Report of BAMIRAC

A HIGH-TEMPERATURE BLACKBODY RADIATION SOURCE

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Institute of Science and Technology
THE UNIVERSITY OF MICHIGAN

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PREFACE

BAMIRAC, the Ballistic Missile Radiation Analysis Center, is a facility of the Institute of Science and Technology at The University of Michigan. Supported by ARPA, the Advanced Research Projects Agency, under Contract SD-91, this center for analysis of scientific and technical information is a part of ARPA's Project DEFENDER (research on ballistic missile defense). A variety of theoretical and experimental investigations pertinent to ballistic missile phenomenology are performed by BAMIRAC. This report describes one such investigation. The facility also aids ARPA by planning and conducting various technical conferences.

BAMIRAC is under the technical direction of the Infrared Physics Laboratory. It draws also upon the capabilities of the Infrared and Optical Sensor Laboratory and the Computation Department of the Institute, and upon those of the Aircraft Propulsion Laboratory of the Department of Aeronautical and Astronautical Engineering and of other departments of The University of Michigan, particularly within the College of Engineering.

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A HIGH-TEMPERATURE BLACKBODY RADIATION SOURCE

ABSTRACT

A high-temperature blackbody radiation source, consisting of an electrically heated graphite tube with a small centrally located hole through one wall, was developed for use as a secondary standard in the calibration of radiometric and spectrometric instruments. The spectral emissivity of this source, at 0.65 μ, was calculated by the DeVos method, for which graphite emissivities and temperature gradients were measured in situ with an optical pyrometer. The values of source emissivity ranged from 0.9981 ± 0.0004 at 1000°C to 0.9997 ± 0.0002 at 2000°C.

1 INTRODUCTION

A quantitative measurement of radiant energy requires an absolute calibration of the measuring instrument. The usual procedure is to irradiate the instrument with a properly located source that has a known distribution of spectral radiant intensity or spectral radiance. A cavity radiator which approximates a blackbody is a convenient source for such a purpose because its radiation characteristics can be calculated by the well-known Planck radiation formula, if the temperature, emissivity, and area are known. Commercially available units have been so used by many investigators. However, thermal gradients present in most reference sources and uncertainties in their emissivities introduce uncertainties into the calibration and consequent error into the quantitative measurements. The problems of evaluating the spectral emissivity of such sources become especially difficult at higher temperatures.

This report describes the development and evaluation of a blackbody radiator to be used at temperatures up to 2000°C as a secondary standard in laboratory work. This work is part of a program for the advancement of radiometric calibration techniques.

2 REVIEW OF THE PROBLEM

2.1. DEFINITION OF A BLACKBODY

A blackbody is an object (hypothetical) which completely absorbs all incident radiation and, if its temperature is uniform, will emit radiation as determined by this temperature in accordance with Planck's radiation formula. Such a radiator would be an ideal source for calibrating instruments which measure radiant energy in a broad spectral region from the ultraviolet into the infrared. A blackbody operating at high temperatures would be desirable in calibrating instruments to be used for measuring spectral radiances of high-temperature sources. It is, therefore, of interest to develop high-temperature references that closely approximate the true blackbody.

2.2. PRACTICAL BLACKBODY RADIATION SOURCES

Blackbodies are frequently approximated by hollow bodies with small openings; a ray of radiation falling on the opening passes into the cavity and is reflected so many times on the inside surface before it again reaches the opening that its absorption is very nearly complete. However, approximate blackbodies differ from the ideal blackbody because the size of the opening cannot be reduced to zero and the cavity walls are usually not isothermal. Such "blackbody"* radiation sources have been in existence for many years. In early simple experiments it was observed that the interior of rifle barrels became luminous at a certain temperature [1] and that scratches and conical holes in an incandescent metal surface were brighter than the smooth surface [2]. Wien and Lummer [3] in 1895 built a blackbody consisting of a diaphragmed porcelain tube heated with a platinum ribbon. Since then, many blackbodies (of various sizes and shapes) have been devised. Some were heated by immersion in a freezing metal, as for instance in Au(1336^{o}K), Pd(1827^{o}K), Pt(2046^{o}K), and Ir(2727^{o}K), or heated resistively or inductively. A brief review of these is given by Anacker and Mannkopff [4], who proposed a design capable of attaining 4000^{o}K. Commercially available blackbody radiation sources are usually limited to temperatures of about 1000^{o}C, although two models capable of reaching 2000^{o}K have recently become available [5]. A blackbody radiation source capable of operation at 2800^{o}C has also been recently described [6].

2.3. QUALITY OF SOURCES

The quality (i.e., how closely emissivity approaches unity) of the blackbody radiation source used in the calibration of a radiant energy measuring instrument must be determined in establishing the accuracy to which measurements can be made with such an instrument. Therefore the determination of the emissivity of blackbody radiation sources is an important and necessary adjunct to instrument calibration. Although it might seem that the quality could be determined by methods involving direct measurement of the radiation emitted, the following discussion will show that this approach is unsatisfactory.

The normal spectral emissivity $\epsilon_N(\lambda, T)$ at wavelength λ of a body at temperature T is defined as the ratio of the spectral radiance $N(\lambda, T)$ of the body at temperature T to the spectral

*Inasmuch as ideal blackbodies do not exist, the term "blackbody" is used generically in this report to identify sources the emissivities of which are nearly constant and nearly unity, and are known to high accuracy.

radiance of a blackbody $N_{BB}(\lambda, T)$ at the same temperature T:

$$\epsilon_N(\lambda, T) = \frac{N(\lambda, T)}{N_{BB}(\lambda, T)} \quad (1)$$

The hemispherical emissivity $\epsilon_H(\lambda, T)$ at wavelength λ of a body at temperature T is similarly defined as the ratio of the radiant emittance $W(\lambda, T)$ of the body at temperature T to the radiant emittance $W_{BB}(\lambda, T)$ of a blackbody at the same temperature T:

$$\epsilon_H(\lambda, T) = \frac{W(\lambda, T)}{W_{BB}(\lambda, T)} \quad (2)$$

For a perfectly diffusing flat surface, $W = \pi N$.

