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WADC-TR-59-510
PART III

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STANDARDIZATION OF THERMAL EMITTANCE MEASUREMENTS

PART III. NORMAL SPECTRAL EMITTANCE, 800° - 1400°K

TECHNICAL DOCUMENTARY REPORT No. WADC-TR-59-510, PART III

MARCH 1962

DIRECTORATE OF MATERIALS AND PROCESSES
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

PROJECT No. 7360, TASK No. 73603

(Prepared under Contract No. AF 33(616)-61-02
by National Bureau of Standards, Washington, D. C.;
William N. Harrison, Joseph C. Richmond and Harold K. Skramstad, Authors)

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Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt. No. WADC-TR-59-510, Part III. STANDARDIZATION OF THERMAL EMITTANCE MEASUREMENTS Pt. III. Normal Spectral Emittance, 800° - 1400°K. Interim Rpt, March 1962, 39p incl. illus., tables.
Unclassified report

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2. Spectral emittance
3. Optical system
I. AFSC Project 7360 Task 73603
II. Contract AF 33 (616)-61-02
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blackbody furnace.
Equipment for automatic recording of spectral data in a form suitable for direct entry into an electronic computer, and on-line computation of total emittance or solar absorptance, was designed.
Working standards of normal spectral emittance were prepared and calibrated.
An equation relating the normal spectral emissivity to five other parameters of a metal was solved "by hand" for one set of data. Some progress was made in setting up a program for solution of the equation by use of an electronic computer.

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Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt. No. WADC-TR-59-510, Part III. STANDARDIZATION OF THERMAL EMITTANCE MEASUREMENTS Pt. III. Normal Spectral Emittance, 300° - 1400°K. Interim Rpt, March 1962, 39p incl. illus., tables.
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FOREWORD

This report was prepared by the National Bureau of Standards under USAF Contract No. AF (33-616)-61-02, and Amendments 1 and 2 to that contract, and is a continuation of the work initiated under Project No. 7360, "Materials Analysis and Evaluation Techniques", Task No. 73603 "Thermodynamics and Heat Transfer", on Contract No. AF (33-616)-58-20. The contract was administered under the direction of the Directorate of Materials and Processes, Deputy for Technology, Aeronautical Systems Division, with Mr. R. A. Winn acting as project engineer.

This report covers work performed during the third year on the project, from 1 July 1960 through 30 June 1961.

ACKNOWLEDGEMENTS

The authors are pleased to acknowledge the contributions of the following persons:

F. J. Shorten, working with Harrison and Richmond in the Mineral Products Division of NBS on development of equipment and procedures (other than data processing) and on preparation and calibration of working standards.

Horace S. Joseph, working with Skramstad in the Data-Processing Systems Division on development of data-processing equipment.

ABSTRACT

The equipment for direct measurement of normal spectral emittance was extensively modified by incorporation of a new external optical system that increased the amount of radiant energy available for measurement by a factor of about 10, and other associated changes. The test procedure was modified by incorporation of a "zero line" correction. The equipment was calibrated by means of sector-disc attenuators which passed known fractions of the radiant flux from a blackbody furnace.

Working standards of normal spectral emittance were prepared, calibrated, and shipped, by arrangement with the sponsor, to the Boeing Airplane Company.

An equation relating the normal spectral emissivity of a metal to five other parameters of the metal, each of which makes a non-linear contribution to the emissivity, was solved for one set of data by "long hand" methods. Some progress was made in setting up a program for solution of the equation by use of an electronic computer. Application to platinum and other noble metals is the goal.

Equipment for the automatic recording of spectral emittance data in a form suitable for direct entry into an electronic computer, and on-line computation from spectral emittance data of total emittance or solar absorptance, was designed. Specifications for the equipment were prepared and bids received preparatory to placing an order for its procurement.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Jules I. Wittebort

J. I. WITTEBORT
Chief, Thermophysics Branch
Physics Laboratory
Directorate of Materials & Processes

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I. OBJECTIVES

The broad objective of this project is to develop standard procedures, and to select or design suitable equipment, for the measurement of spectral emittance 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 visible radiation to 15 microns or beyond. The specific objectives also include (1) the design or selection of suitable electronic data-processing equipment for on-line or off-line computation, from spectral emittance or reflectance data of (a) total emittance, (b) solar absorptance or (c) absorptance for radiant energy having any other known spectral distribution of flux; and (2) the selection of suitable materials and the preparation and calibration of specimens as working standards of spectral emittance, to be used for calibration of spectral emittance equipment by several different laboratories.

II. COMPONENT PARTS OF THE INVESTIGATION AND ORDER OF PRIORITY

The general objective of this project covers a range of conditions so broad that significant progress on all phases of the work could not be made in a single year with the facilities available. The temperature range of interest can be conveniently divided into four smaller ranges, as follows: (1) below room temperature, (2) room temperature to 800°K (980°F), (3) 800° to 1400°K (980° to 2060°F) and (4) above 1400°K. In general, different equipment or techniques are required in temperature ranges having approximately these limits. The wavelength range of interest was also, for convenience, divided into three smaller ranges, as follows: (1) from about 0.3 microns to about 1.5 microns, (2) from 1.5 microns to 15 microns, and (3) 15 to 35 microns. Again different items of equipment, including prisms and detectors, are required in the different wavelength ranges. A third separation can be made on the basis of the type of specimen to be evaluated, as follows: (1) metals and other materials that can be heated by passing a current through them, and (2) materials, such as ceramics, that cannot be heated by passing a current through them.

Physical working standards of normal spectral emittance of each type are to be selected and calibrated for use in each of the temperature and wavelength ranges mentioned above. The preparation of such working standards must, of course, follow the development of the techniques of measurement in each range. Likewise, the incorporation of data-processing equipment also will logically follow the development and standardization of equipment and techniques.

Priority was assigned to the wavelength range of 1.5 to 15 microns, the temperature range of 800° to 1400°K (980° to 2060°F), and to specimens that can be heated by passing a current through them, as being the ranges of

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greatest current interest to the Air Force. Secondary priority was given to the wavelength range of 0.3 to 1.5 microns, and to measurements at room temperature in the wavelength ranges of 1.5 to 15 microns and 0.3 to 2.5 microns.

III. SUMMARY OF PREVIOUS WORK

In the first annual report on this project the principles governing emission, transmission, reflection and absorption of radiant energy were briefly reviewed; definitions of pertinent terms were given, and mathematical relationships between properties and quantities that are involved in the project were presented.

A double-beam, ratio-recording infrared spectrometer was modified so that it would compare radiant flux in beams emitted (1) by a laboratory blackbody furnace and (2) by a specimen at the same temperature, and record automatically a curve of normal spectral emittance of the specimen as a function of wavelength drum position, which position is a non-linear function of wavelength. Also, equipment for evaluating spectral reflectance over the wavelength range of 1 to 15 microns was designed, and most of the components were procured or ordered. Preliminary designs of equipment were formulated for the automatic data-processing equipment to record the spectral emittance data in a form suitable for direct entry into an electronic computer, and for the on-line, automatic processing of the data to obtain a single value of total emittance or absorptance for solar radiation or radiation from any other source for which the spectral distribution of flux is known. Materials were selected by elimination tests for use in preparing working standards of normal spectral emittance.

During the second year of the project, the equipment developed during the first year was further modified to increase precision and reduce errors in measurement, as described in WADC Technical Report 59-510 Part II. One such modification was to provide means whereby a reference blackbody furnace and the hot specimen could be interchanged at will, each providing a source of radiant flux to be measured relative to that from the comparison blackbody furnace. The ratio of the apparent emittance of the specimen to that of the reference blackbody furnace at each of 100 selected wavelengths was then computed to obtain the corresponding spectral emittance of the specimen. Assembly of the equipment for measuring spectral reflectance of specimens at room temperature, under conditions approximating normal illumination and hemispherical viewing, was completed.

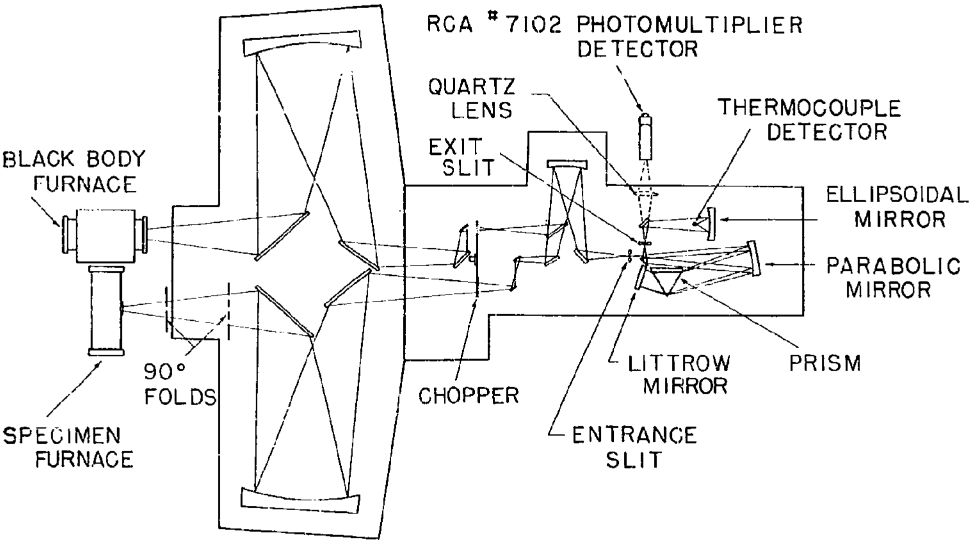
IV. STATUS OF WORK ON THE PROJECT

A. Normal Spectral Emittance Equipment

1. Transfer Optical System

a. External Optical System. A new external optical system was installed on the normal spectral emittance equipment. This replaced the external optical

system which was designed and built at the National Bureau of Standards to permit direct comparison of the radiant flux emitted by a hot specimen with that emitted by a laboratory blackbody furnace at the same temperature. Figure 1 is a sketch, approximately to scale, of the optical paths in the modified equipment.



TOP VIEW OF OPTICAL SYSTEM

Figure 1. Sketch of the optical paths in the normal spectral emittance equipment.

The focusing mirrors in the new system are 254 mm in diameter and have a focal length of 421.5 mm, compared to a diameter of 88.9 mm and a focal length of 457.2 mm for the focusing mirrors in the previous system. The increase in the numerical aperture of the focusing mirrors will result in about a ten-fold increase in radiant flux density of the image formed on the entrance slit of the monochromator, other things being equal.

The new optical system has the advantage that the Nernst glower source and associated optics, used with the standard monochromator for absorption measurements, need not be disturbed. The instrument can be converted back and forth for use in emittance and transmittance measurements within a few minutes. This facility is important in expediting required checking and servicing of the spectrometer, because most of the routine checks and adjustments must be made with a single source supplying energy to the two beams of the instrument. Prior to incorporation of the present external optics, the preparatory operations required before making the needed checks and adjustments consumed quite significant amounts of time.

b. New Furnace Mounts. The first focal points of the respective beams of the spectrometer with the new transfer optical system are only about three inches apart. The hot specimen and the aperture of the laboratory blackbody furnace had previously been centered on the respective foci for the two beams. Because of space limitations, this design could not be retained. The optical path of the specimen beam was modified by introducing two plane mirrors, each mounted at 45° to the optical plane of the spectrometer, to produce two 90° folds, 9 inches apart, one directly above the other. The lathe bed and sliding table which supports the reference blackbody furnace and the specimen furnace were mounted above the optical plane of the instrument, so that either the hot specimen or the aperture of the reference blackbody furnace could be positioned at the first focus of the modified specimen beam. Figure 2 is a photograph of the transfer optical system with covers removed, showing the two 45° mirrors and the three furnaces.

There are two more mirrors in the specimen beam than there are in the comparison beam, with the modified transfer optical system, but the paths of the two beams are of the same length. Some absorption will occur at the two additional mirrors, which, however, will not introduce a significant error into the measured emittance because the ultimate comparison is being made between the hot specimen and the reference blackbody furnace, both of which supply radiant energy to the specimen beam.

