NBS

Technical Note 252

PROCEDURES FOR PRECISE DETERMINATION OF THERMAL RADIATION PROPERTIES NOVEMBER 1962 TO OCTOBER 1963

A Report to: Air Force Materials Laboratory

JOSEPH C. RICHMOND, DAVIS P. DEWITT,
AND WARREN D. HAYES, JR.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS

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Joseph C. Richmond, Davis P. DeWitt,
and Warren D. Hayes, Jr.

A Report to
Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio
Project No. 7381, Task No. 738103
(Prepared Under Contract No. DO 33(616)-61-02)

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FOREWORD

This report was prepared by the National Bureau of Standards under Amendments Nrs. 5 and 6 to Delivery Order (33-616) 61-02. The work was initiated under Project Nr. 7381, "Materials Applications", Task Nr. 738103, "Materials Information Development, Collection and Processing". The Contract was administered under the direction of the AF Materials Laboratory, Research and Technology Division, United States Air Force, with Mr. D. F. Stevison acting as Project Engineer.
This report covers work performed during the period 1 November, 1962 through 31 October, 1963.

Joseph C. Richmond,
National Bureau of Standards.

ABSTRACT

The preliminary design of an intergrating-sphere reflectometer, utilizing a helium-neon continuous-wave gas laser as the source, for measuring the reflectance of specimens at high temperature, was completed. Development work on an ellipsoidal mirror reflectometer for measuring spectral reflectance in the wavelength range of 2 to 15 microns of specimens at room temperature was continued. The study of equations relating spectral emissivity of metals to other properties was continued. Platinum-13% rhodium and oxidized Inconel working standards of normal spectral emittance were calibrated over the wavelength range of 1 to 15 microns at temperatures of 800, 1100 and 1300°K. Several modifications of the normal spectral emittance equipment were made to permit operation in the 15-35 micron range.

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NOVEMBER 1962 TO OCTOBER 1963

1. OBJECTIVES

The broad objective of this program is to develop standard procedures, and to select or design suitable equipment for the measurement of normal spectral emittance[1] and/or spectral reflectance of materials, particularly those used in aircraft, missiles and space vehicles, at temperatures from below room temperature to near the melting point of refractory materials of interest, and over the wavelength range from the ultraviolet into the far infrared. The specific objectives for the report period included (1) development of instrumentation and techniques for measurement of normal spectral emittance in the temperature range of 2000 to 4000°F (1366 to 2478°K), and over the wavelength range of 0.3 to 15 microns (2) extension of existing equipment and procedures for measurement of normal spectral emittance in the temperature range of 1000 to 2000°F (811 to 1366°K) and wavelength range of 1 to 15 microns to the wavelength range of 15 to 35 microns and (3) preparation and calibration of working standards of normal spectral emittance in the temperature range of 1000 to 2000°F and the wavelength range of 15 to 35 microns. A further objective, covered by Amendment No. 6 to the delivery order, called for the preparation and calibration of disc standards of normal total emittance of polished platinum-13% rhodium alloy and oxidized, sandblasted inconel over the temperature range of 1000 to 2000°F.

The work on development of equipment and procedures for measuring normal spectral emittance at temperatures in the 2000 to 4000°F (1366 to 2478°K) range has proceeded on another project sponsored by the George C Marshall Space Flight Center of N.A.S.A. Reports covering work sponsored by the Research and Technology Division of the Air Force Materials Laboratory have been sent to both sponsors.

2. HIGH-TEMPERATURE INTEGRATING SPHERE REFLECTOMETER

The accuracy of a direct measurement of emittance depends primarily upon the accuracy with which the temperatures of the specimen and blackbody are known. The percentage error in an emittance measurement that is due to the error in temperature measurement (or temperature difference between blackbody and specimen) may be expressed as

$$\frac{dW_\lambda}{W_\lambda} = K\frac{dT}{T} \quad (1)$$

where dW_λ is the change in emitted energy, W_λ, accompanying a change

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[1] Emittance is a property of a specimen; it is the ratio of the emitted radiant flux per unit area to that of a blackbody radiator at the same temperature and under the same conditions.

in temperature, dT. The factor K may be evaluated from the expression

$$K = \frac{C_2 e^{C_2/\lambda T}}{\lambda T(e^{C_2/\lambda T} - 1)} \qquad (2)$$

where C_2 is the second Planck radiation constant, e the base of the natural logarithms, λ the wavelength and T the absolute temperature. At $\lambda T = 0.29$ cm °K, which is the peak of the Planck distribution function, K = 5.0. At shorter wavelengths, K increases rapidly with decreasing wavelength, and at longer wavelengths, K decreases slowly with increasing wavelength.

Thus it can be seen that the errors in direct emittance measurements are inherently large at short wavelengths, below the peak of the Planck distribution function. Also, accurate temperature (or temperature difference) measurements are difficult to make at temperatures above those at which conventional thermocouples can be used, particularly on materials whose spectral emittance at the optical pyrometer wavelength is not accurately known. As a result, errors in direct emittance measurements at such temperatures are inherently large.

In contrast to emittance, the accuracy of a reflectance measurement is not affected by the accuracy with which the temperature of the specimen is known. Hence, reflectance measurements appear to offer inherently greater accuracy than emittance measurements both at short wavelengths and at high temperatures.

Because of these apparent advantages of the reflectance approach, consideration has been given to the design of an integrating sphere reflectometer utilizing a continuous-wave gas laser as the illuminating source. The principal difficulty in making high-temperature spectral reflectance measurements with conventional techniques and apparatus arises from the inability to detect the dispersed reflected radiation in the presence of a large quantity of undispersed radiation emitted by a heated specimen. Even when the incident radiation is modulated (chopped) to facilitate detection, the signal to noise ratio is small unless the incident radiation is extremely intense. Utilizing a gas laser as the source removes this experimental difficulty, since the chopped flux reflected from the specimen can be of an intensity many orders of magnitude larger than the flux emitted by the specimen. Consequently, the precision with which the radiation detector can sense the reflected flux is greatly increased and high-precision reflectance measurements at high temperatures should be possible. To be sure, there are disadvantages encountered in utilizing the laser as a radiometric source, the principal one being that the high-intensity output is available only at discrete wavelengths, making it impossible to obtain measurements over a continuous wavelength interval, as is possible with conventional techniques. Notwithstanding this objection, it seems probable that this difficulty may at least be partially overcome by future developments in laser technology.

Even if measurements can be made only at a relatively few discrete wavelengths, the data thus obtained will be valuable. Available evidence indicates that if no phase transition is encountered, the general shape of the spectral reflectance curve of a material does not change appreciably with an increase in temperature. Hence, it should be possible to interpolate between wavelengths with the aid of continuous spectral reflectance curves obtained at room temperature by more conventional methods.

The basic objectives of the work with lasers are three-fold:

(1) To investigate and evaluate the practicability of utilizing the continuous-wave gas laser as a radiometric source.

(2) To develop techniques and apparatus for high-precision reflectance measurements on specular and diffuse specimens at elevated temperatures and at discrete wavelengths.

(3) To investigate coatings and coating techniques for integrating spheres that will permit operation with this method into the far infrared portion of the spectrum (from 3 to 15 microns or beyond).

There are many features of the continuous-wave gas laser in addition to its high monochromaticity and intensity that make the laser desirable as a radiometric source. The output can be electronically modulated (chopped), removing the necessity for cumbersome mechanical chopping and rectifying assemblies. Outputs are available using various gas combinations at high intensities at discrete wavelengths in the spectral region 0.4 to 40μ. These features - and others - will be given close scrutiny and, if possible, the advantages will be exploited to further advance techniques for making thermal property measurements with greater accuracy, especially at the higher temperatures and the longer wavelengths.

One immediate need is for high-accuracy spectral emittance data to further advance the art of optical pyrometry. Recently developed optical pyrometers are capable of high-precision measurement of brightness temperatures. The accuracy with which these brightness temperatures can be converted to true temperatures, however, is dependent on a knowledge of emittances at 0.65μ. At present there is no gas system which will lase at this wavelength, but by a series of measurements close to 0.65u, it should be possible to use the appropriate theoretical model to arrive, by interpolation, at an accurate emittance at the optical pyrometer wavelength.

The integrating sphere technique for measurement of spectral data in the visible and to 2.5μ is well established. Such a sphere is usually coated with smoked magnesium oxide which has high reflectance (> 95%) in the visible and near infrared, and is in addition a good diffuser of radiation. The same coating is also used for a reflectance standard. Unfortunately no such coating has been developed for integrating spheres operating at wavelengths longer than 2.5μ. Flowers of sulphur is a possibility but more work is needed. One of the principal goals in this phase of the program is to select and evaluate a coating for an integrating sphere for use at long wavelengths.

During the report period a preliminary design was completed for an integrating-sphere reflectometer to be used with a helium-neon source for measuring the spectral reflectance at 0.635 and 1.15 microns of specimens heated to high temperatures.

3. SPECTRAL REFLECTANCE EQUIPMENT

Equipment for measurement of spectral reflectance under conditions approximating normal illumination and hemispherical viewing was described in WADC Technical Report 59-510, Parts II and III. The equipment utilizes a 12 in. diameter ellipsoidal mirror with the specimen placed at the first focus and the detector at the second.

During the early part of the contract year construction of a light-tight cover for the equipment was completed permitting the convenience of operating the equipment in normal room lighting. Additional modifications were made on the following features of the apparatus.

(1) Optical system - mounts were designed and constructed to permit greater ease in alignment or adjustment of optical components.

(2) Specimen mount - a mounting jig was designed and constructed to allow convenient removal or installation of specimens; the specimen holders allowed measurements to be made at various fixed angles of incidence.

(3) Detector mount - the method of mounting the detector was modified with a gear rack and pinion mechanism so that the detector could be moved between the ellipsoid first and second focus points.

The principal effort in the past year has been directed toward improvement of the signal-to-noise ratio with the large area (1 cm diam.) Golay detector. It was found that operation of the equipment during the wavelength scanning process did not yield data of the desired accuracy. The reason for the poor performance was traced to mechanical vibrations rather than electronic malfunctions or deficiencies. To eliminate transmission of air-borne vibration to the cell, the interior surfaces of the light-tight cover were covered with a 3/4" thick acoustic matting, and to reduce structure-borne vibration, the detector and mount were supported on an 800 pound seismic table which was independent of other parts of the equipment and rested on the floor. Figure 1 is a photograph of the modified equipment. Despite these precautions to isolate the Golay detector from external mechanical vibrations, the signal-to-noise ratio remained unacceptable. Because of these poor results it seemed desirable to investigate other types of detectors. Two thermopile detectors with 1 cm^2 viewing areas have been ordered and these will be tested in the near future.

Tests on a heated specimen (a white porcelain enamel) were conducted using the Golay cell. The purpose of these tests was to determine the background level of radiation emitted from the heated specimen that the detector could withstand without damage from excessive temperature. It was anticipated that the detector, because of its design, would fail when the specimen reached a moderately high temperature. However, quite surprisingly, the detector failed when the specimen reached a temperature of only 70°C. Calculations indicated that this corresponded to a background flux of about 500 microwatts. Such a result demonstrated that the Golay cell cannot be used in this equipment with heated specimens and this again points to the need for another type of detector. During the coming year efforts will be directed toward obtaining room-temperature reflectance data on various materials through use of the large-area thermopiles.

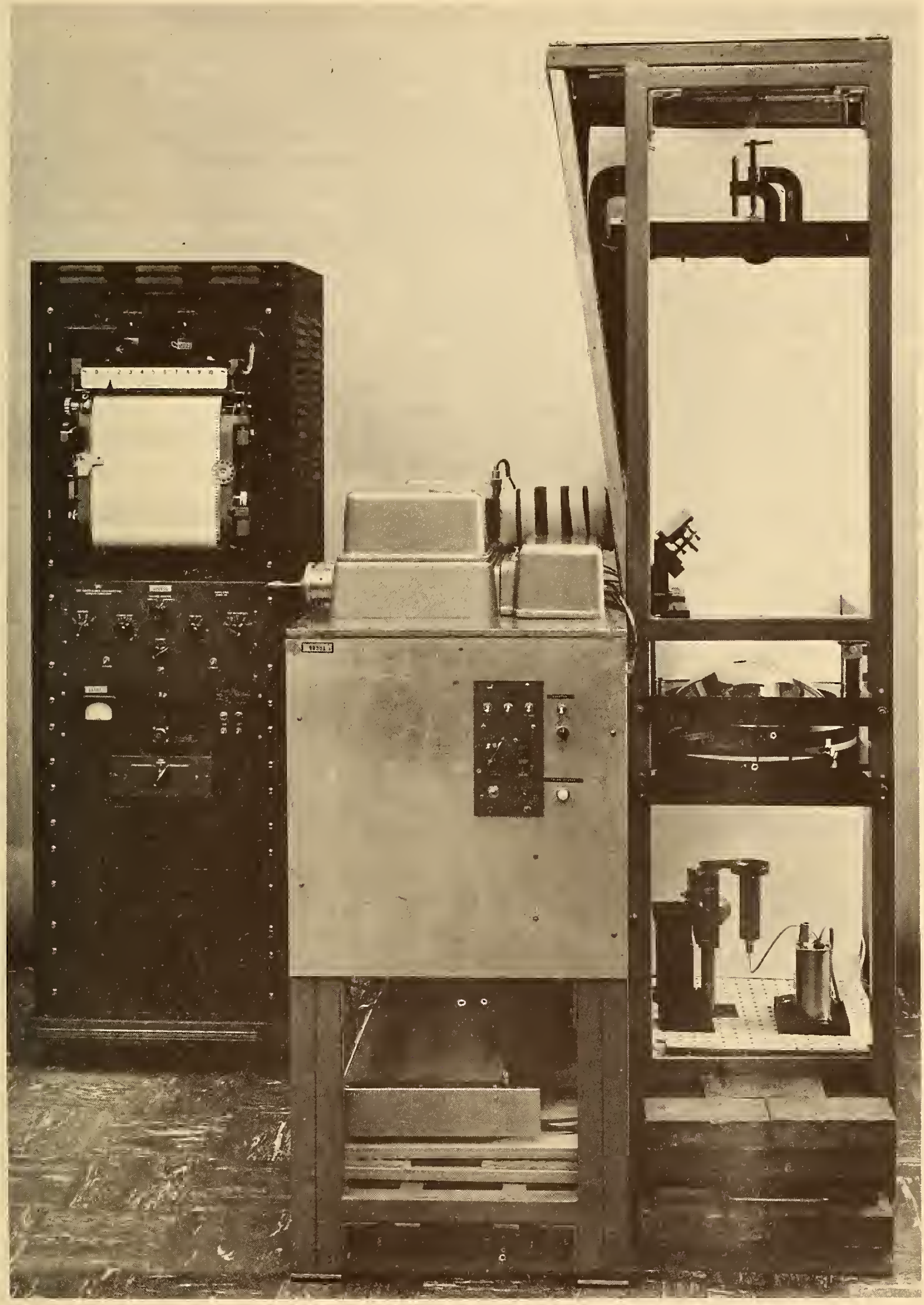

Figure 1. Photograph of the infrared reflectometer with light cover panels removed. The specimen is mounted at the first focus of the ellipsoidal reflector and the detector at the second focus.