The definition of emissivity loses meaning when applied to sources with temperature variations over the interior wall of the radiating cavity. Unfortunately, most practical sources are not perfectly isothermal. However, by assuming that the temperature of the cavity wall viewed through the hole is the temperature for Eq. (1) or (2), a value that we may regard and use as an "emissivity" can be obtained. An experimental evaluation of a source would require a calibrated energy-measuring instrument and precise determinations of temperature. If the temperature were known, then the blackbody radiance (or emittance) could be calculated by the Planck formula and the source radiance (or emittance) could be measured directly with this calibrated instrument. However, such an experimental approach requires knowledge of the quality of the calibration source of the measuring instrument. Evaluation of the quality of this calibration source by the same experimental method would require another calibrated energy-measuring instrument, which in turn would require knowledge of the quality of the source used to calibrate this second instrument. This process could go on ad infinitum. A number of blackbody sources have been experimentally evaluated [7], but on the assumption that one of these was a perfect blackbody. The measurement of temperature also introduces uncertainty; the magnitude of errors involved here is discussed by Schumacher [8], who concludes that the source quality could not be determined within less than several percent.

Theoretical evaluation of the quality of various blackbody radiation sources have been made by a number of investigators [9-13] and generally fall into one of two categories: (1) calculation of the absorptivity of the blackbody hole, i.e., the fraction of incident radiation that does not leave the hole after single or multiple reflections against the walls, and (2) calculation of the total amount of radiation coming from the cavity wall viewed through the hole. The method of DeVos [9], which falls into category 2, considers the effect of enclosure geometry, wall material, type of internal reflection, and temperature distributions, and is judged to yield the most realistic emissivity values, particularly in cases where temperature variations are present.

The blackbody radiation source developed in this laboratory for use at high temperatures has simple geometry and is easy to operate. The DeVos method has been used (Section 5) to evaluate it theoretically. Graphite emissivity measurements that were needed in the quality determination are also reported (Section 4.2).

3
DEVOS THEORY

DeVos [9] first considers a completely closed isothermal cavity and introduces successively the holes and temperature gradients. When a hole is made in the wall of the cavity, the radiant intensity at different points inside is changed to an extent depending on the dimensions of the hole, the position of the hole, and the reflectivity of the inner walls. The radiant intensity I_w^o of the surface element dw in the direction of the hole whose area is δo (see Fig. 1) is calculated by adding to the radiation of dw the radiation from the other elements of the inner surface (except δo) reflected in the direction of δo. In the first-order approximation of the calculation it is assumed that the radiant intensity of the elements dn is not altered; i.e., $I_n^w = I_B$, where I_B is the blackbody radiation for the uniform temperature of an enclosure, according to Planck's law. In the second-order approximation, the value of I_n^w calculated in the first-order approximation is substituted. In the third-order approximation, the I_n^w calculated in the second-order approxi-

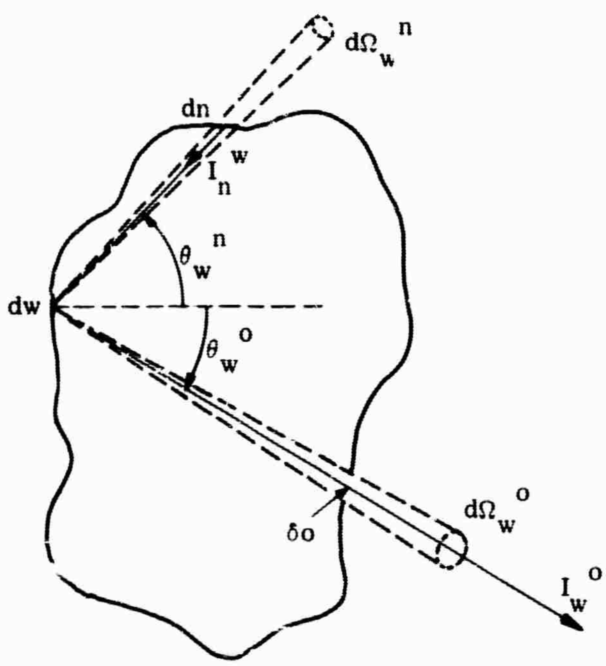

FIGURE 1. ARBITRARY BLACKBODY WITH ONE HOLE

mation is substituted, and so on. For well-constructed bodies, DeVos states that third-order correction terms can be neglected. The procedure described above is followed when additional holes and temperature gradients are introduced.

For an arbitrary blackbody (in the second-order approximation), the emissivity can be calculated by the following formula (using the notation of Ref. [9]):

$$\epsilon_o = 1 - \sum_h r_w^{oh} d\Omega_w^h - \int \sum_h r_n^{wh} d\Omega_n^h r_w^{on} d\Omega_w^n - \int k_n \epsilon_n^w r_w^{on} d\Omega_w^n \tag{3}$$

where h denotes holes and $\sum_h$ summation over holes

r_z^{xy} = fraction of radiation reflected by e surface element dz in the directio $\vec{y}$ per unit solid angle when the radiation is incident from direction $\vec{x}$

$d\Omega_v^u$ = solid angle subtended by du when viewed from dv

$k_n = \frac{I_B(T) - I_B(T_n)}{I_B(T)}$, where $I_B(T)$ = radiant intensity of a blackbody at temperature T,

$I_B(T_n)$ = radiant intensity of a blackbody at temperature T_n

ϵ_n^w = emissivity of the surface element dn in the direction of dw

Applied to a tubular blackbody (see Fig. 2) of length 2L with a hole through one wall at the center, Eq. (3) becomes:

$$\epsilon_o = 1 - r_w^{oo} d\Omega_w^o - 2r_w^{oe} d\Omega_w^e - 2\int r_n^{we} d\Omega_n^e r_w^{on} d\Omega_w^n$$

$$- \int r_n^{wo} d\Omega_n^o r_w^{on} d\Omega_w^n - \int k_n \epsilon_n^w r_w^{on} d\Omega_w^n \tag{4}$$

where the superscript e refers to the ends of the tube.

