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STUDY OF THE SURFACE EMISSIVITY OF TEXTILE FABRICS AND MATERIALS IN THE I TO I5MU RANGE

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Block Engineering, Incorporated
Cambridge, Massachusetts

March 1967

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TECHNICAL REPORT
67-86-CM

STUDY OF THE SURFACE EMISSIVITY OF TEXTILE FABRICS AND MATERIALS IN THE 1 TO 15μ RANGE

By

Mark Mason and I. Coleman

Block Engineering, Inc.
Cambridge, Massachusetts 02139

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U.S.Army Natick Laboratories
Natick, Massachusetts 01760

FOREWORD

Surface emissivity data of textile fabrics are important for many military end uses including studies of comfort, heat stress, heat load in shelters and undercoverings, studies in camouflage against detection systems using infrared radiation, and studies of thermal protective systems, among others.

This study was essentially exploratory in nature to provide general information relative to the properties of typical textile fabrics of varying fiber composition and also guidance as to possible methods of controlling emissivity.

The work covered in this report was performed under Contract DA19-129-AMC-523(N). It was conducted under the leadership of Mr. Myron Block, President of Block Engineering, Inc. The principal participating Block Engineering personnel were Messrs. M. Mason and I. Coleman. The study was initiated under Project 1M643303D547 by Mr. Frank J. Rizzo, who acted as Project Officer, assisted by Mr. A. O. Ramsley, both of the Clothing & Organic Materials Division.

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ABSTRACT

Laboratory measurements of the total and spectral infrared radiation emitted by textile materials, as applicable to the outer layer of a uniform, were made with an interferometer spectrometer. The effects of changes in the environmental parameters of the fabric, such as background temperature, fabric temperature, and humidity, were studied. For this report twelve different fabrics with a diversity of weaves and surface roughnesses were studied. The fifty-five spectra of these fabrics, which are published in this report, cover a wide range of fabric temperature, background temperature, and humidity.

It was found that the weave of the fabric acts as many small blackbody radiators and tends to mask any spectral detail that may be present. Further masking of detail is done by reflected background radiation. It was found that a fluctuation in background temperature, fabric temperature, or humidity caused a change in the spectral characteristics of the fabric.

Spectra of terrain features are presented and are compared to the spectra of the fabrics. It is shown that there is a spectral similarity between the fabric and terrain features because both are subject to spectral masking by background and sample characteristics. In the field, there is inter-reflection between the terrain features and the sample, sky radiance, atmospheric absorption, and reflection from background objects of the fabric, giving a spectrum that is not representative of the sample.

STUDY OF THE SURFACE EMISSIVITY
OF TEXTILE FABRICS AND MATERIALS IN THE 1 TO 15μ RANGE

I. INTRODUCTION

Under the subject contract, Block Engineering, Inc. obtained measurements of the total and spectral infrared radiation emitted by textile materials as applicable to the outer layer of a uniform and related these measurements to comparable characteristics of the terrain. At the outset of this measurement program, little published information was available on the infrared spectra of fabrics, and it was not known whether sample composition or sample environment was the more relevant parameter affecting differences in observed sample spectra. The first group of measurements obtained on this program were spectra of twelve different dry fabric samples maintained at the 50° to 60°C range in a room environment of 20°C. Subsequently, sample measurements were made under various environmental conditions.

Five of these twelve fabrics were selected for further study of the effects that fabric environment has on the spectra. The effects of controlled variations in temperature, humidity, infrared background, and fabric insulation on the spectra of the five selected fabrics were measured. The major part of this report consists of a description of the apparatus and an interpretation of the data taken according to this plan.

The spectra submitted in this report (Appendix A) were obtained with a Block Model I-4T interferometer and a Block Coadder (coherent information adder). Spectral data were computer-processed, using two specially written programs that are included in Appendix B.

II. THEORETICAL CONSIDERATIONS

A. Infrared Radiation Theory

Atomic and molecular activity is found in every object whose temperature is above that of absolute zero Kelvin (-273.15°C). As a result of this atomic and molecular activity, electromagnetic radiation is emitted from these objects. The wavelength of this radiation extends from gamma radiation (.003Å) to beyond the wavelength used in radar (30 cm). The visible region of this electromagnetic spectrum is from about 4000Å (violet light) to about 8000Å (red light). From 8000Å to past 100 microns (1,000,000Å) is the region of the electromagnetic spectrum known as the infrared. The region commonly called "near infrared" extends in wavelength from about 1μ to 25μ and is the region of interest in this discussion[1].