The plate on which the new transfer optical system is mounted overhangs the end of the console on which the spectrometer is mounted by more than three feet. The resulting instability was corrected by rigidly supporting the entire apparatus from the concrete floor of the laboratory. Four planer jacks were used to support the console, and four jack posts were used to support the overhanging plate. The positions of the spectrometer and the overhanging plate were then adjusted by means of the eight jacks and a highly sensitive machinist's level.

c. Alignment and Maintenance of Spectrometer. At the time the new transfer optical system was installed by an engineer representing the manufacturer, the entire spectrometer was inspected by him, the optical system was carefully aligned, the chopper synchronization was adjusted, and all worn and defective parts were replaced. These included: (1) entrance and exit slits to the monochronometer; (2) a slit micrometer; (3) an off-axis paraboloid mirror; (4) an autotransformer to supply power to the Nernst glower source; and (5) all tubes in the electronic circuits. The thermocouple detector was overhauled.

2. Furnace Modifications

a. Rebuilding Blackbody Furnaces. The laboratory blackbody furnaces were originally constructed with cores machined from rolled Inconel rod. These cores were satisfactory except for a tendency toward continued oxidation when operated for extended periods at 1400°K. The oxide that formed on the inside of the cavity tended to flake from the metal on cooling, and had to be removed every few weeks.

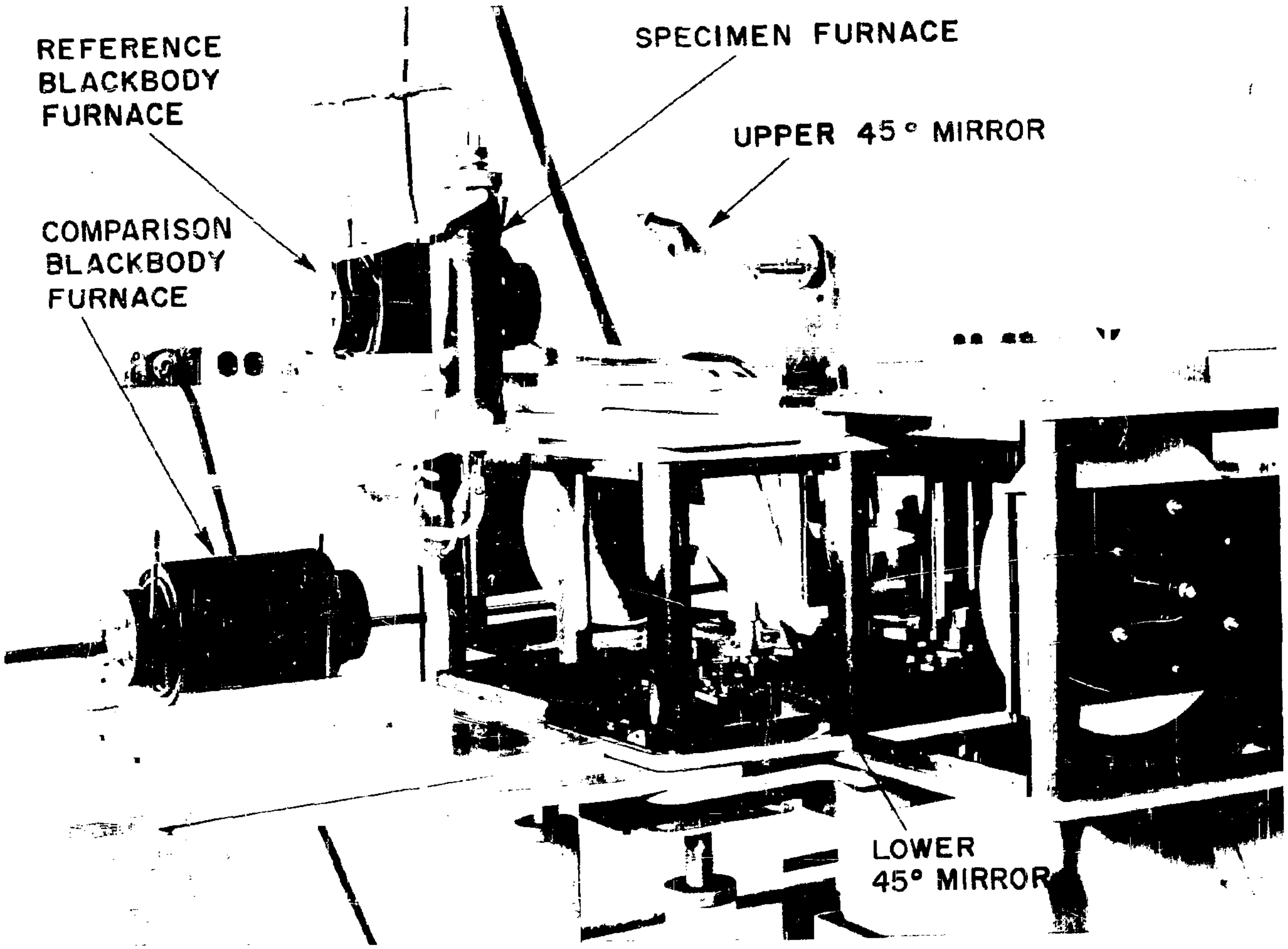


Figure 2. Photograph of the transfer optical system of the normal spectral emittance equipment, showing the blackbody and specimen furnaces. The specimen furnace is in position to supply radiant energy to the specimen beam of the spectrometer.

In an effort to reduce the oxidation rate, new cores were cast from an 80 nickel-20 chromium alloy. This alloy is reported in the literature to have better oxidation resistance at 1400°K than Inconel (nominally 80 nickel, 14 chromium and 6 iron), and to form a tightly-adherent oxide layer, in air. Tests made on oxidized sheet metal specimens showed that, when the oxide layer is fully opaque, the oxidized 80-20 alloy has almost as high an emittance as oxidized Inconel.

The 80-platinum, 20-rhodium heating coils of the blackbody furnaces were also replaced. The length of the coils and the location of the taps on the coils, to which are attached the variable-resistor shunts used to reduce the thermal gradients in the cavity, were relocated to facilitate further reduction of gradients.

Parts for a spare laboratory blackbody furnace were procured, and the furnace is to be constructed.

b. Rebuilding Specimen Furnace. The specimen-furnace electrodes and mounts were modified to permit more convenient mounting of specimens.

The gold-plated copper radiation shields in the specimen furnace that are used to reduce heat loss at the ends of the 1/4 - by 8-inch strip specimen became overheated and badly oxidized during heating of oxidized Inconel specimens to 1400°K. These shields were temporarily replaced by Inconel shields lined with polished platinum foil, and permanently replaced by solid platinum radiation shields.

c. Furnace Control System. All of the power supply and control components for the specimen furnace and the two laboratory blackbody furnaces were previously located in three separate small chassis and one large relay rack. The components from the three small chassis were mounted in a second large relay rack, and the control circuit wiring was simplified.

Power to the comparison blackbody furnace is supplied by means of a manually-adjusted autotransformer. Power to the reference blackbody furnace can be supplied by either a manually-adjusted autotransformer or through the temperature control equipment. The reference blackbody can be shifted from one power supply to the other by transferring a plug from one socket to another. Power to the specimen furnace is supplied through the temperature control equipment.

Permanent wiring for the thermocouple circuits was provided from terminals at each furnace to a plug-board on the temperature control chassis. Thus it is possible to shift back and forth between the thermocouple connections for the control of different furnaces by changing the plugs in the jacks on the plug board; it is also possible to connect the thermocouple in any one of the furnaces directly to a portable potentiometer for direct temperature measurement.

d. Temperature Control. Periodic difficulty has been encountered, which apparently resulted from pickup of an a.c. voltage by the differential thermocouple. This stray electric field appeared to be associated with electrical leakage of the insulation at the temperature of operation of the furnace. Most of the trouble was eliminated by grounding the metal cores of the blackbody furnaces, as described in previous reports. The remaining pickup appears to have been eliminated by inserting a grounded platinum tube between the metal core of each furnace and the porcelain thermocouple insulation.

It was noted that there was occasionally some slight contamination of the thermocouple welds from the copper electrodes of the spot welder. Also, at some settings of the spot welder controls, there was a tendency for the thermocouple wires to stick to the copper electrode. Platinum electrodes were tried, but were found to be unsuitable because of sticking. Sticking and contamination during welding have been virtually eliminated by use of tungsten welding electrodes, and the quality of the welds produced has been enhanced.

Erroneously high values of normal spectral emittance, above 1.0, were observed in a few cases on specimens of oxidized Inconel. Investigation revealed that the true temperature difference between the comparison blackbody furnace and specimen as observed by comparative optical pyrometer readings corrected for emittance of the oxidized metal specimen, was considerably larger than that indicated by the differential thermocouple. Any error in these readings was not large enough to invalidate the finding mentioned above. This discrepancy has not been observed on specimens of other metals, and only occasionally on oxidized Inconel. The reason for the discrepancy is under continuing study, but has not as yet been definitely ascertained. Meantime, as a precautionary measure, the temperature of the hot specimen and the comparison blackbody furnace are compared with an optical pyrometer before and after each determination, and no observable temperature difference is tolerated.

e. Safety Features. One of the blackbody furnaces became overheated during a week end due to stoppage of the cooling water. The overheating caused (1) leakage in the water-cooled shell, due to melting of solder at joints, (2) excessive oxidation of the core, and (3) deterioration of the heating coil. The damaged furnace was rebuilt, and the following safety features were incorporated into the cooling water system.

> (a) Metal-contact needle valves had been specified for control of flow rates, but it was found that the contractor had installed a type of valve having a fiber seat. The flow rate through these valves was found to decrease with time, due to swelling of the fiber. The fiber-seat valves were retained for use as on-off valves, but new metal-seat needle valves were installed between the on-off valves and the furnaces, for use in adjusting flow rates.

(b) Flow-rate control valves were installed on the outlet line of each furnace. These valves are adjusted to cut off the power to the furnace if the flow rate of cooling water from the furnace drops below 0.1 gallon per minute.

(c) Limit controls have been procured for use on the furnaces. The control will cut off the power to a furnace if its temperature exceeds the preset limit.

3. New Detectors

The spectrometer was originally equipped with (1) a thermocouple detector, which was recommended by the manufacturers for use over the wavelength range of approximately 2 to 40 microns, and which could be used with reduced sensitivity at wavelengths as short as 0.5 micron, and (2) a photomultiplier detector (1P21) which was recommended for use in the wavelength range of approximately 0.4 to 0.55 micron. It had originally been hoped that the ranges of sensitivity of these detectors would overlap with sufficient minimum sensitivity. However, the amount of radiant energy emitted by specimens at the lower temperatures (800°K or below) having wavelengths below about 1.5 microns was so small that very wide slits and high amplifier gains had to be used, with the result that a low signal-to-noise ratio resulted. Several new detectors were procured, in order to cover adequately the wavelength range from 0.23μ to 2.0μ.

a. Lead Sulfide Detector. A lead sulfide detector, together with mounting bracket and associated optics, was procured and installed in the normal spectral emittance equipment. This detector has appreciably higher response than the thermocouple detector in the range of about 1.0 to 2.5 microns when used with the fused silica prism.

b. 1P28 Photomultiplier Tube. This detector, which can be used interchangeably with the 1P21 photomultiplier tube, has adequate sensitivity in the 0.23 to 0.55 micron range; it is now being used in place of the 1P21 tube, which was not satisfactory at wavelengths below 0.4 micron.

c. 7102 Photomultiplier Tube. This detector was procured to cover the gap between the 1P28 photomultiplier tube and the lead sulfide detector. It is reported by the manufacturer to have maximum sensitivity in the range of 0.7 to 0.9 microns, and usable sensitivity in the range 0.55 to 1.0 microns. Tests have indicated that these limits are conservative.

d. English Photomultiplier Tube. It was reported that a 9529B photomultiplier tube manufactured in England gives adequate response over the wavelength range of 0.5 to 1.5 microns. In order to confirm this report, a tube was ordered, but the manufacturer reported that this tube has been discontinued. However, another tube having nearly the same response range was recommended, and has been ordered. If tests confirm the reported range, the tube may replace both the lead sulfide and 7102 detectors, thus eliminating time loss in changing from one of the latter detectors to the other.

