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SUMMARY

This report covers the development of a radiometric technique for determining the spectral and total normal emittance of materials heated to temperatures of 800, 1100, and 1300 K by direct comparison with National Bureau of Standards (NBS) reference specimens. Emittances are measured over the spectral range of 1 to 15 μm and are statistically compared with NBS reference specimens. Results are included for NBS reference specimens, René 41, alundum, zirconia, AISI type 321 stainless steel, nickel 201, and a space-shuttle reusable surface insulation.

INTRODUCTION

In heat-transfer work, where radiation equilibrium is significant, knowledge of emittance is essential. Emittance is defined as the ratio of energy radiated by a body to that radiated by an ideal radiation source at the same temperature and wavelength (for spectral emittance). At the Langley Research Center total-emittance measurements are required in high-temperature materials research. For example, materials of prime interest are those to be used as heat shields for the space shuttle where reradiation will be the principal heat-rejection mode and an optimum emittance at high temperature will thus be required. Also, spectral emittance is a critical parameter in inferring surface temperatures with pyrometers and radiometers.

Emittance-measurement techniques can generally be classified as reflective, calorimetric, or radiometric. For the reflective technique, energy of a specified wavelength band at a specified angle is impressed on the test-material surface, and the amount reflected is measured. If the material is opaque and Kirchoff's law holds, the spectral emittance can be calculated from the reflectance. The calorimetric technique gives only total hemispherical emittance by equating input power into a material to radiative heat loss from the material, since conduction and convection losses are minimized by design.

Finally, the radiometric technique compares energy radiated by a material with the energy radiated by a blackbody at the same temperature and wavelength. This report describes a radiometric technique in which samples are compared with National Bureau of Standards reference specimens. The spectral and total normal emittances of selected materials heated in air from 800 to 1300 K over the wavelength range from 1 to 15 μm are reported.

SYMBOLS

c_1	first radiation constant, W-m^2
c_2	second radiation constant, m-K
K	proportionality constant, V-m^3/W
N	number of measurements
R	voltage ratio, $\dfrac{V_{sp} - V_o}{V_{ref} - V_o}$
T	temperature, K
V	thermopile output voltage, V
V_o	thermopile output voltage due to background radiation, V
W	Planck distribution function, irradiance, W/m^3
ϵ	normal emittance, dimensionless (in appendix, ϵ is defined as normal spectral emittance)
λ	wavelength, μm
σ_m	average standard deviation of reference specimen
σ_R	standard deviation of voltage ratio
σ_{ref}	standard deviation of reference specimen

σ_s standard deviation of average of reference specimen

σ_{sp} standard deviation of test specimen

Subscripts:

b blackbody

i index

ref NBS reference specimen

sp specimen

t total

λ spectral

EQUIPMENT AND TESTING TECHNIQUE

Furnace

The furnace interior (fig. 1) consists of three sections. The outer section is made of firebrick refractory material within which is an alumina core wound with heater wire. The inner liner is an oxidized-inconel cubical chamber (ref. 1). The furnace is in two halves (fig. 2) which are placed together to form this cube. In the lower half of the furnace is a water-cooled aperture. (See fig. 1.)

Extending through the center of the furnace is a rotating shaft on which a typical specimen holder (fig. 3) is mounted. The specimen holder accommodates three samples, a reference specimen located at the center and two test specimens located 90° from the reference. Typical specimens are 3 by 3 by 2.5 cm.

The furnace temperature is controlled by two potentiometric controllers, each with a platinum/platinum—13-percent-rhodium thermocouple, one to control the upper portion of the furnace and the other to control the lower portion. Only the lower thermocouple is shown in figure 1.

Spectrometer

An NaCl prism spectrometer with a thermopile is used to detect and to measure the spectral radiance from the samples at discrete wavelengths between 1 and 15 μm. Data are ordinarily taken at uniform intervals (usually 1.0 μm) except when large variations in emittance are encountered. The spectrometer system has a resolution capability of 0.02 μm at 10 μm. Since the measurement of emittance uses a ratio technique of data taken at the same time, atmospheric effects are negligible, and therefore the spectrometer is used in an unpurged mode.

Readout

The incoming radiation to the spectrometer is chopped at a frequency of 13 Hz. The output from the thermopile detector is amplified by a lock-in amplifier from μV to mV levels and is recorded on a potentiometric recorder with an uncertainty of 0.25 percent. The actual signal level is not critical; it is the voltage ratio between an unknown specimen and the reference which is important.

Reference Specimens

Three National Bureau of Standards (NBS) reference specimens used are inconel (high emittance range), Kanthal (medium emittance range), and Pt-0.13Rh (low emittance range) disks which are 2.14 cm in diameter and 1.6 mm thick. Calibrations for the inconel and Kanthal specimens are available at temperatures of 800, 1100, and 1300 K and at a wavelength range from 1 to 15.2 μm. For the Pt-0.13Rh specimens, data are available at temperatures of 800, 1100, 1400, and 1600 K at a wavelength interval from 1 to 36.65 μm. A typical reference calibration is presented in the appendix.

Testing Technique

A diagram of the apparatus used in the radiometric technique is shown in figure 4. The inconel reference material is used as the standard from which spectral normal measurements are made in the wavelength interval from 1 to 15 μm and at temperatures corresponding to the inconel data. Total data collection time is about 30 min at each temperature.

In 12 sec the holder is rotated from the position in the upper part of the furnace, past a water-cooled aperture located in the lower part of the furnace, and then back to the top of the furnace. As the specimens pass the aperture, energy from them is dispersed by an NaCl prism spectrometer, is measured by a thermopile detector, and is recorded by a strip-chart potentiometer. After each measurement (at each wavelength) the specimens are held in the upper part of the furnace for at least 1 min to assure that they are at the same temperature as the furnace. For nonmetallic materials, which may be transparent, a platinum foil is used to back the material in order to avoid transmission of energy from the rear of the furnace.

Radiometric Method

The Planck distribution function relates emitted energy to surface temperature and wavelength in the equation

$$W_b(\lambda,T) = \frac{c_1}{\lambda^5\left(e^{c_2/\lambda T} - 1\right)} \tag{1}$$

for an ideal radiator where c_1 and c_2 are the first and second radiation constants and λ is the wavelength.

For a nonideal radiator

$$W(\lambda,T) = \epsilon(\lambda,T)W_b(\lambda,T) \tag{2}$$

where W and ϵ refer to the nonideal radiator and $\epsilon(\lambda,T)$ is the spectral normal emittance

$$\epsilon(\lambda,T) = \frac{W(\lambda,T)}{W_b(\lambda,T)} \tag{3}$$

The output voltage from the thermopile transducer is linearly related to the irradiance on its surface. With K representing the proportionality constant,

$$V_i(\lambda,T) = KW_i'(\lambda,T) = K\epsilon_i(\lambda,T)W_b'(\lambda,T) \tag{4}$$

where i equals sp for the test specimen and ref for the reference specimen. The prime indicates quantities that account for losses through the optical system. After solving for K by alternately substituting the reference and specimen values and then equating these two results, equation (4) can be rearranged as

$$\epsilon_{sp}(\lambda,T) = \frac{V_{sp}(\lambda,T)}{V_{ref}(\lambda,T)}\,\epsilon_{ref}(\lambda,T) \tag{5}$$

The thermopile output due to background radiation V_o is subtracted from the signal in each case. Thus

$$\epsilon_{sp}(\lambda,T) = \frac{V_{sp}(\lambda,T) - V_o}{V_{ref}(\lambda,T) - V_o}\,\epsilon_{ref}(\lambda,T) \tag{6}$$

Equation (6) is the working relationship for the measurements in this paper.

At temperatures between 800 and 1300 K, at least 95 percent of the energy radiated by the test specimen is located in the band from 1 to 15 μm. Therefore, a reasonably accurate value of total normal emittance can be calculated by means of the equation

$$\epsilon_t(T) = \frac{\int_1^{15} \epsilon_{sp}(\lambda,T)W_b(\lambda,T)\,d\lambda}{\int_1^{15} W_b(\lambda,T)\,d\lambda} \tag{7}$$

Trapezoidal integration was used to approximate the integral.

DATA ANALYSIS AND DISCUSSION

Measurement accuracy is affected by the precision of the measurement, by the variability in sample specimens, and by the accuracy of the standard. These errors can be classed as nonindependent or correlated (ref. 2). Nonindependent errors are due to external causes and cannot be detected by a study of the specimen deviations. Specifically, those errors attributed to NBS standards are present as nonindependent errors. Correlated errors are those in which the deviations of the independent variables are systematically related to those of the dependent variables. Specifically, the deviations in measurement of the voltage ratio in equation (6) are systematically related to those of the spectral-emittance measurement. Thus the total error in the measurement is expressed as the square root of the sum of the squares of their standard deviations

$$\sigma_{sp} = \sqrt{\sigma_R^2 + \sigma_{ref}^2} \tag{8}$$

The unbiased standard deviation of the voltage ratio σ_R from equation (6) is defined as

$$\sigma_R = \sqrt{\frac{\sum_{i=1}^{N} (\bar{R} - R_i)}{N - 1}} \tag{9}$$

where $\bar{R}$ is the average ratio of the voltages and N is the number of measurements.

Since

$$\frac{\epsilon_{sp}}{\epsilon_{ref}} = \frac{V_{sp} - V_o}{V_{ref} - V_o} = R \tag{10}$$

equation (9) reduces to

$$\sigma_R = \frac{1}{\epsilon_{\lambda,ref}^{1/2}} \sqrt{\frac{\sum_{i=1}^{N} \left(\bar{\epsilon}_{\lambda,sp} - \epsilon_{\lambda,sp,i}\right)}{N - 1}} \tag{11}$$

where $\bar{\epsilon}_{\lambda,sp}$ is the average spectral emittance of the test specimen. (In eqs. (10) and (11), the functional notation has been dropped for convenience.)

The NBS values in the appendix were established by making three measurements on each of seven samples of the same material. The value listed for spectral normal emittance is the arithmetic mean of the 21 measured values. The computed average standard deviation of the three measurements σ_m on each of the seven specimens about the mean value for each specimen is a measure of the precision of the measurement. The standard deviation of the average value σ_s for each of the seven specimens about the overall mean is indicative of the variation in specimens. Therefore, the standard deviation of the reference sample σ_{ref} is calculated from data furnished in the appendix and is expressed as the square root of the sum of the squares of the standard deviations due to precision of the measurement σ_m and the variations in the specimens σ_s

$$\sigma_{ref} = \sqrt{\sigma_s^2 + \sigma_m^2} \tag{12}$$

Inconel was considered the working reference specimen because it had high emittance and also because the coating had a self-cleaning and self-renewing property (ref. 3). With an inconel specimen as the reference, emittance data were determined for another inconel reference specimen as well as for Kanthal and Pt-0.13Rh specimens. Figures 5, 6, and 7 show data from these reference specimens. The shaded area represents the value of spectral normal emittance for the reference specimen as measured by the NBS (see appendix) plus or minus the standard deviation as established by equation (12). The area contained within the dashed lines represents the value of spectral normal emittance measured at Langley Research Center (LaRC) plus or minus the standard deviation as established by equation (8). The difference between the two standard-deviation bands is indicative of the measurement precision. Since the LaRC data in most cases exhibit an excellent precision (repeatability), an immediate and significant decrease in measurement uncertainty would result if reference specimens with individual certification from the NBS could be obtained.

In figure 5, the spectral normal emittance of inconel measured at LaRC is compared with NBS data for the reference specimen. Good agreement is shown except in the region from 1 to 4 μm.

Figure 6 shows Kanthal emittance data determined by means of the inconel working reference for two Kanthal reference specimens. Again the NBS data are presented in the shaded area. Five tests were made on new (previously unused) Kanthal specimens, and the disagreement is evident between NBS and LaRC data. Richmond, in the discussion at the end of his report (ref. 3), indicates that Kanthal has a nonregenerative oxide film and is subject to permanent degradation by a reaction or deposition from other materials present.

In figure 7, Pt-0.13Rh emittance data determined by means of the inconel working reference are shown. The same procedures were used to generate the data as were used with inconel and Kanthal. The data are in good agreement with the NBS data except in the region from 12 to 15 μm.

