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Publication Date

1960-06-01

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June 1960
Index Number NS 714-100

SIO REFERENCE 60-29

Bureau of Ships
Contract NObs-72092

Project S FO01 05 01

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SOME SPECTRAL SKY RADIANCES WITH DIFFERENT RELATIVE HUMIDITIES *

by

Almerian R. Boileau

INTRODUCTION AND SUMMARY

When sky spectral radiance measurements which were made during operational tests of a spectroradiometer were compared it was seen that there was a close relationship between the value of spectral radiances and relative humidities.

A comparison of six sky spectral radiance measurements for a path of sight 11° above the horizontal after normalization at the maximum value in each case shows that in the red end of the spectrum the spectral radiance values varied in the same order as the relative humidities varied and, excluding the measurement made during misty weather, the relationship was almost linear. A comparison of the measured spectral radiance curves for the four lowest values of relative humidity shows that there was an almost linear change of sky radiance with change of relative humidity over the range of wavelengths from 480 μ to 700 μ . The relative humidities in this discussion were 14%, 37%, 58%, 79%, 83%, and very high (misty).

*This report is a result of research which has been supported by the Geophysics Research Directorate, Air Force Research Division, Bedford, Massachusetts, and the U.S. Navy Bureau of Ships.

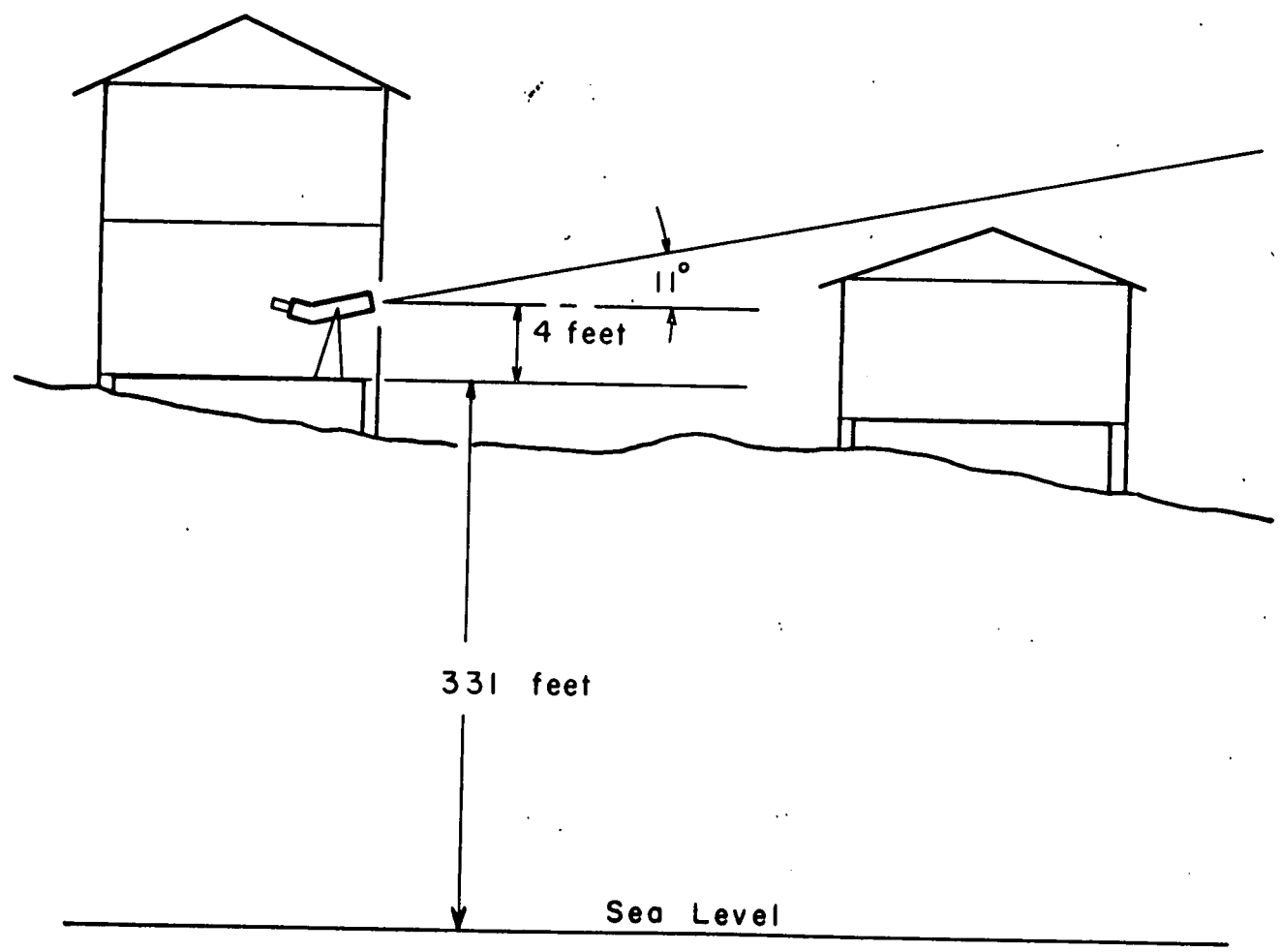
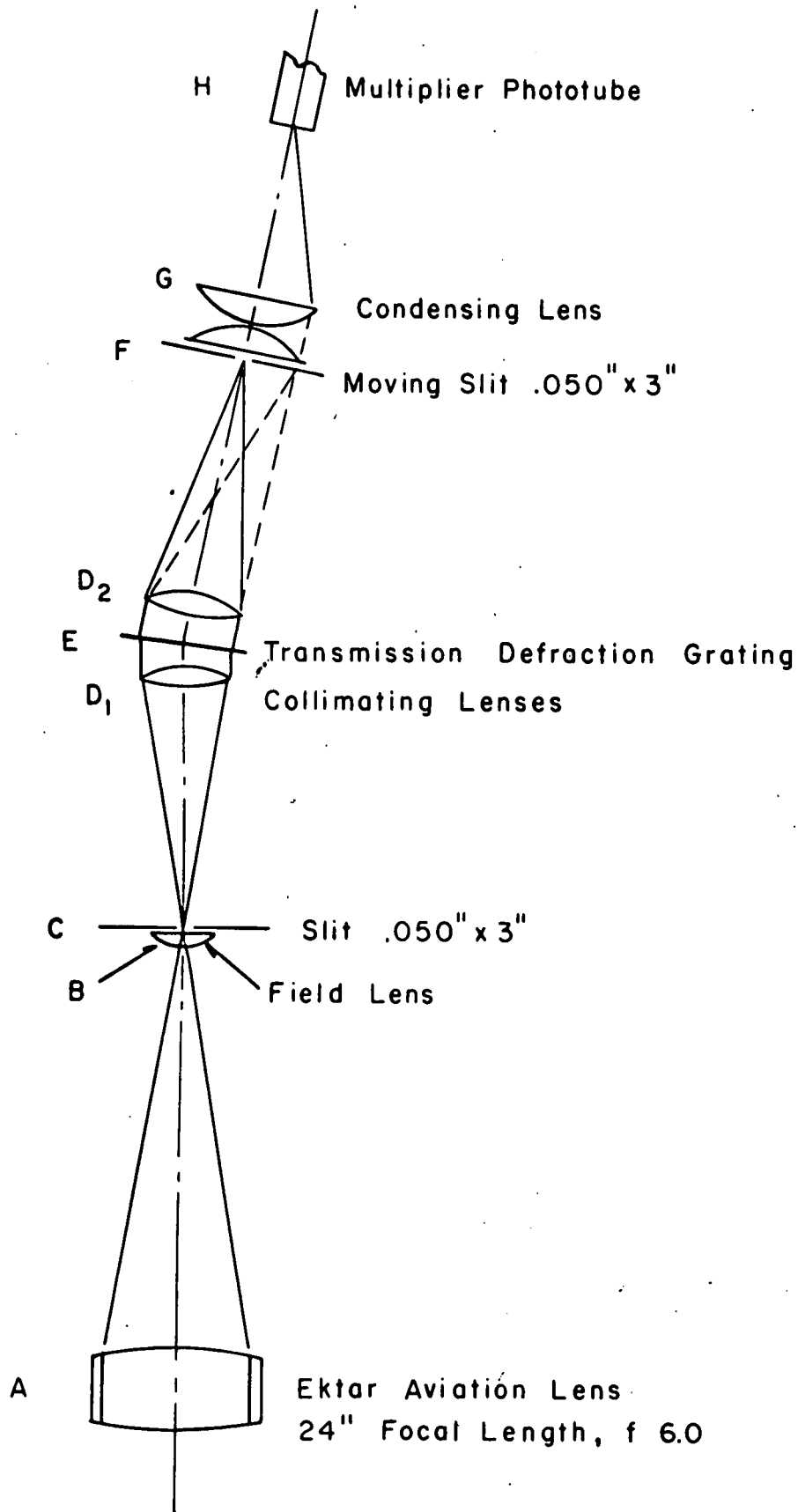