4. Controlled Atmosphere Enclosure

Previous work with the normal spectral emittance equipment indicated the desirability of working in a controlled atmosphere consisting of a non-absorbing gas. The principal absorbing gases in the normal atmosphere are carbon dioxide and water vapor. Super-dry nitrogen was used as the non-absorbing atmosphere.

A gas-tight enclosure for the entire normal spectral emittance equipment was designed and installed. Because trouble has been encountered occasionally from scattered light getting into the monochromator, the top of the enclosure was made completely opaque.

5. Humidity Control of Room Air

Water vapor in the room atmosphere is undesirable from the standpoint of absorption. If the relative humidity becomes very high, condensation will occur on cooling water lines, and sodium chloride and cesium bromide windows and prisms may be fogged. In order to prevent such condensation and fogging, as well as to reduce the time required for flushing when using controlled atmosphere, the air conditioning equipment in the laboratory housing the normal spectral emittance equipment was modified to incorporate humidity control. The air-conditioning equipment is now designed to maintain the room air at 74°F and 40% relative humidity.

6. Calibration of Instrument

a. Wavelength Calibration of Prisms. The wavelength calibration of the sodium chloride prism was checked after installation of the new transfer optical system. It was found that the wavelength calibration was essentially unchanged from that previously obtained.

After the optical elements had been realigned the fused silica prism was calibrated for use at wavelengths in the range of 0.25 to 2.5 microns. A mercury-vapor arc-lamp with a fused silica window was placed in position to supply radiant energy to the specimen beam of the spectrometer. The emission spectrum of the mercury lamp was recorded, and the peaks were identified. The known wavelength of each peak, taken from published tables, was plotted against the corresponding drum setting at which the peak was observed. Similar points were obtained by use of a helium-discharge lamp. A smooth curve was drawn through the resulting points to obtain the wavelength calibration curve of the prism.

b. Sector-Disc Attenuator. A sector-disc attenuator for use in calibrating the normal spectral emittance equipment was designed and built. The attenuator consists of a variable-speed motor, up to 4000 rpm, with an attenuator disc mounted on its shaft.

Five interchangeable attenuator discs were prepared, having nominal transmissions of 75, 50, 25, 12.5, and 5.0 percent respectively. The discs were machined from sheet aluminum, 0.065 inch thick. The 5% disc is 10 inches in diameter, and has four equally spaced radial notches, each 4.5° wide, extending inward from the rim for 3 inches. The other discs are 9 inches in diameter, and have eight notches each, extending inward from the rim for 2½ inches. The notches in the 75% disc are 33-3/4° wide; for the 50% disc, 22½° wide; for the 25% disc, 11¼° wide; and for the 12.5% disc, 5-3/8° wide.

The attenuator is normally operated at about 1300 rpm, and the direction of rotation is opposite to that of the spectrometer chopper. At this speed the beam is interrupted at a frequency of more than 85 cycles per second by the 5% disc, and more than 170 cycles per second by the other discs. The chopper in the spectrometer interrupts the beam at a frequency of 13 cycles per second. No coupling has been observed between the attenuator and chopper frequencies.

The attenuator discs were calibrated in the Engineering Metrology Section of NBS by measuring the angular width of the notches and blades on each disc, at two positions corresponding roughly to the radial positions at which the top and bottom, respectively, of the interrupted beam strike the discs when in use. The unobstructed area of the disc between the two circles was computed as a percentage of the total area between the circles, with the results shown below.

Nominal Transmittance %	Measured Unobstructed Area %
75	75.10 ± 0.02
50	50.00 ± 0.02
25	25.28 ± 0.14
12.5	12.73 ± 0.14
5	5.07 ± 0.03

The measured values were assigned to the respective sector-disc attenuators.

c. <u>Calibration of Detectors.</u> All of the work done with the spectrometer had been based on the assumption that the response of the instrument (the height of the recorded emittance curve above the recorded "zero curve") was linear with respect to (1) the radiant flux (within the varying wavelength interval encompassed by the exit slit) passing through the monochromator, when the instrument is operated single-beam in direct mode, or (2) the ratio of the fluxes (within the varying wavelength interval encompassed by the exit slit) in the respective beams that pass through the monochromator when the instrument is operated double-beam in ratio mode. This assumption had not previously been checked, and because of the deviations from flatness of the "100% curve" referred to in previous reports and in Section 10-7 of this report, a check of items (1) and (2) above was considered desirable.

The entrance and exit slits of the monochromator open and close simultaneously, and both are controlled at the same width by the slit micrometer. Because of this construction, when a true image of a source is formed at the entrance slit of the monochromator, somewhat larger than the slit at its maximum width, the radiant flux reaching the detector from the monochromator varies as the square of the slit width(neglecting any small variation in spectral distribution of flux that may occur within such restricted spectral limits).
This relationship was used to check the linearity of detector response when the instrument is used single-beam in direct mode (item (1) above). A single blackbody furnace, at 1400°K, was used as a source, and each series of measurements at varying slit widths was made at a single central wavelength. Measurements were made at a number of central wavelengths throughout the sensitive range of the thermocouple detector. Experimental results were in conformity with the theoretical relationship. In every case, when the height of the recorder curve was plotted against the square of the slit width, the points obtained with the sodium chloride prism and thermocouple detector fell on a straight line intersecting the origin, within the error of measurement.

Similar measurements were also made at several wavelengths when the spectrometer was operated with the fused silica prism and the lead sulfide detector. Again experimental results were in conformity with the theoretical relationship.

When the spectrometer was used with the fused silica prism and 1P21 detector, appreciable deviations from the theoretical relationship were found at first, but after careful realignment of the monochromator optics, all of the points again fell on a straight line, within experimental error.

In the next group of experiments, made for additional checking of item (1) above, the sector-disc attenuator was introduced into the beam near the blackbody furnace. Each series of measurements was made at a single wavelength, a single slit width, and a single gain setting. In each case the gain was adjusted to give a reading of slightly less than 100 units on the strip chart without the attenuator. The attenuator was then introduced into the beam, and operated with each of the discs in turn. The height of the recorder curve was plotted against the previously measured fraction of the beam passed by the attenuator. In every case the points fell on a straight line passing through the origin, indicating linear detector response for every combination of slit width and wavelength tested, with both the sodium chloride and fused silica prisms, and with the thermocouple, as well as the lead sulfide and photomultiplier detectors.

In the preceding experiments for which the instrument was being used in direct mode,with single beam, the height of the recorder curve varied linearly with the signal produced by the detector. This signal was proportional to the radiant flux passing through the monochromator. Normally, however, the instrument is used in ratio mode, with double beam. In this case the height of the recorder curve should vary linearly with the ratio of the two signals produced by the detector when it is receiving flux alternately from the respective beams.

In order to check item (2) above, the two blackbody furnaces, controlled very closely to the same temperature (about 1400°K), were used as sources for the two beams. The instrument was adjusted so that the "100% curve" would actually fall between 90 and 100 on the chart, after which such a curve was obtained over the wavelength range of interest. The sector-disc attenuator was then introduced into the specimen beam near the blackbody furnace, and operated with each of the discs in turn, to obtain "75%, 50%, 25%, 12.5% and 5% curves", each over the wavelength range of interest. The heights of the respective curves were then measured at 100 selected wavelengths, and the height of each curve above the experimentally obtained zero for the pertinent wavelength was plotted against the percentage of the flux in the specimen beam that was passed by the attenuator. In every case the points fell on a straight line intersecting the origin, within the error of measurement. No significant departures from linearity of response were detected for any combination of prism and detector, at any point within the wavelength range at which they could be used.

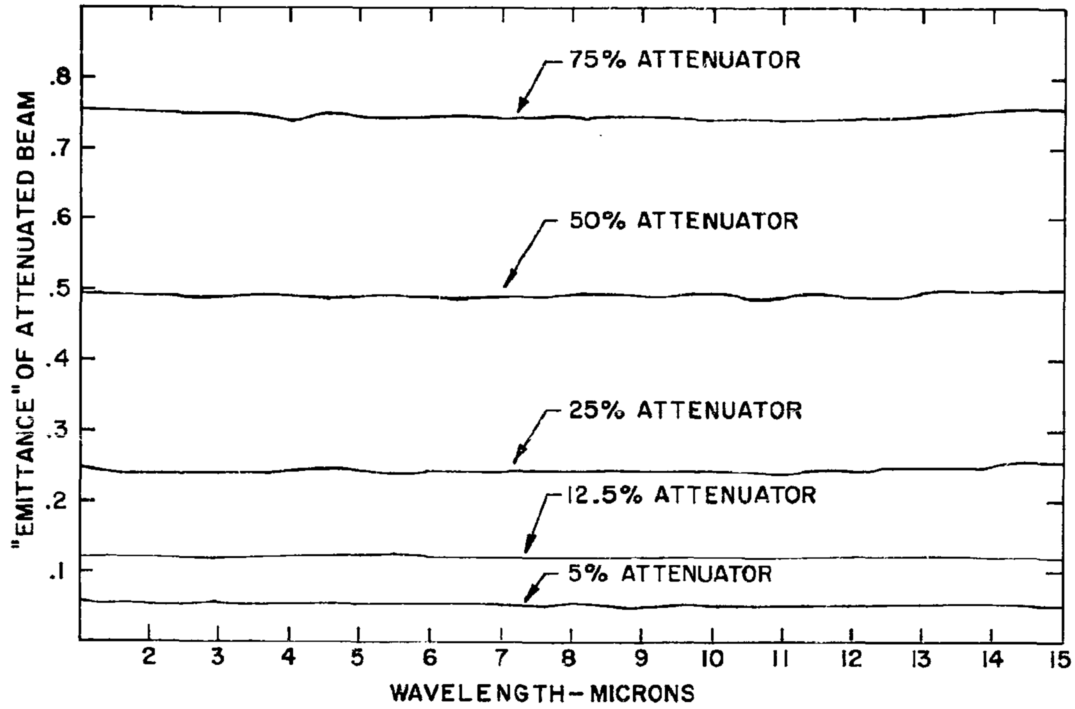


Figure 3. Apparent emittance of the combination of the reference blackbody furnace and sector-disc attenuator when using the 75%, 50%, 25%, 12.5% and 5% attenuator blades. Data are for the spectrometer with sodium chloride prism and thermocouple detector.

The data for the thermocouple detector and sodium chloride prism are shown in Figure 3. In this case the "apparent emittance" of the combination of the reference blackbody furnace and each attenuation disc is plotted as a function of wavelength. Every value of apparent emittance was within ±0.01 of the measured transmittance of the respective disc.

7. Modifications of Test Procedure

It was mentioned in WADC Technical Report 59-510 Part II that the "100% curve" deviated appreciably from flatness, and a test procedure was described to correct for these deviations, by taking the emittance at each point on the curve as the ratio of the height of the specimen curve to that of the "100% curve" at the same point. Prior to recording the respective curves, the instrument was set to read zero on the chart with the specimen beam blocked at the entrance to the combining optics. Experience had shown that the zero line obtained in this manner was flat over the entire range from 1 to 15 microns, and a complete "zero curve" was considered unnecessary.