Shown in figures 8(a) and 8(b) are data gathered on oxidized René 41 material compared with data from the Lockheed Missiles and Space Co., Inc. (LMSC) from reference 4. No comparison data were available at 1300 K (fig. 8(c)). Reasonably good agreement is noted with the LMSC data except in the region from 1.5 to 5 μm. If LMSC had included their measurement uncertainty, the error bars would probably intersect. Because LMSC used a wide-band radiometer in this region, the data from 8 to 16 μm were shown as a single-point band measurement.

Figures 9(a), 9(b), and 9(c) show data generated on space-shuttle reusable surface insulation (RSI) material and coating manufactured by LMSC designated as LI-1500 and LMSC/0042 (ref. 5). Comparisons are made with data generated by Ames Research Center (ARC) (ref. 6) and by LMSC (ref. 4). All data are taken from emittance-measurement techniques using self-emission methods. No comparison data were available at 800 K (fig. 9(a)). LMSC data existed at 1100 K, and the comparison was excellent (fig. 9(b)). In figure 9(c), LMSC and LaRC data at 1300 K were not in reasonable agreement except in the region from 8 to 16 μm. Some ARC data at 1600 K were also plotted from 1 to 5 μm. These data, as with the LMSC data, did not correlate, although closer agreement may be indicated if the ARC measurement uncertainty were included and if the temperatures were somewhat closer.

In figures 10 to 12, values of spectral and total normal emittance are presented for several ceramic and metallic materials in comparison with published data (ref. 7). Sufficient recalibration data were not available to generate standard-deviation data for these materials. The agreement was generally good, considering the difference in material preparation. Values for alundum mixture AN498 and zirconia deviated more than the metallic specimens, although the overall spectral data trends were similar to those in published data for the ceramics. The total-normal-emittance values were well within the scatter of the published data. Similarly, for the AISI type 321 stainless steel, both spectral- and total-normal-emittance data fell within the spread of the published data.

Figures 13(a), 13(b), and 13(c) show data taken on nickel 201 for which no comparison data could be found in literature. Average values were used to calculate total normal emittance (fig. 13(d)).

CONCLUDING REMARKS

A statistical analysis of a radiometric system developed to measure spectral and total normal emittance indicates that the system can be used as a means for establishing reproducible high-temperature emittance values. The system was established to acquire high-temperature material emittance data on space-shuttle heat-shield materials since surface reradiation will be the principal heat-rejection mode and on other materials for which spectral emittance is a critical parameter in inferring surface temperature with pyrometers and radiometers. The system compares test specimens with National Bureau of Standards (NBS) reference specimens by a ratio technique which eliminates most systematic errors inherent in other measurement methods. Comparison of reference specimens shows that the system closely approximates NBS calibration data with most of the deviation directly related to the NBS error band. Uncertainty in measurements can be significantly reduced by having the specific reference materials certified by NBS.

The spectral- and total-normal-emittance values reported for René 41, alundum, zirconia, and AISI type 321 stainless steel are compared with corroborating data. Data, statistically analyzed, are reported for the space-shuttle reusable surface insulation (RSI) material manufactured by Lockhead Missiles and Space Co., Inc., and for nickel 201. These RSI material data compare favorably with Lockheed data at 1100 K but are significantly different at 1300 K. Data presented for nickel 201 should be valuable since they are the only known published information on the material.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., December 17, 1974.

APPENDIX

The symbols used in the following certificate are defined at the end of the certificate:

U. S. Department of Commerce
John T. Connor, Secretary
National Bureau of Standards
A. V. Astin, Director

Certificate of Normal Spectral Emittance

Standard Reference Materials 1440 to 1447
Oxidized Inconel

Wavelength	At 800 °K			At 1100 °K			At 1300 °K		
Microns	ϵ	σ_m	σ_s	ϵ	σ_m	σ_s	ϵ	σ_m	σ_s
1.09	0.753	0.013	0.040	0.830	0.021	0.050	0.870	0.015	0.050
1.15	.751	.009	.039	.828	.020	.050	.871	.016	.049
1.22	.752	.009	.039	.829	.018	.050	.870	.015	.049
1.28	.755	.008	.042	.828	.015	.047	.869	.012	.050
1.36	.758	.009	.043	.827	.014	.046	.866	.012	.046
1.44	.763	.008	.044	.828	.016	.045	.862	.011	.044
1.52	.768	.009	.042	.829	.014	.042	.859	.012	.043
1.63	.770	.008	.042	.829	.015	.039	.857	.013	.038
1.74	.776	.007	.040	.830	.014	.039	.856	.012	.037
1.88	.781	.007	.038	.831	.014	.038	.855	.012	.035
2.10	.786	.007	.036	.831	.014	.035	.854	.012	.034
2.36	.791	.007	.034	.833	.012	.033	.854	.012	.033
2.60	.794	.007	.031	.834	.012	.034	.854	.012	.032
2.81	.798	.007	.031	.834	.013	.032	.854	.012	.031
3.02	.798	.006	.029	.834	.012	.033	.854	.012	.031
3.25	.802	.006	.027	.835	.012	.032	.855	.012	.030
3.45	.804	.006	.027	.837	.013	.032	.855	.012	.030
3.65	.806	.006	.027	.838	.013	.032	.855	.012	.030
3.87	.808	.006	.027	.839	.012	.032	.856	.012	.030
4.09	.809	.005	.025	.839	.012	.031	.856	.012	.030
4.30	.809	.006	.026	.837	.014	.030	.856	.011	.029
4.50	.812	.005	.025	.840	.012	.031	.857	.012	.030
4.67	.812	.005	.024	.839	.012	.031	.857	.012	.030
4.83	.812	.006	.024	.840	.012	.031	.856	.012	.029
4.99	.812	.006	.024	.839	.012	.030	.856	.012	.029
5.13	.812	.006	.024	.840	.011	.030	.857	.012	.030
5.27	.812	.006	.024	.839	.011	.030	.856	.012	.029
5.40	.813	.005	.024	.839	.011	.030	.856	.012	.029
5.45	.812	.005	.024	.839	.011	.030	.856	.012	.030
5.69	.812	.005	.024	.838	.011	.031	.855	.011	.030
5.83	.811	.005	.024	.838	.012	.030	.854	.012	.030
5.97	.811	.005	.024	.837	.012	.031	.854	.011	.029
6.10	.810	.005	.024	.837	.012	.031	.854	.011	.030
6.22	.810	.005	.024	.837	.012	.030	.854	.012	.030
6.35	.810	.005	.024	.837	.011	.030	.855	.012	.030
6.47	.809	.005	.024	.837	.012	.030	.854	.012	.030
6.58	.810	.005	.024	.838	.011	.031	.855	.012	.030
6.70	.812	.005	.024	.838	.011	.031	.856	.012	.030
6.80	.813	.005	.024	.839	.011	.031	.856	.011	.030
6.91	.814	.005	.024	.840	.010	.031	.857	.011	.031

Wavelength	At 800 °K			At 1100 °K			At 1300 °K		
Microns	ϵ	σ_m	σ_s	ϵ	σ_m	σ_s	ϵ	σ_m	σ_s
7.01	0.817	0.005	0.024	0.841	0.011	0.031	0.858	0.011	0.031
7.13	.819	.005	.024	.843	.011	.031	.859	.011	.031
7.25	.822	.005	.024	.845	.011	.030	.861	.011	.031
7.37	.823	.005	.024	.847	.011	.030	.863	.011	.031
7.49	.824	.005	.024	.848	.011	.030	.863	.011	.031
7.60	.826	.005	.024	.849	.012	.030	.864	.011	.031
7.71	.827	.005	.024	.850	.011	.031	.865	.011	.031
7.83	.829	.005	.024	.852	.011	.031	.867	.012	.032
7.94	.833	.005	.024	.854	.011	.030	.868	.011	.031
8.03	.839	.005	.024	.858	.012	.030	.871	.012	.031
8.12	.846	.006	.024	.863	.012	.030	.874	.011	.031
8.22	.852	.005	.024	.867	.011	.031	.878	.011	.031
8.32	.856	.005	.024	.872	.012	.030	.881	.011	.031
8.41	.859	.005	.025	.875	.011	.031	.883	.011	.032
8.50	.862	.005	.024	.878	.010	.030	.886	.011	.031
8.60	.864	.005	.024	.880	.011	.031	.888	.011	.032
8.70	.866	.005	.024	.881	.011	.030	.889	.011	.032
8.79	.868	.005	.025	.882	.011	.031	.890	.011	.032
8.88	.870	.005	.025	.885	.011	.031	.892	.011	.032
8.96	.872	.005	.025	.886	.011	.031	.893	.011	.031
9.05	.874	.005	.025	.888	.011	.031	.895	.012	.031
9.14	.875	.005	.025	.889	.011	.032	.896	.011	.031
9.22	.877	.005	.026	.891	.010	.032	.897	.011	.031
9.30	.876	.005	.025	.891	.010	.032	.898	.011	.031
9.38	.873	.005	.025	.891	.010	.031	.898	.012	.032
9.46	.870	.005	.025	.888	.010	.031	.897	.012	.031
9.55	.868	.005	.024	.887	.011	.031	.896	.011	.031
9.63	.866	.005	.025	.885	.010	.031	.895	.011	.032
9.71	.865	.005	.025	.884	.011	.031	.894	.011	.032
9.79	.863	.006	.024	.884	.011	.031	.894	.012	.032
9.87	.862	.005	.024	.883	.011	.031	.893	.011	.032
9.95	.861	.004	.024	.882	.011	.031	.893	.011	.032
10.03	.861	.005	.024	.882	.011	.031	.893	.011	.032
10.10	.862	.005	.024	.882	.011	.031	.893	.011	.032
10.18	.862	.004	.024	.882	.011	.031	.893	.011	.032
10.26	.863	.005	.024	.882	.011	.032	.893	.011	.032
10.34	.864	.005	.024	.883	.011	.031	.893	.011	.032
10.42	.866	.005	.024	.884	.010	.031	.894	.011	.032
10.50	.868	.005	.024	.885	.011	.031	.895	.011	.031
10.57	.868	.005	.024	.886	.011	.031	.896	.011	.031
10.64	.868	.005	.024	.887	.011	.031	.897	.011	.031
10.72	.868	.005	.024	.888	.011	.031	.898	.012	.031
10.80	.868	.005	.024	.888	.010	.031	.898	.011	.032
10.87	.869	.005	.025	.888	.010	.032	.898	.011	.032
10.94	.870	.005	.025	.888	.011	.032	.898	.011	.032
11.01	.871	.005	.024	.889	.011	.031	.899	.011	.031
11.08	.871	.006	.024	.889	.011	.032	.899	.011	.032
11.05	.872	.005	.024	.890	.010	.032	.899	.011	.031
11.22	.871	.006	.024	.890	.011	.032	.900	.011	.031
11.28	.871	.006	.024	.891	.011	.031	.900	.011	.031

