARC DESIGNED TO OPERATE AT 50 KILOWATTS

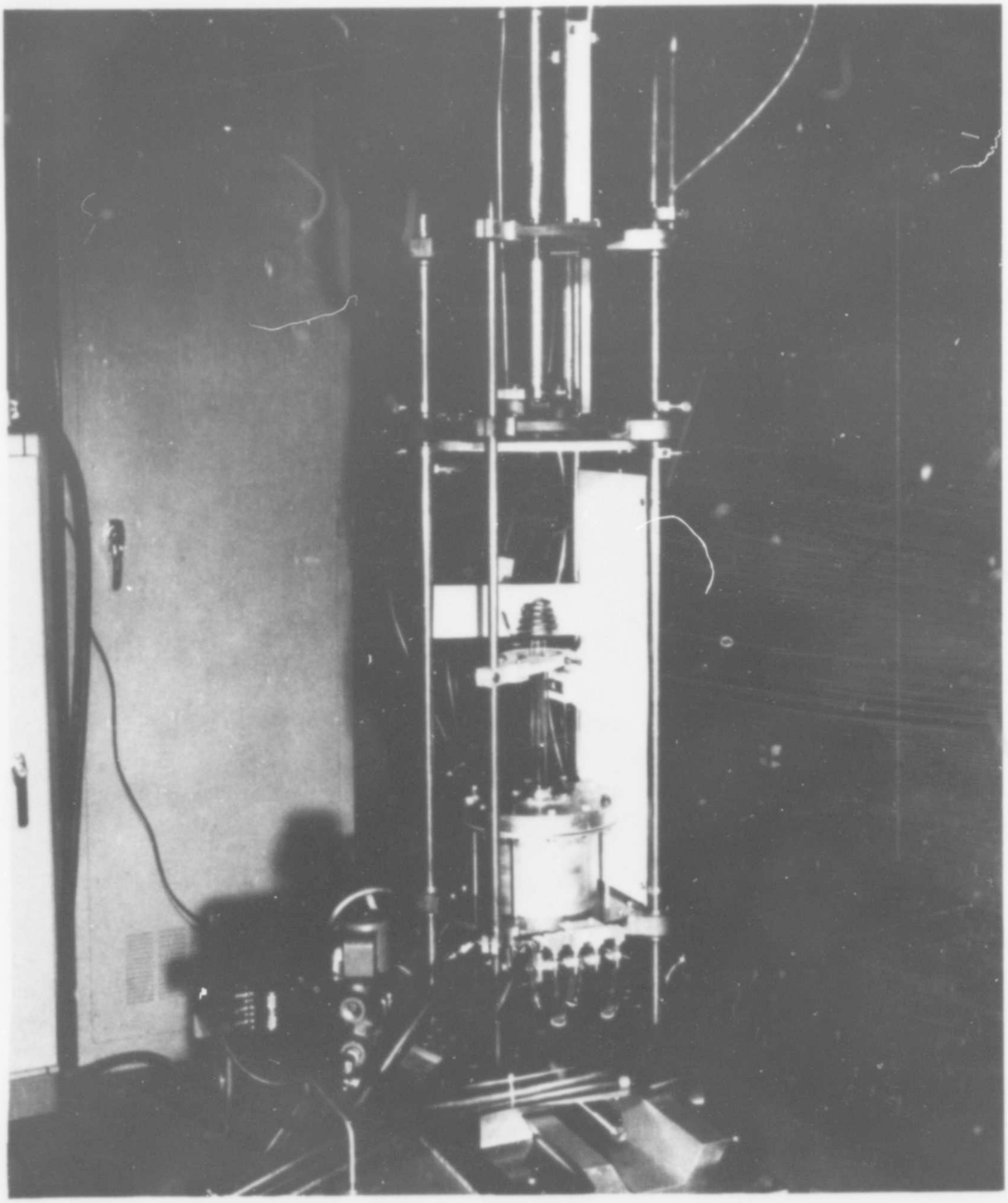


FIG. 7 WALL STABILIZED ARC DESIGNED