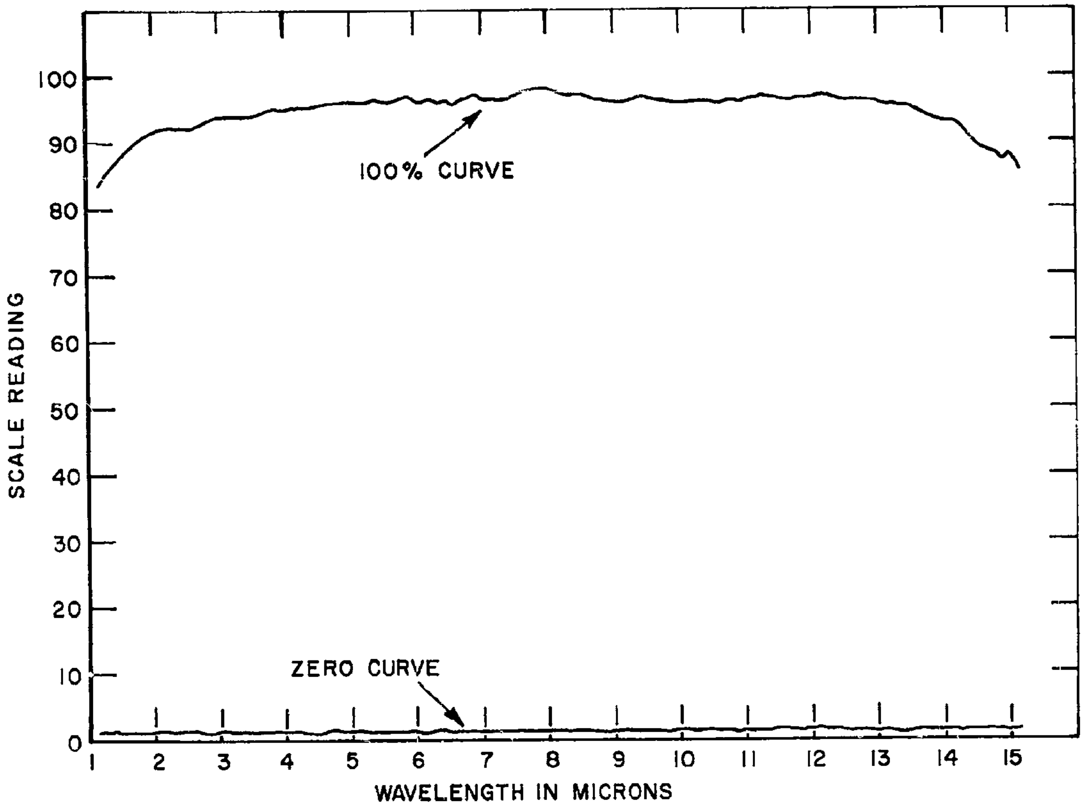


Figure 4. Typical "100%" and "zero" curves obtained when using the sodium chloride prism and thermocouple detector.

After installation of the transfer optical system, it was observed that the "zero curve" obtained by blocking the specimen beam near the source was not flat. The over-all deviation was on the order of 0.8 scale division. However, the curve was found to be reproducible to better than 0.2 scale division from one run to another. Typical "100% and "zero" curves are shown in Figure 4.

The test procedure was modified to include a "zero curve" correction as well as a "100% curve" correction. The procedure is as follows: (1) The two blackbody furnaces are placed in position to act as sources for the respective beams of the spectrometer, and are brought to the same temperature. (2) The "Full Scale" control of the spectrometer is adjusted to bring the "100% curve" to a position between 90 and 100 on the chart. (3) The specimen beam is blocked, and the "Ratio Zero" control on the spectrometer is adjusted to bring the "zero curve" to a position between 1 and 3 on the chart. The specimen beam is unblocked and the position of the "100% curve" is checked. The instrument settings remain fixed throughout the emittance determination on the specimen being tested. (4) The "100% curve", over the wavelength range of interest, is obtained by automatic recording of the strip chart. The chart paper is then rerolled. (5) The specimen beam is blocked near the source, and the "zero curve" is similarly obtained over the wavelength range of interest. The chart paper is then rerolled. (6) The specimen furnace is substituted for the reference blackbody furnace, and the specimen is brought to the temperature of the comparison blackbody furnace. The specimen beam is unblocked, and the "specimen curve" is obtained over the wavelength range of interest.

The heights of the respective curves are measured at preselected positions of the wavelength drum (corresponding to known wavelengths), and the normal spectral emittance is computed for each such wavelength. If Z_λ is the height of the "zero curve", S_λ the height of the specimen curve and H_λ the height of the "100% curve" at some wavelength λ, the normal spectral emittance, E_λ, is given by

$$E_\lambda = \frac{S_\lambda - Z_\lambda}{H_\lambda - Z_\lambda} \qquad [1]$$

Values of E_λ are computed for 100 wavelengths, and E_λ is plotted as a function of wavelength. A curve is drawn through the plotted points to represent the spectral emittance curve.

B. 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 Part II, and is shown in Figure 5.*

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*Construction and calibration of this equipment was financed in part by the Marshall Space Flight Center of NASA.

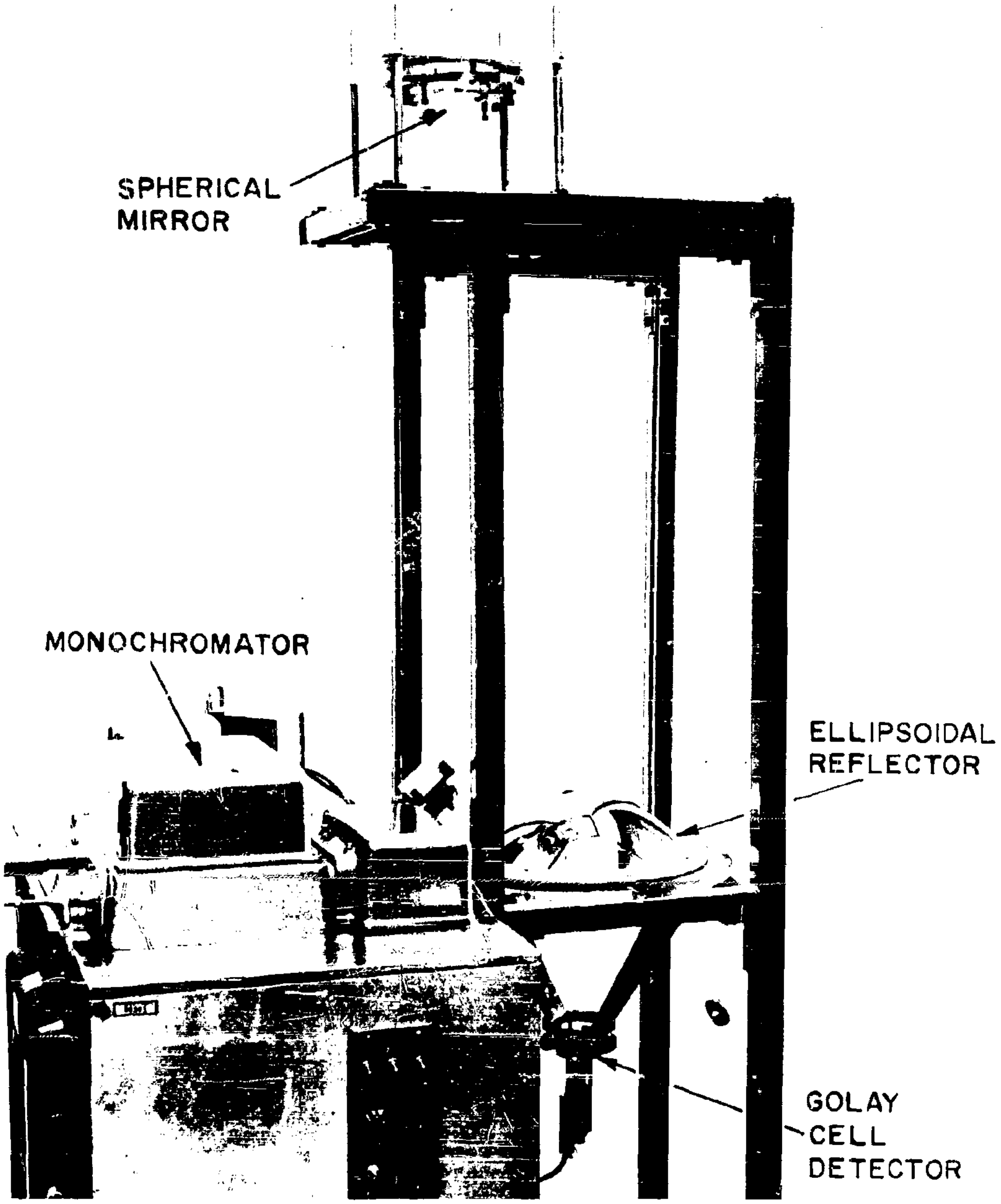

Figure 5. Photograph of the spectral reflectance equipment. The specimen is mounted at the first focus of the ellipsoidal reflector, and is hidden from view.

The Golay Cell detector used with the reflectance equipment requires a different amplifier than the one used with the thermocouple and photomultiplier detectors. The amplifier supplied with the detector did not have the marker circuit required for use with the wavelength drive. A suitable marker circuit was therefore incorporated into the amplifier.

When the work of calibrating the reflectance equipment was started, several malfunctions producing lack of sensitivity and high noise level of output signal were discovered. There was insufficient filtering in the power supply of the amplifier, which was corrected by adding additional filtering. Erratic response of the detector was traced to intermittent shorting of adjacent turns of the filament lamp. The trouble was corrected by replacing the lamp. The detector was found to be extremely sensitive to vibration. To reduce noise from this source to a tolerable level, vibration-dampening supports were installed. The receiver film of the detector failed, and was replaced by the manufacturer. All other malfunctions were corrected to the point that satisfactory results were obtained. The Golay Cell detector is so sensitive that any light in the room interferes with the measurements. So far, all work has been done in a darkened room. However, a light-tight cover for the equipment was designed and is under construction at this writing.

If the spectral reflectance data are to be used to compute solar absorptance, data are needed at wavelengths down to about 0.25 micron. If total emittance is to be computed, data are needed at wavelengths beyond 15 microns, as is indicated in the following table. For these reasons, it is planned to calibrate and use the spectral emittance equipment at wavelengths from 0.25 to about 36 microns, the longest wavelength at which a cesium bromide prism is recommended for use.

Wavelength limits, in microns, bracketing 98% of emitted flux

Temperature, °K	300	500	1000	1500	2000
99% of energy at $\lambda >$	4.8	2.9	1.45	0.97	0.72
99% of energy at $\lambda <$	76.2	45.8	22.90	15.30	11.40

Equipment for heating reflectance specimens to temperatures up to 600°K or above has been designed. Construction and installation of this equipment will await completion of the calibration at room temperature.

C. Equations Relating Spectral Emissivity of Platinum to Other Properties

Figure 6 is a spectral emittance curve for a specimen of platinum. Repeated experiments have confirmed the presence of the peak in emittance at about 0.4μ. This fact is not surprising, since it conforms in principle with a variety of well established data, much of which concern room temperature reflectance of metals. However, the formulation of equations whose loci incorporate such peaks and reversals is not a part of the usual mathematical treatment.