APPENDIX

Wavelength	At 800 °K			At 1100 °K			At 1300 °K		
Microns	ϵ	σ_m	σ_s	ϵ	σ_m	σ_s	ϵ	σ_m	σ_s
11.35	0.871	0.005	0.024	0.891	0.010	0.032	0.900	0.011	0.032
11.42	.871	.005	.024	.891	.011	.032	.901	.011	.032
11.49	.871	.005	.024	.891	.010	.032	.901	.011	.031
11.55	.871	.005	.024	.892	.011	.032	.901	.011	.031
11.62	.871	.005	.025	.891	.011	.031	.902	.011	.031
11.68	.871	.006	.024	.892	.011	.032	.902	.011	.032
11.74	.871	.005	.024	.892	.011	.032	.902	.011	.032
11.80	.871	.006	.024	.892	.011	.032	.902	.011	.032
11.87	.872	.006	.024	.892	.011	.032	.903	.011	.032
11.94	.872	.006	.024	.893	.011	.032	.903	.011	.032
12.00	.872	.005	.024	.893	.010	.032	.904	.012	.032
12.07	.873	.005	.024	.894	.010	.031	.904	.011	.032
12.13	.874	.005	.024	.894	.011	.032	.904	.011	.032
12.19	.874	.005	.024	.895	.011	.032	.904	.011	.032
12.26	.875	.005	.024	.895	.011	.032	.905	.011	.033
12.32	.877	.005	.024	.895	.010	.032	.906	.011	.032
12.38	.878	.005	.024	.896	.011	.032	.906	.011	.033
12.44	.879	.005	.024	.897	.010	.032	.907	.011	.033
12.50	.880	.005	.024	.898	.011	.032	.908	.011	.033
12.57	.881	.005	.024	.899	.010	.033	.908	.011	.033
12.63	.882	.005	.024	.899	.011	.032	.909	.011	.033
12.69	.883	.005	.024	.900	.011	.033	.910	.011	.033
12.75	.884	.005	.024	.902	.011	.033	.910	.011	.033
12.82	.885	.005	.024	.902	.010	.033	.911	.011	.034
12.88	.886	.005	.024	.903	.010	.033	.912	.011	.034
12.84	.887	.005	.025	.904	.011	.033	.913	.011	.034
13.00	.888	.005	.025	.904	.011	.033	.914	.011	.034
13.06	.889	.005	.025	.905	.011	.034	.915	.011	.035
13.12	.891	.005	.025	.906	.011	.034	.915	.011	035
13.18	.892	.005	.025	.907	.010	.035	.916	.011	.035
13.24	.893	.005	.025	.908	.011	.034	.916	.011	.036
13.30	.894	.005	.025	.909	.011	.034	.918	.011	.036
13.36	.894	.005	.026	.910	.011	.035	.918	.011	.036
13.42	.895	.005	.026	.910	.011	.035	.918	.011	.037
13.48	.894	.004	.026	.910	.011	.035	.919	.011	.037
13.54	.894	.005	.027	.911	.011	.035	.920	.011	.038
13.60	.893	.005	.026	.911	.011	.036	.920	.011	.038
13.66	.892	.005	.027	.910	.011	.037	.920	.011	.038
13.72	.890	.005	.027	.910	.011	.037	.920	.010	.039
13.78	.887	.005	.028	.909	.011	.037	.920	.011	.040
13.84	.883	.005	.028	.908	.011	.038	.919	.011	.041
13.89	.878	.005	.029	.906	.011	.038	.918	.011	.041
13.95	.873	.005	.029	.904	.011	.039	.918	.012	.042
14.00	.867	.005	.030	.902	.011	.039	.917	.012	.043
14.06	.860	.005	.030	.898	.010	.039	.915	.012	.044
14.11	.853	.005	.031	.895	.011	.040	.913	.011	.044
14.17	.845	.005	.031	.890	.011	.040	.910	.011	.045
14.22	.838	.005	.031	.885	.011	.040	.907	.011	.046
14.28	.831	.005	.032	.879	.011	.041	.904	.011	.047
14.33	.825	005	.033	.873	.011	.041	.900	.011	.047

APPENDIX

Wavelength	At 800 °K			At 1100 °K			At 1300 °K		
Microns	ϵ	σ_m	σ_s	ϵ	σ_m	σ_s	ϵ	σ_m	σ_s
14.38	0.818	0.005	0.033	0.867	0.010	0.042	0.896	0.011	0.048
14.44	.811	.005	.034	.861	.010	.042	.891	.011	.050
14.49	.806	.005	.034	.854	.011	.043	.886	.011	.051
14.55	.800	.005	.035	.848	.011	.043	.881	.011	.051
14.60	.795	.005	.036	.842	.011	.044	.875	.011	.052
14.65	.789	.005	.037	.834	.011	.045	.871	.011	.053
14.71	.784	.005	.038	.831	.010	.045	.865	.011	.054
14.76	.779	.005	.039	.825	.012	.046	.861	.011	.055
14.82	.774	.005	.040	.820	.011	.047	.855	.011	.056
14.87	.768	.004	.042	.813	.011	.048	.850	.011	.057
14.92	.762	.004	.044	.805	.012	.049	.844	.011	.058
14.98	.756	.004	.044	.799	.011	.048	.838	.012	.058
15.03	.753	.004	.043	.796	.011	.047	.834	.012	.058
15.08	.751	.004	.044	.794	.011	.048	.831	.012	.060
15.14	.746	.004	.046	.789	.011	.050	.826	.012	.061
15.20	.740	.004	.048	.783	.012	.051	.822	.012	.062

The standards of normal spectral emittance are intended for use in calibrating equipment used in various laboratories for measuring this property of materials. All of the specimens were prepared from a single sheet of metal at one time, and were subjected as nearly as possible to identical preparation treatments. Because the equipment used for the calibration of these standards was suitable only for making measurements on ¼ inch by 8 inch strips, seven such specimens were prepared from selected locations in the sheet so that the strips measured were statistically representative of the entire lot of specimens.

Three measurements were made on each of the seven samples. The value listed for normal spectral emittance (ϵ) is the arithmetic average of the 21 measured values. The computed average standard deviation (σ_m) of the three measurements on each of the seven specimens about the average value for each specimen is a measure of the precision of measurement. The standard deviation (σ_s) of the average value for each of the seven specimens about the overall average, is indicative of the variation in specimens.

Procedures used for the measurements are described in detail "Standardization of Thermal Emittance Measurements, part 4, Normal Spectral Emittance, 800–1400 °K." Technical Report No. WADC-TR-59-510, Part IV, by William N. Harrison, Joseph C. Richmond, Frederick J. Shorten and Horace M. Joseph, available from the Clearinghouse for Federal Scientific and Technical Information, 5285 Port Royal Road, Springfield, Virginia 22171, as publication AD 426846, price $2.25.

Samples are available as ½ inch disks, SRM No. 1440; as ⅞ inch disks, SRM No. 1441; as 1 inch disks, SRM No. 1442; as 1⅛ inch disks, SRM No. 1443; as 1¼ inch disks, SRM No. 1444; as 2 inch by 2 inch squares, SRM No. 1445; as 1 inch by 10 inch strips, SRM No. 1446; and as ¾ inch by 10 inch strips, SRM No. 1447.

WASHINGTON, D. C.
December 16, 1965

W. Wayne Meinke, Chief
Office of Standard Reference Materials

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   Volume 4 – Oxides and Their Solutions and Mixtures, Part I, pp. 28-32, 589-593.

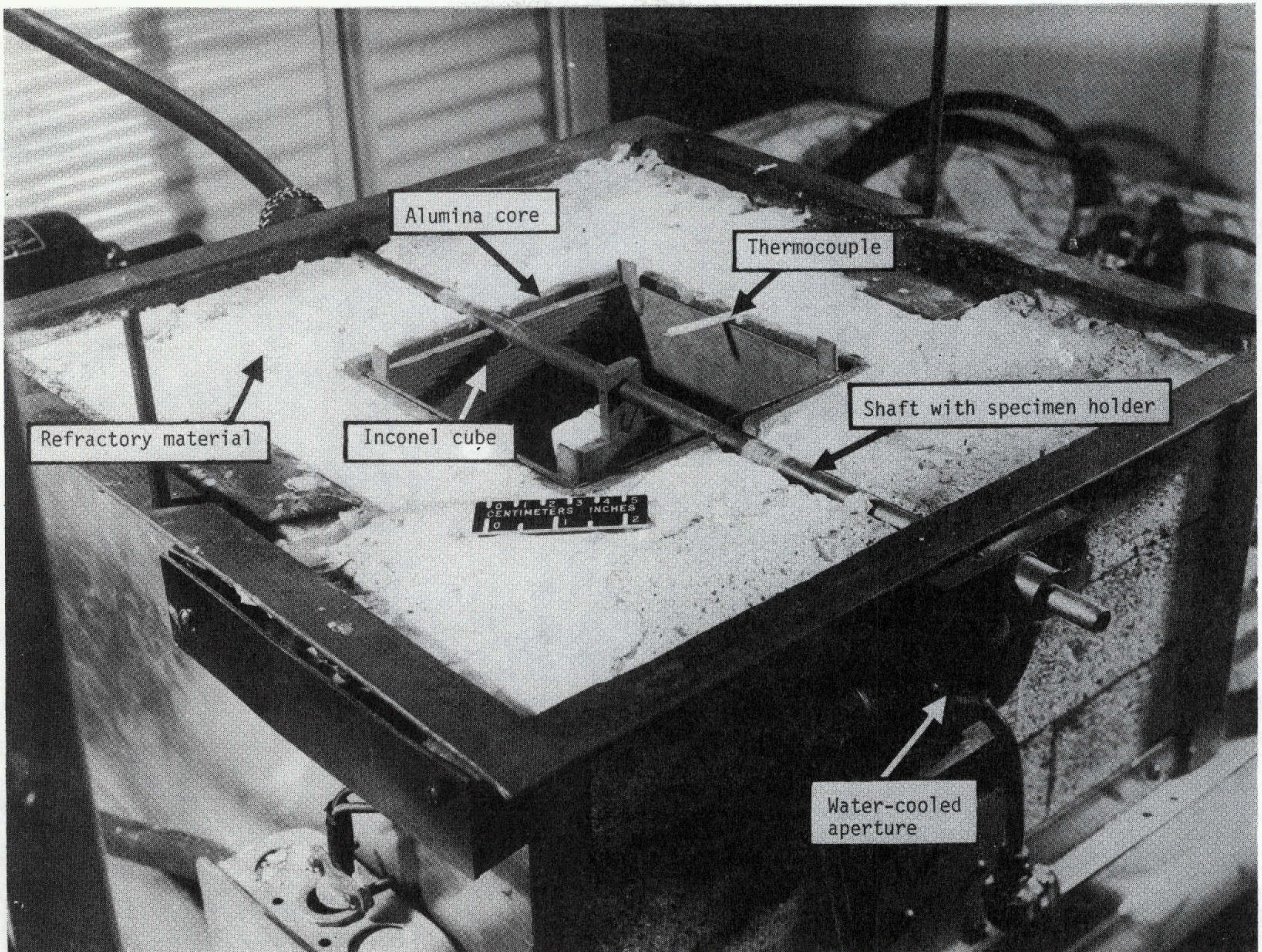

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Figure 1.- Emittance-furnace interior.

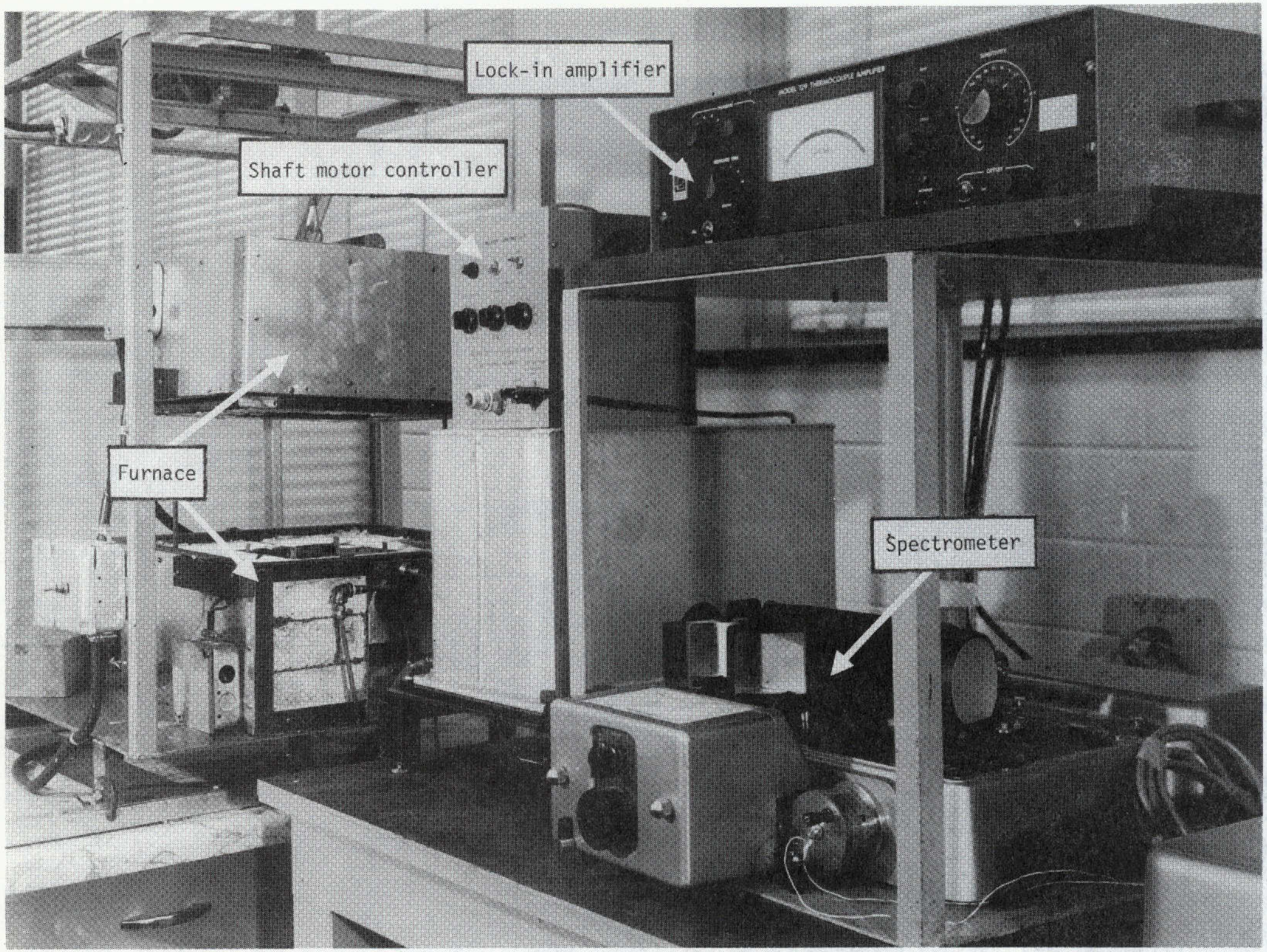

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Figure 2.- Emittance-measurement setup.