TO OPERATE AT 50 KILOWATTS

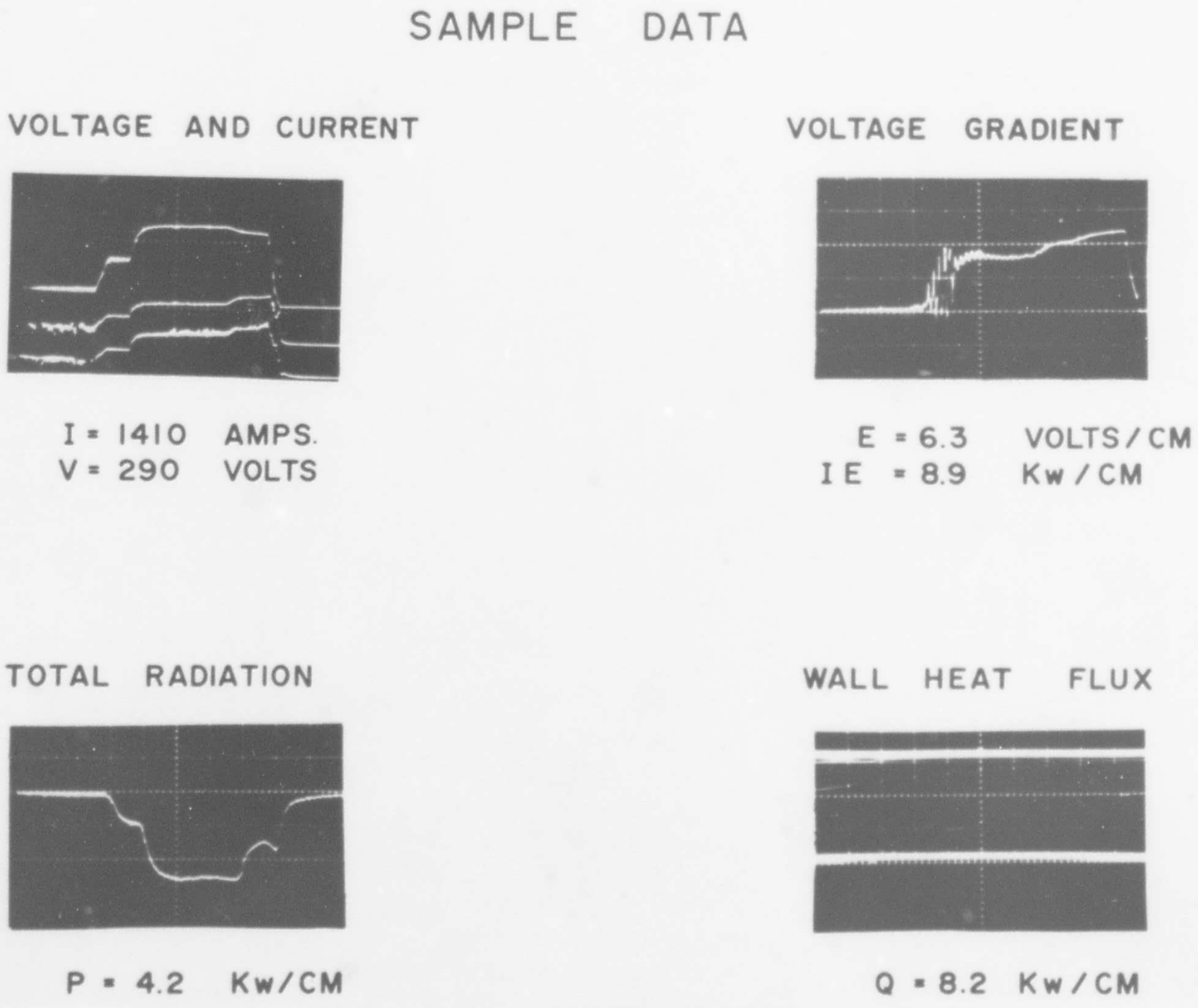
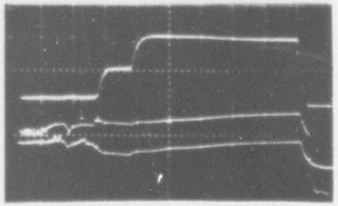