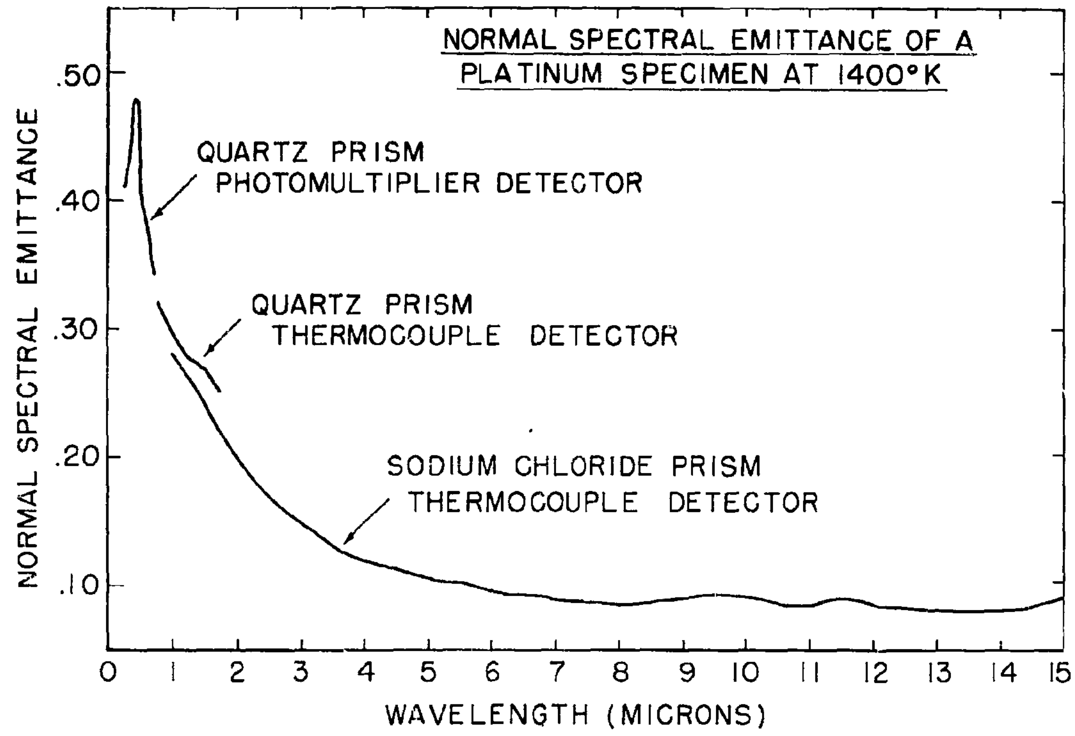

Figure 6. Normal spectral emittance of platinum at 1400°K. Note maximum at about 0.4 micron.

Previous reports[a/] in this series have referred to the use of an equation, based at least in part upon theoretical considerations, that yields a locus for the emissivity of metals - specifically platinum - as a function of wavelength. This equation was known to be applicable only at longer wavelengths. The equation used was the Schmidt & Eckert modification of Davisson and Week's equation, which in turn was evolved from a simpler expression by Hagen & Rubens. It was considered the best available expression for the longer wavelengths. The lower limit of applicability of this equation varies with the temperature, and is different for different metals. For platinum at 1400°K it is taken to be about 1.5 to 2.0 microns. For any wavelength, these equations (as well as those given later in this report) apply rigorously only to optically smooth specimens, and small-scale deviations of the surface may have an effect that increases with diminishing wavelength. An optically smooth surface is not retained by platinum and similar metals at 1400°K. However, a good fit of good data is attainable on reasonably smooth specimens.

[a/] Quarterly Report, NBS No. 6671, Oct. 1 - Dec. 31, 1959. Annual Summary Report WADC Tech. Rept. No. 59-510, Pt II, November 1960.

The wavelength interval between 0.2μ and 2.0μ brackets most of the solar energy, the absorption and reflection of which often plays a dominant role in the control of heat balance through thermal emission phenomena. Likewise it is the range within which the emissivity of many metals, including platinum, varies widely with wavelength. Therefore a satisfactory equation, applicable to metals within this wavelength interval, was sought, preferably one based upon the motions of charged "particles" within the metal as affected by incident radiation. The lightest ion is considered too massive to account for observed phenomena and the charged particles on which the equations are based are electrons. Free electrons (unbound electrons composing the "electron plasma" of a metal) exercise a dominant role in controlling the thermal emission properties of metals. (The term "thermal emission properties", as used here, refers to the identical fundamental characteristics that are covered by the term "optical properties", which is sometimes used in reference to metals as applicable to wavelengths far beyond the visible range.)

The Schmidt-Eckert equation provides for computing the spectral emissivity from the (d.c.) electric resistivity (resistance to motion of "free" electrons) over distances many times greater than those separating the crystal lattice sites. In this situation the metal may be considered to behave as a homogeneous material. But when the frequency of the radiant energy is high enough (its wavelength short enough) to reverse the direction of motion of the electrons within less distance than that separating atoms in the metal crystal, the response of the metal to the incident radiant energy may not conform to that of a homogeneous material.

The usual treatment of this latter phenomenon, as developed by Drude, Zener[b/] and others, is also confined to the behavior of free electrons, which behavior accounts for the rapid decline in the reflectance (increase in emittance) of metal specimens as the wavelength of the incident radiation is decreased within this interval of relatively short wavelengths. But this treatment takes no cognizance of the inflections in the spectral emittance (or reflectance) curves of metals that occur within this wavelength interval. Its users have pointed out that the bound electrons must have an effect, but that the quantitative treatment of this effect by quantum theory would be prohibitively difficult.

A less complicated approach has been attempted by several investigators and one of these, which has not been confined to the status of a semi-private report or thesis, is included in a published book on radiation phenomena[c/].

[b/] "Lehrbuch der Optik", translated by Mann and Millikan in 1902. "The Theory of the Properties of Metals and Alloys", Mott & Jones, Clarendon Press, Oxford, England, 1936.

[c/] "Radiation Pyrometry and its Underlying Principles of Radiant Heat Transfer", by T. R. Harrison, John Wiley & Sons, 1960.

The treatment presented therein is based upon classical electron theory, and accounts for the inflections or "humps" that interrupt the smooth sweep of the curves for spectral emittance of metals within or near the range of visible wavelengths. These inflections are accounted for by the resonance of certain categories of bound electrons. The conditions required for resonance include the existence of a restoring force, and the bonds of the affected electrons to the nuclei provide this restoring force. The natural frequency of a given category of bound electrons determines the principal frequency of the absorption band which is manifested by higher absorptance and emittance, with correspondingly lower reflectance than would otherwise be exhibited by the metal at these wavelengths.

The equations in the referenced book by T. R. Harrison, which were not solved for specific data, are not limited in their application, as to wavelength interval or type of material (conductor vs dielectric) or type of charged particle that resonates. These equations may be written in various forms which are convenient in particular applications. The forms convenient for the case at hand are as follows:

$$n^2 (1 - \varkappa^2) = 1 + \frac{G_a (\omega_a^2 - \omega^2)}{(\omega_a^2 - \omega^2)^2 + \omega^2 h_a^2} - \frac{G_e}{\omega^2 + h_e^2} \qquad [2]$$

$$2n^2\varkappa = \frac{G_a \omega h_a}{(\omega_a^2 - \omega^2)^2 + \omega^2 h_a^2} + \frac{G_e h_e}{\omega^3 + \omega h_e^2} \qquad [3]$$

The first terms pertain to the bound electrons, denoted by the subscript (a), and the last terms pertain to free electrons, denoted by the subscript (e). The latter terms comprise the usual mathematical treatment. The angular frequency of the radiant energy, radians per second, is signified by ω, and ω_a is the natural frequency of the bound electrons that resonate when ω and ω_a are equal or nearly so. $G = 4\pi N\xi^2/m$, where N denotes the number of affected electrons per unit volume, ξ is the charge of an electron, and m is the mass of an electron. Appendage of a suitable subscript to G indicates its applicability to bound or free electrons, as the case may be. The damping forces are signified by h, with appropriate subscripts for bound and free electrons respectively. The symbol n is used as usual for index of refraction (not the complex index used for metals) and $\varkappa$ is the absorption index (not absorption coefficient). The product $n\varkappa$ is the extinction coefficient. When this product is given the symbol k, the complete Fresnel equation relating these properties for a non-transmitting specimen may be written as follows:

$$E' = 1 - R' = \frac{4n}{(n + 1)^2 + k^2} \qquad [4]$$

where E' and R' stand for spectral emittance and reflectance, respectively (consistent with previous reports in this series). In this equation, E' and R', n, and k are all functions of wavelength, and hence of frequency, ω.[d]

The simplified form of the Fresnel equation that does not include extinction coefficient, which is commonly used for computations involving glass and visible radiation, does not apply when absorption is important, as it is for a metal or for glass at long wavelengths at which it does not transmit.

The parts of equations [2] and [3] to the right of the equality signs contain five parameters to be evaluated, all of which make nonlinear contributions to the spectral emittance (or reflectance) curve of the specimen. The computation of these parameters from data, and their use through equation [4] to obtain a computed spectral emittance curve for the specimen yielding the data, is somewhat involved, and must be approached by the method of approximation.

A "longhand" solution for the values of all five parameters, for a particular set of data, was provided the Applied Mathematics Division, with the request that procedures be developed for using a digital computer such as IBM 704 in attaining the best fit for all points in a given set of data (within the wavelength interval where large variations in the thermal emittance of metals occur). The objectives are (a) to obtain more precise values for the parameters than can be attained feasibly without automatic computers, and (b) to reduce the quantity and level of individual effort required, sufficiently to make the whole operation widely usable.

A satisfactory program for electronic computers for the mathematical process followed in the "longhand" solution referred to above was not accomplished during a period of several months (part-time effort) prior to departure of the mathematician from the staff of NBS. The next approach was designed[e] to simulate the effects of free and bound electrons of a metal in an analog computer. A program or "hook-up" was prepared and patchboard connections made. This approach was investigated during a period of several weeks at the end of which the designer of the hook-up for the analog computer also left the Bureau staff.

At this juncture, an approach was introduced which holds promise of significantly reducing the initial and eventual effort required for fulfillment of the plan, and which would greatly facilitate the mathematical handling, as

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[d] Rigorously, the equation applies to optically smooth specimens that do not transmit any incident radiant energy, and the properties are "emissivity", E_∞, and "reflectivity", R_∞. These terms are, however, special cases of "emittance" and "reflectance." (See WADC Tech. Rept. 59-510, Page 4.)

[e] By Dr. H. K. Skramstad, Assistant Chief, Data Processing Systems Division.

well as programing for solution by computers. This latest approach is based upon the assumption that the d.c. electrical conductivity of a metal provides certain information, and the pertinent parameters, concerning the behavior of free electrons, which is applicable to alternating fields not only at wavelengths as low as 1½ to 2 microns (in the case of platinum) but also for shorter wavelengths at which the inflections in the emittance or reflectance curves occur. The validity of this assumption was under investigation at the close of the report period. If it proves to be essentially correct the consequent reduction in the number of unknowns to be handled will constitute an important facilitation of the task that was undertaken.

D. Calibration of Working Standards of Normal Spectral Emittance

1. Working Standards For Boeing Airplane Co.

At the request of WADD, working standards of emittance were prepared and shipped to the Boeing Airplane Co., Seattle, Washington. Two standards were prepared, one of platinum-13% rhodium alloy and one of oxidized Inconel. Each of these working standards was in the shape of a disc, and two specimens cut from adjoining areas of the same metal sheets were measured at the National Bureau of Standards; the latter consisted of strips ¼ by 8 inches in size. The three specimens cut from each sheet of metal were subjected as nearly as possible to identical annealing and surface preparation. Figure 7 shows the relative positions of the three specimens in the original sheet of metal.

The 0.040-inch thick platinum-13% rhodium disc, 4½ inches in diameter, and the two ¼ by 8-inch strips, cut from the same sheet of alloy, were procured in the shapes described. The specimens had unsatisfactory surface condition when first delivered, and were sent back for reworking. When delivered the second time, the surface finish was still unsatisfactory but in the interest of saving time it was decided to polish them at NBS rather than return them again for reworking.

The platinum specimens were hand polished on No. 0 emery polishing paper with kerosene as a coolant and lubricant, then on the successively finer grit papers Nos. 2/0, 3/0 and 4/0. They were then lap polished on low nap rayon polishing cloths with 5μ αAl_2O_3, followed by final polishing with 0.1μ γAl_2O_3.

The polished platinum specimens were carefully washed with soap and water to remove all of the abrasive, then rinsed with distilled water and absolute ethyl alcohol. They were then cleaned ultrasonically in acetone, and allowed to dry.

The platinum specimens were placed in a cold furnace, surrounded by a porcelain and platinum muffle. The furnace was brought to 1523°K (2282°F) and held at that temperature for one hour, after which the specimens were allowed to cool in the furnace over night. The annealed disc specimen was then transferred directly to a specially machined plastic case in which it was supported at the periphery only, to minimize contamination. The strip specimens, similarly, were supported by the ends only during storage.