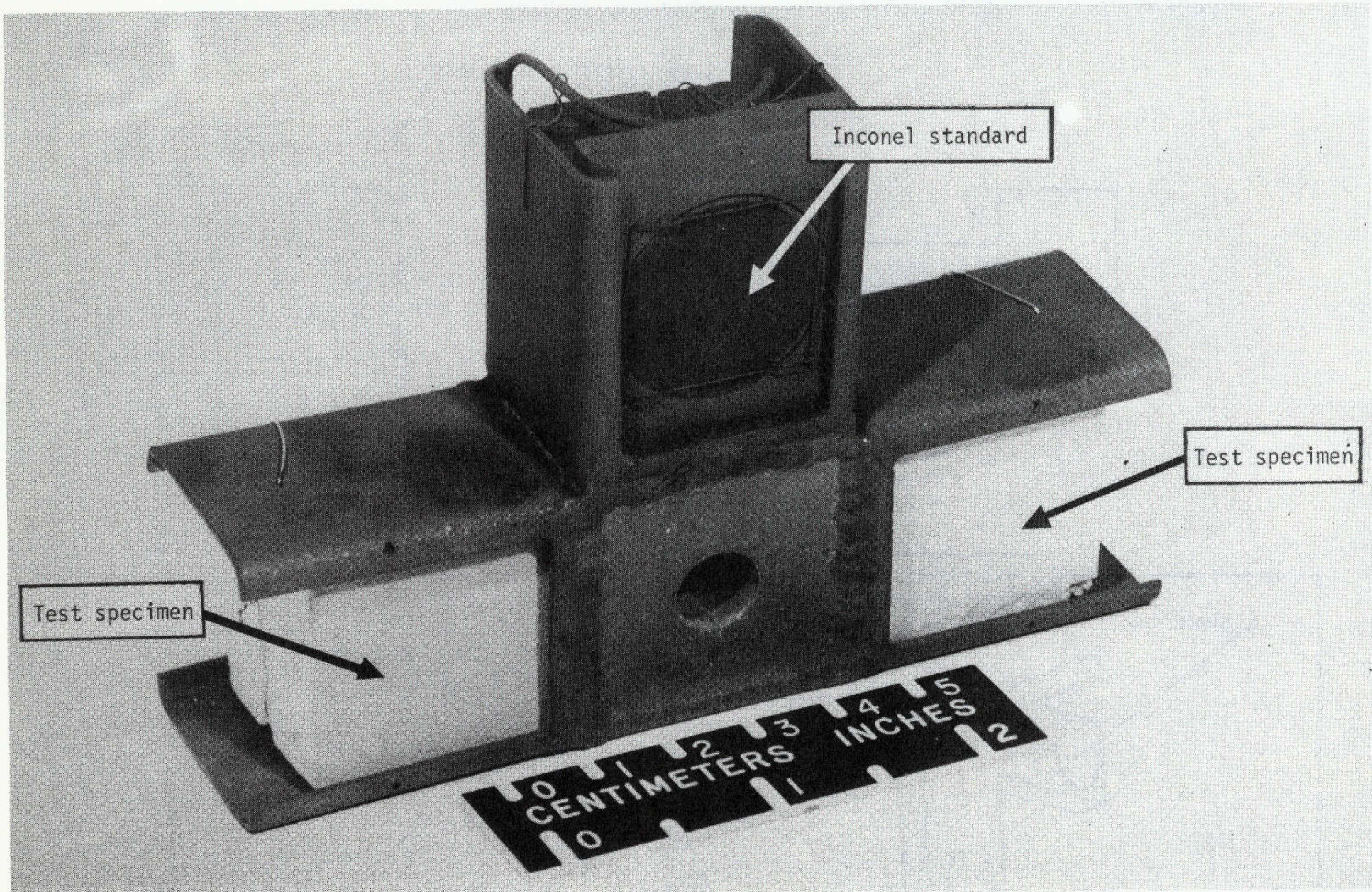

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Figure 3.- Specimen holder.

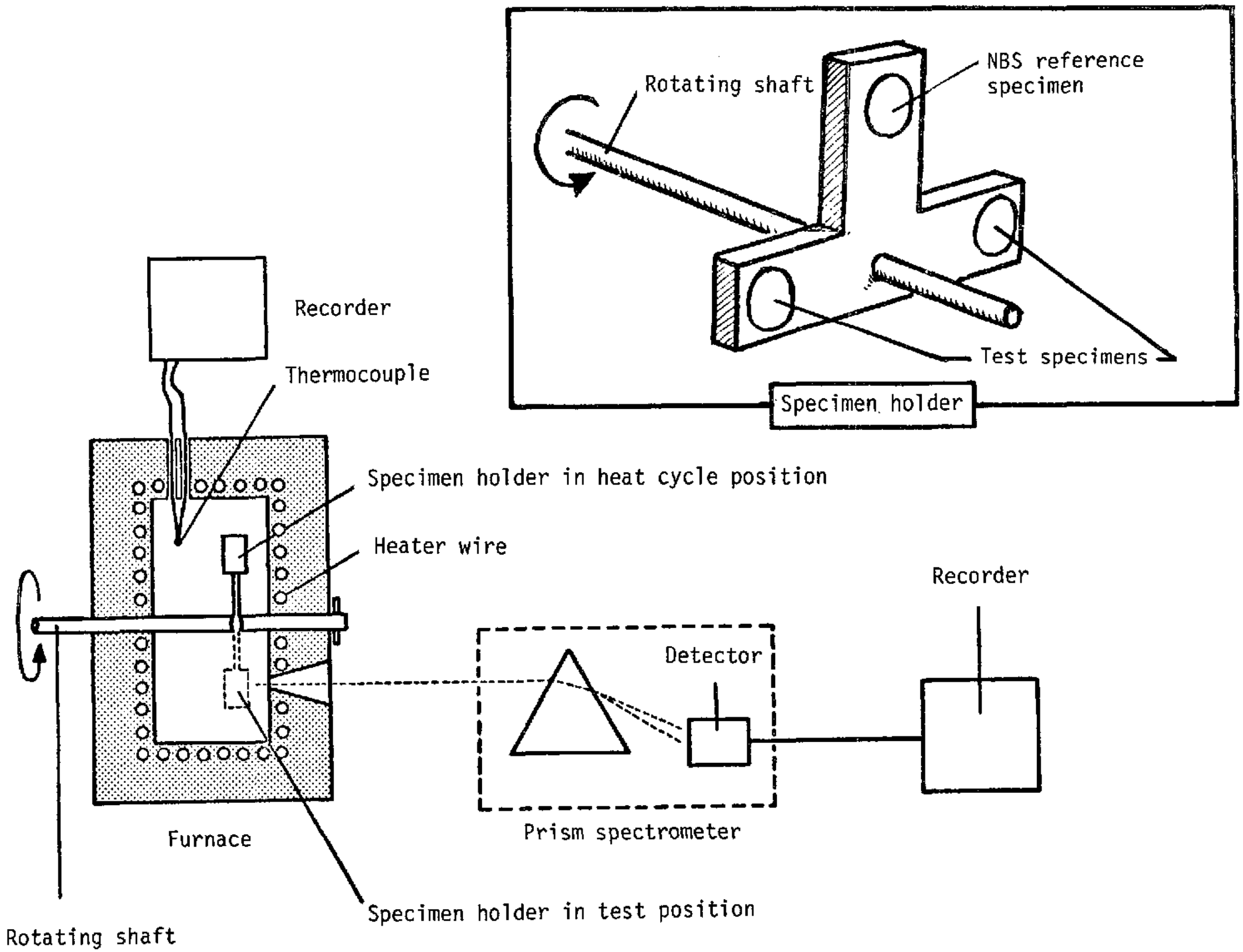


Figure 4.- Diagram of setup used in radiometric technique with inset of specimen holder.

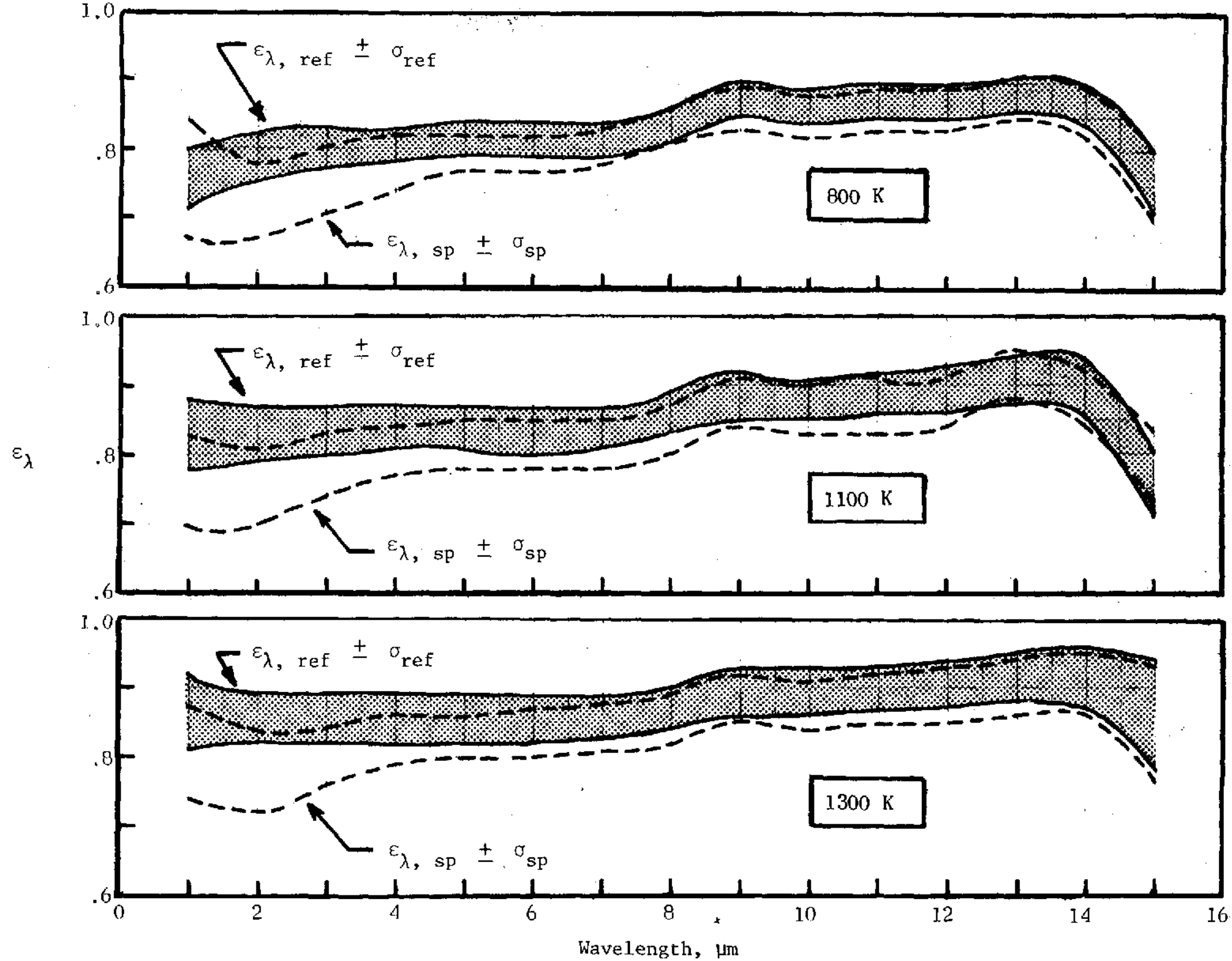


Figure 5.- Spectral normal emittance of inconel determined by LaRC emittance apparatus compared with NBS data.