Figure 1

PROCEDURE

During December 1957 and January 1958 operational tests were made at the Visibility Laboratory of a spectroradiometer following minor modification and adjustment. To test the instrument it was placed as shown in Fig. 1 so that the line of sight was out the shop window and above the horizontal to clear the roof of the adjacent building. With the instrument in this position the spectral radiance of the sky during different weather conditions was measured and the data compared. The total of six measurements were made.

Spectrogeograph. The instrument with which the measurements were made was developed by Eastman Kodak Company during World War II for measuring the spectra of ground targets from the air. The instrument in its original form, designated as the SPECTROGEOGRAPH, recorded photographically both the ground target and the ground target spectrum. The Spectrogeograph has been converted at the Visibility Laboratory in recent years into a recording photoelectric spectroradiometer by the addition of a moving exit slit and the replacement of the photographic recording equipment with an end-on multiplier phototube and attendant optical and electronic accessories. The name of the instrument, Spectrogeograph, is still applicable and is retained.

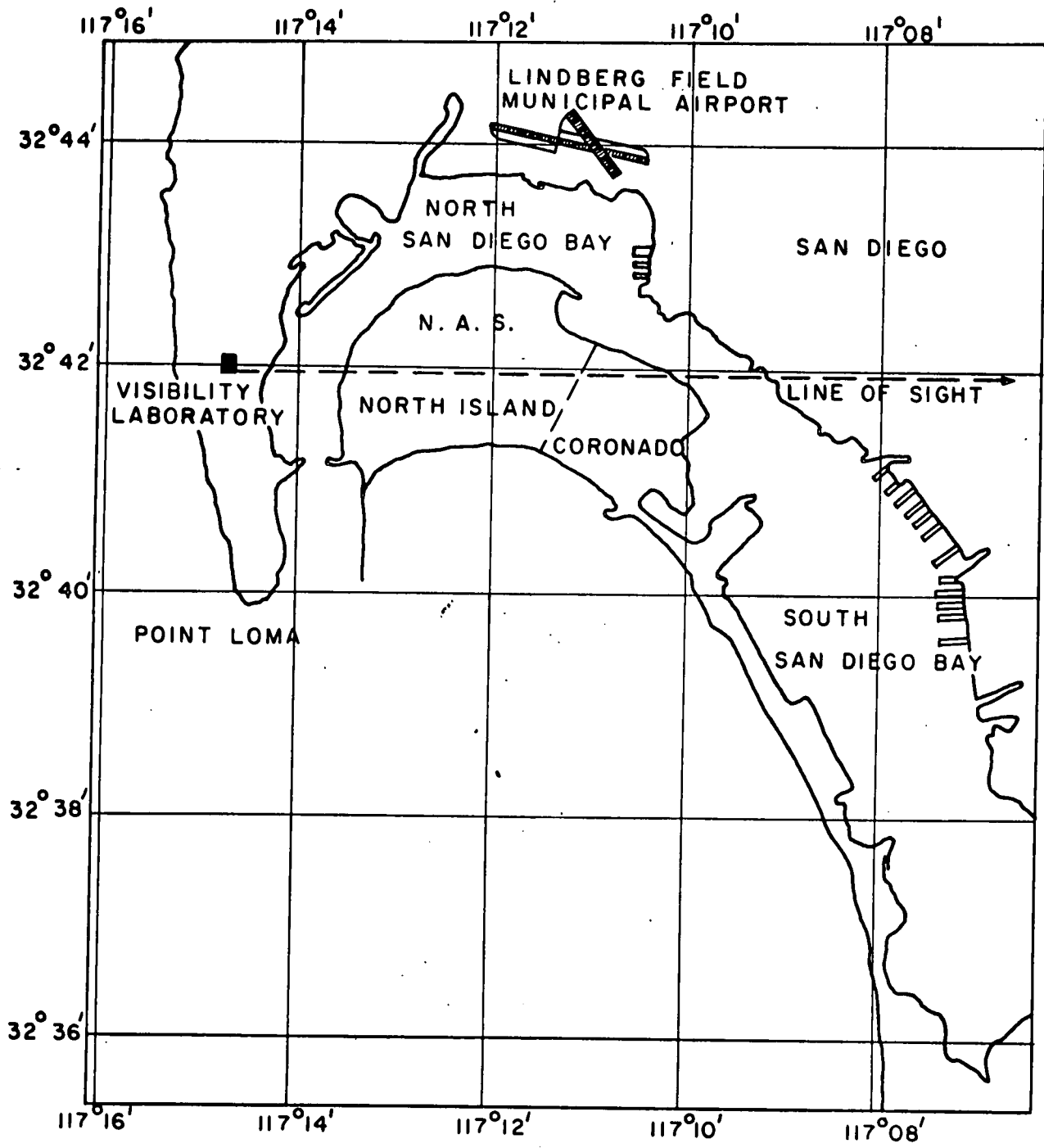


OPTICAL SYSTEM OF SPECTROGEOGRAPH

Figure 2

Description of Spectrogeograph. The Spectrogeograph optical system is shown in Fig. 2. It consists of an EKTAR aviation lens A which images a target at the entrance slit C. The image at the entrance slit C is re-imaged at the moving exit slit F by the collimating lenses D_1 and D_2 . Between these lenses there is located a transmission diffraction grating. This causes a series of colored images at F, the short wavelength being the first one observed. The rays which pass through the slit F as it traverses the spectrum are collected by the condensing lenses G and are incident on the end-on multiplier phototube H. The moving slit F is moved across the spectrum in slightly less than one second of time.

The EKTAR aviation lens has a focal length of 24". The slit length and width are 3" and .050" respectively. Hence the angles subtended by the instrument are 7.2° and $7.2'$, respectively. The slit bandwidth is 10 μ .