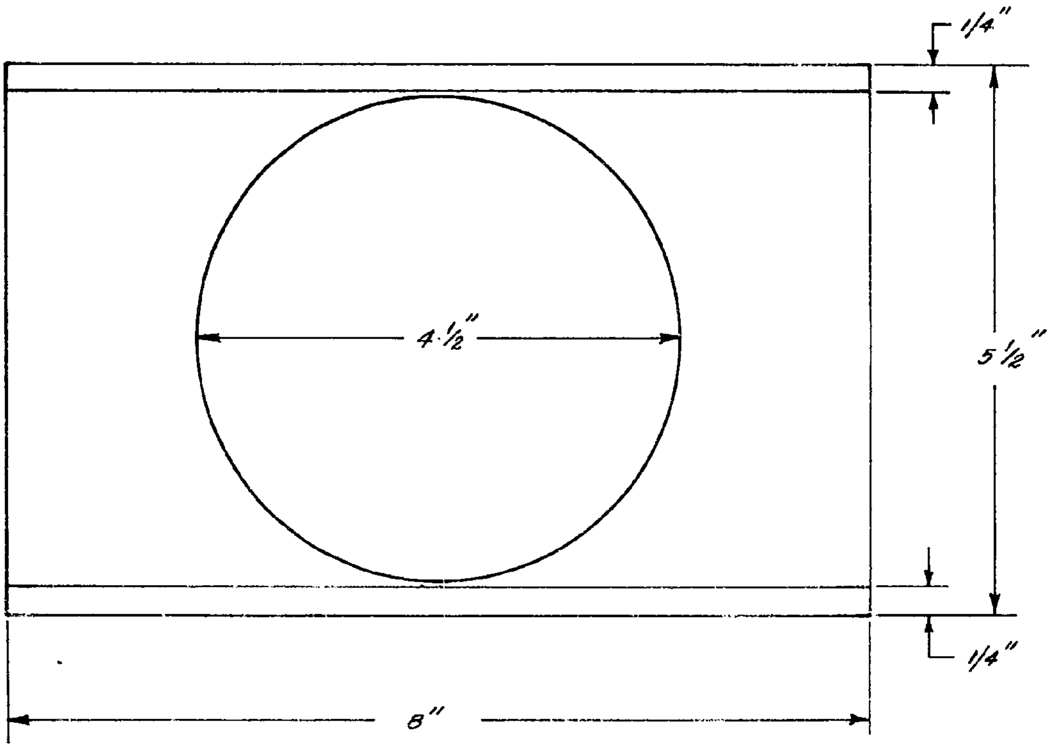


Figure 7. Sketch showing positions in the original sheet of disc specimen sent to Boeing Airplane Company and two strip specimens measured for emittance at the National Bureau of Standards.

A slightly modified procedure was used in preparing the oxidized Inconel specimens, from 0.052-inch sheet. A small hole was drilled near the edge of the 5-inch diameter disc, and near one end of each of the strips, to facilitate hanging them during oxidation. These specimens were blasted with 60-mesh fused alumina grit at an air pressure of about 70 psi. The grit-blasted specimens were rinsed in acetone, then cleaned ultrasonically in acetone, and dried. They were then hung on an alloy rack and inserted into a furnace that had been preheated at 1273°K (1832°F), and were allowed to oxidize in air atmosphere at that temperature for 10 hours, then cooled in air at ambient temperature. The disc specimen was transferred directly to the plastic storage case; the strip specimens were transferred to a closed cabinet, in which they were hung for protection from contamination. Before attachment to the furnace electrodes for testing, the oxide coating was ground from the ends of the strip specimens, to provide a good electrical contact, and from a small area at the center of the specimen at which the control thermocouple was welded. Handling of the strip specimens was kept to a minimum, the central portions were not touched, and surgical rubber gloves were worn while handling them, in order to eliminate any possibility of contamination of the surface by fingerprints.

The normal spectral emittance of the strip specimens of oxidized Inconel and platinum-13% rhodium alloy was measured at 800°, 1100° and 1400°K. Three determinations were made at each temperature, except for the platinum-13% rhodium specimens at 1400°K, where only two determinations (which agreed closely) were made.

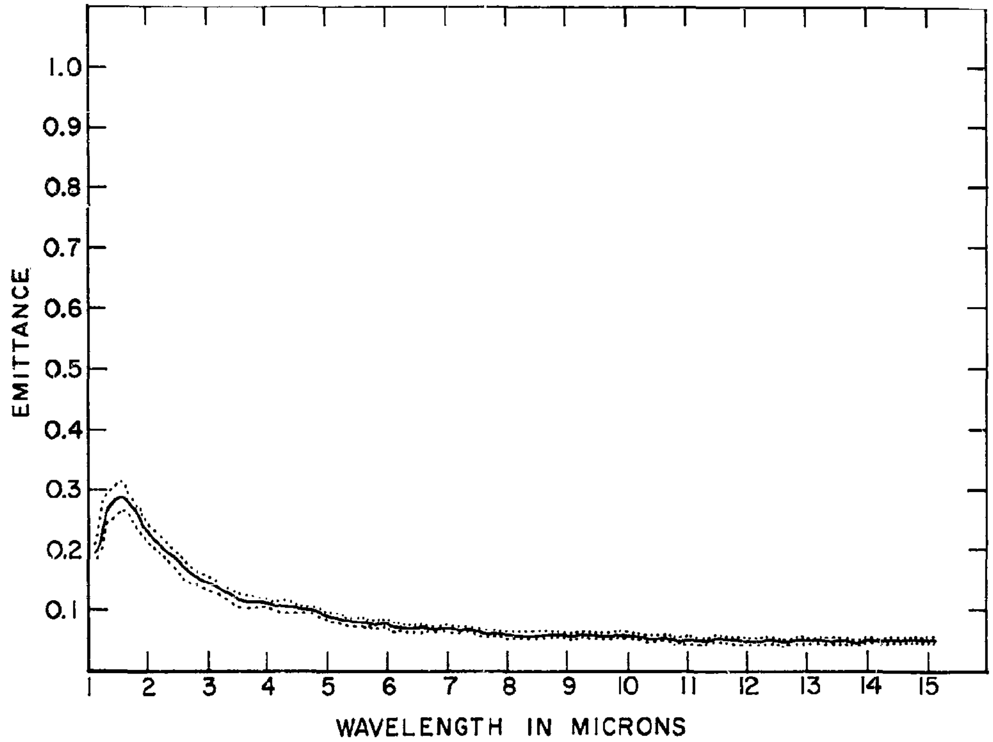


Figure 8. Average normal spectral emittance at 800°K of the strip specimens cut from the same sheet as the disc of platinum-13% rhodium alloy sent to the Boeing Airplane Company. The center curve is the average of six determinations, three each on two specimens, and the dotted curves are the limits of the average plus one standard deviation and the average minus one standard deviation, respectively.

Corrected values of emittance were computed at 100 points, selected at uniform increments of wavelength drum position, within the wavelength range of 1 to 15 microns. The corrected emittance values for two strip specimens of each material at each temperature (usually six values at each selected wavelength drum position) were then averaged, and their standard deviation was computed. As an indication of precision, values of the average plus one standard deviation and also the average minus one standard deviation were recorded. The three sets of emittance values were then plotted as a function of wavelength to produce the curves shown in Figures 8 through 13.

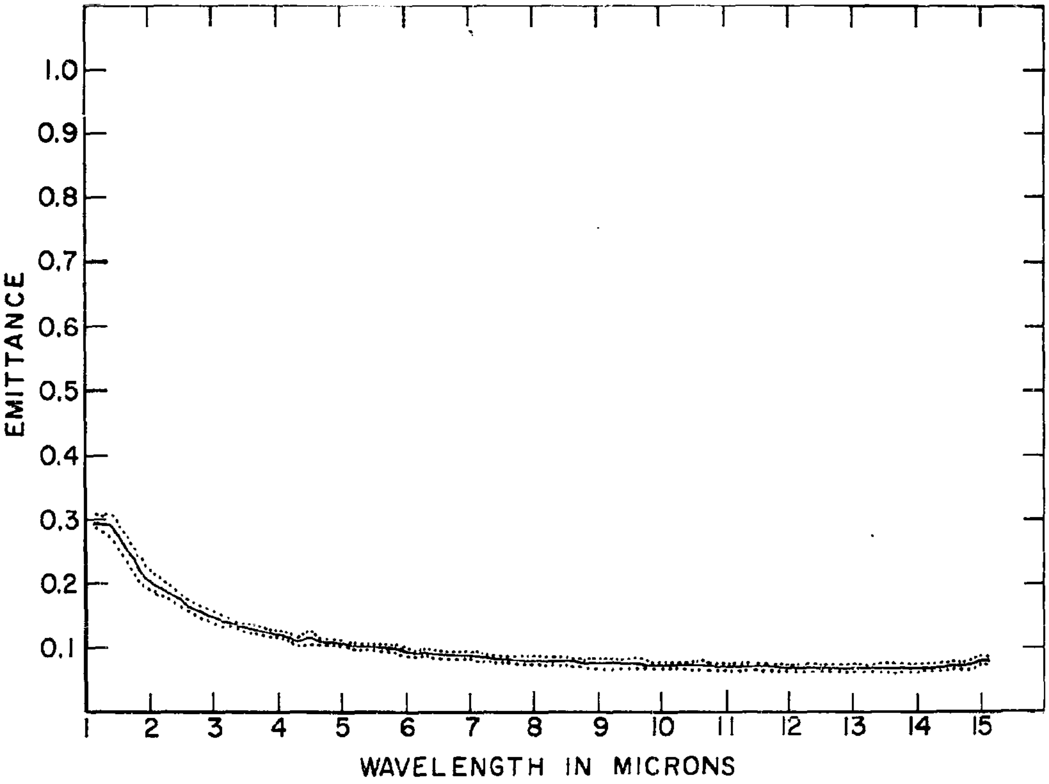


Figure 9. Average normal spectral emittance at 1100°K of the strip specimens cut from the same sheet as the disc of platinum-13% rhodium alloy sent to the Boeing Airplane Company. The center curve is the average of six determinations, three each on two specimens, and the dotted curves are the limits of the average plus one standard deviation and the average minus one standard deviation, respectively.

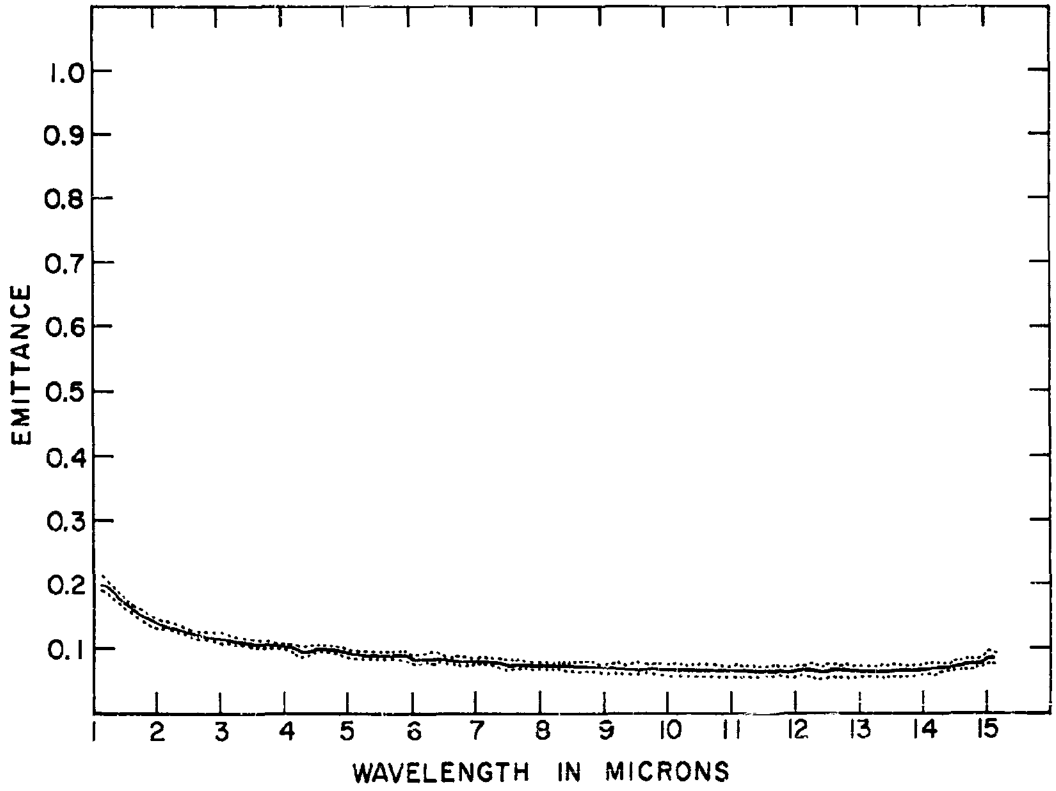


Figure 10. Average normal spectral emittance at 1400°K of the strip specimens cut from the same sheet as the disc of platinum-13% rhodium alloy sent to the Boeing Airplane Company. The center curve is the average of four determinations, two each on two specimens, and the dotted curves are the average plus one standard deviation and the average minus one standard deviation, respectively.