FIG. 8 SAMPLE DATA FOR 1-INCH DIAMETER WALL-STABILIZED ARC

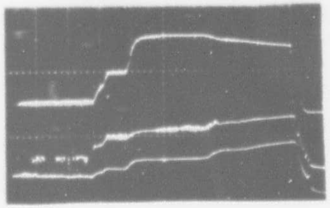
ARC WALL CONTAMINATION

NITROGEN

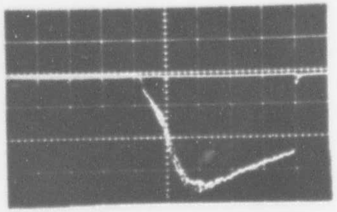


600 AMPS/CM
250 VOLTS/CM

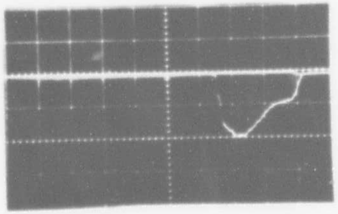
ARGON



600 AMPS/CM
250 VOLTS/CM



Si LINE
λ = 3905.5 Å
0.2 VOLTS/CM



Si LINE
λ =3905.5 Å
0.2 VOLTS/CM

FIG. 9 INVESTIGATION OF PLASMA WALL CONTAMINATION

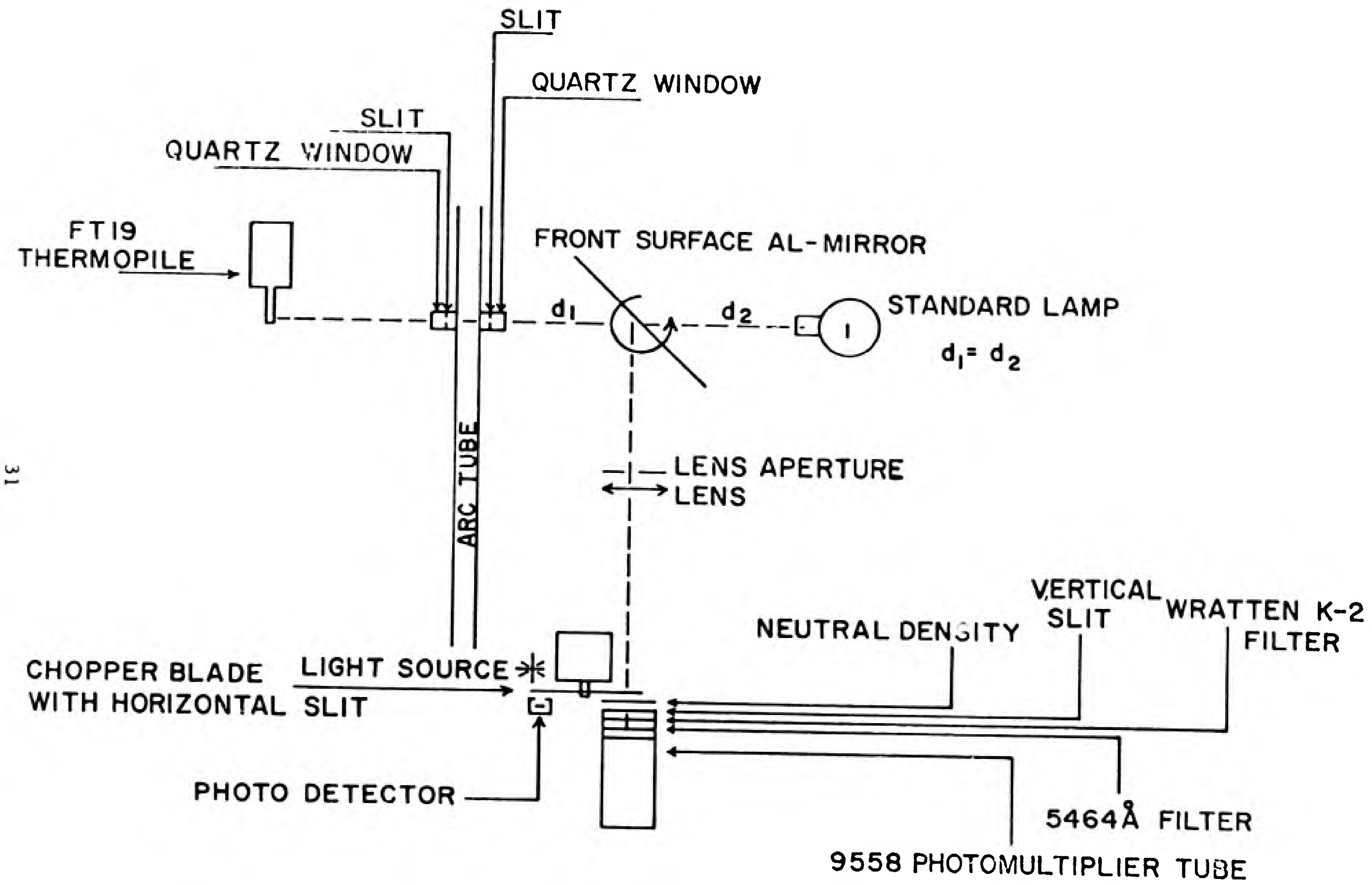


FIG. 10 OPTICAL SYSTEM

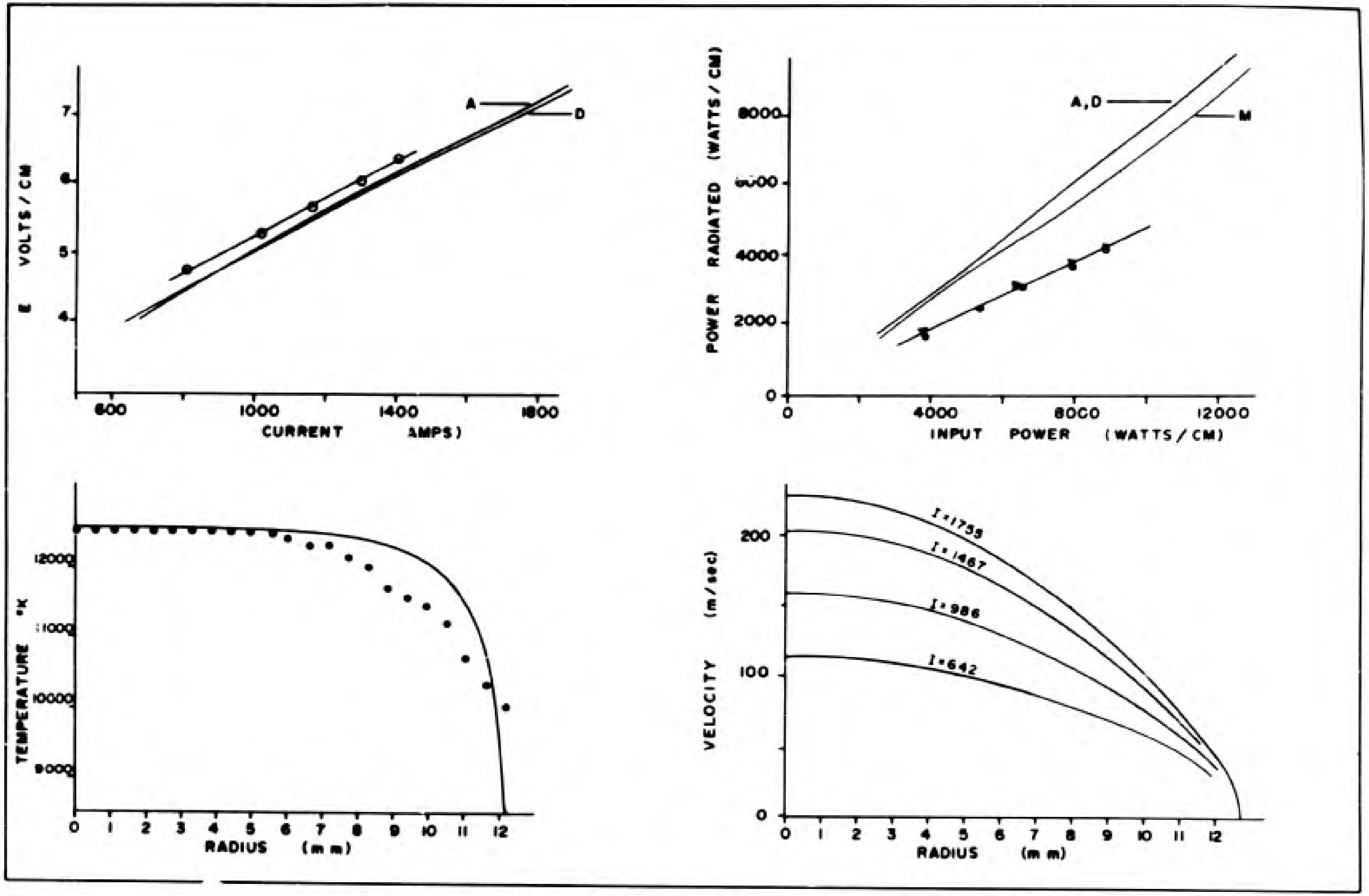


FIG. 11 COMPARISON OF MEASURED AND CALCULATED DATA FOR 1-INCH DIAMETER ARC

]