Certain bodies, known as "black" or "grey" bodies, emit a continuous band of radiation which has its maximum intensity at a particular wavelength depending on the temperature of the body; the lower the temperature, the longer the wavelength of this maximum. For example, a body at room temperature emits maximum intensity radiation at about 9.6μ, and a source at 900°C has a maximum in the region of 2.4μ. Fabrics and terrain normally emit as black or grey bodies since they have no discrete spectral emissions.

The ideal emitter and absorber of radiation is a body that absorbs all the radiation incident on it. This is called a blackbody radiator. If such a body were placed in a uniform temperature enclosure, it would come to equilibrium at the temperature of the enclosure and would therefore emit just as much radiation as it absorbs. The radiant power emitted between the wavelengths λ to $(\lambda + d\lambda)$ is given by Planck's distribution law:

$$E_\lambda d_\lambda = \frac{2\pi hc^2}{\lambda^5} \cdot \frac{1}{\exp \frac{c_2}{\lambda T} - 1}$$

h = Planck's constant

c = Velocity of light

c_2 = hc/k when k is Boltzmann's constant.

The curves described by the blackbody equation for several different temperatures are shown in Figure 1. The integral of this equation would be the total emission of the blackbody at a given T[2,3].

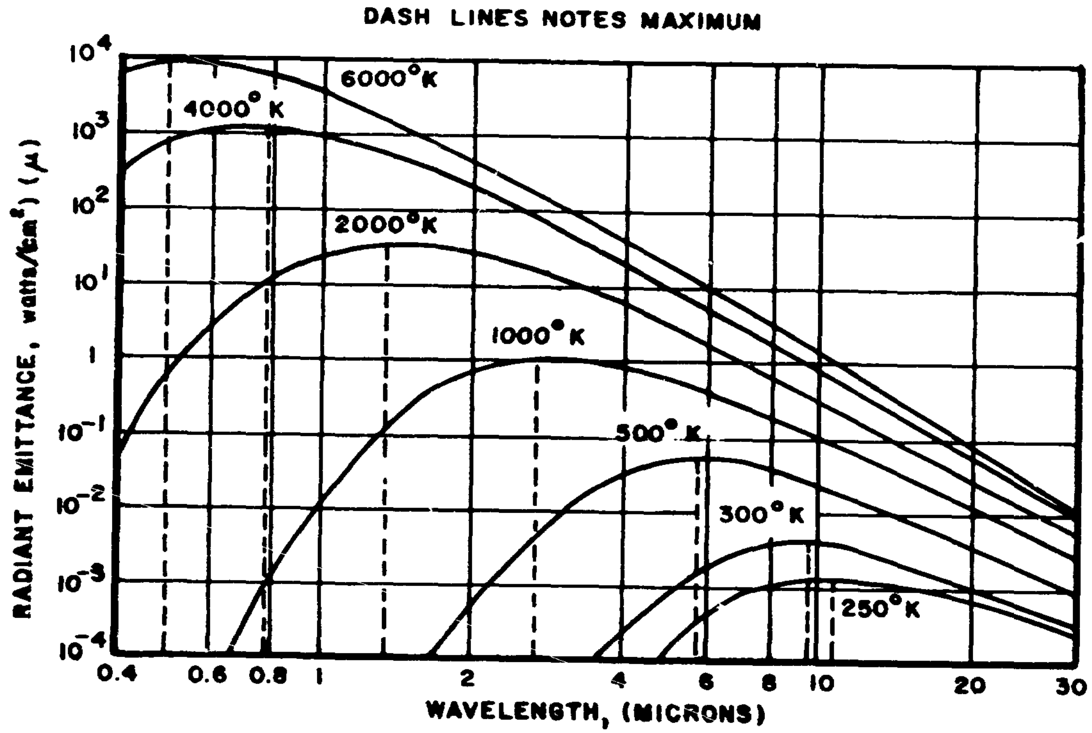

Figure 1: BLACKBODY SPECTRAL EMITTANCE At Various Temperatures.

Reference: Jamieson, John A., McFee, Raymond H., Plass, Gilbert N., Grube, Robert H., Richards, Robert G., Infrared Physics and Engineering, McGraw Hill, N.Y. 1963.

The emissivity of the ideal blackbody radiator is taken as 1 at all wavelengths. Then all bodies whose emissivity is less than that of a blackbody would have an emissivity of something less than 1. Such a body is called a grey body. The value for the emissivity of various materials is given below:[2]

TABLE I

EMISSIVITY OF VARIOUS MATERIALS

Material	Emissivity
Paper	.94
Cotton Cloth	.77
Wool Cloth	.78
Nylon	.85
Sand	.95
Wood	.90 - .92
Bricks	.93

With a properly calibrated spectrometer, it is possible to determine the total emission from an infrared source with emissivity less than 1. In this report, the total emission of various fabrics will be studied with respect to the spectral distribution of radiation for each type of fabric. The measurements made, show that a fabric emits nearly as a blackbody. The small cavities due to the weave of the fabric act as good blackbody radiators, thus explaining why the spectrum of the fabric is very similar to Planck's curve for a blackbody at the same temperature.