The fifth term in Eq. (4) is dropped since in second-order approximation the influence ($\sim 10^{-7}$) of the hole δo on the value of I_n^w can be neglected (the radius of the cylinder is much greater than the radius of the hole). Equation (4) then reduces to:

$$\epsilon_o = 1 - r_w^{oo} d\Omega_w^o - 2r_w^{oe} d\Omega_w^e - 2\int r_n^{we} d\Omega_n^e r_w^{on} d\Omega_w^n - \int k_n \epsilon_n^w r_w^{on} d\Omega_w^n \tag{5}$$

If we assume diffuse (Lambertian) reflection and substitute for reflectivities and solid angles in terms of known parameters,

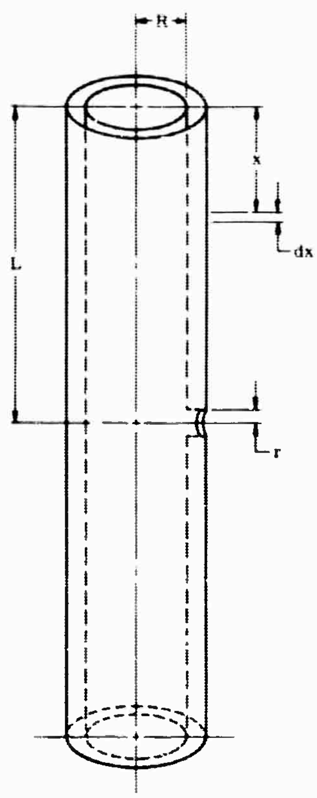

FIGURE 2. SCHEMATIC OF TUBULAR BLACKBODY

$$\epsilon_0 = 1 - \frac{\rho^{\perp} r^2}{4R^2} - \frac{2\rho^{\perp} R^3}{L^4 [R^2 + L^2]^{1/2}} - 4\int \frac{(\rho^{\perp})^2 R^6}{[R^2 + x^2]^{3/2} [R^2 + (L - x)^2]^2} dx$$

$$- 2\int \left[\frac{I_B(T) - I_B(T_x)}{I_B(T)}\right] \frac{\rho^{\perp}(1 - \rho^{\perp}) R^3}{[R^2 + (L - x)^2]^2} dx \qquad (6)$$

where $\rho^{\perp}$ = reflectivity for perpendicular incidence (for diffuse reflection, the reflectivity does not depend on the direction of incidence)

r = radius of hole (see Fig. 2)

R = inner radius of cylinder (see Fig. 2)

x = distance along length of cylinder from the end (see Fig. 2)

Let a = L/R

y = x/R

β = 2R/r

Equation (6) then reduces to:

$$\epsilon_0 = 1 - \frac{\rho^{\perp}}{\beta^2} - \frac{2\rho^{\perp}}{a^2[1 + a^2]^{1/2}} - 4(\rho^{\perp})^2 \int_0^a \frac{1}{[1 + y^2]^{3/2}[1 + (y - a)^2]^2} dy$$

$$- 2(1 - \rho^{\perp})\rho^{\perp} \int_0^{2a} \frac{I_B(T) - I_B(T_x)}{I_B(T)[1 + (y - a)^2]^2} dy \qquad (7)$$

4
EVALUATION OF QUALITY

In order to use Eq. (7) to evaluate the quality of a tubular source with one hole, we must know the reflectivity ρ of the material of which the tube i made (Section 4.2), the physical dimensions of the tube (Section 4.1), and the temperature gradient along the length of the tube (Section 4.2).

4.1. DESCRIPTION AND OPERATION OF THE BLACKBODY RADIATION SOURCE

The blackbody radiation source described here is a graphite tube, with a circular hole through one wall at the center (Fig. 2). The tube is heated resistively in an argon atmosphere. The use as blackbodies of graphite tubes heated resistively in vacuo, or in a reducing atmosphere, has been reported previously in the literature [14-16].

Cross-sectional views of the assembled blackbody radiation source are shown in Fig. 3 and an exploded view of the components in Fig. 4. The dimensions of the radiator are as follows:

Length (between end plugs)	9.00 ± 0.025 in.
Outside diameter (center section)	0.468 ± 0.005 in.
Inside diameter	0.312 + 0.002 in.
Central hole diameter (aperture)	0.046 + 0.001 in. / - 0.0005 in.

The length and diameters of the tube were chosen as a compromise between power and mechanical strength requirements on the one hand and a low ratio of inner diameter to length favorable for increasing emissivity on the other. The hole size was chosen such that its image could completely fill a spectrometer slit, although a low ratio of hole to tube diameter is desirable in order to increase emissivity.

Speer Grade 866S graphite, a fine-grained, dense, extruded electro-graphite, was used to fabricate the radiators, several of which were made. After machining, the tubes were wiped