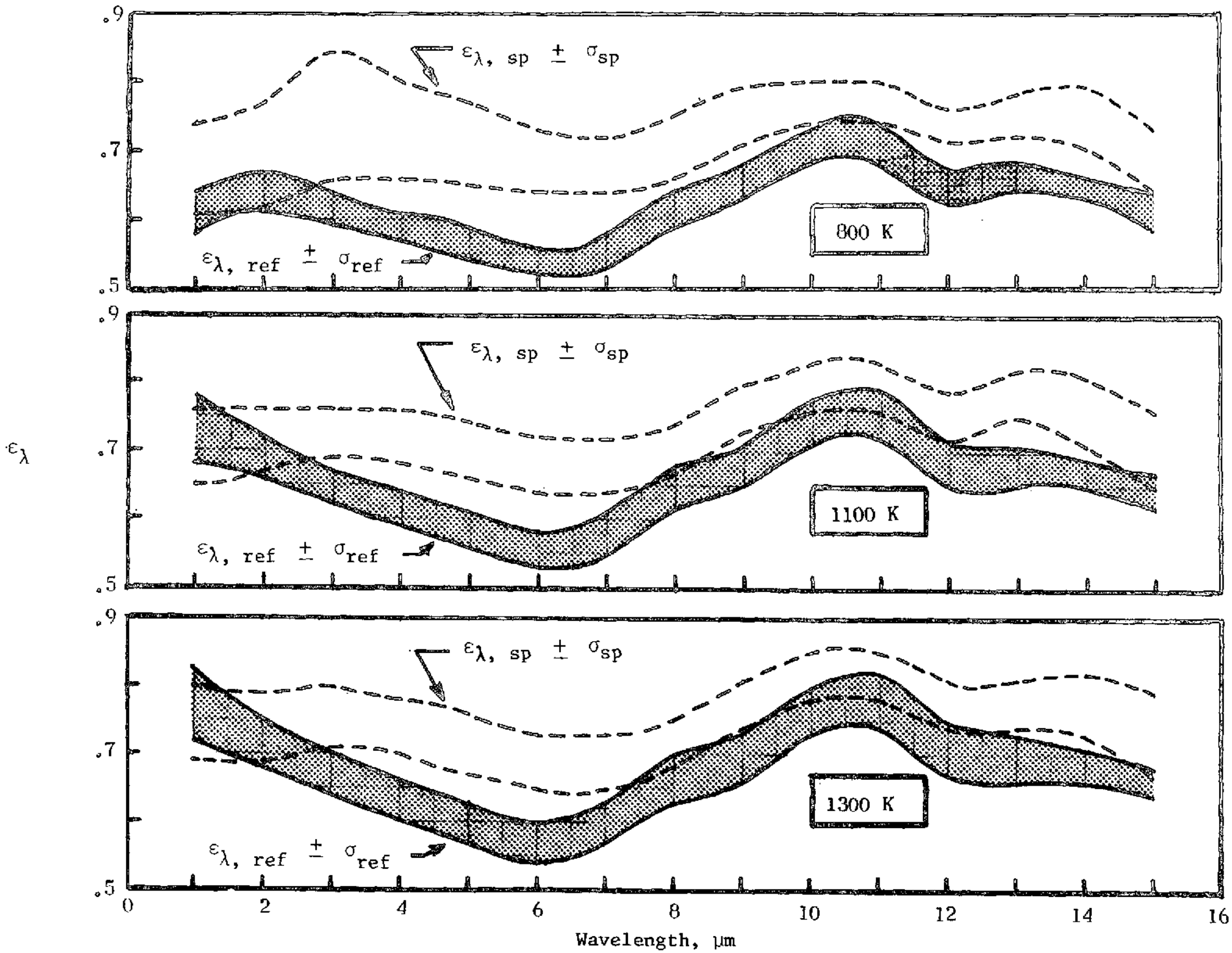


Figure 6.- Spectral normal emittance of Kanthal determined by LaRC emittance apparatus compared with NBS data.

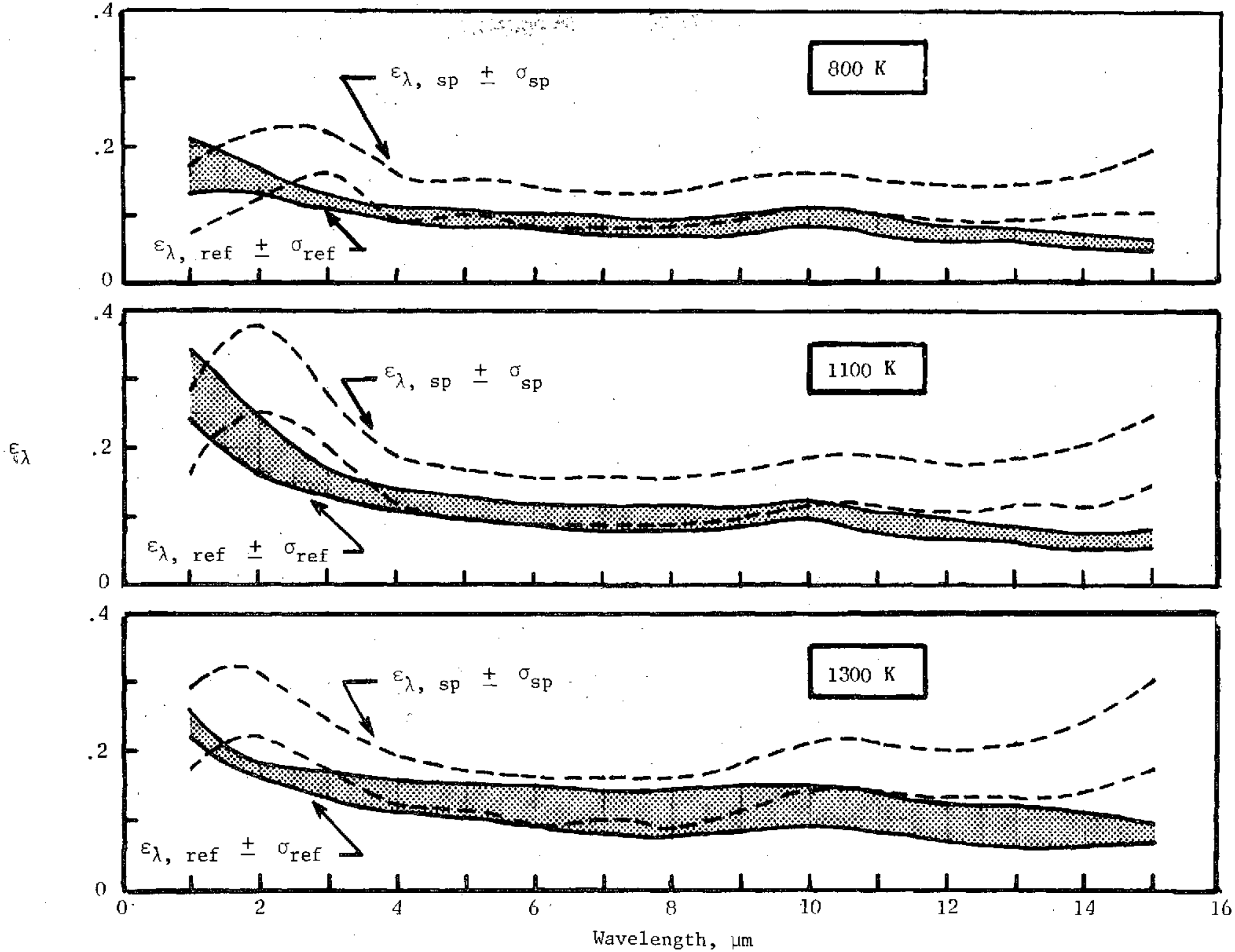
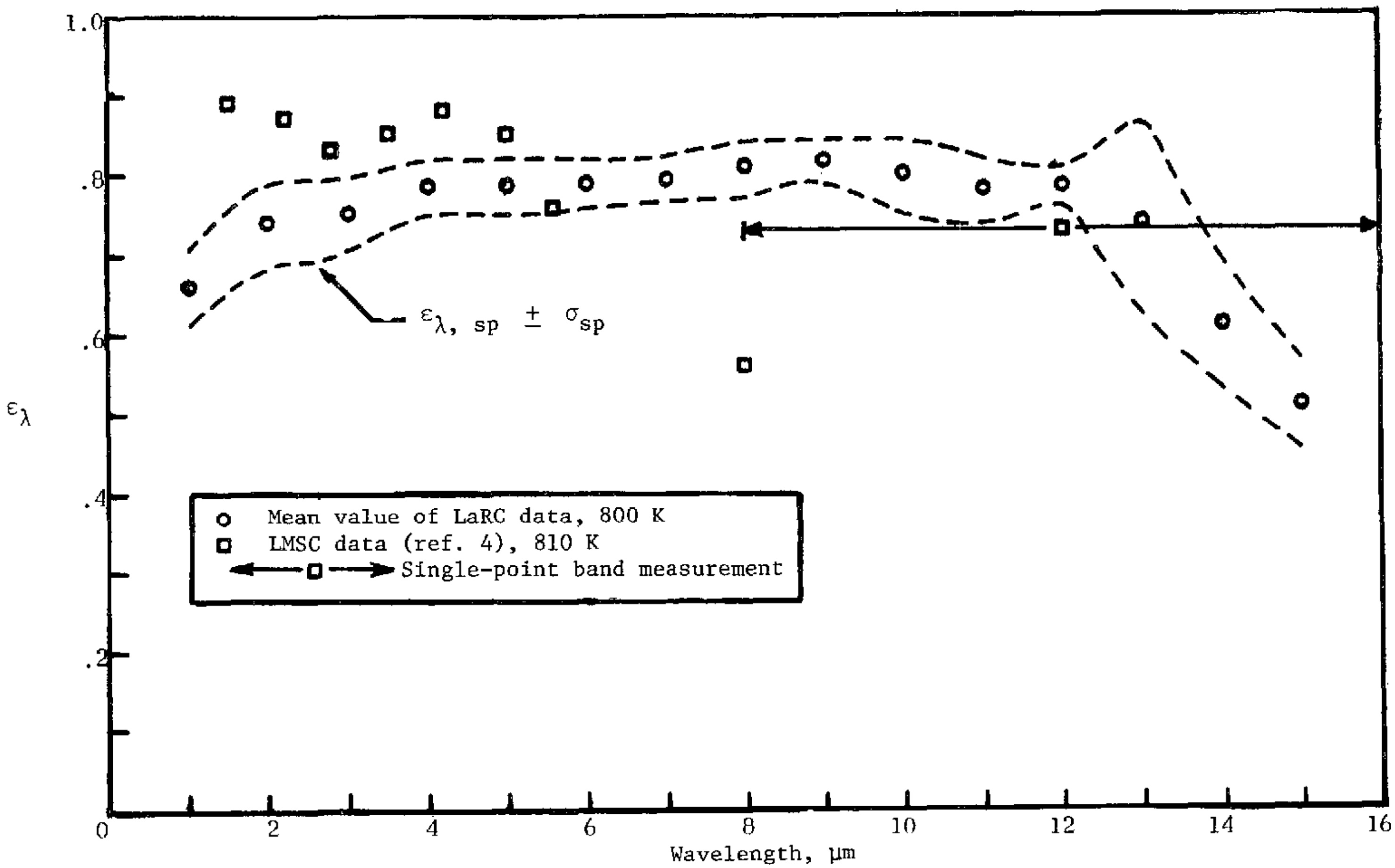
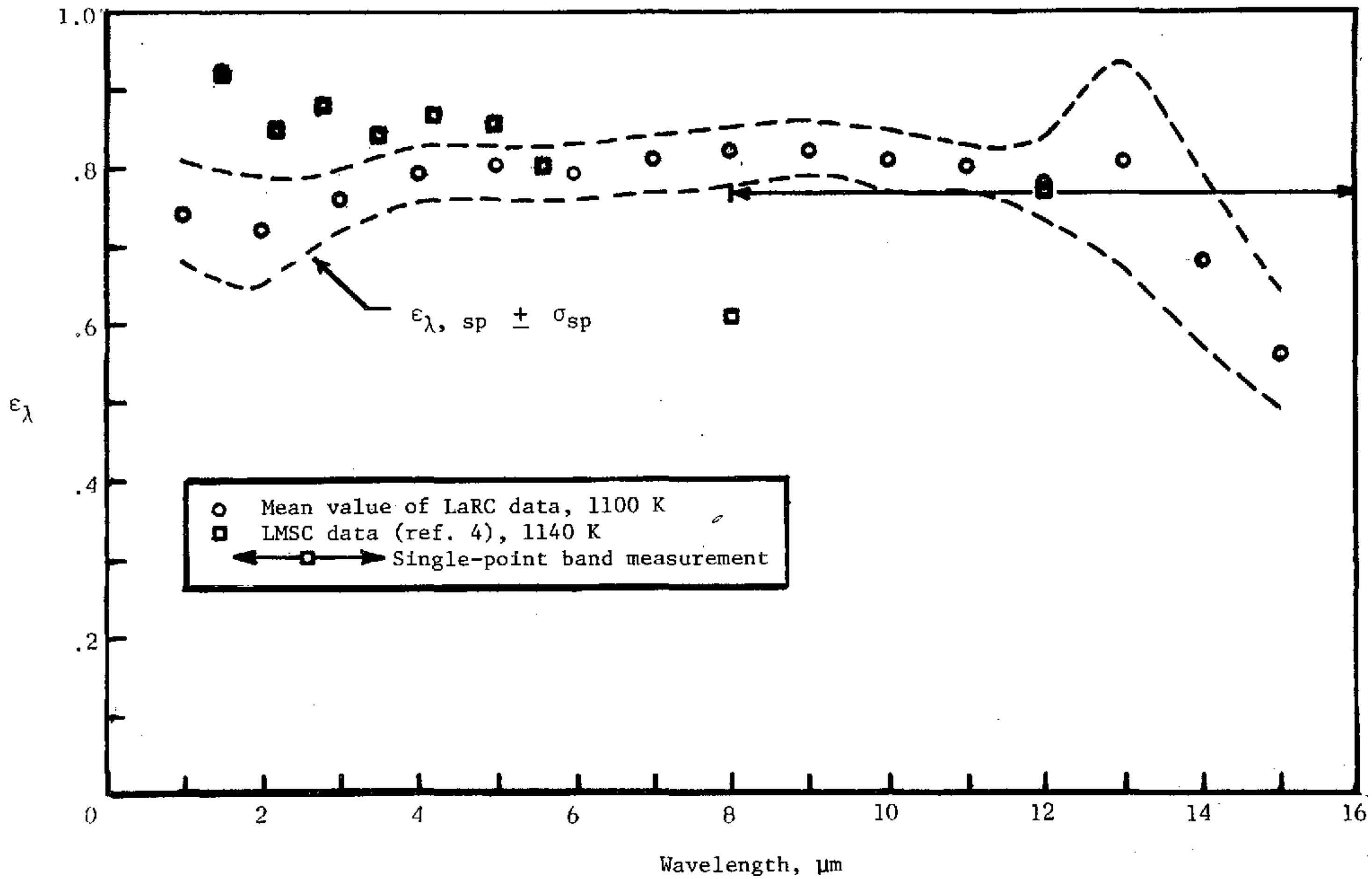