B. Theory of Operation and Calibration of Instrument

As the operation of the Block Interferometer Spectrometer is unique when compared to other spectrometers, a discussion of the theory of operation and circuitry of the Block Model I-4T will be given before the calibration procedure so that the calibration and experimentation may be more fully understood.

1. Optics: An optical diagram of a Michelson interferometer is given in Figure 2. There are two mirrors, M1 and M2; a beamsplitter plate, S; and a compensator plate, C. Plates S and C are made to the same thickness and of identical material. On its inner surface the beamsplitter plate carries a semi-reflecting coat, shown dotted in the diagram. The planes of the two mirrors and the semi-reflecting coat intersect in one line when the moving element of the transducer is crossing its zero position, i.e., when M1 is at $x = 0$.

Consider a beam such as a entering the interferometer. The ray is divided into two beams, a_1 and a_2, at the semi-reflecting coat. If beams a_1 and a_2 return to the beamsplitter in phase, they will constructively interfere. That is, their amplitudes will add vectorially, and 50% of the energy (neglecting losses except for the 50% transmission at the beamsplitter) of beam a will appear as beam b_1. However, if there is a phase difference between the two, caused by unequal paths, there will be partial destructive interference. This interference manifests itself in two ways: (1) it is seen by the detector as a decrease in signal level; and (2) it can be seen in the corresponding increase in amplitude of b_2, since $b_1 + b_2$ are 180° out of phase with $a_1 + a_2$.

Now the phase of a_1 with respect to that of a_2 can be changed by moving mirror M1. In the interferometer, the mirror corresponding to M1 is attached to a linear actuator. The relationship of the position of M1 to the intensity of $a_1 + a_2$ can be stated as:

$$I = I_o A\,(1 + \cos 2\pi\nu x) \qquad (1)$$

where I is the intensity of $a_1 + a_2$, I_o is the intensity of a, x is the mirror excursion, ν is the wave number, and A is the modulation efficiency, a number always less than 0.5. The excursion of M1 is always measured from zero-retardation, the position at which the paths taken by rays a_1 and a_2 are equal. Note that for an excursion of x, the retardation or difference in path lengths of a_1 and a_2 is 2x. Also note that so long as these rays remain parallel, the wave fronts