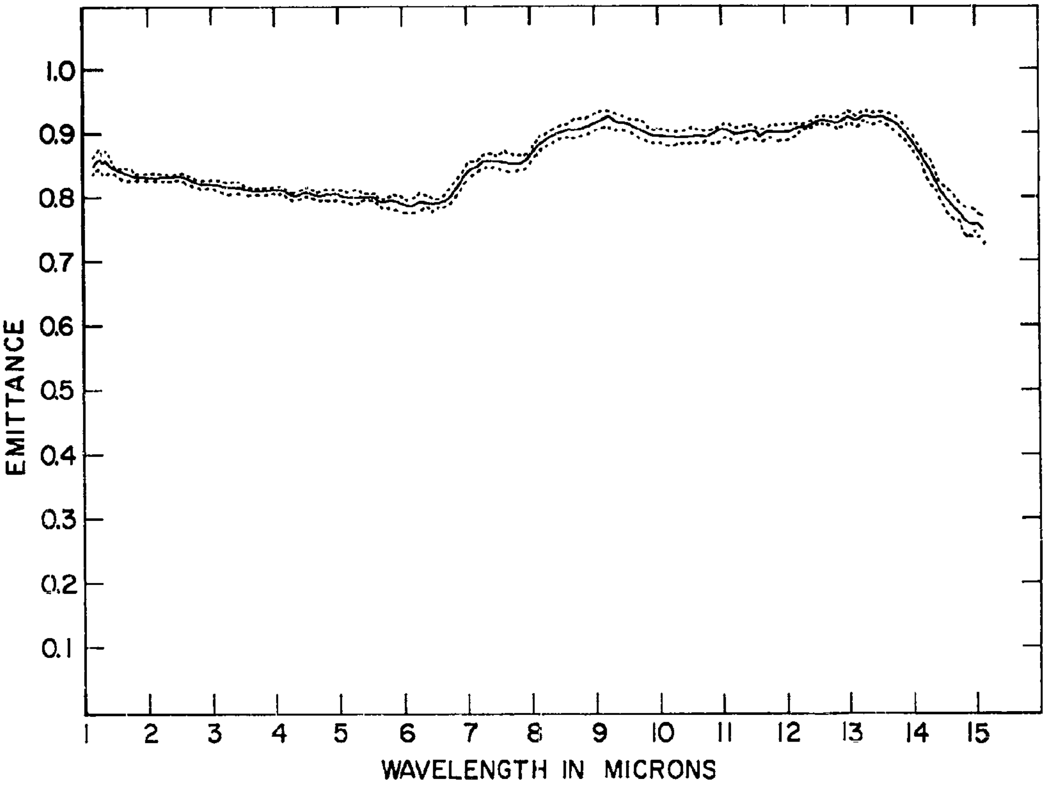


Figure 11. Average normal spectral emittance at 800°K of strips cut from the same sheet as the oxidized Inconel disc sent to the Boeing Airplane Company. The center curve is the average of six determinations, three each on two specimens, and the dotted curves are the average plus one standard deviation and the average minus one standard deviation, respectively.

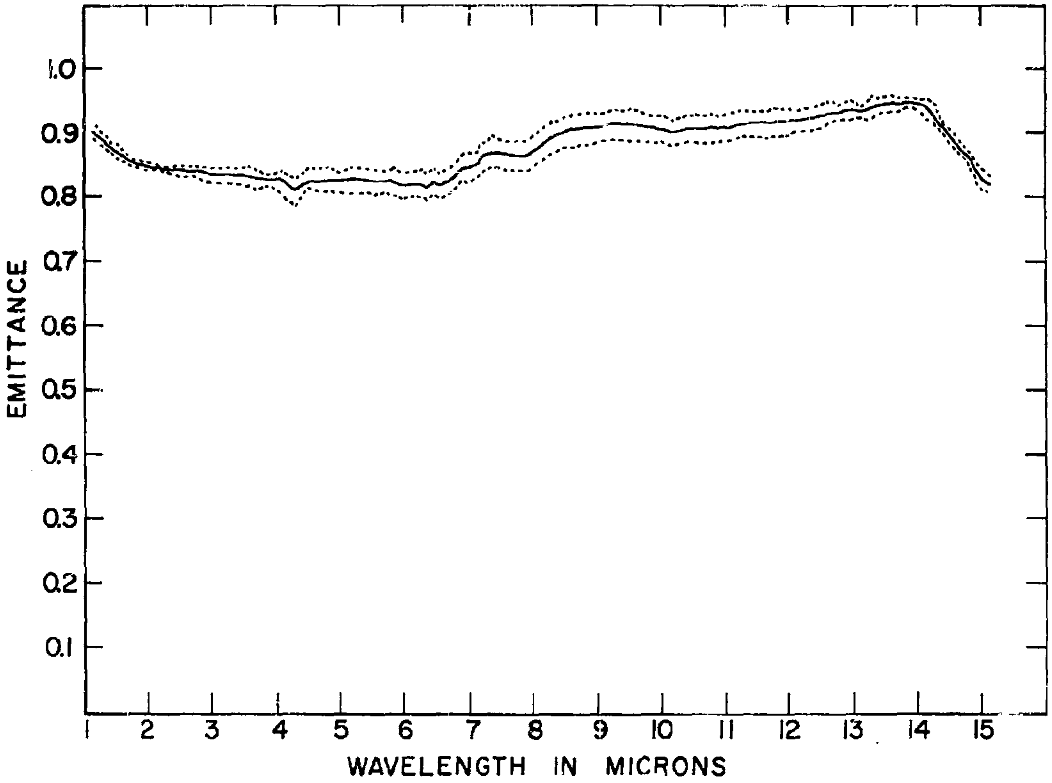


Figure 12. Average normal spectral emittance at 1100°K of strips cut from the same sheet as the oxidized Inconel disc sent to the Boeing Airplane Company. The center curve is the average of six determinations, three each on two specimens, and the dotted curves are the average plus one standard deviation and the average minus one standard deviation, respectively.

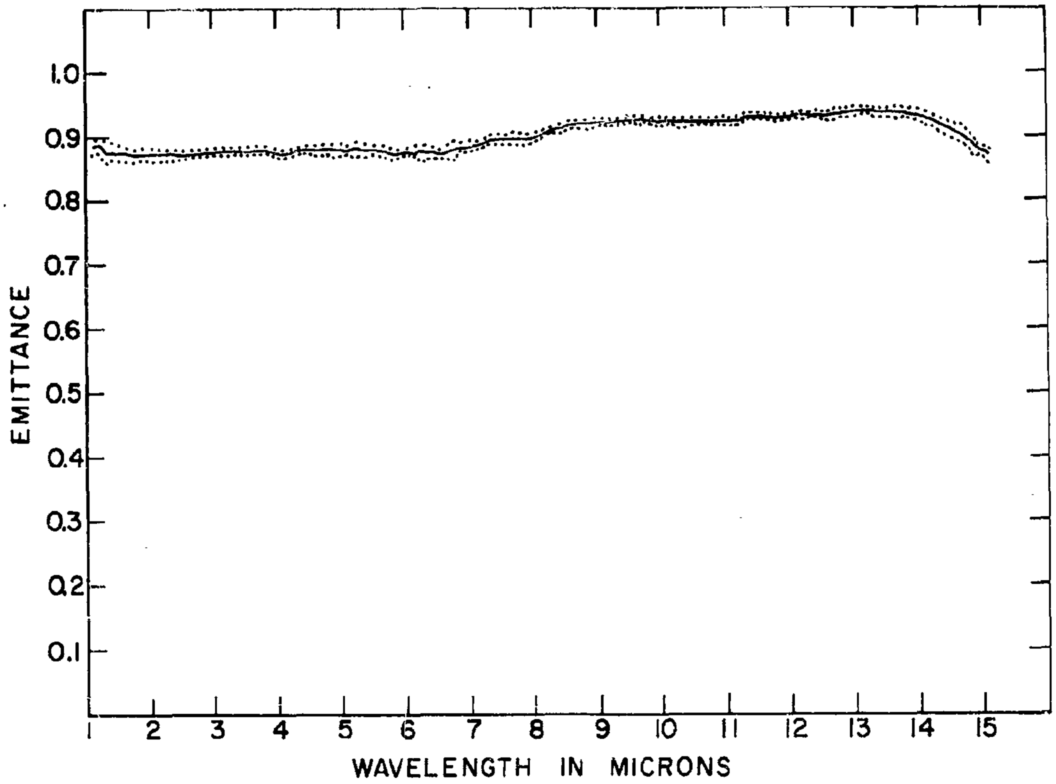


Figure 13. Average normal spectral emittance at 1400°K of strips cut from the same sheet as the oxidized Inconel disc sent to Boeing Airplane Company. The center curve is the average of six determinations, three each on two specimens, and the top and bottom curves are the average plus one standard deviation and the average minus one standard deviation, respectively.

The data showed that in general there was a small but statistically significant difference in spectral emittance between the two specimens of each material, at most of the 100 selected wavelengths.

Table I gives the values for total normal emittance (E_{TN}) computed for each material from the average normal spectral emittance data by the weighted ordinate method, from the appropriate blackbody distribution of flux for each temperature. (See WADC TR 59-510.) The reported standard deviations were obtained by averaging the standard deviations at the 100 different wavelengths at each temperature.

Table I also includes values for the total hemispherical emittance (E_{TN}) of one of the two 1/4 by 8-inch strip specimens of each material at each of the three temperatures. These values are believed to be accurate to at least ±0.02 emittance. Jakob, in his book "Heat Transfer" states (p.43) that for a dielectric material having a normal emittance of 0.90 the ratio of hemispherical to normal emittance should be 0.935, and for a normal emittance of 0.80, it should be 0.94. For conducting materials (p.51) the ratio is much larger; for a material of normal emittance of 0.10 the ratio should be 1.225. On this basis, the measured total normal and total hemispherical emittance values check within the experimental error, with the possible exception of the values for oxidized Inconel at 800 °K.

Table I

Material	Temp. °K	E_{TN} 1/	S.D. Avg.	E_{TH} 2/	E_{TH}/E_{TN}
Oxidized	1400	0.88	.0074	0.82	0.93
Inconel	1100	0.84	.0160	0.78	0.93
"	800	0.83	.0103	0.74	0.89
Platinum-	1400	0.12	.0074	0.16	1.33
13% Rhodium	1100	0.13	.0070	0.15	1.15
"	800	0.10	.0065	0.14	1.40

1/ Total normal emittance computed by the weighted ordinate method from the average normal spectral emittance over the wavelength range 1 to 15 microns.