LINE OF SIGHT OF SPECTROGEOGRAPH

Figure 3

The Spectrogeograph was placed in the Visibility Laboratory building as shown in Fig. 1, its line of sight was due east, 11° above the horizontal, with the slit parallel to the horizon. The Building in which the instrument was located is 331 feet above sea level. The instrument was four feet from the floor or 335 feet above sea level.

The line of sight as shown in Fig. 3 was directly over the Naval Air Station on North Island, over the northern edge of the city of Coronado, and over the city of San Diego. The line of sight was at 4400 feet altitude over the northern edge of Coronado and 6150 feet altitude over the San Diego shore line. There are no industries on North Island or in the city of Coronado which produce industrial wastes other than vehicular exhaust gases and building heating equipment exhaust gases. San Diego does have industry in the vicinity of the line of sight but the waste products are observed to be in the first two to three thousand feet above sea level.

At the time of the measurements the atmospheric temperature and pressure and the relative humidity were obtained from the U. S. Department of Commerce Weather Bureau located at Lindberg Field Municipal Airport Administration Building. This is located north of North Island, across North San Diego Bay as shown in Fig. 2. The weather bureau instruments are approximately 25 feet above sea level.

Information pertinent to the measurements and subjective notes made at the time of the measurements are presented in Table 1.

TABLE 1^{*}

MEASUREMENT	1	2	4	5	6	7
DATE	16 Dec 1957	18 Dec 1957	26 Dec 1957	30 Dec 1957	7 Jan 1958	15 Jan 1958
TIME - PST	1330	0830	0830	0815	0830	1245
ELEVATION - SUN	30°	15°	15°	12.5°	15.5°	35.2°
AZIMUTH - SUN	204°	131°	131°	128°	131°	193°
SCATTERING ANGLE ^{**}	118.9°	41.4°	44.5°	41.8°	42.9°	103.3°
TEMP.-FAHR.	66°	54°	53°	49°	57°	72°
PRESSURE in.Hg	30.05"	30.12"	29.97"	29.92"	30.18"	30.06"
REL. HUMIDITY	Very High	83%	58%	79%	37%	14%

Notes made at Time of Measurements

- No. 1 "Overcast and stormy. At time of measurement instrument was looking at low fog or mist (almost rain)."
- No. 2 "Clear blue sky."
- No. 4 "Very clear day."
- No. 5 "Morning clear after all-night heavy fog."
- No. 6 "Very clear day. Santa Ana condition."^{***}
- No. 7 "Clear, dry day."