4. EQUATIONS RELATING SPECTRAL EMISSIVITY OF METALS TO OTHER PROPERTIES

A summary of the background and current status of this phase of the work follows. Equations relating the emissivity of metals to their electrical resistivities have been available for many years. The earlier attempts by Hagen and Rubens have been modified through the years to produce relations that are generally applicable in the longer wavelength and elevated temperature regions. While this approach to prediction of properties has been very successful for restrictive conditions, it is not satisfactory for explaining the inflections and irregularities observed in experimental emissivity and reflectivity data.

A more realistic approach to prediction of the property must consider the mechanism of the transport process to be characterized by more than one family of free electrons. Recent publications by Roberts [1] and T. R. Harrison [2] have given equations that are applicable or adaptable, including the effects of several families of free and bound electrons on the transport process. This classical approach is in harmony with quantum mechanics, as electrons in different energy zones are shown to have different behaviors.

The equations suggested by Harrison, with terms to provide for the effects of free and bound electron families, have been considered. Attempts were made to compute values of the equation parameters from reliable normal spectral reflectivity values of the metal rhodium at room temperature. As stated in a previous report (WADC TR 58-510 Pt IV), first only one category of free electrons and one of bound were used. Within the wavelength range of visible radiation a curve obtained in this way gave very creditable agreement with experimental data and followed the inflection corresponding to a maximum in emittance of about 0.45 micron. In the attempt to extend the range of good fit out to about 10μ, it became evident that additional parameters, making at least 10 in all, would be required for insertion into more than one term for free electrons and more than one for bound electrons.

Work will continue on the rhodium data until parameters for proper theory-data comparison can be better determined. Special consideration will be given to the effect on the parameters due to uncertainties in the reflectivity data. Optical constants determined from the parameters derived from reflectivity data will be computed and examined to determine the physical creditability of this approach.

With the fraction of total effort on this study that could be devoted to this aspect, no set of parameters has yet been found that will produce a normal spectral reflectivity curve which fits the observed data over a wide wavelength interval both generally and in detail. However the findings have not been negative and show promise that further exploration could produce some useful results.

Several additional attempts to determine the proper parameters for the theoretical expression using a different approach did not yield any significant results. It was found impossible to theoretically fit the experimental data in a general and detailed manner. Further study indicated that the experimental reflectivity curve for rhodium might be at fault. Hence, the sources of the rhodium reflectivity data were re-evaluated and several inflection points were found to be caused by improper smoothing of data that were obtained in different determinations. Even when the data were readjusted, it was not possible to determine a set of parameters for the expression that provided a detailed match with the experimental curve. Optical parameters (index of refraction and absorption coefficient) when computed from parameters that gave a general fit proved to be physically unrealistic. This led to consideration of the Kramers-Kronig dispersion relations which permit calculation of the optical constants from knowledge of the reflectivity over the entire frequency (wavelength) spectrum. At present a computer program is being developed which will perform these calculations. Further study of this technique reveals that the shape of the reflectivity curve at very short wavelengths (vacuum ultraviolet) is quite significant. It is also evident that the shape of the curve (or optical activity) in this region has an important bearing in predicting the optical constants in other wavelength regions.

It is apparent that special consideration must be given to the reliability of the reflectivity data at wavelengths in the ultraviolet and below. In this region, the reflectivity is extremely sensitive to surface conditions. This is a serious consequence since there is not always an abundance of data in this region. This region is of primary significance to our study of optical behavior in other regions of the spectrum where there is a comparatively large amount of reliable reflectivity data.

It is expected that work on relation of spectral emissivity to other properties will continue to be only a small fraction of the total effort.

5. CALIBRATION OF WORKING STANDARDS

The platinum, oxidized Kanthal and oxidized Inconel working standards of normal spectral emittance that had been transmitted to the Physics Laboratory, Aeronautical Systems Division, in 1962 were returned to the National Bureau of Standards early in 1963 with a request that the Bureau arrange to distribute them as requested.

The standards are now offered for sale at a price of $175.00 each, plus a surcharge of $4.00 per gram for the platinum standards. It is anticipated that the supply of working standards will be augmented from time to time, as required, by preparation and calibration of additional standards. The sale price of the standards is intended to cover the replacement cost. They are described in WADC TR 59-510 Pt IV.

Two types of 0.484 inch diameter disc working standards were prepared for use at R.T.D. during the report period. These were of polished platinum-13% rhodium alloy and oxidized Inconel, respectively. Preparation of these working standards is described in the following section.

5.1. Platinum-13% Rhodium Working Standards

The platinum-13% rhodium specimens were received from the fabricator in the form of 0.035-in. sheet, cut into two strip specimens 1/4 x 8 in. in size and five discs 0.484 in. in diameter. The original sheet of alloy from which the specimens were cut was approximately 1 1/16 x 8 in. in size. The 1/4 x 8 in. strips were cut from the two edges of the original sheet, and the discs were cut from the central portion of the remaining strip.

Each specimen was washed in hot tap water to which a commercial detergent had been added, rinsed in running hot tap water, then in distilled water, and finally in ethyl alcohol. Rubber surgical gloves were worn at all times while handling the specimens, and they were touched only at the ends or edges after cleaning. The specimens were dried in air and placed in a closed container, supported by the ends or edges only, for storage prior to annealing.

All specimens were annealed in an electric furnace with silicon carbide heating elements. The strip specimens were hung by means of platinum hooks, suspended from aluminum oxide rods in the furnace; the disc specimens were supported by the edges only on ceramic forms resting on a rigid ceramic slab. All of the specimens were then enclosed in a ceramic muffle. Starting with ambient conditions, the temperature of the furnace was raised to 2282°F (1523°K) over a period of six hours, and held at that temperature for one hour. The power was then turned off, and the specimens were allowed to cool in the furnace, which required two days.

The specimens were removed from the furnace by means of cleaned, platinum-tipped tongs and were placed in individual cardboard boxes, supported by the ends or edges only, to protect them from contamination.

The two 1/4 x 8-in. strips were prepared for measurement by welding a platinum-platinum 10% rhodium thermocouple to each specimen. A shallow groove was scratched in each specimen, normal to its long axis and located at the mid-length. The 10-mil thermocouple wires were separately welded to the specimen by means of a condenser-discharge type of electronic spot welder. Each wire was laid in the shallow groove to position it for welding, and the welding operation was observed through a low-power microscope.

Three sets of spectral curves were made for each strip specimen at each of three temperatures, 800°, 1100° and 1300°K. Each set of curves consisted of (1) a 100% curve, obtained when the two blackbody furnaces at the test temperature served as sources for the respective beams, (2) a zero curve, obtained with the specimen beam blocked near the specimen furnace, and (3) a specimen curve, obtained with the comparison blackbody at the test temperature as source for the comparison beam, and the hot specimen at the same temperature serving as source for the specimen beam. The height of each curve was recorded on punched paper tape at each 0.1 revolution of the wavelength dial over the range corresponding to approximately 1 to 15 microns.

The punched paper tape containing the raw emittance data was fed into the National Bureau of Standards SEAC computer, which then adjusted the recorded emittance of the specimen at each wavelength on the basis of the recorded 100% and zero curves.

The adjusted emittance values for the six measurements, three each on two specimens, were then fed back into the computer, and the following values were computed at each of the approximately 110 wavelengths: (1) E, the average emittance (2) σ_m, the standard deviation[1] due to error of measurement, computed as the average standard deviation of the three measurements on each specimen about the mean for that specimen, and (3) σ_s, the standard deviation principally due to differences in specimens.

The values obtained on the platinum-13% rhodium specimens are tabulated in Table I, and are shown in Figures 2 through 7.

The spectral emittance curves for the platinum-13% rhodium alloy, shown in Figure 2 at 800°K, Figure 3 at 1100°K, and Figure 4 at 1300°K, are quite similar to the corresponding curves for platinum.

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[1] All standard deviations in this study are precisely defined as "estimates of the standard deviation of the parent population from which the measurements were drawn." Mathematically

$$\sigma_m = \sqrt{\frac{\sum_1^n (x-\bar{x}_1)^2 + \sum_1^n (x-\bar{x}_2)^2 \ldots + \sum_1^n (x-\bar{x}_p)^2}{(n-1)p}}$$

where x is an individual measurement, $\bar{x}_1$ is the average of n measurements on specimen one, and p is the number of specimens. (For data in this report, n = 3 in all cases, and p = 2 for platinum-13% alloy and 6 for oxidized sandblasted Inconel.)

$$\sigma_s = \sqrt{\frac{\sum_1^p (\bar{x}-\bar{\bar{x}})^2}{p-1}}$$

where $\bar{\bar{x}}$ is the overall average of the n × p measurements, n each on p specimens.

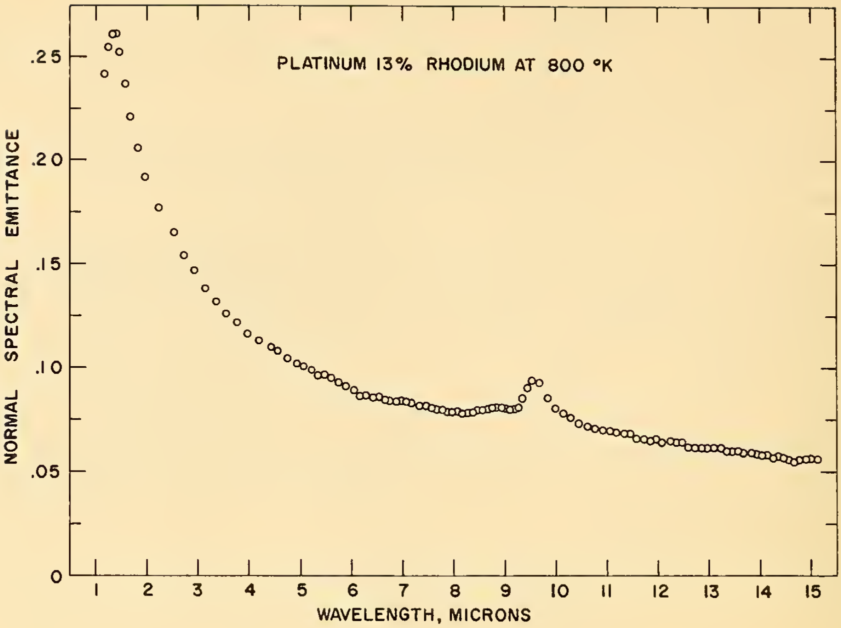

Figure 2. Normal Spectral Emittance of 0.484-in. Disc Working Standards of Platinum-13% Rhodium Alloy at 800°K.

The plotted values are averages of six measured values, three each on two specimens.

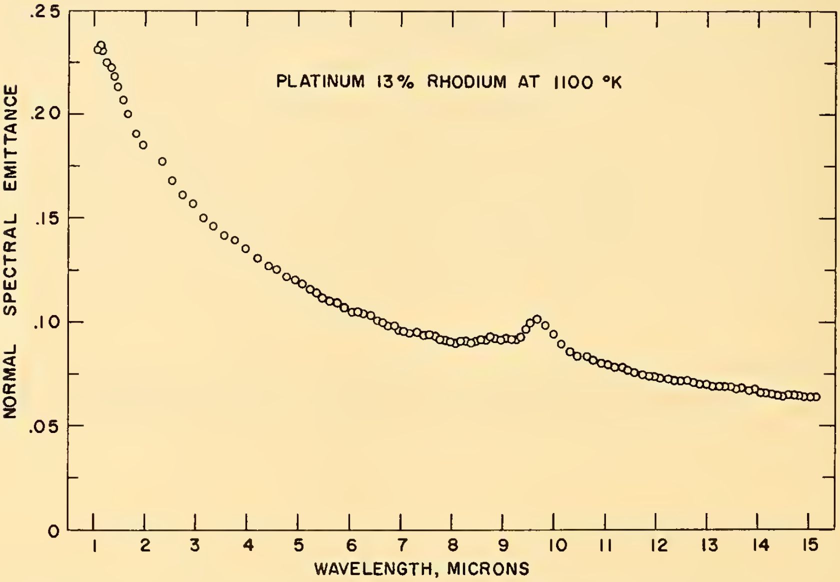

Figure 3. Normal Spectral Emittance of 0.484-in. Disc Working Standards of Platinum-13% Rhodium Alloy at 1100°K.