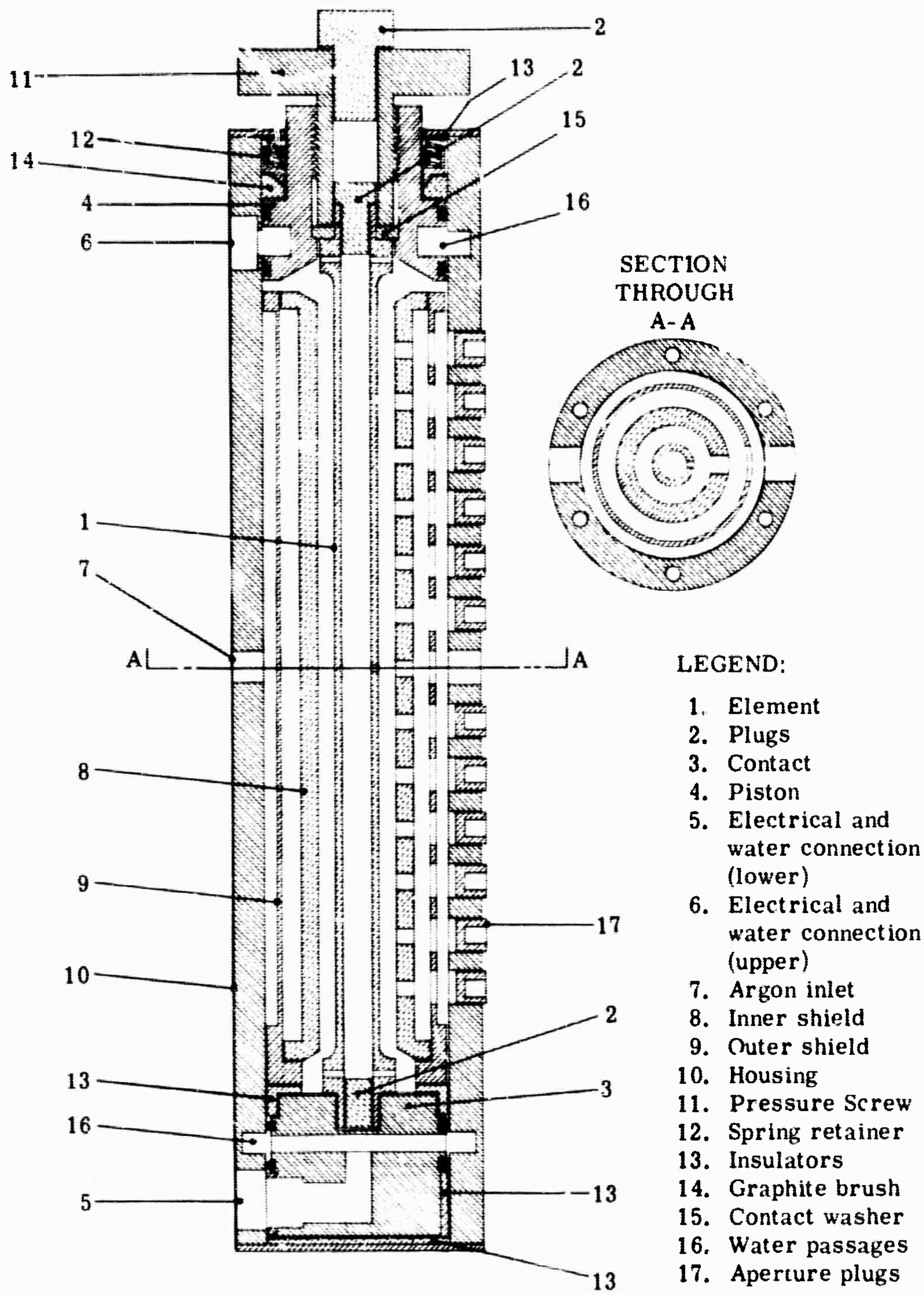

FIGURE 3 CROSS-SECTIONAL VIEWS OF THE ASSEMBLED BLACKBODY RADIATION SOURCE

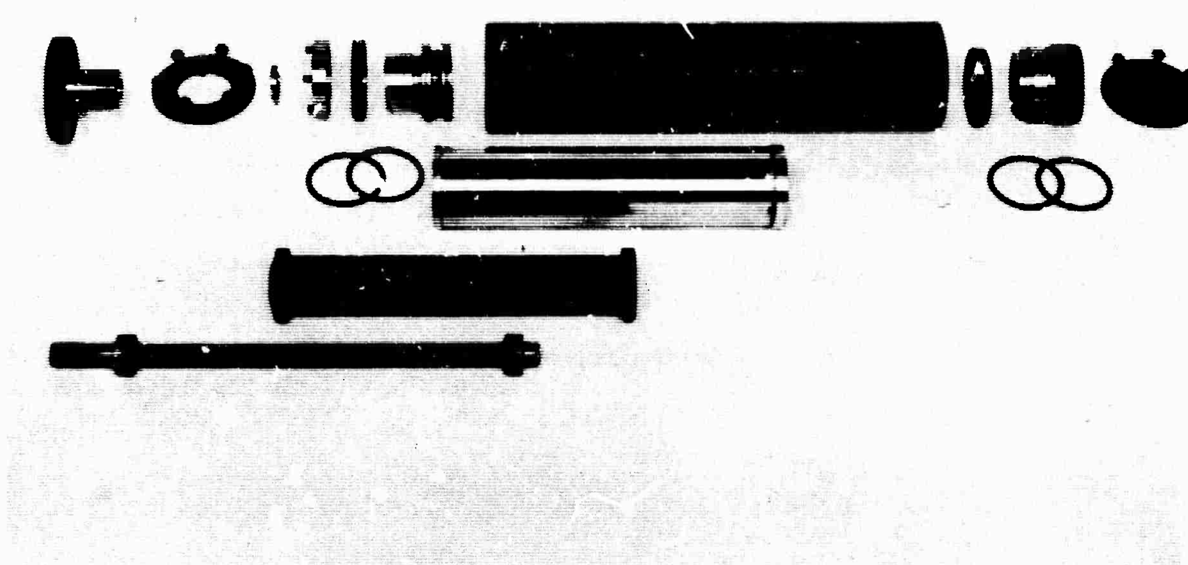

FIGURE 4. EXPLODED VIEW OF THE COMPONENTS OF THE BLACKBODY RADIATION SOURCE

lightly but not polished. They were then aged for about 4 hours at approximately 1400°C in an argon atmosphere. The surfaces obtained in this manner did not appear from visual inspection to change during the period of operation. These tubes appear to be durable under use in an argon atmosphere; one was used for more than 25 hr without signs of deterioration. (Three-inch graphite tubes in a similar arrangement [16] have been run for more than 50 hr without deterioration.) Examination of the interior of a tube used for several hours revealed a surface similar to the exterior except for the presence of small smooth areas scattered throughout. The effect of this difference is discussed in Section 4.3.