* No. 3 measurement was not part of the sky series and is not included here.

** Scattering angle is defined as the angle between the incident ray extended and the scattered ray. Thus scattering at zero scattering angle is coincident with the incident ray, and scattering at a scattering angle of 180° is a ray returning along the path of the incident ray.

*** From Weather Glossary, U.S. Dept. of Commerce. p. 228, "Santa Ana, n - Local name for a FOEHN Wind, ..., in southern California..." During this condition winds are from the north, gusty, warm and dry.

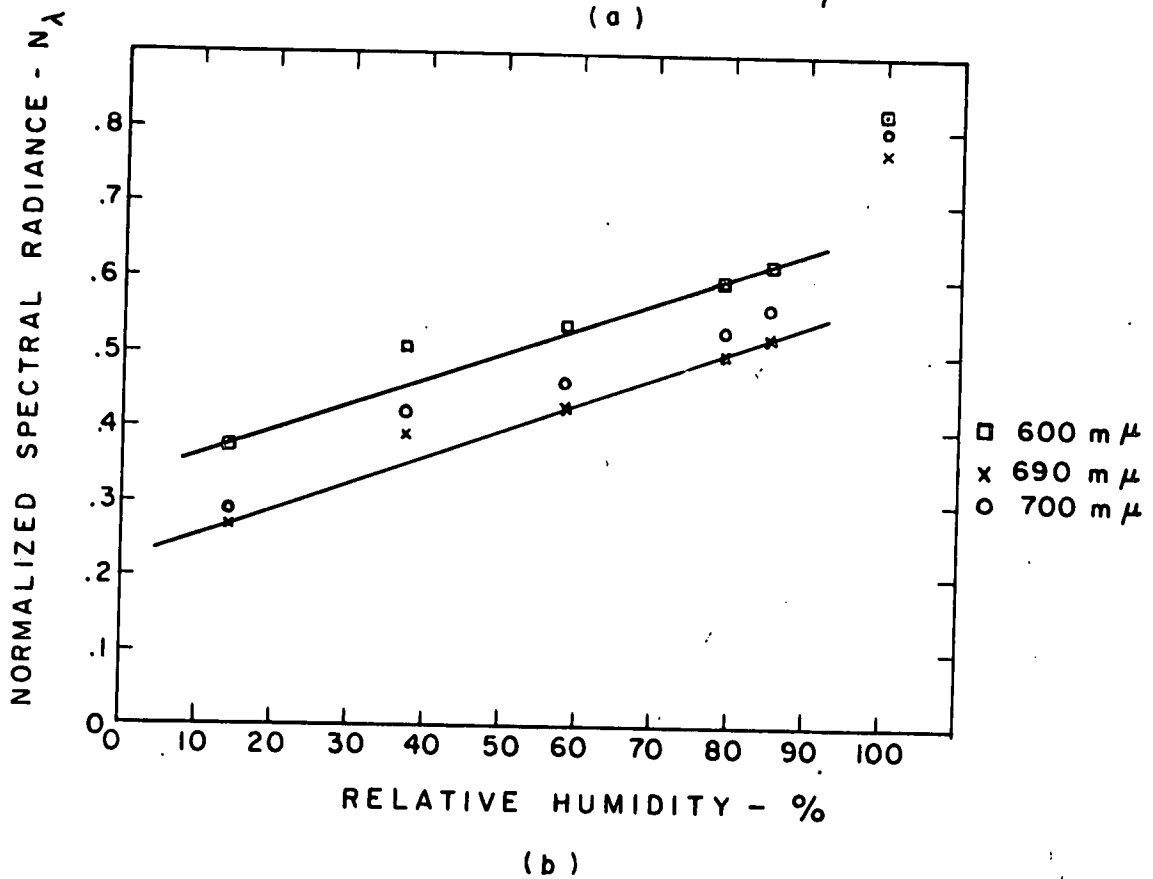
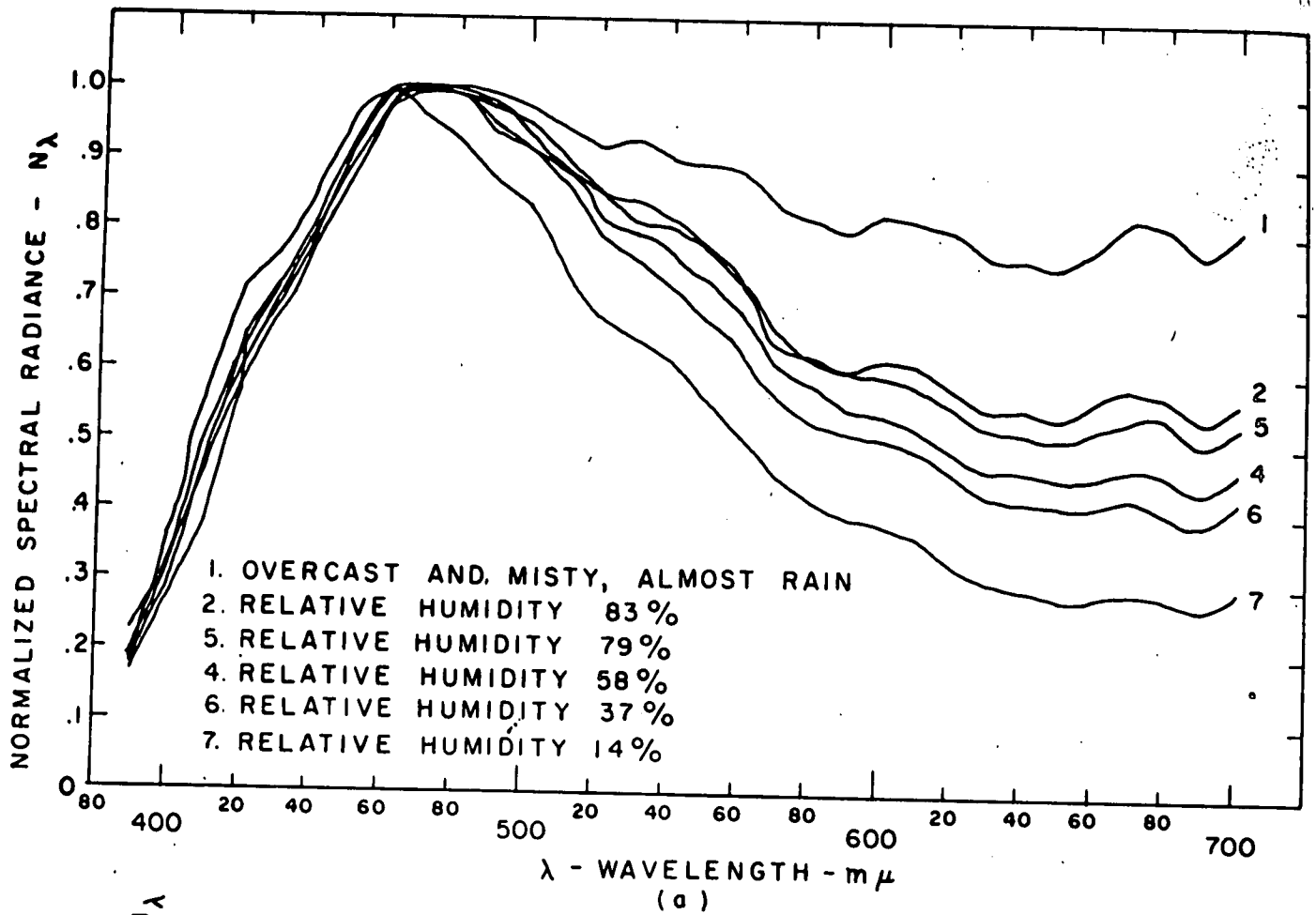