The plotted values are averages of six measured values, three each on two specimens.

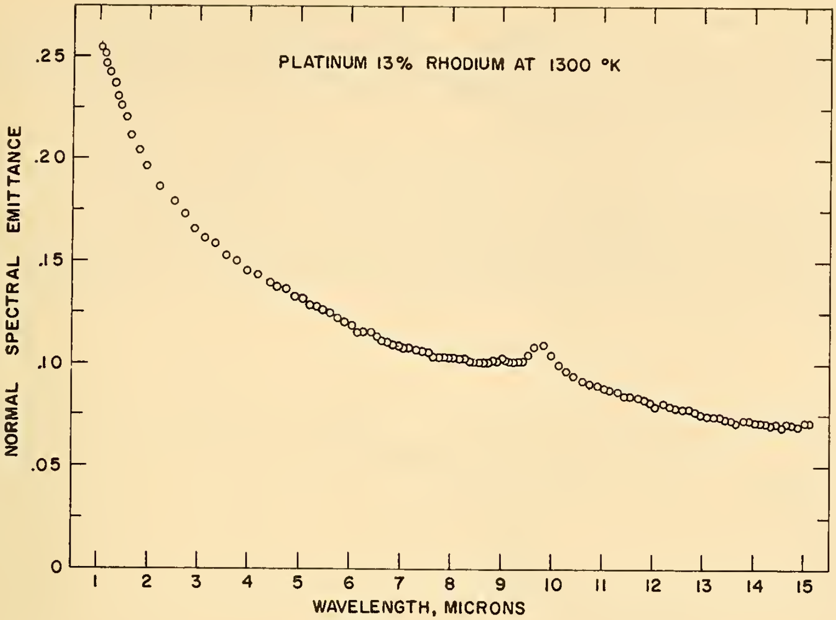

Figure 4. Normal Spectral Emittance of 0.484-in. Disc Working Standards of Platinum-13% Rhodium Alloy at 1300°K.

The plotted values are averages of six measured values, three each on two specimens.

The principal differences are that (1) in general, the emittance of the platinum-13% rhodium alloy is higher than that of platinum at the same temperature and at the same wavelength, (2) the maximum at about 1.4 micron at 800°K is lower for the platinum-13% rhodium alloy than for platinum, (3) the maximum at about 1.36 micron for platinum and 1100°K has moved to about 1.12 microns for platinum-13% rhodium, and (4) no evidence of a maximum at 15 microns or beyond is seen in the platinum-13% rhodium data.

The standard deviations σ_s and σ_m are plotted as a function of wavelength in Figure 5 at 800°K, Figure 6 at 1100°K, and Figure 7 at 1300°K.

There was considerable scatter in the individual standard deviations, as can be seen in Table I. A statistical technique known as a moving average was used to smooth the data and thus bring out more clearly the trend of σ_s and σ_m with wavelength. In applying this technique the standard deviations at five adjacent wavelengths were averaged, and the average was plotted as a function of the wavelength of the center point. In this way an average value was obtained for each wavelength at which data were available, except for the two shortest and two longest wavelengths.

In general, the σ_m values show less variation with wavelength than the σ_s values. The average values of σ_m were 0.23 at 800°K, 0.19 at 1100°K, and 0.33 at 1300°K, and the corresponding values of σ_s were 0.25 at 800°K, 0.57 at 1100°K, and 0.91 at 1300°K. However, the σ_s values are based on only two specimens, and hence are not highly reliable.

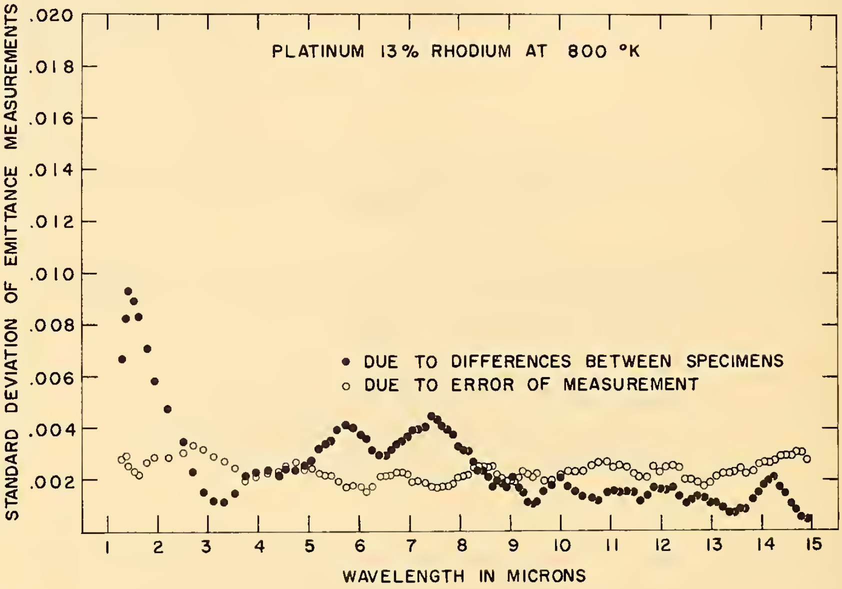

Figure 5. Spectral Distribution of Two Categories of Standard Deviations, Each Computed From Six Measured Emittance Values Obtained at 800°K, Three Each on Two Specimens of Platinum-13% Rhodium Alloy.

The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves each point represents the moving average of five adjacent values.

The increase in precision (lower σ_m values) over what was obtained in the tests on platinum reported in WADC TR 59-510 Pt IV can be ascribed in part to the reduction in error due to direct recording of data by the data-processing attachment as compared to reading the curves with a variable scale.

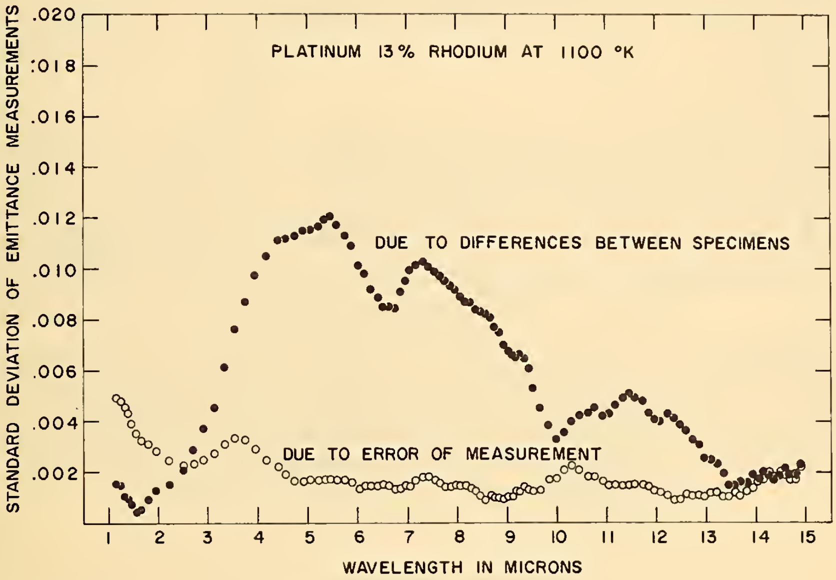

Figure 6. Spectral Distribution of Two Categories of Standard Deviations, Each Computed From Six Measured Emittance Values Obtained at 1100°K, Three Each on Two Specimens of Platinum-13% Rhodium Alloy.

The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves each point represents the moving average of five adjacent values.

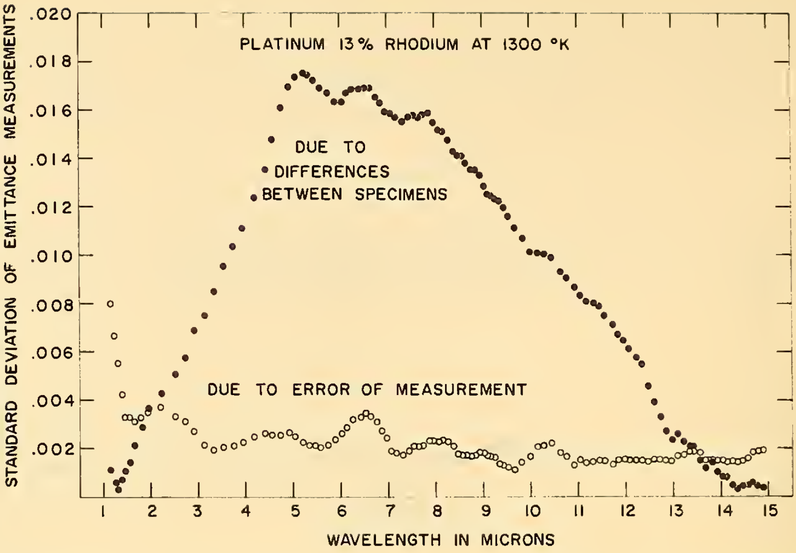

Figure 7. Spectral Distribution of Two Categories of Standard Deviations, Each Computed From Six Measured Emittance Values Obtained at 1300°K, Three Each on Two Specimens of Platinum-13% Rhodium Alloy.

The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves each point represents the moving average of five adjacent values.

5.2. Oxidized Inconel Working Standards

Specimens were cut from 2 x 8 in. Inconel sheet. Six strips, 1/4 x 8 in. in size, were cut from the two edges of the sheet, three from each edge. Twelve discs, 0.484-in. in diameter, were cut from the center of the sheet. All specimens were marked for identification, and the position and orientation of each specimen in the original sheet was recorded. The specimens were sandblasted with 60-mesh fused alumina grit and an air pressure of approximately 70 psi, care being taken to obtain a uniformly rough surface on all specimens. The sandblasted specimens were cleaned ultrasonically in acetone, passivated for one minute in 10% nitric acid at 109°F (316°K), rinsed in distilled water and then in freshly distilled acetone. The cleaned specimens were subjected to a minimum of handling. When handling was unavoidable, rubber surgical gloves were worn, and the specimens were touched only by the ends or edges.

The strip specimens were suspended from a metal rack by means of oxidation-resistant metal hooks, and the rack was inserted into a cold furnace. The disc specimens were supported by the edges only on special ceramic supports placed on the hearth of the furnace, and enclosed in a ceramic muffle.

The furnace was brought to 1952°F (1340°K) and held for 24 hours, then dropped to 1520°F (1100°K) and held for an additional 24 hours, after which the specimens were allowed to cool in the furnace.

The specimens were removed from the furnace by means of cleaned stainless steel tongs, and were placed in individual plastic holders, in which they were supported by the ends or edges only. Each plastic holder, containing a specimen, was then placed in an individual cardboard box, to protect the specimen against contamination.

The six 1/4 x 8 in. strips were prepared for measurement by welding a platinum-platinum 10% rhodium thermocouple to each specimen. A shallow groove was scratched in each specimen near its midlength and normal to its axis, which penetrated through the oxide coating to the bare metal. The oxide was also removed from each end of the specimen by grinding for a distance of approximately one inch from each end. The thermocouples were welded by a procedure similar to that used for the platinum-13% rhodium specimens.

The normal spectral emittance of each of the six specimens was measured three times at each of three temperatures, and the data were analyzed statistically, as in the case of the platinum-13% rhodium specimens. The results are shown in Table II and are plotted as a function of wavelength in Figures 8 through 13.

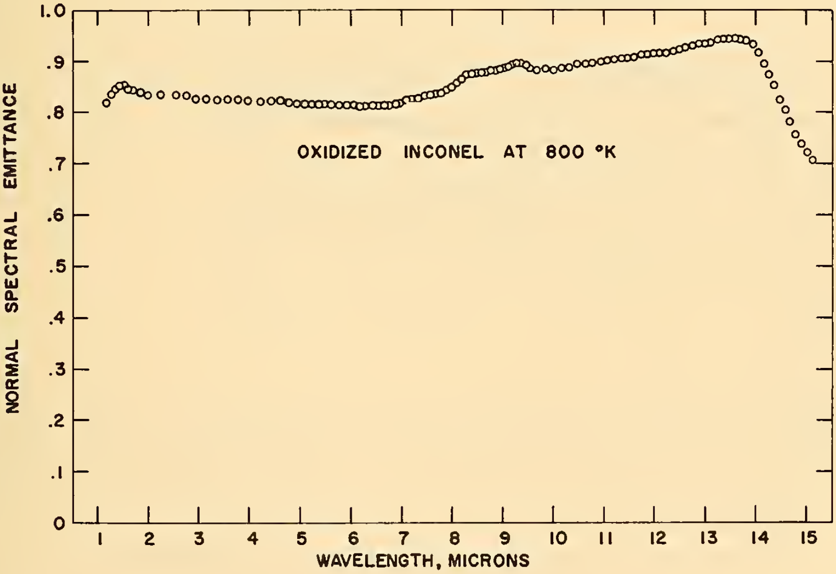

Figure 8. Normal Spectral Emittance of 0.484-in. Disc Working Standards of Oxidized Sandblasted Inconel at 800°K.