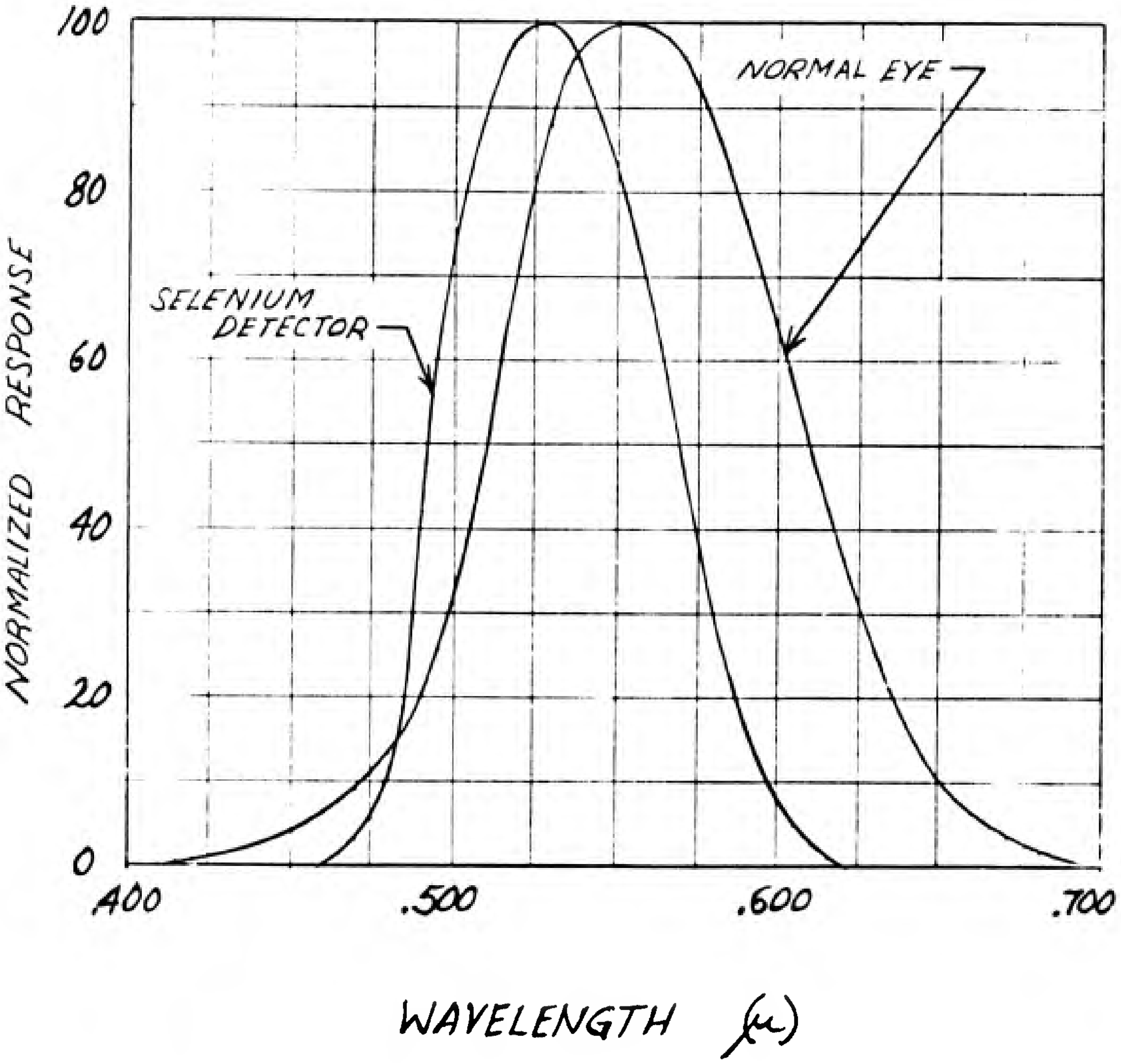


FIG 12. SPECTRAL RESPONSE OF NORMAL EYE AND SELENIUM DETECTOR WITH FILTER

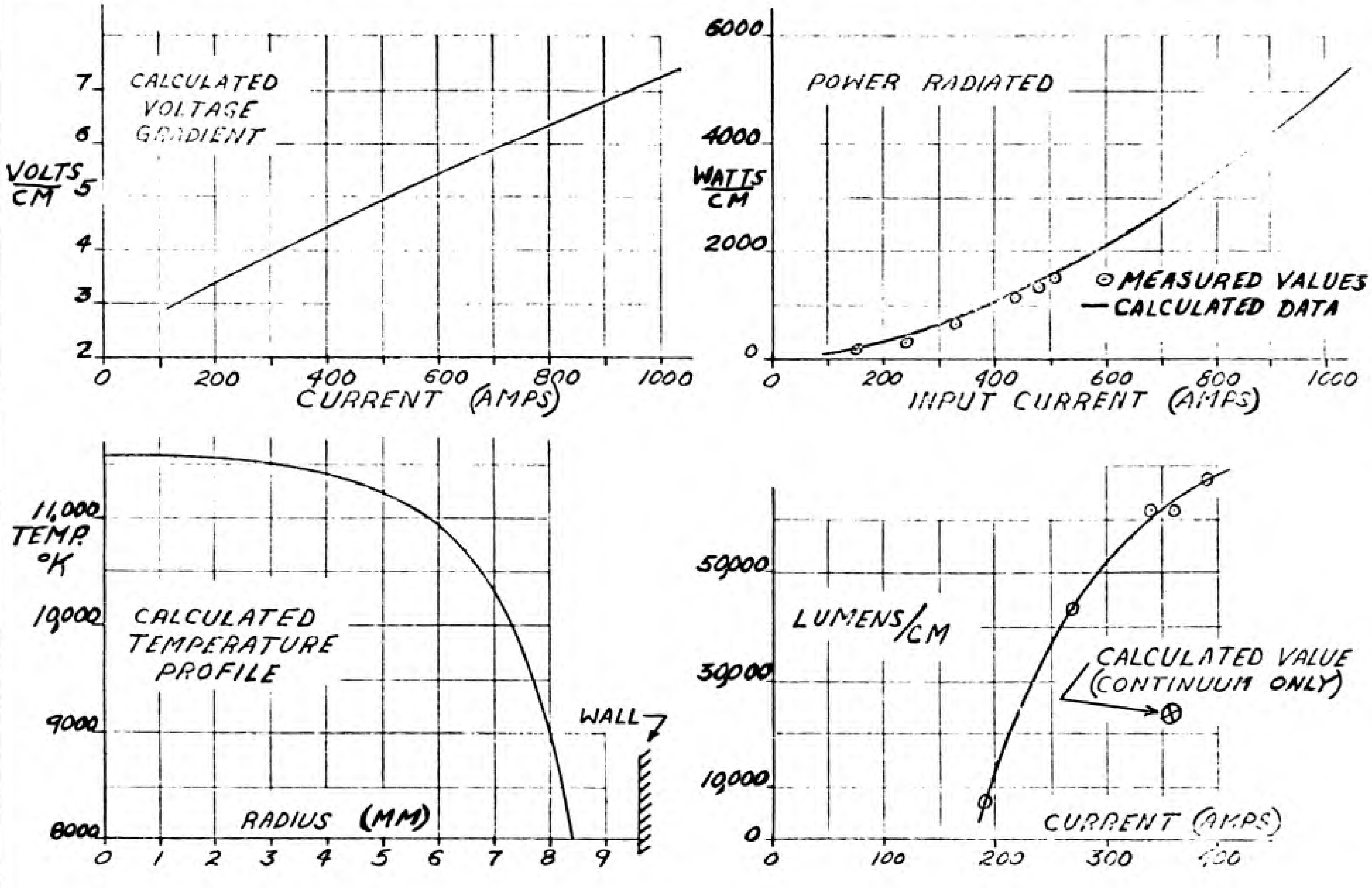


FIG. 13. COMPARISON OF DATA FOR 3/4-INCH DIAMETER ARC

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Thermomechanics Research Laboratory
Aerospace Research Laboratories
Office of Aerospace Research, USAF 45433

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
AN APPROACH TO RADIATION SOURCE DESIGN FOR MILITARY APPLICATIONS UTILIZING THE WALL-STABILIZED ARC AS AN EXAMPLE

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Scientific, Final.

5. AUTHOR(S) (First name, middle initial, last name)