Figure 4

DATA AND ANALYSIS

The measured data normalized at the maximum value in each case are shown in Fig. 4(a) opposite this page. The curves in the long wavelength part of the spectrum, 600 μ to 700 μ , show an almost linear relationship with relative humidity, except for the very high humidity condition, as shown in Fig. 4(b). Apparent also are inflections and/or minima in the curves which appear to be reflections of the spectral characteristics of the solar radiation and the effect of water vapor absorption bands.

It is questionable whether or not there is justification for normalizing these data when two of the measurements were made at midday with scattering angles greater than 90° and the other four were made in the mornings with scattering angles approximately 45° , and when two of the measurements (not the same two) were made with the relative humidity higher than 80%, when small changes of relative humidity higher than this are accompanied by large changes of scattering, and the other four were made in the relative humidity range where changes of relative humidity are accompanied by small changes of scattering.¹ Accordingly the following analyses are made of the measured data.

¹ "Correlation between Measured Path Function and Relative Humidity,"
A. R. Boileau, SIO Ref. 59-5, Feb. 1959.

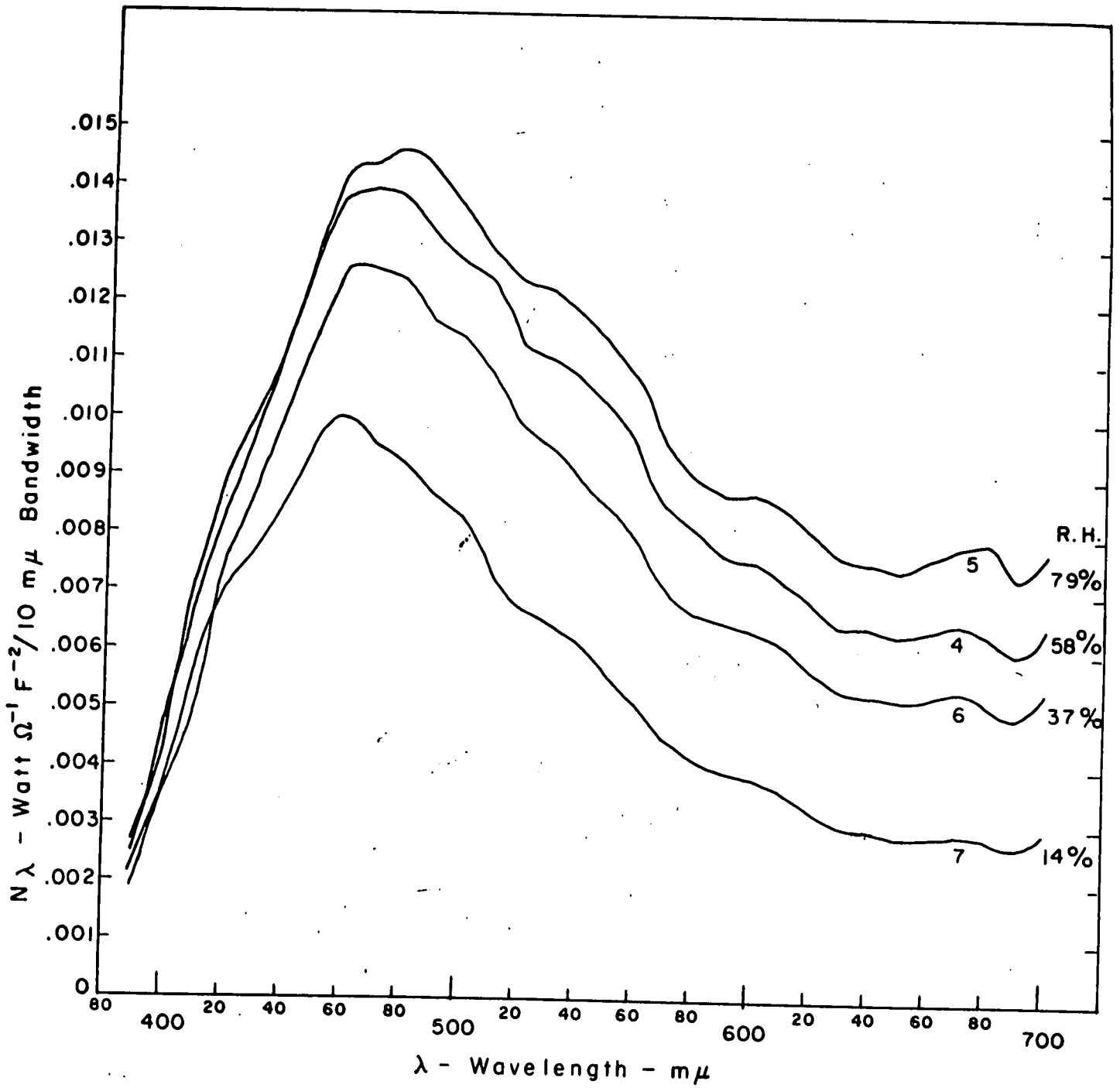


Figure 5

In Fig. 5, facing this page, data from measurements Nos. 4, 5, 6, and 7 are plotted. Noted by each curve is the relative humidity for sea level recorded at the U.S. Weather Bureau office at Lindberg Field. The differences in spectral radiance with the different relative humidities is very apparent. In Fig. 6, immediately following this page, the spectral radiances vs relative humidity have been plotted for several different wavelengths. Note that for relative humidities of 37%, 58%, and 79% the change of spectral radiance is virtually linear with changes of relative humidity but in the case of the relative humidity of 14% there is a departure from linearity. With references to Table I it will be noted that for the first three cases, i.e., in measurements Nos. 4, 5, and 6, the scattering angles were 44.5° , 41.8° , and 42.9° , respectively, while in the case of 14% relative humidity, measurement No. 7, the scattering angle was 103.3° . Calculations for the scattering by haze particles, i.e., Mie scattering, made at the Visibility Laboratory, show that the intensity of the scattered radiation is maximum at the zero scattering angle and progressively less as the scattering angle increases. Accordingly the data of measurement No. 7 would have been greater had the scattering angle been comparable with measurements 4, 5, and 6.