The plotted values are averages of 18 measured values, three each on six specimens.

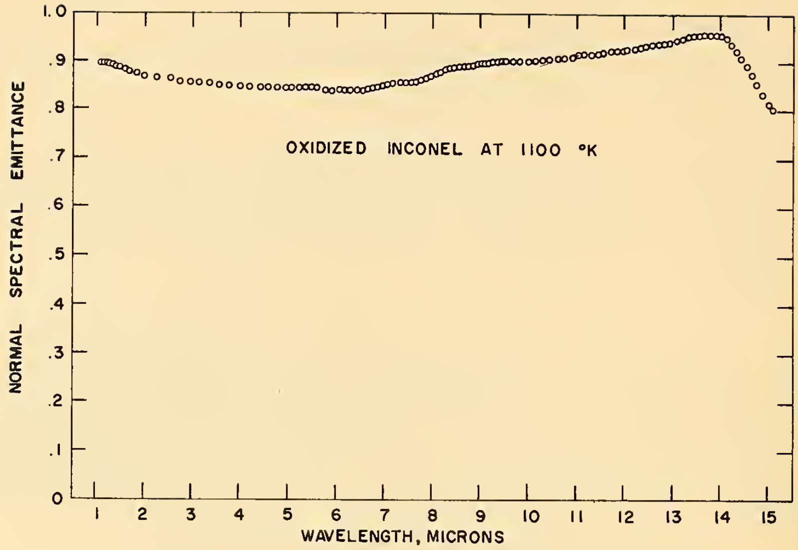

Figure 9. Normal Spectral Emittance of 0.484-in. Disc Working Standards of Oxidized Sandblasted Inconel at 1100°K.

The plotted values are averages of 18 measured values, three each on six specimens.

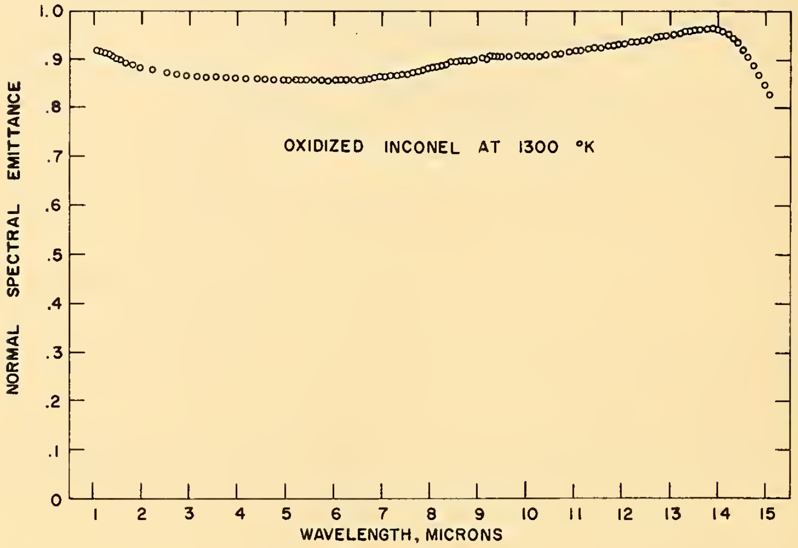

Figure 10. Normal Spectral Emittance of 0.484-in. Disc Working Standards of Oxidized Sandblasted Inconel at 1300°K.

The plotted values are averages of 18 measured values, three each on six specimens.

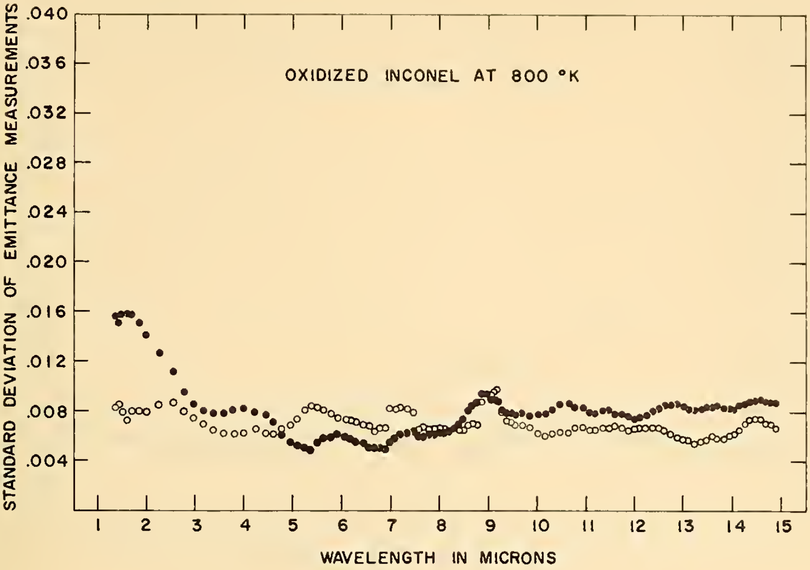

Figure 11. Spectral Distribution of Two Categories of Standard Deviations, Each Computed From 18 Measured Emittance Values Obtained at 800°K, Three Each on Six Specimens of Oxidized Sandblasted Inconel.

The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves, each point represents the moving average of five adjacent values.

The general shape of the spectral emittance curves is similar to that obtained on the previous standards, but the emittance at each wavelength is somewhat higher. There was a slight increase in emittance with an increase in temperature at each wavelength.

The values of σ_m[2] and σ_s[2] obtained at 800°K are plotted in Figure 11, at 1100°K in Figure 12, and at 1300°K in Figure 13.

In general the values of σ_s were somewhat larger than those of σ_m, and showed greater variation with wavelength. The average values of σ_m were 0.70 at 800°K, 0.59 at 1100°K, and 0.63 at 1300°K, and the corresponding values of

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[2] See footnote 1 on page 9.

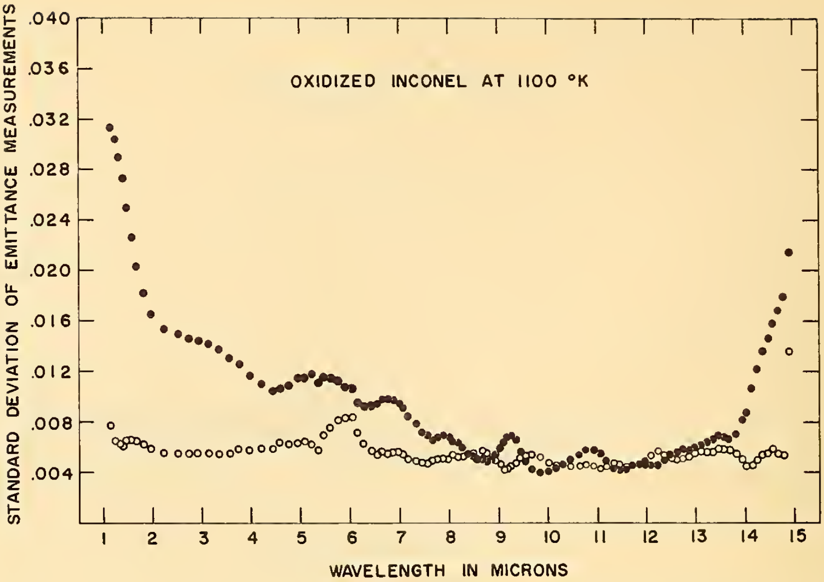

Figure 12. Spectral Distribution of Two Categories of Standard Deviations, Each Computed From 18 Measured Emittance Values Obtained at 1100° K, Three Each on Six Specimens of Oxidized Sandblasted Inconel.

The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves, each point represents the moving average of five adjacent values.

σ_s were 0.82 at 800° K, 1.04 at 1100° K, and 1.00 at 1300° K. This is a considerable improvement in reproducibility of specimens over what was obtained in the tests reported in WADC TR 59-510 Pt IV, and is partly due to the fact that the specimens were cut from adjacent portions of the original sheet.

There is also some improvement in precision over the corresponding data reported in WADC TR 59-510 Pt IV, which can again be ascribed to a reduction in the reading error due to use of the data-processing attachment.

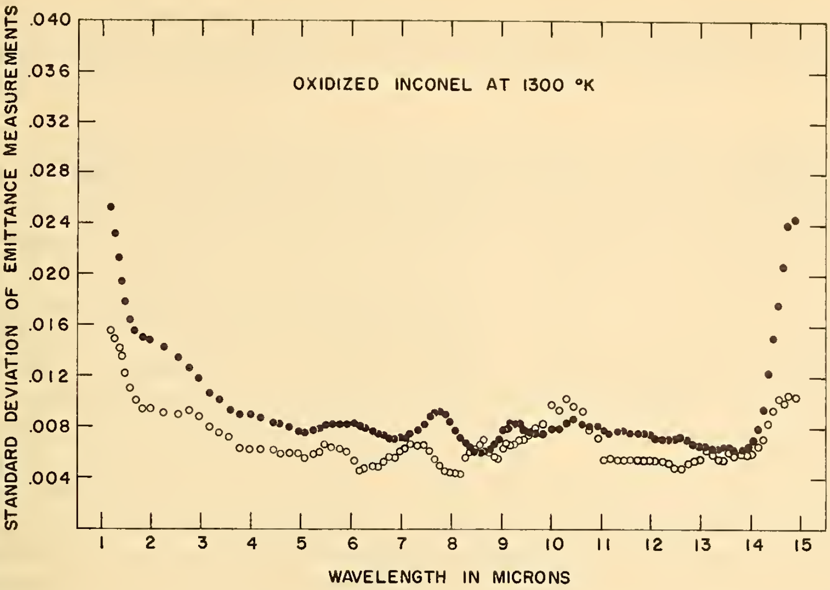

Figure 13. Spectral Distribution of Two Categories of Standard Deviations, Each Computed From 18 Measured Emittance Values Obtained at 1300°K, Three Each on Six Specimens of Oxidized Sandblasted Inconel.

The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves, each point represents the moving average of five adjacent values.

6. NORMAL SPECTRAL EMITTANCE EQUIPMENT

During the report period the major effort with the normal spectral emittance equipment has been to extend the wavelength range of satisfactory operation from 1 to 15 microns to 1 to 38 microns or beyond. A cesium bromide prism and a thermocouple detector with a cesium bromide window were available for use in the wavelength range of 15 to 40 microns.

The principal problem involved when working in this long wavelength range is in maintaining a satisfactory signal-to-noise ratio. At a temperature of 800°K the radiant energy, per unit wavelength interval and unit area, emitted by a blackbody radiator at 15 microns is about 33.6 times that emitted at 40 microns. At 1400°K, this ratio increases to about 43.5. Obviously, in order to maintain a satisfactory signal-to-noise ratio, the noise will have to be reduced proportionately. To further complicate the problem, absorption by atmospheric carbon dioxide and water vapor greatly reduce the intensity of the flux reaching the detector, particularly at wavelengths beyond about 34 microns.

In order to maintain a satisfactory signal-to-noise ratio, it was necessary to (a) keep the energy level as high as possible by reducing atmospheric absorption, and (b) reduce all possible sources of noise to the lowest possible levels. These sources include (1) Johnson noise in the thermocouple detector, (2) noise from variable resistance of the rectifier contacts on the chopper shaft, (3) noise from the preamplifier and amplifier, (4) background radiation from the chopper blade and interior of the monochromator, and (5) scattered radiation within the monochromator. Although the latter two tend to be of constant intensity, they represent a spurious signal and, hence, may be considered as noise.

The Johnson noise, item (1) above, could be reduced by cooling the detector, which was not considered desirable. Significant reduction of noise from items (2) and (3) would involve major modifications in the electronic circuits of the equipment, which is considered beyond the scope of the investigation at this time. Noise from source (4) could be reduced by cooling the entire monochromator, which would make the cesium bromide optical elements particularly vulnerable to attack by atmospheric moisture. Source (5), scattered radiation within the monochromator, appeared to be one area where a sizeable reduction in noise could be achieved without major changes in the equipment.

The two approaches selected to improve the signal-to-noise ratio, especially in the long-wavelength region, were (1) to reduce scattered radiation within the monochromator as much as possible, and (2) to operate in a moisture-free CO_2-free atmosphere.

6.1. Reduction of Scattered Radiation

A special filter kit accessory was purchased for use with the Model 13 spectrophotometer. This consisted of (1) a silver chloride disc, (2) a black polyetheylene filter, and (3) a calcium fluoride reststrahlen plate. The silver chloride disc transmits at wavelengths from 4.5 to 28 microns, but is opaque to radiation of shorter wavelengths. The black polyethylene filter transmits at wavelengths from 15 to 40 microns, but is opaque at shorter wavelengths. The calcium fluoride reststrahlen plate is a good mirror at wavelengths longer than 22 microns, but scatters radiation of shorter wavelengths.

A special filter holder was built to accommodate the silver chloride disc and black polyethylene filter. The filter holder was arranged so that either filter could be inserted or removed from a position immediately in front of the entrance slit to the monochromator, without opening the optical path to the atmosphere.

The restrahlen plate was mounted on the movable mirror mount in the monochromator, where it could be inserted or removed by a remote control lever mounted on the exterior of the monochromator case.

At the time these changes were made, it was decided that two mirrors in the specimen beam, mounted between the chopper and combining optics, could be removed and thus reduce absorption losses in the specimen beam. In order to accomplish this, it was necessary to redesign the opaque air-tight cover for this portion of the optical path.

Several baffles had previously been installed in the monochromator to reduce as much as possible the stray radiation reaching the detector. The design of these baffles was again examined, and several adjustments and modifications were made to improve their effectiveness.