Figure 7.- Spectral normal emittance of Pt-0.13Rh determined by LaRC emittance apparatus compared with NBS data.



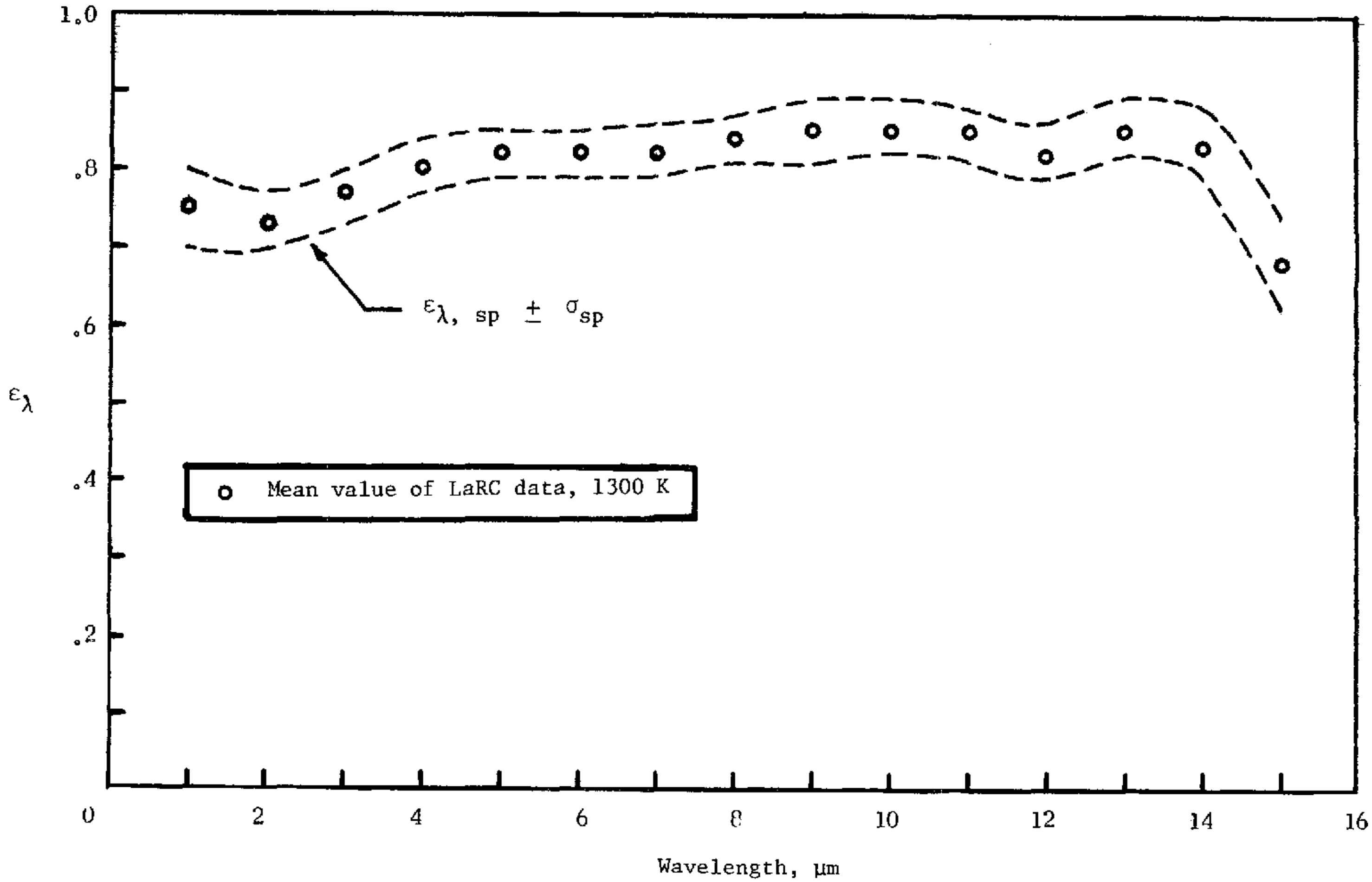
(a) At 800 K.

Figure 8.- Spectral normal emittance of René 41.



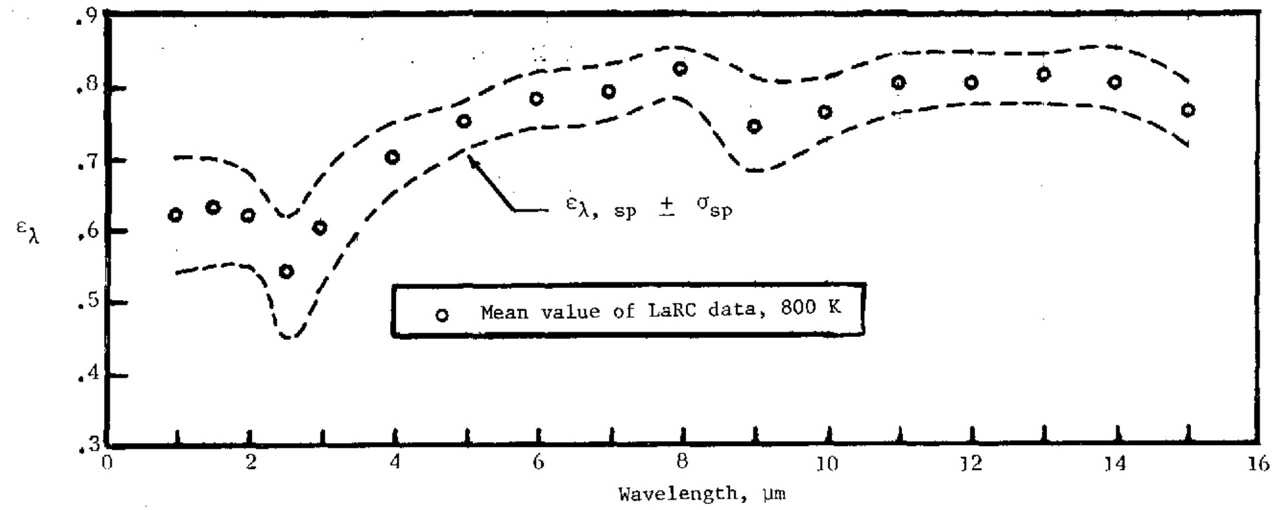
(b) At 1100 K.

Figure 8.- Continued.

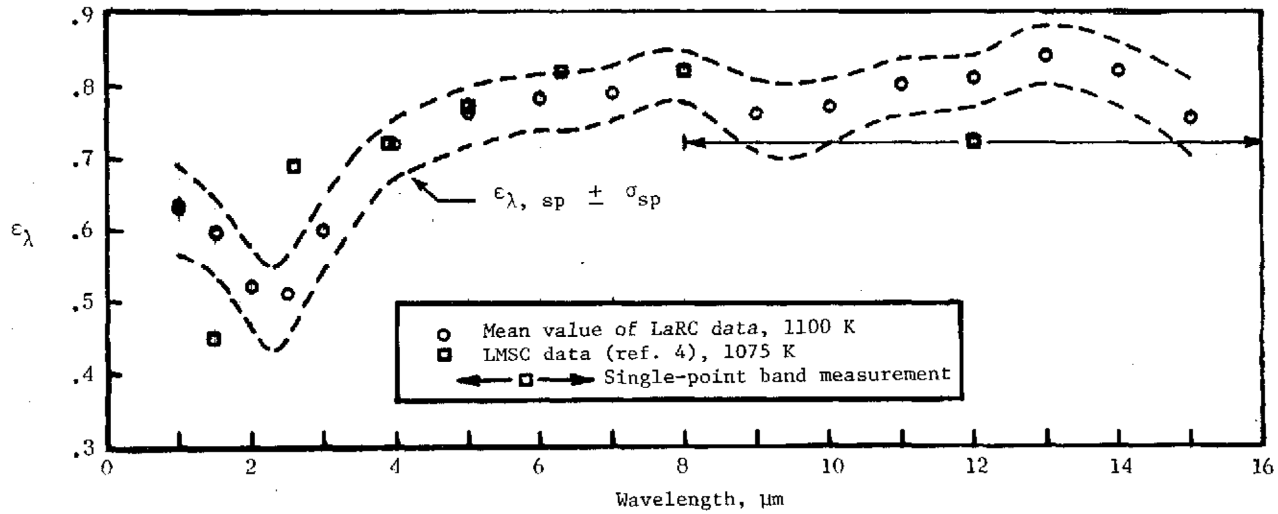


(c) At 1300 K.

Figure 8.- Concluded.

