NBS TECHNICAL NOTE 594-13

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Optical Radiation Measurements:

The 1973 NBS Scale of Spectral Irradiance

measurements on each irradiance lamp.

5. Data Reduction

Twenty-six wavelengths were chosen for this realization. Eight of the wavelengths in the UV spectral region, however, were used to check the validity of an equation (discussed below) defining spectral irradiance as a function of wavelength and computed blackbody temperature. These eight wavelengths (260 nm, 270 nm, 280 nm, 290 nm, 310 nm, 320 nm, 330 nm and 340 nm) have only been measured twice. The gas-filled strip lamps are used at the wavelengths 250 nm, 300 nm, 350 nm, 400 nm, 450 nm, 500 nm, 555 nm, 654.6 nm, 700 nm and 800 nm. Vacuum strip lamps are used at the wavelengths 700 nm, 800 nm, 900 nm, 1050 nm, 1150 nm, 1200 nm, 1300 nm, 1540 nm, and 1600 nm.

Because of stabilization times (20 min) and the integration time required to smooth short-term radiance fluctuations, the total time for each wavelength is approximately an hour for the first two steps of the realization. In step 3 (irradiance to irradiance) the measurement time for all wavelengths on an irradiance lamp is approximately two hours. The large number of operating hours involved means that lamp drift cannot be ignored. Therefore, for each lamp an equation was developed to allow its spectral irradiance to be calculated at any time t.

Based upon the drift data exemplified by figure 5 an adequate model for the drift of spectral irradiance of constant current tungsten halogen lamps is given by the equation

$$E_\lambda = \lambda^{-5} \exp (A_\lambda + Ct + (D + Bt)/\lambda).$$

Comparing this equation with Wien's law for a gray body: $E_\lambda = \varepsilon\lambda^{-5} \exp (C_2/\lambda T)$ one sees that $\exp (A_\lambda + Ct)$ represents the effective emissivity (and envelope transmission) which is assumed to change with time. The term $(D + Bt)$ represents C_2/T, again assumed to change with time. D was set at 4.7 µm corresponding to $T = 3061$ K. The remaining coefficients (B, C, and one A_λ for each of the twenty-six wavelengths) were determined by least-squares fitting techniques.

In a similar way an interpolation formula was developed for calculating the spectral irradiance of tungsten-halogen lamps at wavelengths intermediate between the 26 calibrated wavelengths. This formula is:

$$E_\lambda = (A_0 + A_1\lambda + A_2\lambda^2 + \ldots + A_n\lambda^n)\, \lambda^{-5} \exp (a + b/\lambda).$$

The quantities a and b are determined by fitting the data to $\ln(E_\lambda\, \lambda^5) = a + b/\lambda$ in which it will be recognized that $\exp (a)$ is an effective gray-body emissivity and b is closely related to the reciprocal of the distribution temperature. With a and b thus fixed

$A_0, A_1, \ldots A_n$ are least squares fitted using $1/E^2_\lambda$ weighting (assuming constant percentage measurement error). In practice it has been found that the final fit is considerably improved if the spectrum is broken into two spectral regions, 250 - 400 nm and 350 - 1600 nm, for separate fitting.

Figures 6, 7 and 8 show the different fittings to the equations given above. This method is only valid for the continuous spectrum and does not predict the emission lines and absorption bands.

6. Uncertainties

The significance of this new method for determining the spectral irradiance is best appreciated by examining the basic uncertainties associated with the method. These are listed in Table 1. The total absolute uncertainties in the last two lines of the table are obtained by adding all the uncertainties at a given wavelength in quadrature.

The systematic uncertainty in the radiance-to-irradiance transfer (line II a) is obtained by adding in quadrature estimated contributions from a number of error sources. Each of the following error sources contributed 0.01% or less: Non-linearity of the detector-amplifier system, wavelength error, stray light, lamp polarization, lamp current measurements, and the integrating sphere response to the different solid angles of the radiance image and irradiance sources. Each of the following contributed less than 0.05%: The projected solid angle determination, uniformity of mirror M1, and spectral light scattering due to the slit function wings. Finally, the non-uniformity of the radiance sources over the viewing area contributes an uncertainty varying from 0.12% in the UV to .05% in the IR.