6.2. Reduction in Atmospheric Absorption

A controlled atmosphere system, using super-dry nitrogen(dew point-100°C), had previously been built for use with the normal spectral emittance equipment. This was found necessary for the attainment of the desired accuracy, particularly in the spectral regions where the water vapor and carbon dioxide absorption peaks occur.

The enclosure was designed to permit controlled leakage, so that during a measurement it could be continuously swept out with CO_2-free super-dry nitrogen, which was supplied from a cylinder under a slight positive pressure. With this system it was possible to maintain the relative humidity, as measured with a recording humidigraph, below 5% for periods of several hours at a flow rate of nitrogen of about 2.5 cubic feet per minute. These conditions were satisfactory while working in the 1 to 15 micron wavelength range. However, serious absorption occurred under these conditions in the 35-40 micron range.

The plastic enclosure to the external optics was redesigned to reduce the enclosed volume and all joints in the system were sealed to minimize leakage. A new atmospheric purification system was designed and installed. The new train is shown schematically in Figure 14.

Air from the enclosure reaches the oil-less compressor by a pipe, not shown on the diagram. A valve in this pipe is adjusted to provide the desired resistance to flow, so that a slight positive pressure is maintained in the instrument enclosure, and a slight vacuum is maintained at the compressor inlet. A needle valve, connected to a tee in the vacuum portion of this line, is adjusted to provide a controlled leak of room air into the compressor inlet, to compensate for the loss by leakage from the high-pressure portion of the system. The loss is approximately 15 cubic feet per hour (CFH), out of approximately 185 CFH that is being circulated.

Air from the compressor goes to a tank that serves as a ballast for the system. Air from the tank, at a pressure of about 75 psi, is fed through the coarse air filter (2), and air filter (6), where coarse dust and condensed liquid are removed. The pressure is then reduced to about 60 psi by the pressure regulator (7), and fed through the silica gel drying tower (10), Ascarite carbon dioxide absorbent (11), the molecular sieve water filter (12), oil filter(14), and dust filters (15) and (16). The pressure drops from about 60 psi to about 10 psi in passing through these units. A second pressure regulator (18), is used to decrease the pressure to a few ounces per square in., after which the air passes through a surge tank (20), and flow meter (21), and into the instrument enclosure.

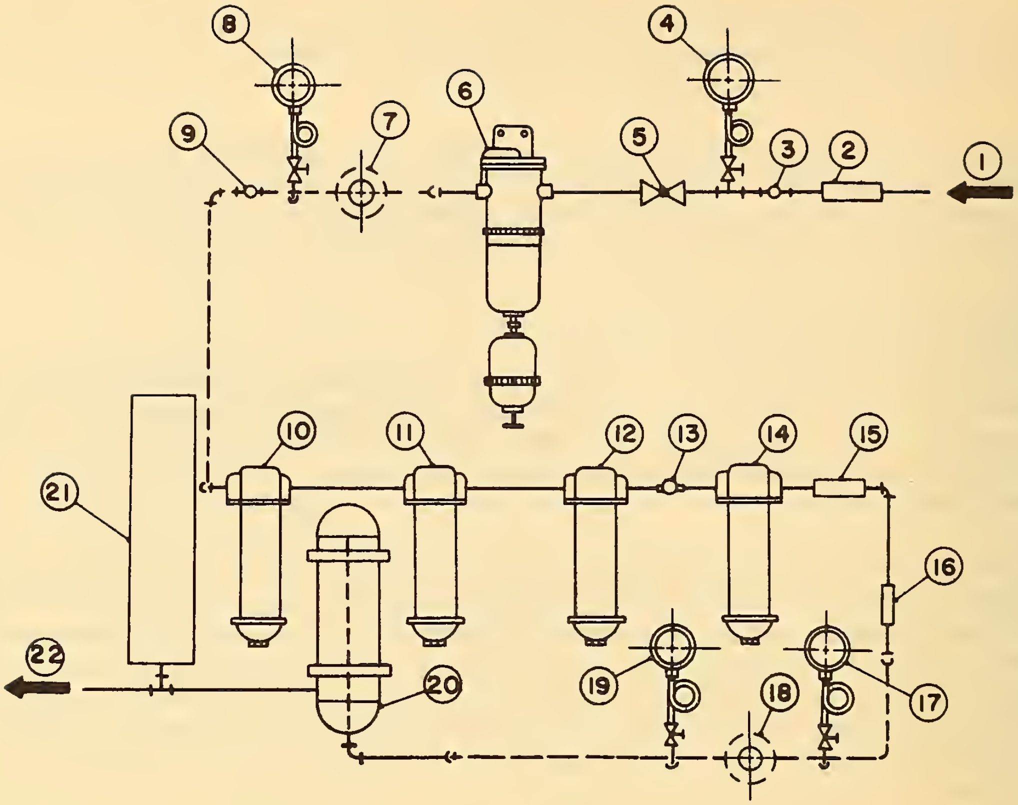

Figure 14. Schematic Diagram of Atmosphere Purification System.

1. Air inlet from compressor and storage tank. 2. Coarse air filter. 3. Purge valve. 4. Combination temperature and pressure gage. 5. Valve. 6. Air filter. 7. Pressure regulator. 8. Gage, combination pressure and temperature. 9. Safety relief valve. 10. Water filter - silica gel. 11. Carbon dioxide filter, Ascarite. 12. Water filter, molecular sieve. 13. Moisture indicator. 14. Oil filter. 15. Dust filter, 11-15 micron. 16. Dust filter, 2-5 micron. 17. Gage, pressure, 0-30 psi, 18. Pressure regulator. 19. Gage, pressure, 0-15 psi. 20. Surge tank. 21. Flow meter. 22. Discharge to spectrometer enclosure.

The manufacturer of the drying towers used in this system indicated that the dew point of the air entering the instrument enclosure should be below -100°C. The humidity within the enclosure was below that measured by the recording humidigraph.

Tests with the equipment have indicated that the water vapor absorption peaks do not disappear until the equipment has been purged for several hours, even though the humidity of the atmosphere in the enclosure, as measured with the humidigraph, drops quite rapidly. It is believed that the continued presence of these peaks may be due to films of water vapor, adsorbed on optical elements and other surfaces within the enclosed volume, which require appreciable time for removal. Because of the relatively long period required for purging, it is considered desirable to maintain the dry atmosphere continuously, except when the enclosure must be opened to permit adjustment of the equipment or insertion of a new specimen.

The drying capacity of the system becomes exhausted in less than 24 hours of operation. Most of the moisture and carbon dioxide enters the system with the air admitted through the controlled leak. An automatically-cycled laboratory air dryer has been ordered to supply predried air to this leak, which should remove at least 95% of the load from the silica gel drying tower (10. in Figure 14) in the main purification train, and correspondingly lengthen the periods between recharges.

7. DATA-PROCESSING ATTACHMENT

The manufacturer of the data-processing attachment to the normal spectral emittance equipment sent an engineer to the Bureau to correct the malfunctions that had been noted. These malfunctions consisted primarily of unstable circuits which resulted in drift from the calibration settings of potentiometers controlling corrections for zero-line and 100%-line errors. The trouble was found to be in the digital portions of the circuits, and was corrected. A mechanical difficulty, binding of the gears in the correcting potentiometer drive mechanism, was also found and corrected.

7.1. Computer Code for Making Corrections

Following these adjustments, the data-processing attachment operated satisfactorily for a time, after which intermittent trouble developed in the automatic correction circuits. However, it was established that the attachment correctly recorded, on punched paper tape, the zero curve, 100% curve, and specimen curve. A program for the Bureau's SEAC computer was therefore designed by means of which the corrected spectral emittances could be computed from the values that had been recorded on punched paper tape. Use of the data-processing attachment and the computer in this way greatly reduced the time required in obtaining useful data with the normal spectral emittance equipment.

7.2. Errors in Correction Circuits

The errors in the correction circuits were difficult to locate and correct. During a calibration run the pulses, produced by the analog-to-digital converter on the recorder pen shaft, are recorded on magnetic tape. During a subsequent specimen run the magnetic tape is played back synchronously and the pulses are read from the tape, amplified, and used to drive a "100% line" and a "zero line" potentiometer up and down scale by means of separate multistable vibrator circuits which actuate reversible ratchet motors. The pulses appeared to be recorded on the magnetic tape satisfactorily, but did not drive the potentiometers up and down scale as required to make the corrections.

The manufacturer sent the engineer who had designed the data-processing attachment to the Bureau, in an effort to find and correct the remaining difficulties.

Plug-in amplifiers of a new design were installed. These amplify the pulses from the tape, and the outputs drive the ratchet motors. The equipment then appeared to operate satisfactorily for short periods of time, but over the 30-minute period required for a complete scan of the spectrum, errors accumulated that exceeded the design specifications. These errors could be due to missed pulses, or spurious pulses (the overall effect of a missed positive pulse or a spurious negative pulse would be the same).

A check of the ratchet motor circuits revealed some weak components, which were replaced, but errors still persisted.

A check of the tape amplifiers indicated that at times the signal strength was weak. The amplifiers were redesigned for more gain, and adjusted for optimum response to the recording tape being used. The basic problem of accumulation of errors over periods of 15 minutes or more was not eliminated.

It was noted that spurious signals were produced when the tape heads were touched. This was attributed to insufficient grounding of the tape heads. The mounting plate containing the tape heads was insulated from ground, and the heads themselves were connected to the ground lead of the amplifiers, in order to provide an adequate ground without the possibility of ground loop pick-up. This change improved operation of the equipment, but did not eliminate completely the spurious counts.

A finite time is required to actuate the stepping motors. If two pulses occur within a time interval shorter than the "dead time", the second pulse is lost. On long runs many of the pulses occur due to random backward or forward steps of only one pulse, which can occur rather rapidly if the recorder pen chatters. In order to reduce this rapid random correction, a buffer register was introduced between the amplifier and stepping motor, which resulted in the stepper motor not having to step for the first forward or reverse signal following a change in direction (the motor did step for the second and all subsequent pulses in one direction, however). This buffer register reduced the operation of the stepper motors by 60 to 80%, but the accumulated errors still persisted.

The pen position counter was temporarily connected to the output of the read amplifier, to follow the pulses at electronic speed. This was done to determine whether the errors were due to the steppers being unable to follow the pulses from the tape, or were due to failure to properly record the pulses on the tape originally. The count showed that the steppers were accurately following the pulses on the tape, indicating that the trouble probably originated in the recording circuits.

Observation of the output of the two recording multivibrators showed apparent spurious pulses. The multivibrators were adjusted by increasing the safety margin against spurious triggering, and by reducing the output impedance. Operation was improved, but the accumulated errors still exceeded specification limits.

The buffer register was moved from between the read amplifier and stepping motor to between the pen analog-to-digital converter and the write multivibrator. The effect of this change was to prevent the extra pulses from being recorded, rather than to record them and then eliminate them before they reached the stepper motor. After this change was made, the equipment operated satisfactorily.

7.3. Computation of 100 Selected Ordinates

The rigorous method of computing normal spectral emittance from spectral data may be expressed mathematically as follows:

$$E_{ts} = \frac{\int_o^\infty \epsilon_{b\lambda} E_{s\lambda} d\lambda}{\int_o^\infty \epsilon_{b\lambda} d\lambda} \qquad (3)$$

where E_{ts} = total normal emittance of specimen

$\epsilon_{b\lambda}$ = rate of blackbody energy emission (radiant flux) per unit area, unit solid angle and unit wavelength interval, within the wavelength interval λ to $(\lambda + d\lambda)$, at temperature T

$E_{s\lambda}$ = normal spectral emittance of specimen at wavelength λ and temperature T.

However, all computations from data are based upon finite wavelength intervals, $\Delta\lambda$. The following equation applies to such computations:

$$E_{ts} = \frac{\sum_{\lambda_1}^{\lambda_2} \epsilon_{b\lambda} E_{s\lambda} \Delta\lambda}{\sum_{\lambda_1}^{\lambda_2} \epsilon_{b\lambda} \Delta\lambda} \qquad (4)$$

λ_1 and λ_2 being selected to include substantially all of the flux emitted by a blackbody radiator at the test temperature T.

In the weighted ordinate method uniform values of $\Delta\lambda$ are used, and each value of $E_{s\lambda}$ must be weighted by a factor proportioned to $\epsilon_{b\lambda}$. This value of $\epsilon_{b\lambda}$ represents the flux emitted per unit area, unit solid angle and within the wavelength interval λ and $(\lambda + \Delta\lambda)$, by a blackbody at the test temperature, T.

In the 100-selected ordinate method, the area under the spectral distribution curve for the radiant flux per unit area and unit solid angle emitted by a blackbody radiator at the test temperature T is divided vertically into

100 slices of equal area. The 100 selected ordinates are then the 100 median wavelengths of the 100 areas. In this case $\Delta\lambda$ varies, but the quantity $\epsilon_{b\lambda}\Delta\lambda$ is held constant at 0.01 Under these conditions, equation (2) can be rewritten:

$$E_{ts} \cong 0.01 \sum_{\lambda_1}^{\lambda_{100}} E_{s\lambda} \tag{5}$$

In practice any desired degree of precision in the computation of E_{ts} can be attained by either the weighted ordinate method or the selected ordinate method, by taking a large enough number of ordinates. With any given number of ordinates, the computation error will be smaller by the selected ordinate method than by the weighted ordinate method. With solids, whose spectral emittance curves do not normally have sharp peaks or valleys, the 100-selected ordinate method gives values that have no significant computation error from this source.