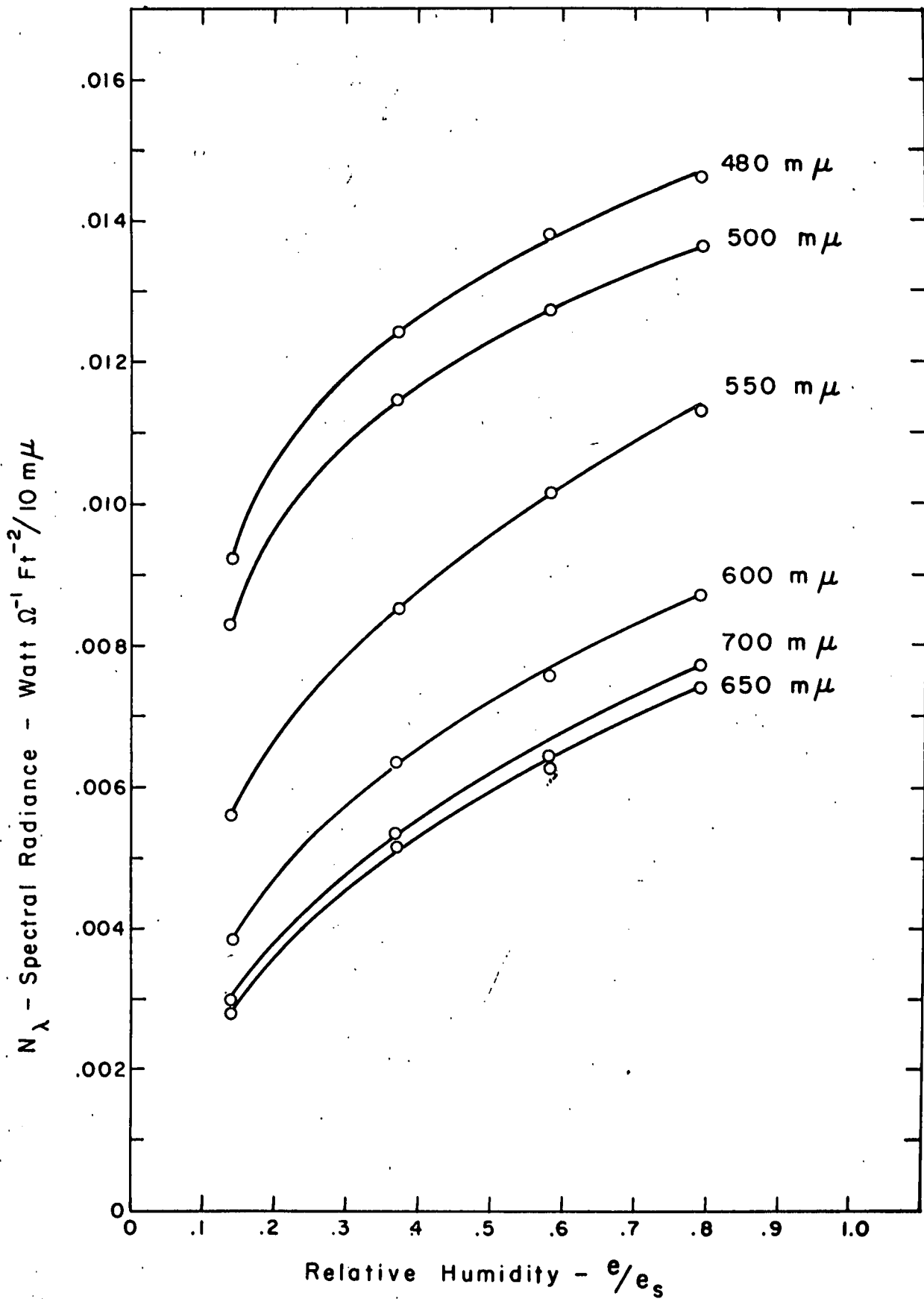


Figure 6

With reference to Fig. 5 there are several other points that should be mentioned.

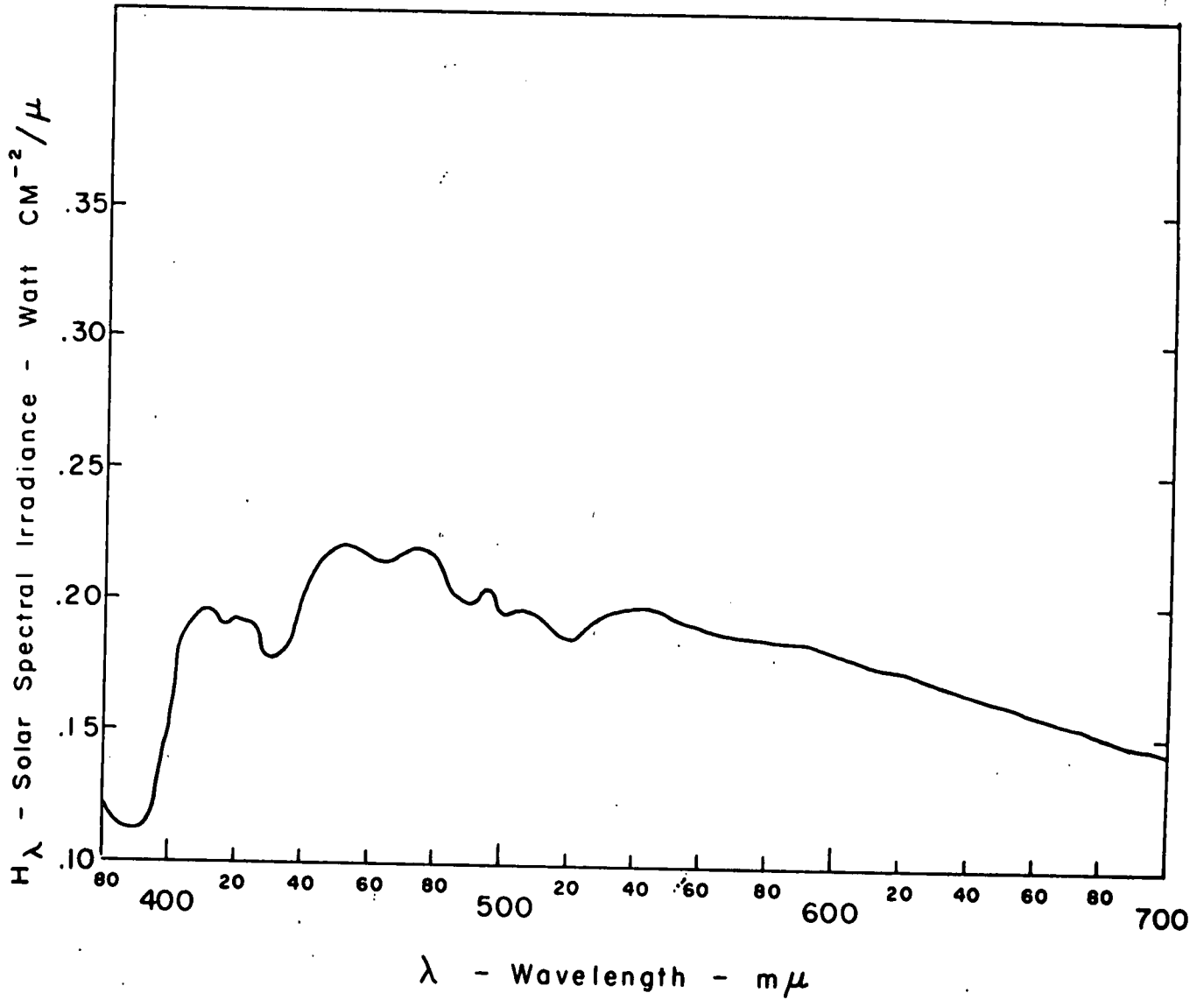
1. The maximum radiance value appears to shift to a longer wavelength with increase in relative humidity. The maximum value of measurement No. 7, 14% relative humidity, occurs at 460 μ . The maximum value of measurement No. 5, 79% relative humidity, occurs at 480 μ . The maximum values of Nos. 4 and 6 fall between these two.