The uncertainties listed in Table 1 are the uncertainties assigned to the mean value of the four working standards at the time that the standards are calibrated. Because lamps drift with time, the spectral irradiance at any other time is obtained from the spectral irradiance vs. time formula described above for the working standards group. The possibility that this drift model may be wrong introduces an additional uncertainty not included in Table 1. This model uncertainty for a particular lamp is estimated as 0.8%. This uncertainty was obtained by comparing the calculated extrapolated spectral irradiance with further scale realizations. When the working group is used between scale realizations, this 0.8% uncertainty must be combined in quadrature with the total uncertainties in Table 1.

7. Conclusion

The method described in this report has made the frequent realization of the spectral irradiance scale feasible. This, in turn, has significantly reduced the uncertainty of the scale by eliminating the reliance upon long-term predictability of the NBS working lamp standards. The method is valid for generating a spectral irradiance scale of any magnitude; the magnitude can be altered either by changing the radiance levels or by changing the solid-angle-defining aperture at mirror M1. At present a scale realization requires about 40 hours to complete. Most of this time is spent stabilizing the strip lamps, which must be done because the lamp current is changed for each wavelength. Other sources of spectral radiance are being investigated which will require less stabilization time. A radiance source requiring

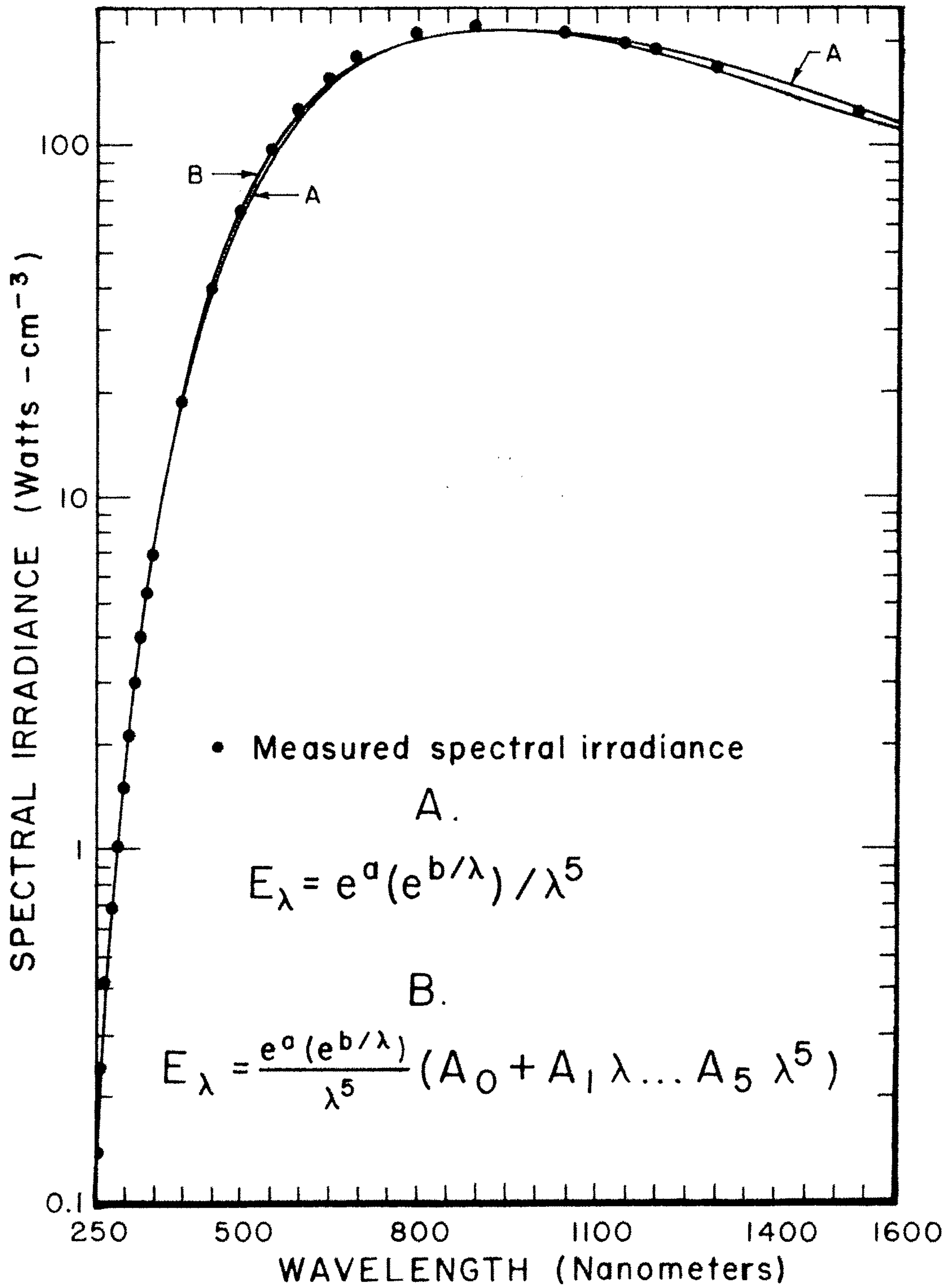

Figure 6. Spectral Irradiance Fit in Spectral Region 250 - 1600 nm.

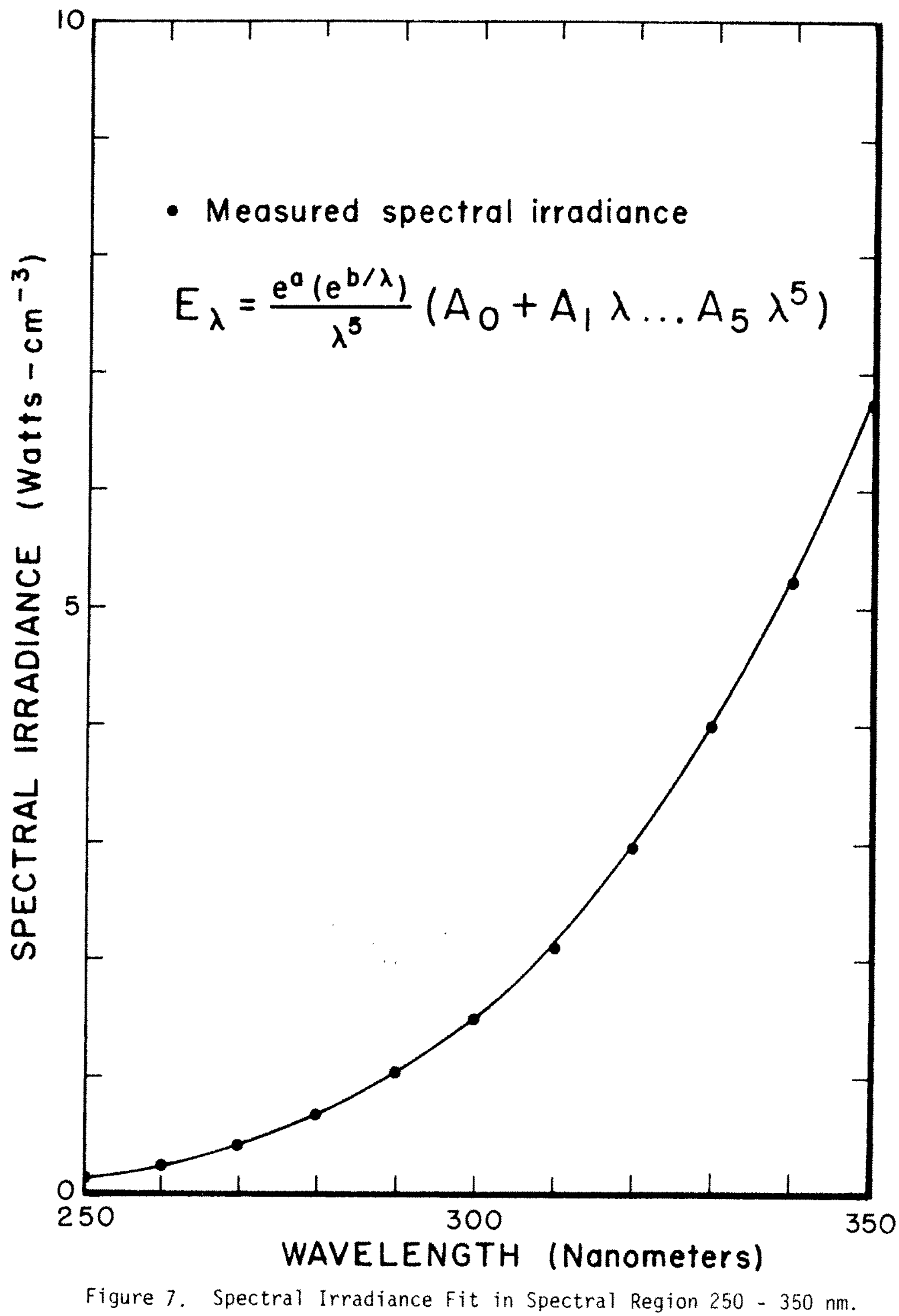

Figure 7. Spectral Irradiance Fit in Spectral Region 250 - 350 nm.