2/ Total hemispherical emittance, measured by a modification of the hot filament method on one specimen of each material.

2. Working Standards for Aeronautical Systems Division

The working standards of polished platinum and sandblasted and oxidized Inconel have been prepared, and plastic cases for storage and shipment of the calibrated working standards have been designed and ordered.

Calibration of the working standards was postponed at the request of Aeronautical Systems Division, until calibration of the working standards for the Boeing Airplane Company had been completed.

E. Data Processing Equipment

During the report year the feasible specifications for an automatic data-processing system were decided upon. Data obtained with current equipment showed that an operation not initially planned was necessary, namely a correction involving the "100% curve" and "zero curve" described above in Section IV A 7.

The automation of data logging was confined to the often repeated, detailed tasks required for each measurement. For items which need be entered once in a spectrum traverse, manual entry of data is sufficient. Such entries can be made on the punched paper by manual operation of a teletypewriter.

Originally two alternative types of system configuration were planned. One of these employs purely digital equipment. The other employs both digital and analog equipment. The choice of an analog-digital system was based primarily on economic factors, since either system will perform the task.

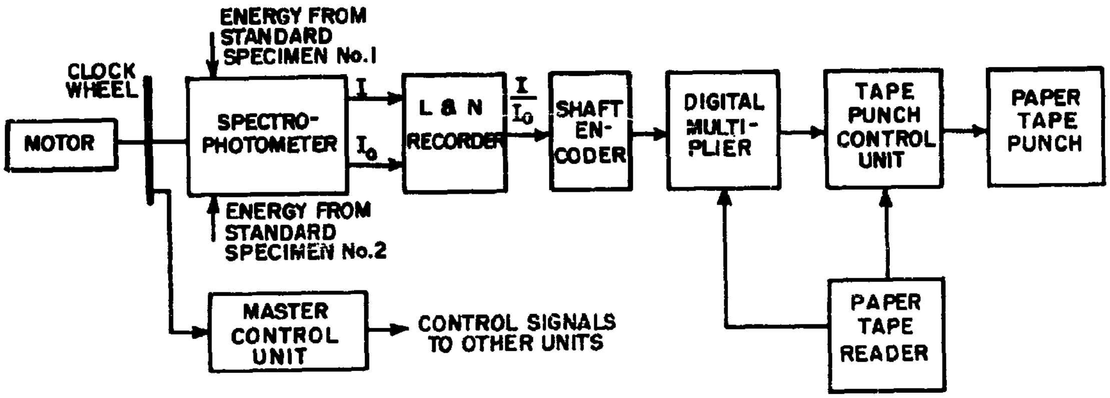
The digital system, (Figure 14) utilizes a shaft position encoder attached to the output potentiometer to provide signals to a digital multiplier. A paper tape reader supplies the second set of input signals to the multiplier. The tape will contain two sets of information. One set is a collection of calibration factors, and the other set is the indicating signals for pre-selection of the measurements to be summed. The output of the multiplier will be the corrected spectral emittance measurements, which will be recorded by a paper-tape punch on a second tape. In addition to being fed to the punch, pre-selected data are also fed into a summing device, for finding the total emittance. The output of this device may be visual, or may be punched on the tape at the end of the testing.

The combined analog-digital system,(Figure 15) will also have a shaft position encoder attached to the output potentiometer, the encoded signal being fed to the paper tape punch. The output signal is, however, multiplied by an analog correction signal, derived from a digital-to-analog converter fed by calibration signals from a tape reader. The shaft position encoder will then indicate the corrected data which will be punched on tape.

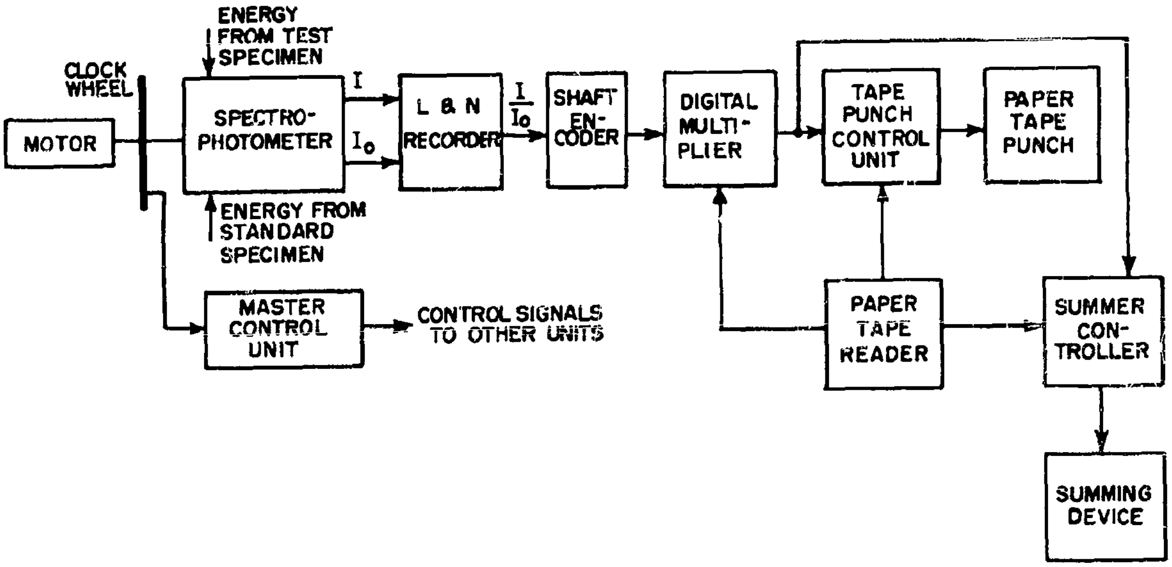
Several companies submitted bids on the equipment, one of which appears to be best from the standpoint of cost and performance. Their proposal involves a type of analog method, in which the intermediate calibration is recorded on magnetic tape.

V. PLANS FOR FUTURE WORK

The specimens that have been prepared for use as working standards of normal spectral emittance will be calibrated for use in air at temperatures of 800°, 1100° and 1400°K (approximately 980°, 1520° and 2060°F) over the wavelength range of 0.7 to 15 microns.

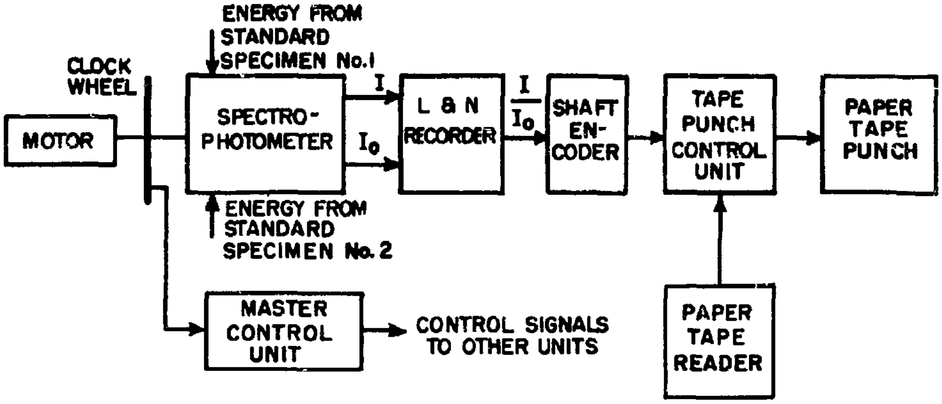


(a) CALIBRATION RUN

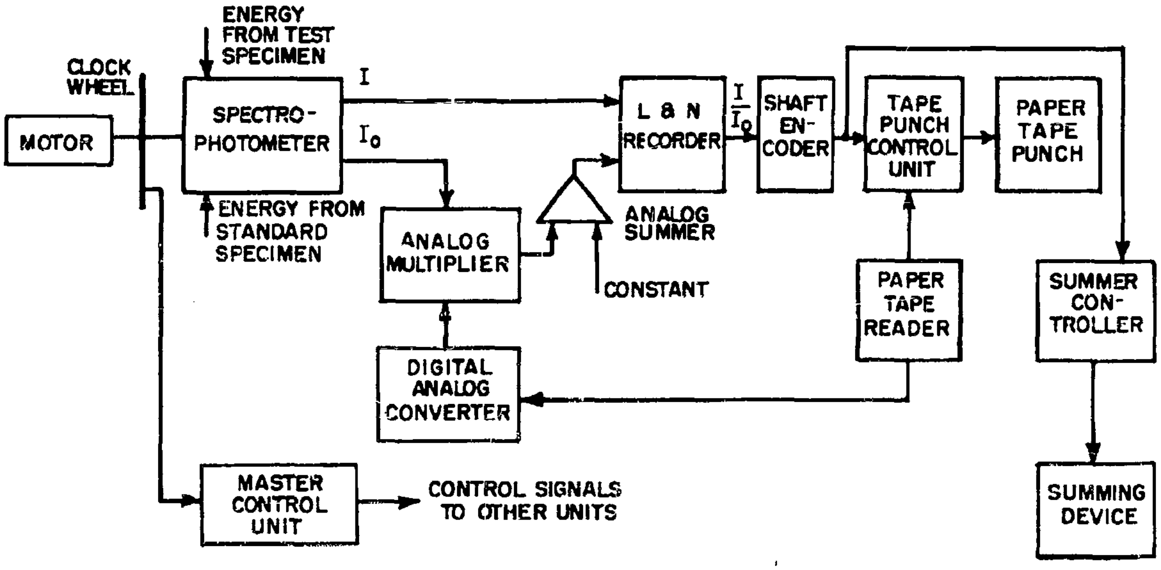


(b) SPECIMEN RUN

Figure 14. Block Diagram of Digital Data-Processing System



(a) CALIBRATION RUN



(b) SPECIMEN RUN

Figure 15. Block diagram of analog-digital data-processing system.

Data-processing equipment will be incorporated in the recording spectrometer to record spectral emittance data automatically in a form suitable for direct entry into an off-line electronic digital computer, and to provide for on-line computation, from spectral emittance data, of a single value of total emittance or solar absorptance by the selected ordinate method.

The existing normal spectral emittance equipment will be modified, by incorporation of suitable blackbody and specimen furnaces, for operation with specimens that cannot be heated by passing a current through them. Provision will be made for determinations in controlled atmosphere at temperatures from about 800°K (980°F) to the maximum at which reliable temperature measurements can be made with conventional noble metal thermocouples (about 2000°K or 3150°F), within the wavelength range of approximately 0.3 to 15 microns.

Test procedures will be developed for use with each type of equipment and when suitable test procedures have been developed, working standards of normal spectral reflectance will be prepared and calibrated over the appropriate ranges of temperature and wavelength.

Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt. No. WADC-TR-59-510, Part III. STANDARDIZATION OF THERMAL EMITTANCE MEASUREMENTS Pt. III. Normal Spectral Emittance, 800° - 1400°K. Interim Rpt. March 1962, 39p incl. illus., tables.
Unclassified report

Equipment for direct measurement of normal spectral emittance was modified in several respects. The test procedure was changed by incorporation of a "zero line" correction. The equipment was calibrated by means of sector-disc attenuators which passed known fections of the radiant flux from a

(over)

UNCLASSIFIED

1. Measurement equipment
2. Spectral emittance
3. Optical system
I. AFSC Project 7360 Task 73603
II. Contract AF 33 (616)-61-02
III. National Bureau of Standards
IV. William N. Harrison
Joseph C. Richmond
Harold K. Skramstad

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blackbody furnace.
Equipment for automatic recording of spectral data in a form suitable for direct entry into an electronic computer, and on-line computation of total emittance or solar absorptance, was designed.
Working standards of normal spectral emittance were prepared and calibrated.
An equation relating the normal spectral emissivity to five other parameters of a metal was solved "by hand" for one set of data. Some progress was made in setting up a program for solution of the equation by use of an electronic computer.

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