The wavelengths representing the 100 selected ordinates referred to above were computed for temperatures of 600°, 700°, 800°, 900°, 1000°, 1100°, 1200°, 1300° and 1400°K, and are given in Table 3.

The 100 selected ordinates for temperatures of 800°, 1100°, 1300° and 1400°K were converted to digital form and punched on paper tape for use with the data-processing attachment for computation of total normal emittance during measurement of normal spectral emittance.

8. SUMMARY AND FUTURE PLANS

Preliminary design was completed for an integrating sphere reflectometer for use with a continuous-wave gas laser as the source. Future plans include (1) construction of the reflectometer and procurement of a helium-neon laser source, a detector-amplifier-recorder system and other accessory items, (2) initial calibration and operation of the equipment at wavelengths of 0.632 and 1.15 microns, at which the helium-neon laser operates, and for which suitable sphere coatings are available, and (3) eventual development of suitable sphere coatings for operation over an extended wavelength range, from the ultraviolet down to perhaps 0.25 micron into the infrared to at least 3.39 microns where the helium-neon laser operates, and procurement of one or more additional lasers to operate at wavelengths in this range.

Extensive tests with the ellipsoidal mirror reflectometer have led to the conclusion that the Golay cell detector is not suitable for use with this equipment. A new large-area thermopile has been ordered. Future plans include calibration of the reflectometer and operation in the wavelength range of approximately 1 to 15 microns.

Attempts to fit parameters to the Roberts equations for the emissivity of rhodium have so far been unsuccessful. A small amount of additional work will be done to conclude this phase of the investigation.

Specimens of platinum-13% rhodium alloy and oxidized Inconel were prepared and calibrated for use as standards of normal spectral emittance over the wavelength range of approximately 1 to 15 microns.

A number of modifications were made in the normal spectral emittance equipment to facilitate operation in the 15 to 38 micron range. These included (1) use of special filters to reduce scattered radiation, and (2) construction of a special atmosphere purification system to reduce absorption by CO_2 and H_2O. Future plans include procurement of a more sensitive thermocouple detector and calibration of working standards of normal spectral emittance in this wavelength range.

The data-processing attachment has continued to give trouble. When one difficulty is corrected, another soon develops. It is believed that at least part of this can be ascribed to the fact that this was the pilot model of the data-reduction system. Many of the weaknesses that have been found have been corrected in the production model. It is hoped that it will be possible to exchange the present attachment for one of current production.

The wavelengths for use in the 100-selected-ordinate method of computing total normal emittance from normal spectral emittance curves were computed for temperatures at 100° intervals from 600° to 1400°K.

TABLE 1

NORMAL SPECTRAL EMITTANCE OF PLATINUM-13% RHODIUM WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
1.18	24.2	.16	.19
1.25	25.5	.49	.26
1.33	26.1	.29	.94
1.40	26.2	.30	.90
1.48	25.2	.15	1.06
1.58	23.7	.23	.97
1.68	22.1	.30	.78
1.81	20.6	.18	.73
1.98	19.2	.24	.64
2.23	17.7	.36	.42
2.51	16.5	.34	.33
2.73	15.4	.29	.26
2.92	14.7	.29	.07
3.14	13.8	.38	.05
3.35	13.2	.27	.07
3.56	12.6	.20	.14
3.77	12.2	.20	.26
3.98	11.7	.16	.19
4.20	11.3	.15	.38
4.41	11.0	.33	.14
4.58	10.8	.26	.19
4.76	10.5	.27	.19
4.91	10.2	.23	.31
5.07	10.1	.23	.35
5.21	9.9	.20	.21
5.34	9.7	.27	.31
5.47	9.7	.17	.42
5.60	9.5	.22	.40
5.76	9.3	.22	.40
5.90	9.1	.09	.45
6.04	8.9	.15	.40
6.16	8.7	.20	.35
6.28	8.7	.15	.28
6.41	8.6	.16	.31
6.53	8.6	.21	.24

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF PLATINUM-13% RHODIUM WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
6.64	8.5	.33	.31
6.76	8.4	.22	.33
6.87	8.4	.16	.38
6.97	8.4	.21	.42
7.07	8.4	.20	.28
7.19	8.3	.21	.40
7.32	8.2	.18	.47
7.44	8.2	.15	.40
7.56	8.1	.19	.45
7.66	8.0	.12	.49
7.77	8.0	.20	.33
7.88	7.9	.21	.35
7.98	7.9	.15	.35
8.08	7.9	.23	.33
8.18	7.8	.23	.26
8.28	7.8	.24	.28
8.38	7.9	.24	.33
8.47	8.0	.31	.12
8.57	8.0	.22	.19
8.66	8.0	.23	.26
8.75	8.1	.22	.14
8.84	8.1	.26	.16
8.93	8.1	.17	.24
9.01	8.0	.13	.12
9.10	8.0	.18	.19
9.18	8.1	.23	.33
9.26	8.1	.24	.16
9.35	8.6	.25	.02
9.43	9.1	.25	.02
9.51	9.4	.13	.05
9.67	9.3	.16	.26
9.83	8.6	.31	.21
10.00	8.1	.14	.19
10.15	7.8	.24	.19
10.30	7.6	.24	.19

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM-13% RHODIUM WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
10.46	7.3	.23	.07
10.61	7.2	.31	.14
10.76	7.1	.15	.09
10.91	7.0	.34	.14
11.05	7.0	.29	.16
11.19	6.9	.23	.24
11.32	6.8	.25	.16
11.45	6.8	.18	.05
11.58	6.6	.30	.16
11.72	6.6	.14	.14
11.84	6.5	.19	.09
11.97	6.6	.24	.26
12.09	6.4	.39	.21
12.22	6.5	.20	.12
12.35	6.4	.22	.12
12.48	6.4	.24	.12
12.60	6.2	.18	.12
12.72	6.2	.16	.09
12.85	6.2	.20	.16
12.98	6.2	.17	.19
13.10	6.2	.18	.09
13.22	6.2	.23	.05
13.34	6.0	.30	.09
13.46	6.0	.23	.05
13.58	6.0	.19	.09
13.69	5.9	.23	.09
13.81	5.9	.28	.12
13.93	5.8	.17	.07
14.03	5.8	.32	.26
14.14	5.8	.30	.24
14.25	5.7	.26	.21
14.36	5.7	.27	.19
14.47	5.7	.22	.14
14.58	5.6	.41	.09
14.68	5.5	.31	.09

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM-13% RHODIUM WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
14.79	5.6	.27	.02
14.90	5.6	.33	.07
15.01	5.7	.22	.02
15.11	5.6	.26	.07

1/ Average of 6 measured values, three each on two specimens.

2/ See footnote 1 on page 9 in the text.

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF PLATINUM-13% RHODIUM WORKING STANDARDS AT 1100°K

Wavelength Microns	Emittance[1] X100	σ_m[2] X100	σ_s[2] X100
1.07	23.1	.45	.14
1.12	23.3	.47	.24
1.18	23.1	.48	.02
1.25	22.5	.56	.14
1.33	22.3	.50	.24
1.40	21.8	.39	.09
1.48	21.3	.37	.02
1.58	20.7	.37	
1.68	20.0	.34	.02
1.81	19.1	.29	.07
1.98	18.5	.26	.16
2.23	17.7	.29	.21
2.51	16.8	.24	.16
2.73	16.1	.17	.14
2.92	15.7	.22	.38
3.14	15.0	.27	.54
3.35	14.6	.34	.61
3.56	14.2	.38	.61
3.77	13.9	.34	.94
3.98	13.5	.35	1.11
4.20	13.1	.23	1.06
4.41	12.7	.16	1.15
4.58	12.5	.16	1.11
4.76	12.2	.21	1.13
4.91	12.0	.21	1.13
5.07	11.8	.10	1.13
5.21	11.6	.14	1.23
5.34	11.4	.20	1.15
5.47	11.2	.18	1.18
5.60	11.0	.24	1.30
5.76	10.9	.13	1.15
5.90	10.7	.12	1.06
6.04	10.5	.18	.97
6.16	10.5	.13	.94
6.28	10.4	.13	.94

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM-13% RHODIUM WORKING STANDARDS AT 1100° K

Wavelength Microns	Emittance [1/] X100	σ_m [2/] X100	σ_s [2/] X100
6.41	10.3	.18	.99
6.53	10.1	.12	.75
6.64	10.0	.17	.80
6.76	9.8	.18	.78
6.87	9.8	.08	.94
6.97	9.6	.14	.94
7.07	9.6	.13	1.08
7.19	9.5	.22	1.04
7.32	9.5	.17	.99
7.44	9.4	.18	1.01
7.56	9.4	.20	1.01
7.66	9.3	.15	.97
7.77	9.2	.15	.94
7.88	9.2	.09	.92
7.98	9.1	.13	.94
8.08	9.0	.19	.90
8.18	9.1	.19	.90
8.28	9.1	.15	.80
8.38	9.0	.09	.82
8.47	9.1	.08	.90
8.57	9.2	.12	.78
8.66	9.2	.11	.87
8.75	9.3	.08	.75
8.84	9.2	.15	.73
8.93	9.2	.06	.73
9.01	9.3	.11	.68
9.10	9.3	.08	.61
9.18	9.2	.12	.64
9.26	9.2	.16	.66
9.35	9.3	.15	.68
9.43	9.7	.11	.73
9.51	10.0	.18	.52
9.67	10.2	.07	.42
9.83	9.8	.12	.31
10.00	9.4	.19	.31

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM-13% RHODIUM WORKING STANDARDS AT 1100°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
10.15	9.0	.31	.35
10.30	8.6	.20	.28
10.46	8.4	.24	.54
10.61	8.4	.20	.52
10.76	8.2	.10	.42
10.91	8.1	.19	.40
11.05	8.0	.19	.38
11.19	7.8	.14	.38
11.32	7.8	.15	.54
11.45	7.7	.11	.61
11.58	7.6	.14	.54
11.72	7.5	.21	.45
11.84	7.4	.16	.33
11.97	7.4	.15	.47
12.09	7.3	.06	.40
12.22	7.3	.08	.38
12.35	7.2	.15	.42
12.48	7.2	.10	.49
12.60	7.2	.08	.38
12.72	7.1	.08	.26
12.85	7.0	.17	.26
12.98	7.0	.11	.24
13.10	6.9	.11	.38
13.22	6.9	.04	.16
13.34	6.9	.17	.21
13.46	6.9	.13	.19
13.58	6.8	.08	.05
13.69	6.8	.09	.14
13.81	6.7	.13	.16
13.93	6.8	.11	.26
14.03	6.6	.22	.19
14.14	6.6	.14	.21
14.25	6.5	.22	.05
14.36	6.5	.20	.31
14.47	6.4	.19	.19

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF PLATINUM-13% RHODIUM WORKING STANDARDS AT 1100°K

Wavelength Microns	Emittance[1] X100	σ_m[2] X100	σ_s[2] X100
14.58	6.5	.16	.12
14.68	6.5	.22	.28
14.79	6.5	.17	.19
14.90	6.4	.14	.19
15.01	6.4	.25	.21
15.11	6.4	.37	.31

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[1] Average of 6 measured values, three each on two specimens.

[2] See footnote 1 on page 9 in the text.

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF PLATINUM-13% RHODIUM WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
1.07	25.4	1.07	.28
1.12	25.2	.94	.14
1.18	24.7	.87	.02
1.25	24.3	.68	.12
1.33	23.7	.43	
1.40	23.1	.40	.02
1.48	22.6	.30	.02
1.58	22.0	.29	.19
1.68	21.2	.24	.28
1.81	20.4	.43	.19
1.98	19.7	.29	.38
2.23	18.7	.39	.40
2.51	18.0	.41	.57
2.73	17.3	.32	.57
2.92	16.6	.23	.59
3.14	16.2	.21	.75
3.35	15.9	.16	.97
3.56	15.3	.15	.87
3.77	15.0	.23	1.06
3.98	14.6	.26	1.11
4.20	14.4	.25	1.18
4.41	14.0	.23	1.30
4.58	13.8	.26	1.53
4.76	13.7	.31	1.65
4.91	13.3	.23	1.72
5.07	13.2	.26	1.81
5.21	12.9	.27	1.77
5.34	12.8	.18	1.74
5.47	12.7	.18	1.74
5.60	12.5	.19	1.65
5.76	12.3	.25	1.70
5.90	12.1	.21	1.60
6.04	11.9	.25	1.63
6.16	11.6	.29	1.60
6.28	11.6	.31	1.65

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF PLATINUM-13% RHODIUM WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance 1/ X100	σ_m 2/ X100	σ_s 2/ X100
6.41	11.6	.36	1.86
6.53	11.3	.38	1.67
6.64	11.2	.29	1.63
6.76	11.1	.38	1.65
6.87	11.0	.27	1.65
6.97	10.9	.22	1.65
7.07	10.8	.20	1.56
7.19	10.8	.15	1.46
7.32	10.7	.13	1.60
7.44	10.7	.22	1.56
7.56	10.6	.18	1.58
7.66	10.4	.28	1.63
7.77	10.4	.24	1.53
7.88	10.4	.13	1.53
7.98	10.4	.25	1.63
8.08	10.4	.27	1.60
8.18	10.3	.29	1.44
8.28	10.3	.19	1.39
8.38	10.2	.19	1.48
8.47	10.2	.20	1.46
8.57	10.2	.15	1.34
8.66	10.2	.17	1.37
8.75	10.2	.17	1.41
8.84	10.3	.19	1.32
8.93	10.2	.17	1.34
9.01	10.3	.18	1.34
9.10	10.2	.22	1.23
9.18	10.2	.15	1.18
9.26	10.2	.15	1.18
9.35	10.2	.16	1.30
9.43	10.2	.13	1.25
9.51	10.5	.10	1.20
9.67	10.9	.12	1.06
9.83	11.0	.10	.99
10.00	10.5	.12	1.06