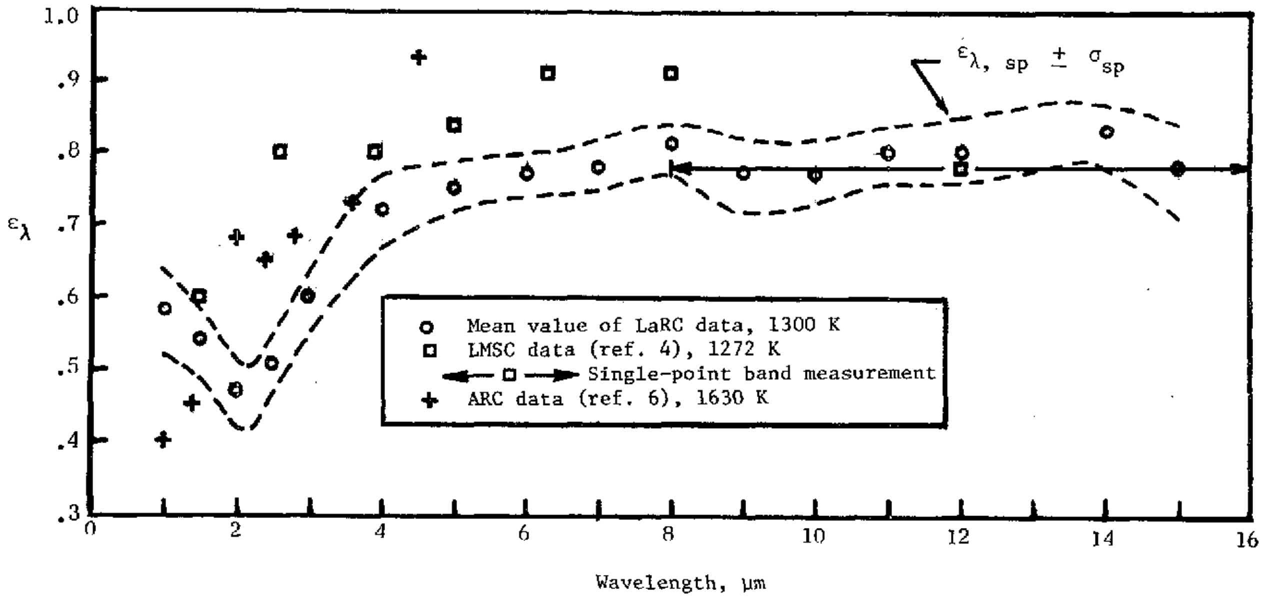


(a) At 800 K.



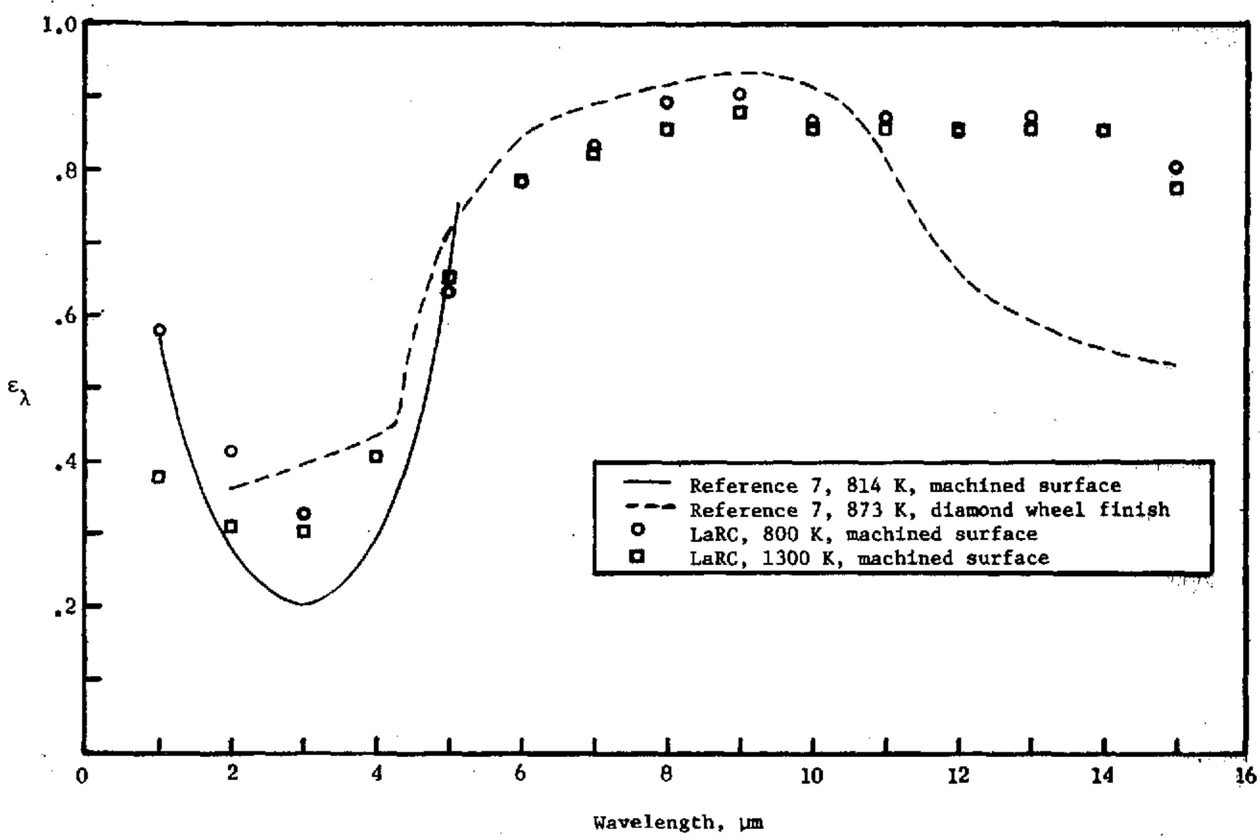
(b) At 1100 K.

Figure 9.- Spectral normal emittance of RSI material.

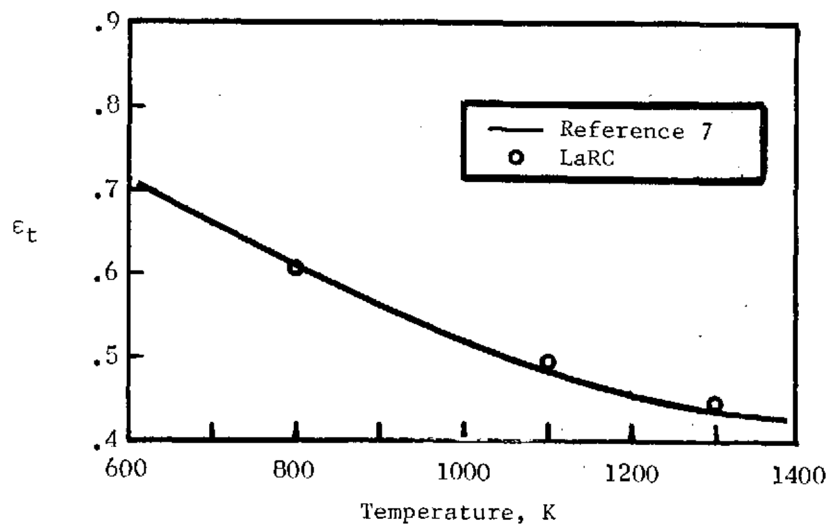


(c) At 1300 K.

Figure 9.- Concluded.

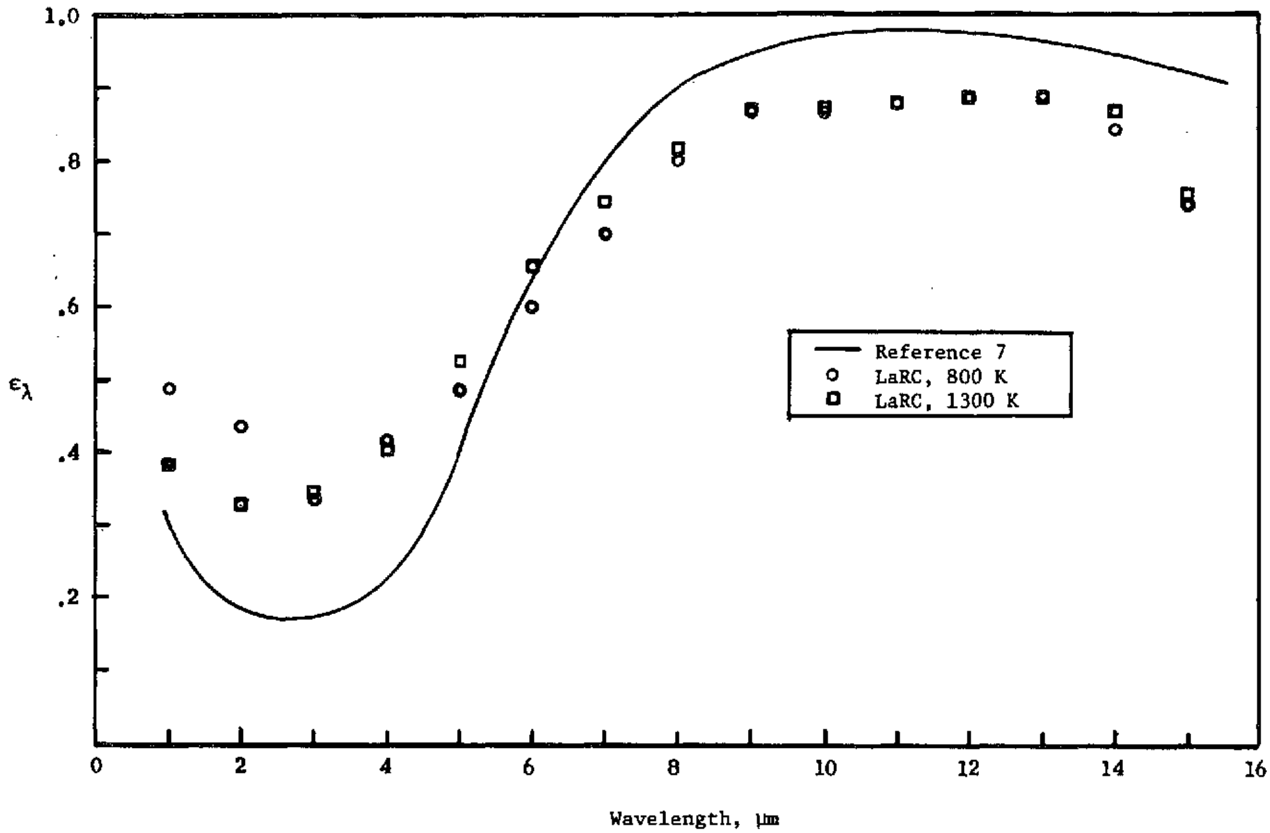


(a) Spectral emittance.

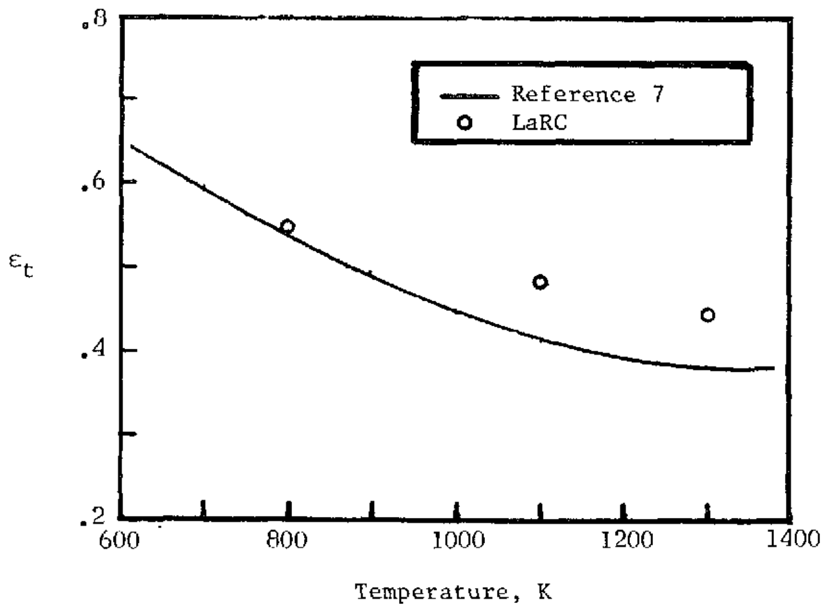


(b) Total emittance.

Figure 10.- Normal emittance of alundum mixture AN498.



(a) Spectral emittance.



(b) Total emittance.

Figure 11.- Normal emittance of flame-sprayed zirconia.