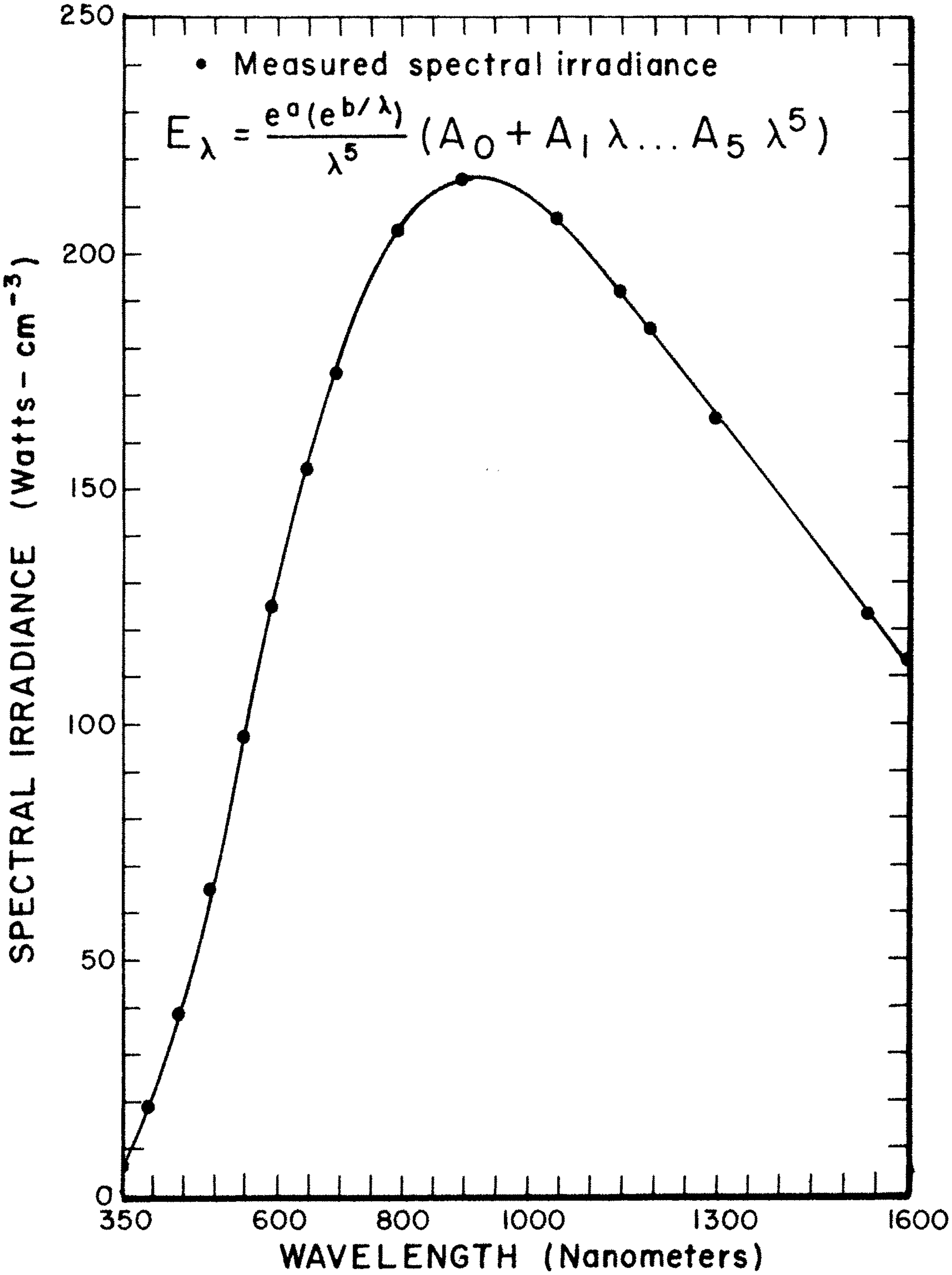

Figure 8. Spectral Irradiance Fit in Spectral Region 350 - 1600 nm.