The tube is heated by passing an electric current through it from contacts (3 and 4 in Fig. 3) at each end. These contacts are water cooled and also provide mechanical support for the tube. Electric power is provided by a 7.5 kva-120 volt transformer, the secondary of which is six turns of 3/8-in. copper tubing through which water is forced. The current through the tube is controlled by manual adjustment of the input voltage to this transformer through a variable voltage transformer connected to a regulated power supply. The constancy of the source temperature depends on the stability of line voltage. The a-c regulator used could not handle the power drawn by the tube above 1800°C.

Concentric with the graphite tube are two shields, the inner (8) of graphite and the outer (9) of stainless steel, and the water-cooled brass housing (10). Apertures in the housing and correspondingly in the two shields permit viewing the tube at 5/8, 1 1/4, 1 7/8, 2 1/2, 3 1/8, and 3 3/4 in. from the center along the length of the tube. The apertures in the housing are closed when not in use.

The volume within the housing is continuously flushed with 99.99% pure argon, which first passes through a molecular sieve desiccant to remove impurities. The blackbody source is flushed out with argon at a rate > 10 ℓ/min for about 10 min before operation and at a rate < 1 ℓ/min during operation. In addition to argon, nitrogen and helium were also tried as flushing gases. Argon appeared to be the best because the higher thermal conductivity of helium necessitated more power to obtain the same temperatures and the use of nitrogen can generate cyanogen [17].

Typical voltages, currents, and temperatures are shown below. The source reaches equilibrium after approximately 15 min of operation.

Voltage Drop Across Tube (volts)	Current in Tube (amp)	Hole Temperature, T (°C)
4.95	160.0	978
5.9	181.8	1099
6.0	201.8	1206
7.0	237.2	1372
7.9	266.6	1500
9.6	309.0	1698

This blackbody radiation source has been run at temperatures up to ~2300°C; however, the steel outer shield started to melt at this temperature. A gold-plated outer shield to be used in the future may remove this limitation, and a more efficient water-cooling system may also help.

4.2. GRAPHITE EMISSIVITY AT $\lambda = 0.65\,\mu$; TEMPERATURE GRADIENT MEASUREMENTS

The emissivity of graphite at $\lambda = 0.65\,\mu$ has been studied experimentally by a number of investigators [14, 15, 18-22]. Reported values vary considerably (see Fig. 7), and graphite itself can vary widely in properties and surface condition. Plunkett and Kingery [21] conclude, after a literature review, that spectral emissivity at $\lambda = 0.665\,\mu$ for graphite and carbon varies between 0.70 for highly polished surfaces to 0.95 for rough surfaces, while the temperature coefficient is in doubt.

In the study reported here emissivity measurements were made in conjunction with measurements of the temperature distribution along the length of the tube, as described below. The experimental arrangement is pictured in Fig. 5. An optical pyrometer (calibrated against an N.B.S. certified tungsten strip lamp) was used to measure the brightness temperatures of the hole, of the surface above and below the hole, and of the surface at 12 positions along the length of the tube through the apertures in the housing and shields described in Section 4.1.

The hole temperature can be corrected for the temperature gradient through the wall [23] to obtain the true outer surface temperature:

$$\Delta T = \frac{i^2 \rho}{2k}\left(r_i^2 \ln \frac{r_o}{r_i} - \frac{r_o^2 - r_i^2}{2}\right)$$

or

$$\Delta T = \frac{\sigma T^4}{k}\left(\frac{r_o}{2} - \frac{r_o r_i^2}{r_o^2 - r_i^2} \ln \frac{r_o}{r_i}\right) \qquad (8)$$

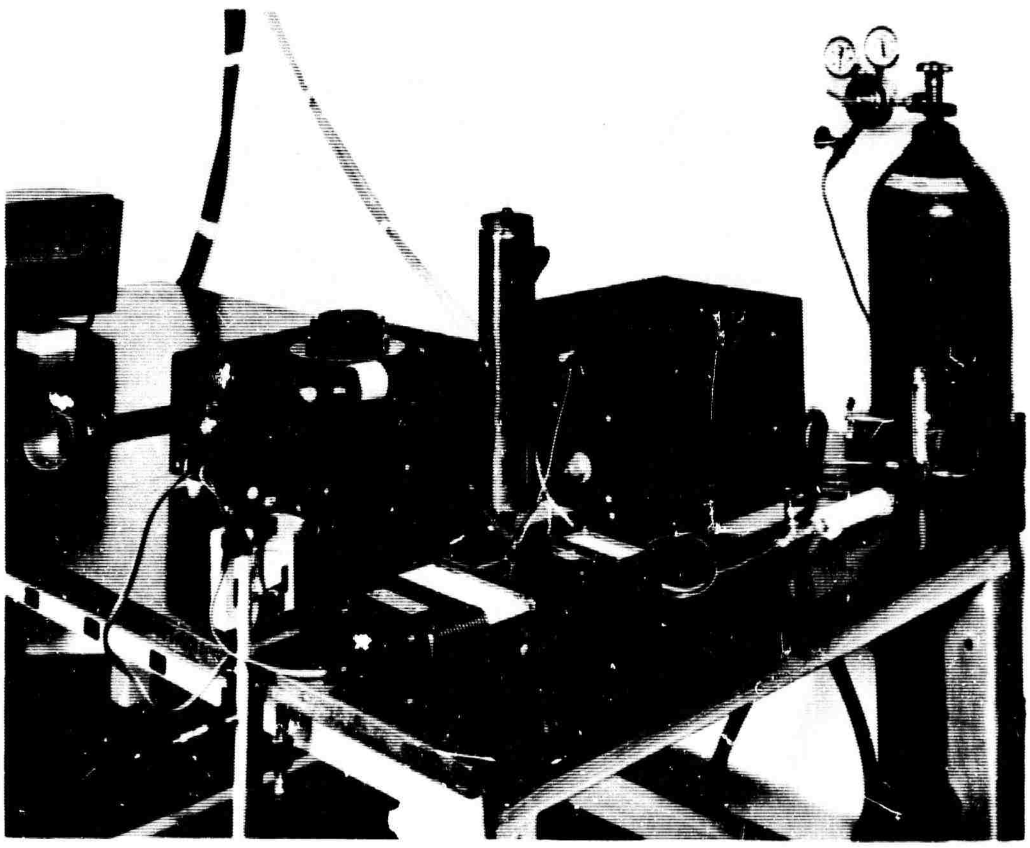

FIGURE 5. EXPERIMENTAL ARRANGEMENT OF APPARATUS FOR GRAPHITE EMISSIVITY AND TEMPERATURE GRADIENT MEASUREMENTS

where k = thermal conductivity = $[1.635 - 4.95 \times 10^{-4} T]$ $(w\text{-}cm^{-1}\text{-}deg^{-1})$ [14, 24, 25]