PAUL W. SCHREIBER, KENNETH R. BENEDETTO

6. REPORT DATE
August 1967

7a. TOTAL NO. OF PAGES
39

7b. NO. OF REFS
23

8a. ~~CONTRACT OR GRANT NO.~~ In-House Research

b. PROJECT NO. 7063-00-14

c. DoD Element 61445014

d. DoD Subelement 681307

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
ARL 67-0179

10. DISTRIBUTION STATEMENT
1. This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES
TECH OTHER

12. SPONSORING MILITARY ACTIVITY
Aerospace Research Laboratories (ARN)
Office of Aerospace Research
United States Air Force
Wright-Patterson Air Force Base, Ohio 45433

13. ABSTRACT

An approach to the selection of radiation sources for military applications is presented. A logical breakdown of the various types of discharge sources and a list of parameters to be considered are given. As an example, an analytical and experimental study of the fully developed, laminar flow, argon electric arc discharge is included. A description of the arc facility and the diagnostic techniques used are presented. The analytical results are compared with experimental results.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
RADIATION SOURCES						
MILITARY APPLICATIONS						
HIGH POWER ELECTRIC ARC DISCHARGE						
DIAGNOSTICS						
ANALYTICAL TECHNIQUES						
TEST FACILITY						
ANALYTICAL AND EXPERIMENTAL COMPARISON						