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM-13% RHODIUM WORKING STANDARDS AT 1300°K

Wavelength	Emittance[1]	σ_m[2]	σ_s[2]
Microns	X100	X100	X100
10.15	10.0	.27	1.04
10.30	9.7	.20	.92
10.46	9.5	.33	1.04
10.61	9.2	.15	.97
10.76	9.1	.15	.97
10.91	9.0	.08	.75
11.05	8.9	.12	.78
11.19	8.8	.16	.85
11.32	8.7	.25	.80
11.45	8.5	.09	.85
11.58	8.5	.09	.73
11.72	8.4	.17	.71
11.84	8.3	.14	.66
11.97	8.2	.19	.59
12.09	8.0	.20	.68
12.22	8.1	.09	.57
12.35	8.0	.15	.57
12.48	7.9	.13	.47
12.60	7.8	.20	.45
12.72	7.8	.16	.21
12.85	7.7	.15	.24
12.98	7.6	.14	.28
13.10	7.5	.11	.19
13.22	7.5	.17	.26
13.34	7.5	.28	.33
13.46	7.4	.19	.05
13.58	7.3	.17	.21
13.69	7.2	.12	.16
13.81	7.3	.15	.02
13.93	7.3	.15	.16
14.03	7.2	.18	.16
14.14	7.2	.16	.02
14.25	7.2	.13	.05
14.36	7.1	.11	.02
14.47	7.2	.16	

TABLE 1 cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM-13% RHODIUM WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance [1/] X100	σ_m [2/] X100	σ_s [2/] X100
14.58	7.0	.16	.09
14.68	7.2	.21	.07
14.79	7.1	.16	.05
14.90	7.0	.23	.07
15.01	7.2	.19	
15.11	7.2	.18	.05

1/ Average of 6 measured values, three each on two specimens.

2/ See footnote 1 on page 9 in the text.

TABLE 2

NORMAL SPECTRAL EMITTANCE OF OXIDIZED INCONEL WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
1.18	82.0	.77	1.84
1.25	83.5	.88	1.19
1.33	84.5	.97	1.53
1.40	85.1	.70	1.67
1.48	85.1	.82	1.59
1.58	84.7	.85	1.50
1.68	84.2	.58	1.60
1.81	83.9	.66	1.55
1.98	83.5	1.07	1.66
2.23	84.5	.81	1.22
2.51	83.3	.81	.98
2.73	83.2	.85	.88
2.92	82.8	.83	.88
3.14	82.7	.66	.78
3.35	82.6	.56	.73
3.56	82.5	.56	.75
3.77	82.4	.63	.76
3.98	82.1	.70	.89
4.20	82.1	.58	.93
4.41	82.1	.66	.76
4.58	82.1	.68	.65
4.76	81.9	.50	.61
4.91	81.7	.67	.64
5.07	81.6	.80	.39
5.21	81.7	.77	.45
5.34	81.6	.93	.52
5.47	81.6	.85	.52
5.60	81.5	.87	.55
5.76	81.3	.72	.64
5.90	81.3	.66	.67
6.04	81.3	.81	.58
6.16	81.1	.65	.58
6.28	81.1	.83	.48
6.41	81.1	.66	.55
6.53	81.1	.63	.57

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF OXIDIZED INCONEL WORKING STANDARDS AT 800°K

Wavelength	Emittance[1]	σ_m[2]	σ_s[2]
Microns	X100	X100	X100
6.64	81.1	.65	.49
6.76	81.3	.63	.47
6.87	81.5	.62	.47
6.97	81.8	.76	.55
7.07	82.1	.70	.49
7.19	82.8	1.40	.80
7.32	82.8	.55	.59
7.44	83.1	.73	.60
7.56	83.3	.66	.61
7.66	83.6	.64	.56
7.77	83.9	.67	.60
7.88	84.2	.66	.61
7.98	85.0	.62	.66
8.08	85.9	.67	.60
8.18	86.5	.67	.62
8.28	87.1	.62	.64
8.38	87.5	.57	.65
8.47	87.5	.70	.75
8.57	87.7	.66	.80
8.66	87.9	.70	.84
8.75	88.1	.81	.95
8.84	88.2	.67	.88
8.93	88.4	.61	.92
9.01	88.4	1.60	1.15
9.10	88.9	1.04	.83
9.18	89.1	.73	.80
9.26	89.3	.78	.83
9.35	89.4	.72	.82
9.43	89.2	.68	.73
9.51	88.8	.73	.76
9.67	88.4	.68	.82
9.83	88.3	.67	.80
10.00	88.3	.68	.72
10.15	88.6	.60	.75
10.30	88.9	.50	.82

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF OXIDIZED INCONEL WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance 1/ X100	σ_m 2/ X100	σ_s 2/ X100
10.46	89.4	.56	.84
10.61	89.5	.78	.98
10.76	89.7	.74	.93
10.91	90.0	.57	.74
11.05	90.2	.73	.71
11.19	90.5	.57	.81
11.32	90.6	.64	.81
11.45	90.7	.79	.87
11.58	90.8	.67	.85
11.72	91.1	.67	.75
11.84	91.3	.65	.67
11.97	91.5	.57	.78
12.09	91.6	.68	.81
12.22	91.8	.77	.76
12.35	92.0	.70	.77
12.48	92.4	.64	.80
12.60	92.9	.60	.89
12.72	93.0	.65	.95
12.85	93.3	.68	.89
12.98	93.4	.55	.80
13.10	93.8	.52	.83
13.22	94.1	.53	.79
13.34	94.2	.59	.81
13.46	94.3	.59	.90
13.58	94.4	.59	.84
13.69	94.3	.61	.86
13.81	94.0	.61	.80
13.93	93.3	.53	.85
14.03	91.7	.59	.85
14.14	89.8	.67	.82
14.25	87.6	.69	.86
14.36	85.2	.79	.91
14.47	82.8	.79	.92
14.58	80.5	.74	.92
14.68	78.2	.70	.87

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF OXIDIZED INCONEL WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
14.79	75.9	.72	.91
14.90	73.9	.61	.84
15.01	72.3	.79	.89
15.11	70.8	.57	.89

1/ Average of 18 measured values, three each on six specimens.

2/ See footnote 1 on page 9 in the text.

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 1100° K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
1.07	89.4	1.10	3.13
1.12	89.5	.80	3.28
1.18	89.4	.76	3.17
1.25	89.3	.59	3.17
1.33	89.1	.57	2.87
1.40	88.9	.55	2.75
1.48	88.6	.66	2.51
1.58	88.1	.70	2.31
1.68	87.7	.77	2.05
1.81	87.4	.59	1.69
1.98	86.9	.50	1.61
2.23	86.7	.52	1.43
2.51	86.3	.55	1.53
2.73	85.7	.59	1.44
2.92	85.5	.60	1.48
3.14	85.4	.52	1.41
3.35	85.2	.53	1.36
3.56	85.0	.53	1.36
3.77	84.9	.58	1.25
3.98	84.8	.59	1.19
4.20	84.6	.66	1.11
4.41	84.5	.52	.92
4.58	84.4	.55	1.01
4.76	84.4	.60	.97
4.91	84.2	.81	1.32
5.07	84.3	.60	1.22
5.21	84.4	.63	1.17
5.34	84.5	.56	1.10
5.47	84.6	.53	1.11
5.60	84.5	.54	.97
5.76	84.0	1.21	1.45
5.90	83.9	.97	1.12
6.04	84.0	.78	.97
6.16	83.8	.69	.87
6.28	83.9	.54	.90

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF OXIDIZED INCONEL WORKING STANDARDS AT 1100°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
6.41	84.0	.61	.93
6.53	83.9	.51	.95
6.64	84.0	.51	.99
6.76	84.2	.57	.99
6.87	84.6	.64	1.03
6.97	84.8	.52	.95
7.07	85.0	.55	.91
7.19	85.2	.53	.87
7.32	85.3	.47	.80
7.44	85.4	.46	.70
7.56	85.6	.44	.67
7.66	85.7	.50	.60
7.77	86.0	.50	.69
7.88	86.2	.57	.67
7.98	86.7	.51	.77
8.08	87.1	.49	.74
8.18	87.6	.51	.56
8.28	88.0	.62	.54
8.38	88.4	.49	.59
8.47	88.6	.53	.56
8.57	88.7	.62	.48
8.66	88.9	.50	.51
8.75	88.9	.57	.45
8.84	89.0	.64	.51
8.93	89.3	.46	.50
9.01	89.4	.42	.60
9.10	89.5	.43	.65
9.18	89.7	.38	.73
9.26	89.8	.44	.74
9.35	89.9	.47	.72
9.43	90.0	.49	.62
9.51	90.0	.62	.47
9.67	89.8	.58	.27
9.83	89.9	.50	.33
10.00	89.9	.53	.44

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF OXIDIZED INCONEL WORKING STANDARDS AT 1100° K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
10.15	90.0	.39	.48
10.30	90.1	.39	.49
10.46	90.2	.47	.45
10.61	90.4	.54	.48
10.76	90.7	.46	.65
10.91	90.9	.38	.71
11.05	91.2	.43	.60
11.19	91.4	.42	.45
11.32	91.6	.47	.33
11.45	91.6	.54	.37
11.58	91.9	.50	.42
11.72	92.1	.37	.53
11.84	92.2	.33	.53
11.97	92.3	.58	.47
12.09	92.5	.57	.41
12.22	92.7	.59	.45
12.35	93.0	.59	.43
12.48	93.2	.52	.53
12.60	93.5	.44	.65
12.72	93.7	.48	.62
12.85	93.8	.53	.57
12.98	94.0	.61	.55
13.10	94.4	.56	.52
13.22	94.9	.62	.71
13.34	95.1	.51	.77
13.46	95.3	.51	.70
13.58	95.4	.63	.64
13.69	95.4	.71	.67
13.81	95.4	.59	.62
13.93	95.4	.46	.71
14.03	95.3	.38	.94
14.14	94.8	.37	1.11
14.25	93.8	.42	1.16
14.36	92.4	.66	1.44
14.47	90.9	.70	1.52

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF OXIDIZED INCONEL WORKING STANDARDS AT 1100°K

Wavelength	Emittance[1]	σ_m[2]	σ_s[2]
Microns	X100	X100	X100
14.58	89.1	.58	1.57
14.68	87.3	.53	1.65
14.79	85.4	.48	1.80
14.90	83.3	.49	1.89
15.01	81.3	.63	2.04
15.11	80.3	4.68	3.36

[1] Average of 18 measured values, three each on six specimens.

[2] See footnote 1 on page 9 in the text.

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF OXIDIZED INCONEL WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance 1/ X100	σ_m 2/ X100	σ_s 2/ X100
1.07	91.7	1.57	2.87
1.12	91.4	1.59	2.68
1.18	91.2	1.45	2.52
1.25	91.0	1.63	2.37
1.33	90.8	1.53	2.10
1.40	90.4	1.22	1.90
1.48	89.8	1.26	1.71
1.58	89.4	1.13	1.57
1.68	88.8	.96	1.57
1.81	88.3	.88	1.45
1.98	87.9	.72	1.46
2.23	87.4	.93	1.38
2.51	86.9	1.15	1.53
2.73	86.5	.83	1.21
2.92	86.3	.83	1.15
3.14	86.1	.84	1.01
3.35	86.0	.72	.94
3.56	86.0	.71	.96
3.77	86.0	.63	.94
3.98	86.0	.66	.79
4.20	85.8	.42	.84
4.41	85.7	.67	.91
4.58	85.7	.73	.85
4.76	85.6	.54	.74
4.91	85.6	.54	.74
5.07	85.6	.49	.71
5.21	85.6	.61	.77
5.34	85.6	.61	.79
5.47	85.6	.63	.83
5.60	85.6	.65	.79
5.76	85.5	.75	.86
5.90	85.4	.49	.80
6.04	85.5	.53	.79
6.16	85.5	.56	.81
6.28	85.6	.31	.81

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF OXIDIZED INCONEL WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance[1] X100	σ_m[2] X100	σ_s[2] X100
6.41	85.7	.38	.80
6.53	85.7	.63	.71
6.64	85.7	.51	.68
6.76	85.8	.56	.69
6.87	86.0	.52	.77
6.97	86.1	.60	.69
7.07	86.1	.59	.75
7.19	86.3	.70	.69
7.32	86.5	.71	.68
7.44	86.7	.65	.88
7.56	86.9	.58	.87
7.66	87.0	.61	.95
7.77	87.3	.45	.97
7.88	87.5	.42	.88
7.98	87.7	.37	.85
8.08	88.0	.40	.79
8.18	88.2	.54	.67
8.28	88.4	.42	.65
8.38	88.8	.36	.62
8.47	89.4	1.05	.66
8.57	89.4	.64	.55
8.66	89.5	.64	.55
8.75	89.6	.59	.61
8.84	89.7	.56	.66
8.93	89.8	.56	.67
9.01	90.0	.49	.82
9.10	90.1	.58	.76
9.18	89.9	.98	.98
9.26	90.2	.68	.76
9.35	90.3	.51	.77
9.43	90.3	.57	.80
9.51	90.4	.69	.79
9.67	90.6	.99	.72
9.83	90.4	.89	.71
10.00	90.3	.83	.72

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
10.15	90.4	.72	.79
10.30	90.5	1.38	.93
10.46	90.8	.79	.79
10.61	90.9	1.36	.95
10.76	91.0	.54	.82
10.91	91.2	.55	.61
11.05	91.4	.59	.81
11.19	91.7	.50	.84
11.32	92.0	.54	.78
11.45	92.1	.58	.71
11.58	92.2	.47	.66
11.72	92.3	.58	.83
11.84	92.6	.53	.80
11.97	92.9	.51	.72
12.09	93.0	.56	.72
12.22	93.2	.52	.62
12.35	93.3	.54	.69
12.48	93.6	.51	.76
12.60	93.9	.45	.70
12.72	94.3	.38	.72
12.85	94.4	.48	.72
12.98	94.7	.74	.59
13.10	94.9	.60	.57
13.22	95.1	.52	.64
13.34	95.5	.67	.68
13.46	95.6	.40	.67
13.58	95.8	.50	.59
13.69	95.8	.57	.64
13.81	96.0	.85	.56
13.93	96.0	.50	.63
14.03	95.8	.46	.62
14.14	95.5	.53	.75
14.25	94.9	.62	.88
14.36	94.0	1.13	1.06
14.47	93.1	.79	1.40

TABLE 2 cont'd.