ρ = resistivity

i = current density

r_o = outer radius

r_i inner radius

σ = Stefan-Boltzmann constant = 5.669×10^{-8} $(w\text{-}m^{-2}\text{-}deg^{-1})$

Graphite emissivities were determined using Wien's law:

$$\epsilon_{0.65\mu} = \exp\left[\frac{-c_2}{0.65\,\mu}\left(\frac{1}{T_h - \Delta T} - \frac{1}{T_s}\right)\right] \tag{9}$$

where T_h = blackbody (hole) temperature (°K)

T_s = brightness temperature of surface (°K)

c_2 = 1.43879 cm (°K)

Emissivity values for graphite (λ = 0.65 μ) obtained in this study are presented in Fig. 6, and are compared with data obtained by other investigators in Fig. 7. The former appear to be

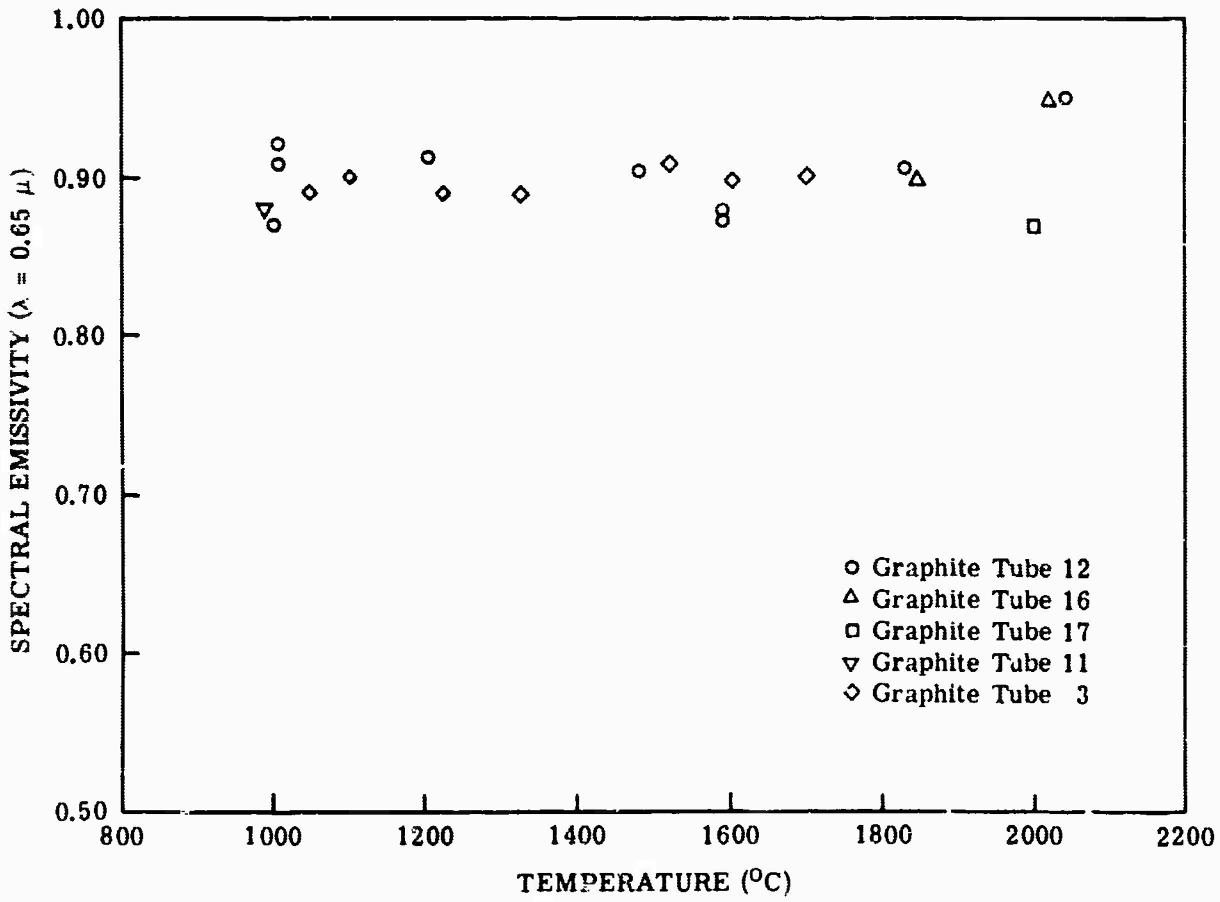

FIGURE 6. SPECTRAL EMISSIVITY OF GRAPHITE AS A FUNCTION OF TEMPERATURE. λ = 0.65 μ.