2. All four measurements show the same general curve shape. The point of inflection that can be seen at 420 to 440 μ in all four curves is caused by the variation in the solar spectral radiance distribution as shown in Fig. 7.² The minima occurring in the solar spectrum at 490 μ and 520 μ are also indicated by the shape of the curves of Fig. 5.

3. Again referring to Fig. 5 inflections and/or minima are observed in the vicinity of 570-580 μ , 630-650 μ , and 690 μ . Fig. 7 shows that there is an inflection occurring in the curve of the solar spectral irradiance distribution at 570-580 μ , but also the Smithsonian meteorological table "Atmospheric Water-Vapor Lines in the Visible Spectrum"³ lists a number of absorption lines in the region of 586-597 μ . There are also absorption lines in the 646-657 and 692-702 μ ranges. It appears, therefore, that the measurements

² "The Solar Constant," Francis S. Johnson, Journ. of Met. Soc., II, No. 6, Dec. 1954, pp 431 - 439.

³ Smithsonian Meteorological Tables, 5th Ed., Lord Baltimore Press, Baltimore, Md., 1939, Table 8, pp. 237-238.



Solar Spectral Irradiance from F. S. Johnson²

Figure 7

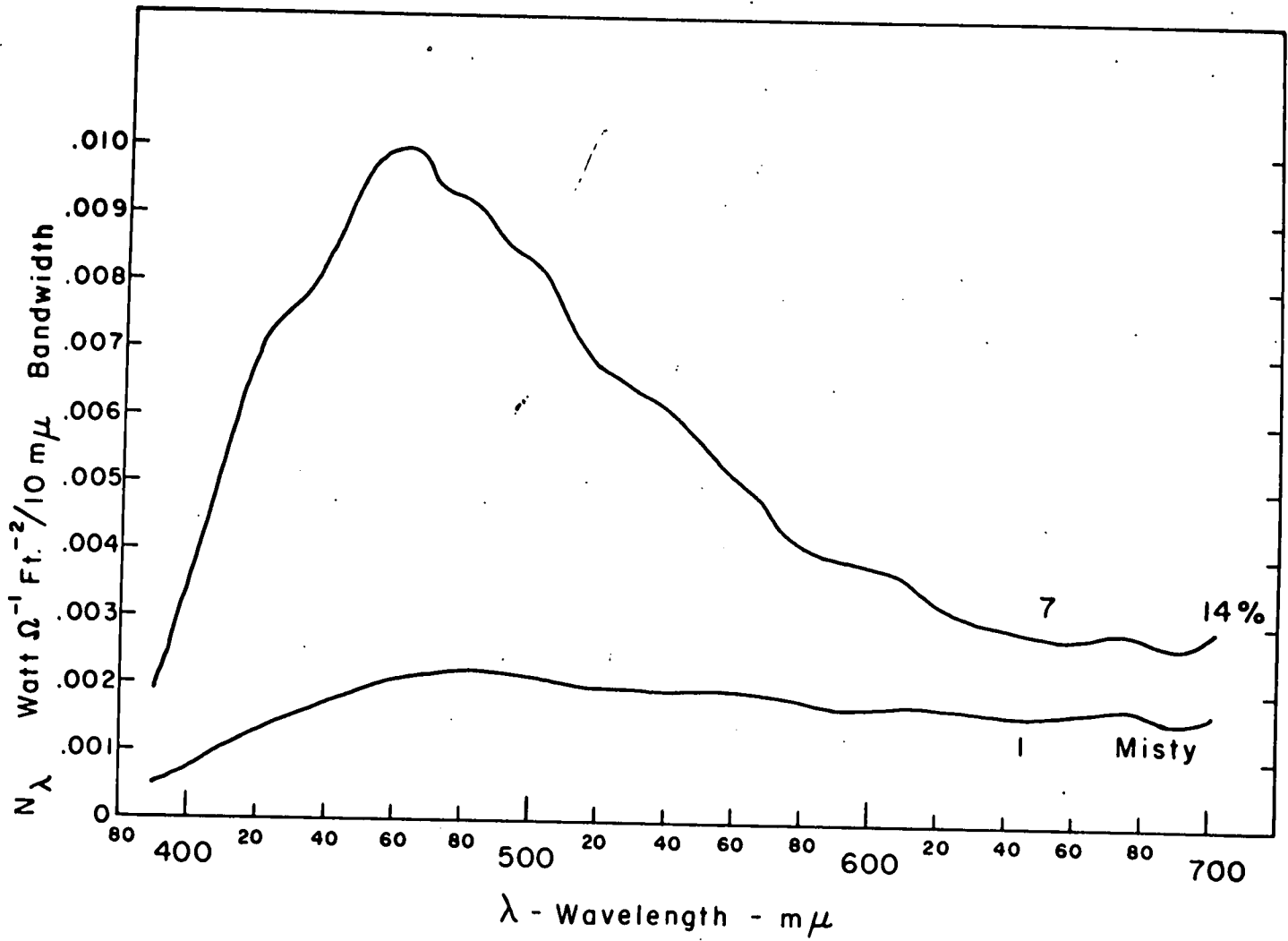


Figure 8

by the spectrogeograph, in addition to reflecting the characteristics of the solar spectral radiance distribution, also shows the integrated effect of the water-vapor absorption in the visible spectrum.

Fig. 8, opposite this page, is a plot of measurements Nos. 1 and 7. This is a comparison of the effects of the difference of humidity, both of these measurements having been made at midday, the scattering angles being 118.9° and 103.3° , but No. 1 having been made during overcast, misty weather and No. 7 having been made during a clear, dry day, the relative humidity being 14%. From Fig. 8 it can be seen that the sky was bright and blue when the relative humidity was low but considerably less bright but "white" in the misty condition.