NORMAL SPECTRAL EMITTANCE OF OXIDIZED INCONEL WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
14.58	91.9	1.09	2.00
14.68	90.1	1.01	2.09
14.79	88.4	1.04	2.28
14.90	86.4	.99	2.51
15.01	84.5	1.07	2.57
15.11	82.7	1.05	2.73

1/ Average of 18 measured values, three each on six specimens.

2/ See footnote 1 on page 9 in the text.

TABLE 3

WAVELENGTHS FOR COMPUTATION OF TOTAL EMITTANCE FROM SPECTRAL DATA BY THE 100-SELECTED ORDINATE METHOD

%1/	λT μ°K	λ in Microns at Temperature in °K 600	700	800	900	1000	1100	1200	1300	1400
.5	1322	2.203	1.889	1.652	1.469	1.322	1.202	1.102	1.017	.944
1.5	1534	2.557	2.191	1.918	1.704	1.534	1.395	1.278	1.180	1.096
2.5	1662	2.770	2.374	2.078	1.847	1.622	1.511	1.385	1.278	1.187
3.5	1762	2.937	2.517	2.020	1.958	1.762	1.602	1.468	1.355	1.258
4.5	1846	3.077	2.637	2.308	2.051	1.846	1.678	1.538	1.420	1.318
5.5	1920	3.200	2.743	2.400	2.133	1.920	1.745	1.600	1.477	1.371
6.5	1989	3.315	2.841	2.486	2.210	1.989	1.808	1.657	1.530	1.424
7.5	2052	3.420	2.931	2.565	2.280	2.052	1.865	1.710	1.578	1.466
8.5	2111	3.518	3.016	2.639	2.346	2.111	1.919	1.759	1.624	1.508
9.5	2168	3.613	3.097	2.710	2.409	2.168	1.971	1.806	1.668	1.549
10.5	2222	3.703	3.174	2.778	2.469	2.222	2.020	1.852	1.709	1.587
11.5	2274	3.790	3.249	2.842	2.527	2.274	2.067	1.895	1.749	1.624
12.5	2325	3.875	3.321	2.906	2.583	2.325	2.114	1.937	1.788	1.661
13.5	2374	3.957	3.391	2.968	2.638	2.374	2.158	1.978	1.826	1.696
14.5	2423	4.038	3.461	3.029	2.692	2.423	2.203	2.019	1.864	1.731
15.5	2470	4.117	3.529	3.088	2.744	2.470	2.245	2.058	1.900	1.764
16.5	2517	4.195	3.596	3.146	2.797	2.517	2.288	2.097	1.936	1.798
17.5	2563	4.271	3.662	3.204	2.848	2.563	2.330	2.136	1.972	1.831
18.5	2609	4.348	3.727	3.261	2.899	2.609	2.372	2.174	2.007	1.864
19.5	2654	4.423	3.792	3.318	2.949	2.654	2.413	2.212	2.042	1.896
20.5	2698	4.496	3.854	3.372	2.998	2.698	2.453	2.248	2.075	1.927
21.5	2743	4.571	3.919	3.429	3.048	2.743	2.494	2.286	2.110	1.959
22.5	2787	4.645	3.982	3.484	3.097	2.787	2.534	2.322	2.144	1.991
23.5	2831	4.718	4.044	3.539	3.146	2.831	2.574	2.359	2.178	2.022
24.5	2876	4.793	4.109	3.595	3.196	2.876	2.615	2.397	2.212	2.054
25.5	2920	4.866	4.172	2.650	3.244	2.920	2.655	2.433	2.246	2.086

TABLE 3 cont'd.

%1/	λT μ°K	λ in Microns at Temperature in °K								
		600	700	800	900	1000	1100	1200	1300	1400
26.5	2964	4.940	4.234	3.705	3.293	2.964	2.695	2.470	2.280	2.117
27.5	3008	5.013	4.297	3.760	3.342	3.008	2.735	2.507	2.314	2.149
28.5	3052	5.086	4.360	3.815	3.391	3.052	2.775	2.543	2.348	2.180
29.5	3097	5.161	4.424	3.871	3.441	3.097	2.815	2.581	2.382	2.212
30.5	3141	5.235	4.487	3.926	3.490	3.141	2.855	2.617	2.416	2.244
31.5	3186	5.310	4.552	3.982	3.540	3.186	2.896	2.655	2.451	2.276
32.5	3231	5.385	4.616	4.039	3.590	3.231	2.937	2.692	2.485	2.308
33.5	3277	5.461	4.682	4.096	3.641	3.277	2.979	2.731	2.521	2.341
34.5	3323	5.538	4.747	4.154	3.692	3.323	3.021	2.769	2.556	2.374
35.5	3369	5.615	4.813	4.211	3.743	3.369	3.063	2.807	2.592	2.406
36.5	3415	5.691	4.879	4.269	3.794	3.415	3.105	2.846	2.627	2.439
37.5	3462	5.770	4.946	4.328	3.847	3.462	3.147	2.885	2.663	2.473
38.5	3510	5.850	5.014	4.388	3.900	3.510	3.191	2.925	2.700	2.507
39.5	3558	5.930	5.083	4.448	3.953	3.558	3.235	2.965	2.737	2.542
40.5	3607	6.011	5.152	4.509	4.008	3.607	3.279	3.006	2.775	2.576
41.5	3656	6.093	5.223	4.570	4.062	3.656	3.324	3.047	2.812	2.611
42.5	3706	6.176	5.294	4.632	4.118	3.706	3.369	3.088	2.851	2.647
43.5	3757	6.261	5.367	4.696	4.174	3.757	3.415	3.131	2.890	2.684
44.5	3809	6.348	5.441	4.761	4.232	3.809	3.463	3.174	2.930	2.721
45.5	3861	6.435	5.516	4.826	4.290	3.861	3.510	3.217	2.970	2.758
46.5	3914	6.523	5.592	4.892	4.349	3.914	3.558	3.262	3.011	2.796
47.5	3968	6.613	5.669	4.960	4.409	3.968	3.607	3.307	3.052	2.834
48.5	4023	6.705	5.747	5.029	4.470	4.023	3.657	3.352	3.095	2.874
49.5	4079	6.798	5.827	5.099	4.532	4.079	3.708	3.399	3.138	2.914

TABLE 3 cont'd.

%1/	λT μ°K	λ in Microns at Temperature in °K								
		600	700	800	900	1000	1100	1200	1300	1400
50.5	4136	6.893	5.909	5.170	4.596	4.136	3.750	3.447	3.182	2.954
51.5	4194	6.990	5.992	5.242	4.660	4.194	3.813	3.495	3.226	2.996
52.5	4254	7.090	6.077	5.318	4.727	4.254	3.867	3.545	3.272	3.039
53.5	4314	7.190	6.163	5.392	4.793	4.314	3.922	3.595	3.318	3.081
54.5	4377	7.295	6.253	5.471	4.863	4.377	3.979	3.647	3.367	3.126
55.5	4440	7.400	6.343	5.550	4.933	4.440	4.036	3.700	3.415	3.171
56.5	4505	7.508	6.436	5.631	5.006	4.505	4.095	3.754	3.465	3.218
57.5	4572	7.620	6.532	5.715	5.080	4.572	4.156	3.810	3.517	3.266
58.5	4640	7.733	6.629	5.800	5.156	4.640	4.218	3.867	3.569	3.314
59.5	4710	7.856	6.729	5.888	5.233	4.710	4.282	3.925	3.623	3.364
60.5	4782	7.970	6.832	5.978	5.313	4.782	4.347	3.985	3.678	3.416
61.5	4856	8.093	6.937	6.070	5.396	4.856	4.415	4.047	3.735	3.469
62.5	4932	8.220	7.046	6.165	5.480	4.932	4.484	4.110	3.794	3.523
63.5	5010	8.350	7.157	6.262	5.567	5.010	4.555	4.175	3.854	3.579
64.5	5091	8.485	7.273	6.364	5.657	5.091	4.628	4.242	3.916	3.636
65.5	5175	8.625	7.393	6.469	5.750	5.175	4.705	4.312	3.981	3.696
66.5	5262	8.770	7.517	6.578	5.847	5.262	4.784	4.385	4.048	3.759
67.5	5351	8.918	7.644	6.689	5.945	5.351	4.865	4.459	4.116	3.822
68.5	5444	9.073	7.777	6.805	6.049	5.444	4.945	4.536	4.188	3.889
69.5	5541	9.235	7.916	6.926	6.157	5.541	5.037	4.617	4.262	3.958
70.5	5641	9.401	8.059	7.051	6.268	5.641	5.128	4.701	4.339	4.029
71.5	5745	9.575	8.207	7.181	6.383	5.745	5.223	4.787	4.419	4.105
72.5	5854	9.756	8.363	7.318	6.504	5.854	5.322	4.878	4.503	4.181
73.5	5968	9.946	8.526	7.460	6.631	5.968	5.425	4.923	4.591	4.263
74.5	6087	10.145	8.696	7.609	6.763	6.087	5.533	5.072	4.682	4.348
75.5	6212	10.353	8.874	7.765	6.902	6.212	5.647	5.176	4.778	4.437

TABLE 3 cont'd.

%[1]	λT μ°K	λ in Microns at Temperature in °K								
		600	700	800	900	1000	1100	1200	1300	1400
76.5	6343	10.571	9.062	7.929	7.048	6.343	5.766	5.286	4.879	4.531
77.5	6482	10.803	9.260	8.102	7.202	6.482	5.893	5.401	4.986	4.630
78.5	6628	11.046	9.469	8.285	7.364	6.628	6.025	5.523	5.098	4.734
79.5	6783	11.304	9.690	8.479	7.537	6.783	6.166	5.652	5.218	4.845
80.5	6948	11.580	9.926	8.685	7.720	6.948	6.316	5.790	5.345	4.963
81.5	7123	11.871	10.176	8.904	7.914	7.123	6.475	5.936	5.479	5.088
82.5	7311	12.185	10.444	9.139	8.123	7.311	6.646	6.092	5.624	5.222
83.5	7514	12.523	10.735	9.392	8.349	7.514	6.831	6.261	5.780	5.367
84.5	7732	12.886	11.046	9.665	8.591	7.732	7.029	6.443	5.948	5.523
85.5	7969	13.281	11.385	9.961	8.854	7.969	7.245	6.641	6.130	5.692
86.5	8228	13.712	11.755	10.285	9.142	8.228	7.480	6.856	6.329	5.877
87.5	8513	14.188	12.162	10.641	9.459	8.513	7.739	7.094	6.548	6.081
88.5	8829	14.714	12.613	11.036	9.810	8.829	8.026	7.357	6.791	6.306
89.5	9183	15.304	13.119	11.479	10.203	9.183	8.348	7.652	7.064	6.559
90.5	9583	15.971	13.690	11.979	10.648	9.583	8.712	7.986	7.371	6.845
91.5	10042	16.736	14.346	12.552	11.158	10.042	9.129	8.386	7.725	7.173
92.5	10577	17.628	15.110	13.221	11.752	10.577	9.615	8.813	8.136	7.555
93.5	11215	18.524	16.022	14.019	12.461	11.215	10.195	9.345	8.627	8.011
94.5	11996	19.993	17.137	14.995	13.329	11.996	10.878	9.996	9.228	8.569
95.5	12990	21.649	18.558	16.238	14.433	12.990	11.809	10.825	9.992	9.278
96.5	14327	23.877	20.468	17.909	15.919	14.327	13.025	11.939	10.021	10.233
97.5	16295	27.157	23.279	20.369	18.105	16.295	14.814	13.579	12.535	11.639
98.5	19724	32.872	28.178	24.655	21.915	19.724	17.931	16.436	15.172	14.088
99.5	29372	48.951	41.961	36.715	32.635	29.372	26.702	24.476	22.594	20.980

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[1] The wavelength λ is chosen so that the indicated percentage of blackbody radiation occurs at wavelengths shorter than the indicated wavelength. Expressed mathematically

$$\frac{\int_o^{\lambda} E_{B\lambda} d\lambda}{\int_o^{\infty} E_{B\lambda} d\lambda} \text{ X } 100 = \%$$

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