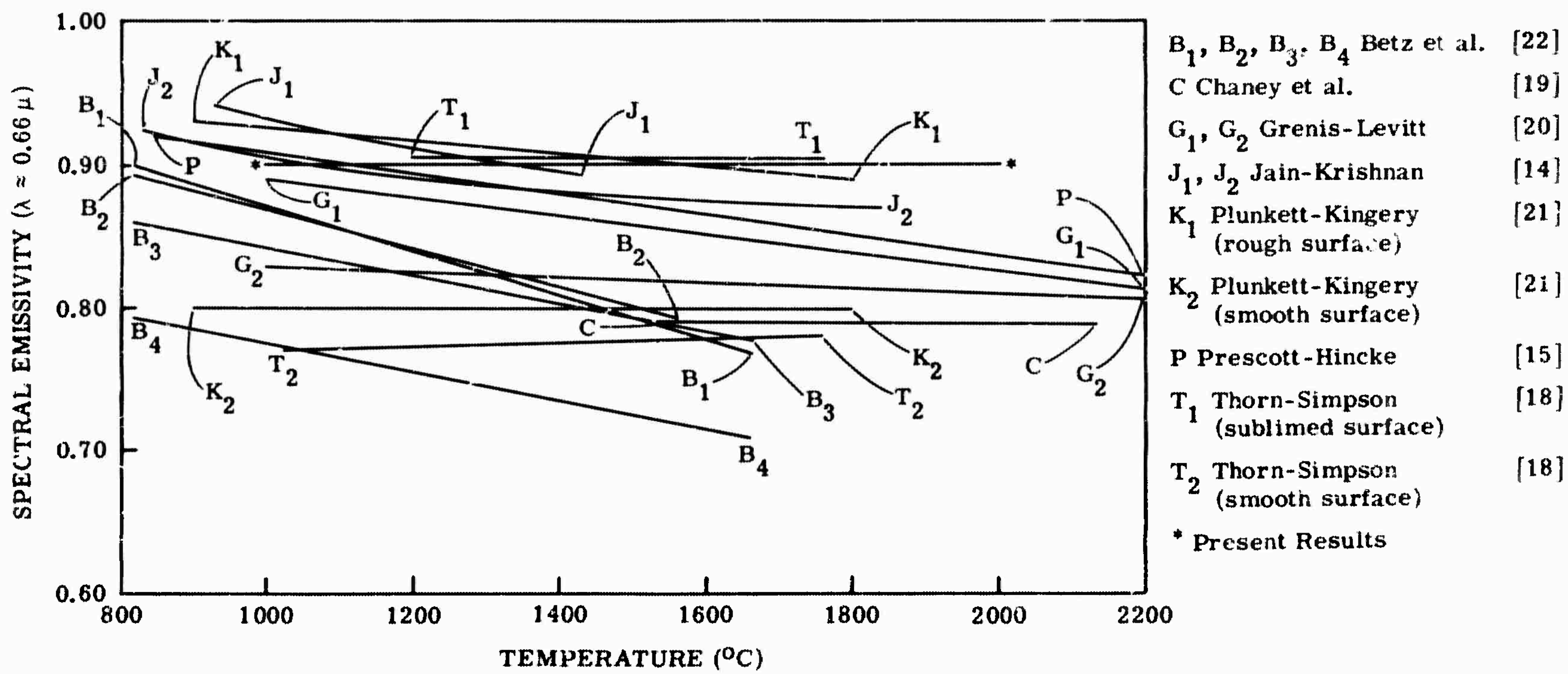

FIGURE 7. SPECTRAL EMISSIVITY OF GRAPHITE AS A FUNCTION OF TEMPERATURE AS REPORTED BY VARIOUS INVESTIGATORS. $\lambda = 0.66\ \mu$.

fairly constant over the temperature range 1000^{o} to $2000^{o}C$ and agree generally with the results obtained by other investigators. Comparison with other results indicates that the exterior surface of the tube used in this laboratory is rough rather than smooth.

Temperature gradients within the cavity along the length of the tube were obtained as follows. The measured surface brightness temperatures were corrected to true surface temperatures by using the measured surface emissivities in Eq. (9), with its form changed to

$$\frac{1}{T_{ts}} = \frac{1}{T_s} + \frac{\ell n\, \epsilon_{0.65\mu}}{c_2/0.65\mu} \qquad (10)$$

The true inner surface temperatures, T'_{ts}, are then obtained using Eq. (8). The resulting temperature distributions along the length of the graphite tube at various blackbody temperatures are shown in Fig. 8.

4.3. EVALUATION OF THE BLACKBODY RADIATION SOURCE, USING DEVOS' METHOD

The dimensions of the radiator given in Section 4.1 and the data on graphite emissivities and temperature gradients given in Section 4.2 are used in the evaluation of our blackbody radiation source by DeVos' method.

In the notation of Section 2,

$R = 0.312/2 = 0.156$ in.

$L = 9.00/2 = 4.50$ in.

$\rho^{\perp} = 1 - \epsilon_{0.65\,\mu}$

Let

$a = L/R = 4.50/0.156 = 28.8$

$y = x/R$

$\beta = 2R/r = 0.312/0.023 = 13.6$

These values are substituted into Eq. (7):

$$\epsilon_o = 1 - 5.41 \times 10^{-3}(\rho^{\perp}) - 8.37 \times 10^{-5}(\rho^{\perp})$$
$$-4(\rho^{\perp})^2 \int_0^a \frac{1}{[1 + y^2]^{3/2}\,[1 + (y - a)^2]^2}\, dy$$
$$- 2\rho^{\perp}(1 - \rho^{\perp}) \int_0^{2a} \frac{[I_B(T) - I_B(T_x)]}{I_B(T)\,[1 + (y - a)^2]^2}\, dy \qquad (11)$$