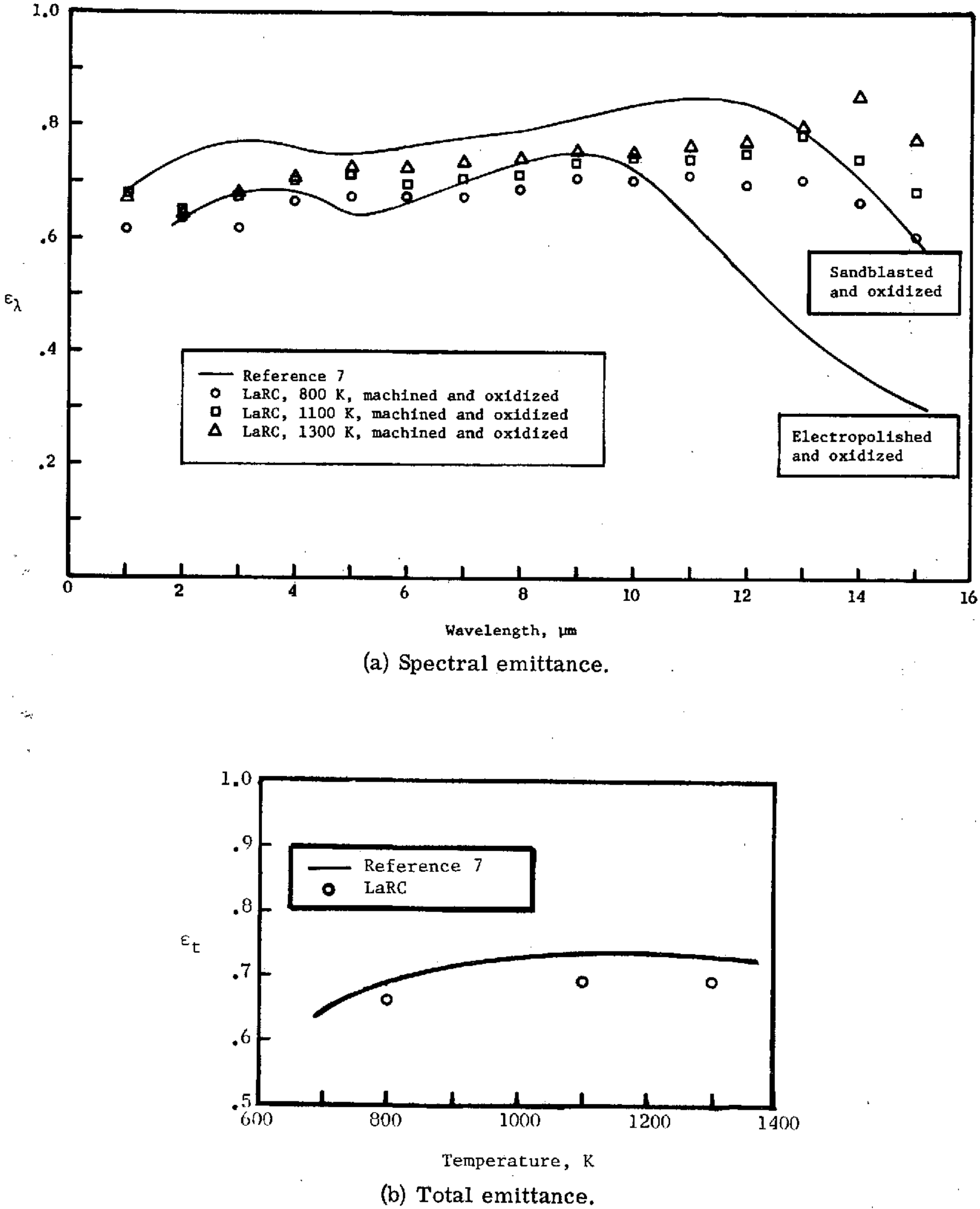
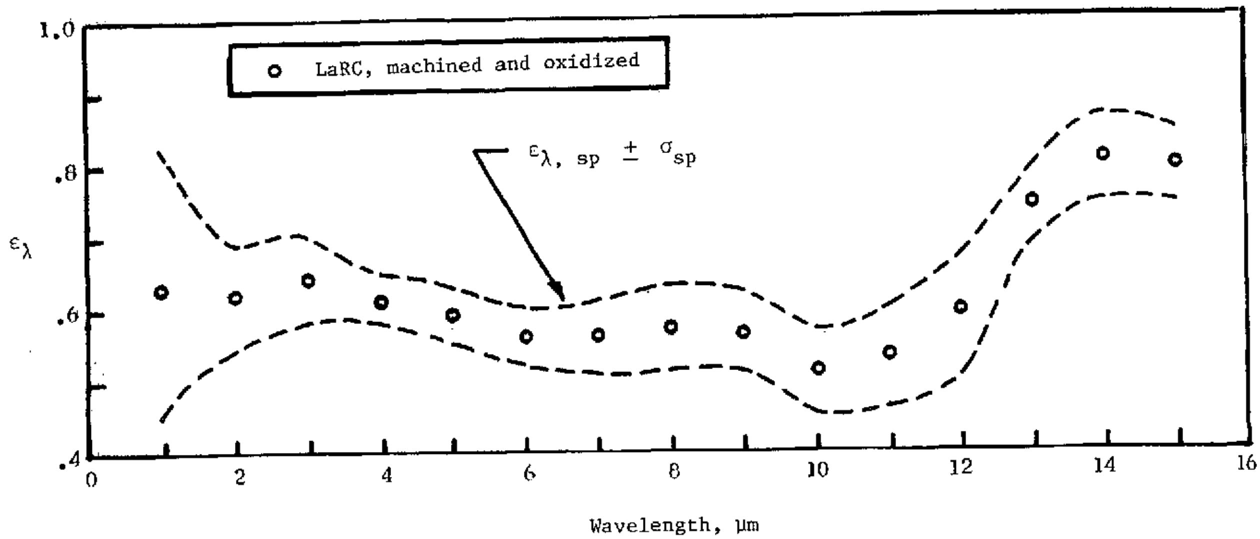
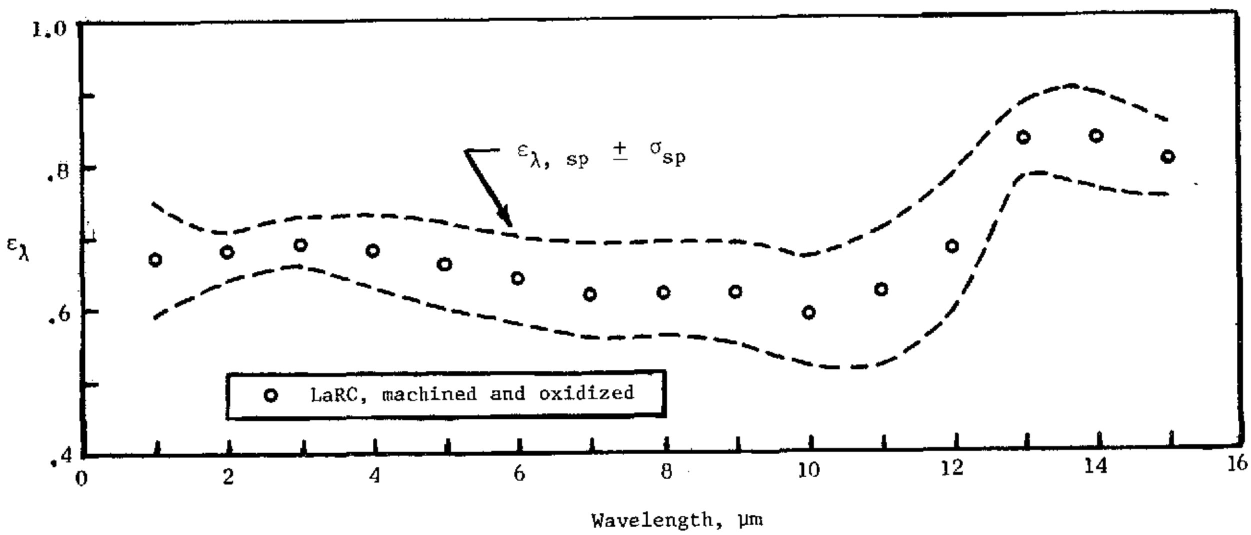


Figure 12.- Normal emittance of AISI type 321 stainless steel.

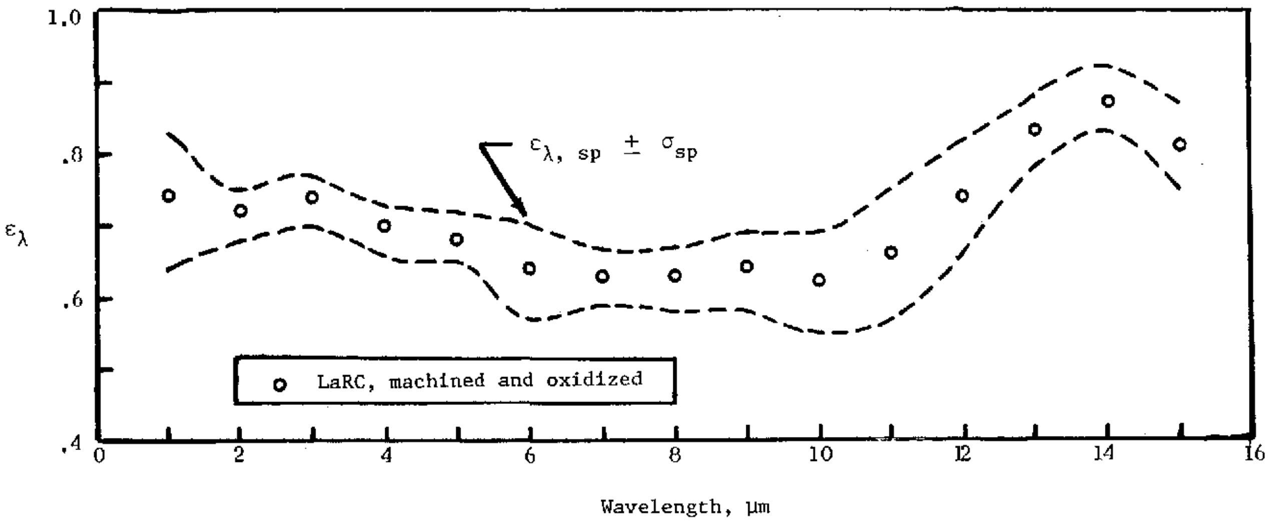


(a) Spectral emittance at 800 K.

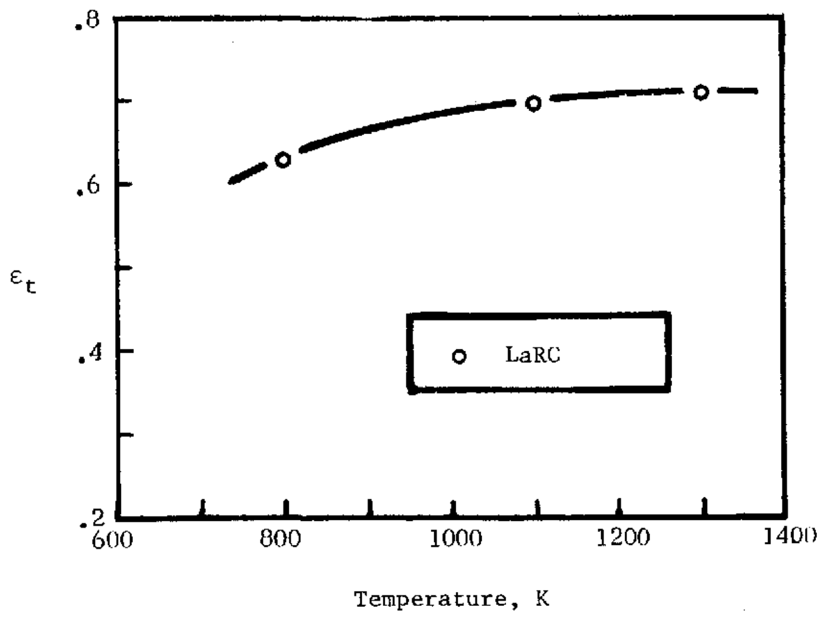


(b) Spectral emittance at 1100 K.

Figure 13.- Normal emittance of nickel 201.



(c) Spectral emittance at 1300 K.



(d) Total emittance.

Figure 13.- Concluded.

NASA-Langley, 1975 L-9774