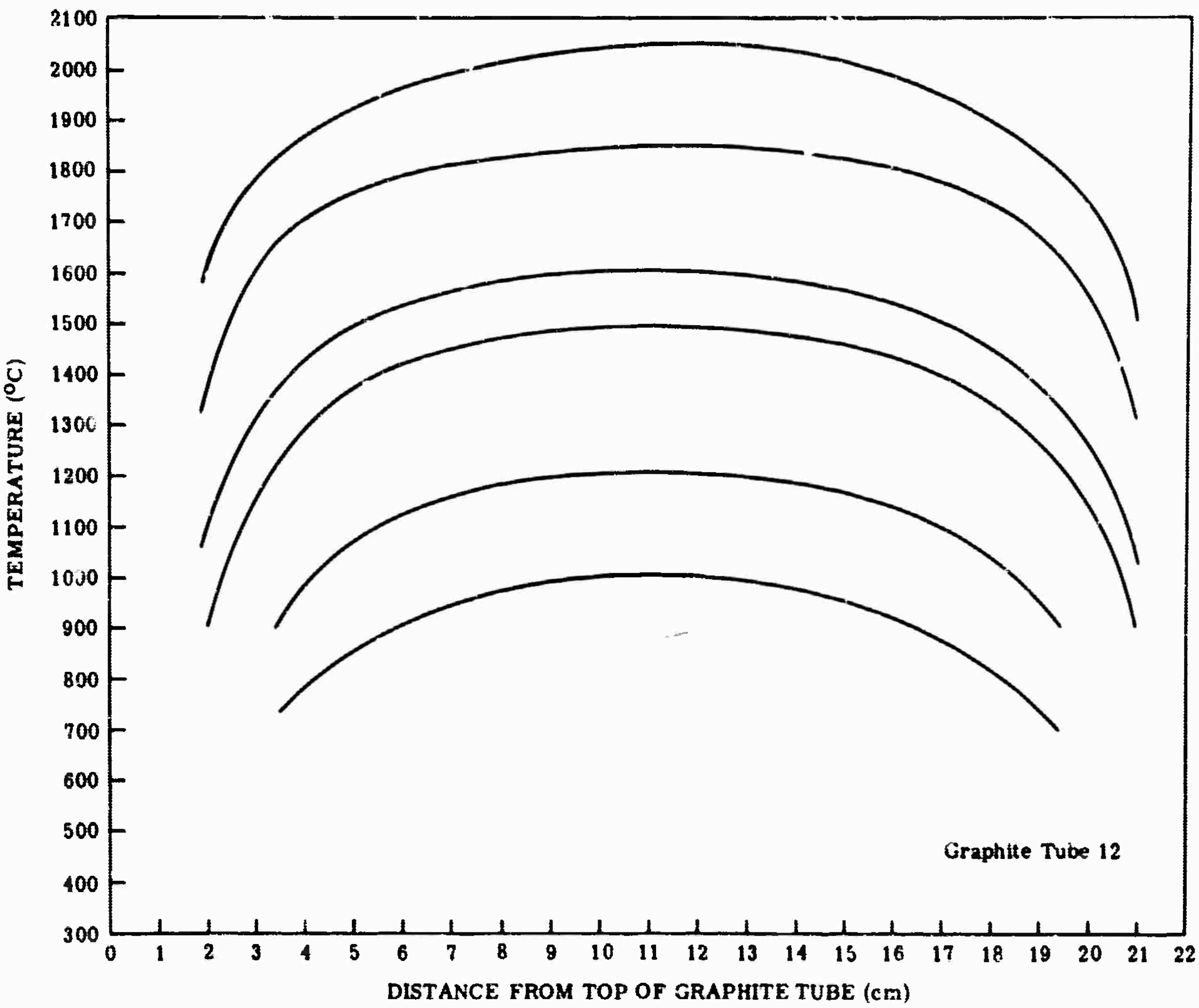

FIGURE 8. TEMPERATURE DISTRIBUTION CURVES FOR THE GRAPHITE TUBE

The values shown in Table I for the temperature range 1000^0 to 2000^0C at 200^0 intervals were obtained by numerically integrating the fourth and fifth terms of Eq. (11) by the trapezoidal rule, with $\Delta x = R = 0.156$ in. and $\Delta y = 1$, using the measured temperature gradients and spectral intensity values taken from published tables [26]. The emissivities in the second column of Table I were calculated using the observed values for graphite emissivity; those in the third column, the calculated average value of 0.90.

The assumption implicit in the use of the measured graphite emissivity in the calculation of the quality of the blackbody radiation source by Eq. (11) is that the machining of the graphite tube is done so that the interior and exterior surfaces are identical in roughness. As noted previously (Section 4.1), there were slight differences for some of the initial elements used in this investigation. Therefore, a treatment to make the condition of the inner surface of the tube identical to the outer is necessary in order to make the values of calculated emissivities, such

TABLE I. CALCULATED EMISSIVITY OF THE HIGH-TEMPERATURE BLACKBODY RADIATION SOURCE

Temperature (^{o}C)	ϵ_o*	ϵ_o†
1000	0.9981 ± 0.0004	0.9976 ± 0.0004
1200	0.9990 ± 0.0002	0.9989 ± 0.0002
1400	0.9993 ± 0.0002	0.9993 ± 0.0002
1600	0.9992 ± 0.0001	0.9992 ± 0.0001
1800	0.9994 ± 0.0001	0.9994 ± 0.0001
2000	0.9997‡ ± 0.0002	0.9994‡ ± 0.0002

*Calculated by Eq. (11) using measured graphite emissivity values.

†Calculated by Eq. (11) using the calculated average graphite emissivity value 0.90.

‡At this temperature, the increased pyrometer error in measuring temperature, and the radiator temperature instability due to the absence of a line voltage regulator, result in emissivity values which are not as reliable as those calculated for lower temperatures.

as those presented in Table I, more reliable. However, the differences in the resultant emissivities due to this effect are expected to be small. For example, a graphite emissivity of 0.85 would change the values in Table I, column 2, to 0.9966 at 1000^{o}C and to 0.[illegible] at 2000^{o}C.

5
CONCLUSION

The high-temperature blackbody radiation source reported on here has been evaluated by the DeVos method and is shown to be a good approximation to a blackbody at 0.65 μ over the temperature range 1000^{o} to 2000^{o}C. The uncertainties in the calculated source emissivity values depend on how good the values for the observed surface emissivity are, whether the reflectivity is diffuse, and how well DeVos' equation represents reality. The emissivities of this source at other wavelengths will be comparable in value to those calculated for $\lambda = 0.65\ \mu$ (Table I), provided that the surface emissivity of graphite does not exhibit significant spectral variation. Spectral emissivities of graphite are now being determined in the wavelength range 0.5 to 5.0 μ in this laboratory. Evaluations of the quality of radiation from several commercially designed blackbody sources, using this source as a standard, are planned.

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