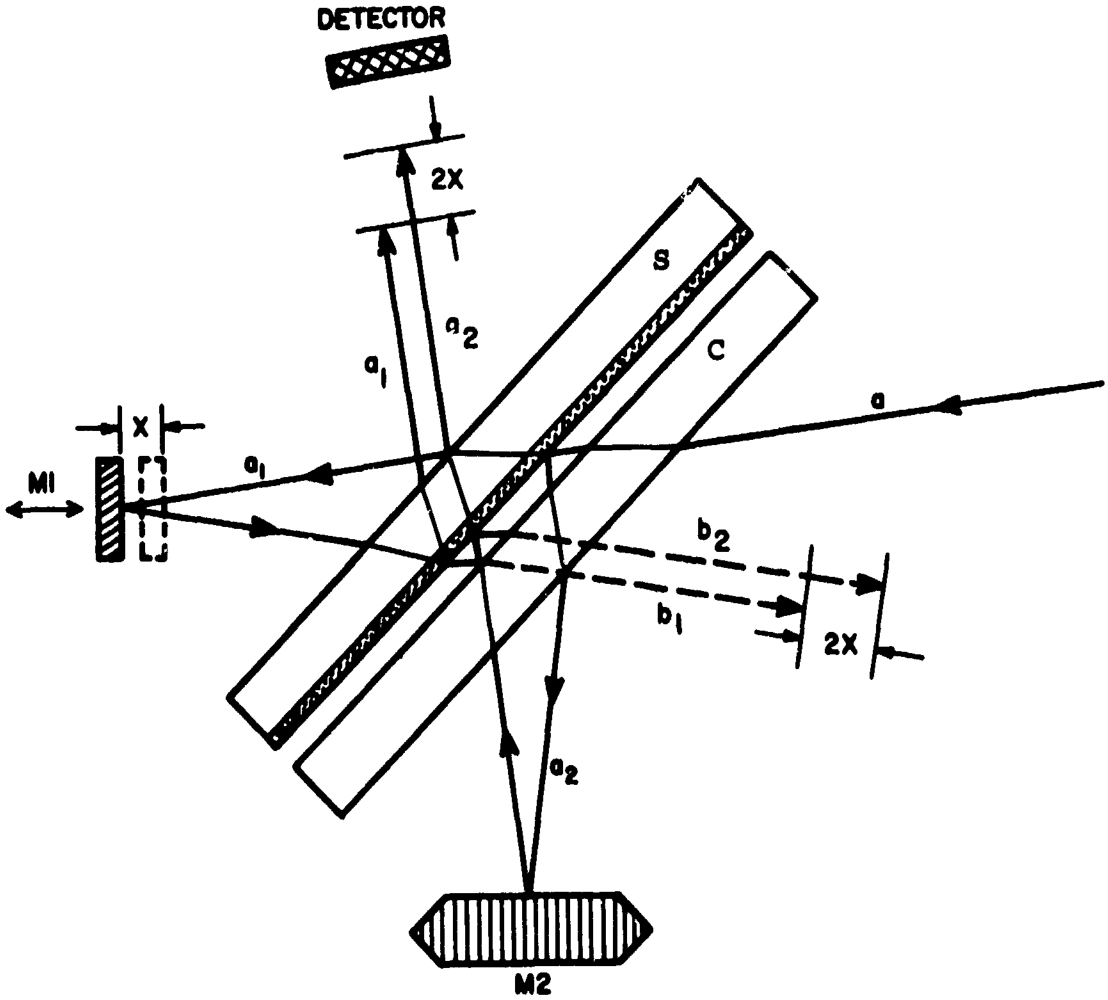

Figure 2: Optical Diagram of a Michelson Interferometer
(Displacement X of MI Producing Retardation 2X)

remain parallel and will interfere, even though they are laterally separated.

In the interferometer, mirror M1 is moved by a transducer (linear actuator) responding to a voltage supplied as a sawtooth wave, so that the mirror travels at constant velocity for most of the scan cycle. This velocity can be defined in terms of a peak-to-peak retardation B, mirror M1 moving from -B/4 to +b/4 during the constant velocity period, T_B. Thus, we have

$$x(t) = B(t)/2 \quad (2)$$

where x is the instantaneous displacement of mirror M1.

Substituting Equation (2) into Equation (1), the intensity transmitted by the interferometer is given by:

$$I = I_o A \ 1 + \cos 2\pi\nu B(t). \quad (3)$$

Thus, it is seen that the transmission is periodic and has a frequency f_ν, which depends upon the wave number of the incident radiation:

$$f_\nu = \nu B/T_B. \quad (4)$$

Equation (4) is derived by considering the number of waves of incident radiation, νB, contained within the retardation distance B. Therefore, the frequency which results when a retardation interval B, scanned at a time T, is $\nu B/T$. This fundamental relationship shows that the output frequencies of the interferometer spectrometer are related one-to-one to the wave number of the input radiation and that B and T_B can be varied to adjust the output frequency and resolution.

2. Electronics: Infrared radiation incident on the Bolometer detector causes a change in the resistance of the active element, or flake, in direct proportion to the intensity of the energy. The detector is biased with a high frequency voltage to

provide a signal suitable for amplification. A low noise preamplifier amplifies the detector signal and provides the low output impedance needed for minimum pick-up in the long inter-connection cable between the optical head and data reduction unit. See Figure 3 for a flow diagram of the circuitry.

The preamplifier is followed by a constant impedance stepped attenuator consisting of a compensated resistance divider. The five attenuation steps, selected by a front panel control, are unity, 1/3, 1/10, 1/30, and 1/100 of the signal level.

The 3-stage post amplifier has a gain of approximately 400. A feedback loop provides added high frequency stability to the system. The amplifier is designed to render an undistorted signal output of approximately 14 volts peak-to-peak into a load exceeding 100K ohms; maximum output is 20 volts peak-to-peak. Lower impedances are permissible but some dynamic range is sacrificed.

Figure 4 illustrates the mirror drive circuitry. The sweep generator and transducer drive are coupled at the SWEEP LENGTH control on the front panel so, as the sweep length is reduced, the sweep time is also reduced. The sweep time control uses an operational amplifier and a monostable multivibrator. The ramp rise time of the sawtooth waveform is determined by increasing or decreasing the charging rate of a resistance-capacitance network in the feedback loop of the operation amplifier. The linear drive for the mirror transducer is obtained from a low impedance output amplifier. Sweep length, or the physical movement of the mirror, is controlled by varying the transducer drive voltage.

The output from the post-amplifier shown in Figure 2 is modified by a variable bandpass filter. The filter has a roll-off of 12 db per octave on both the high and low side. It is used to reduce the spurious noise entering the analog-to-digital converter.

The Coadder repeatedly samples the filtered output of the interferometer electronics (interferogram) at a rate which is more than twice the maximum frequency present in the signal of interest. The samples are sequentially digitized and stored in the core memory. Each series of samples

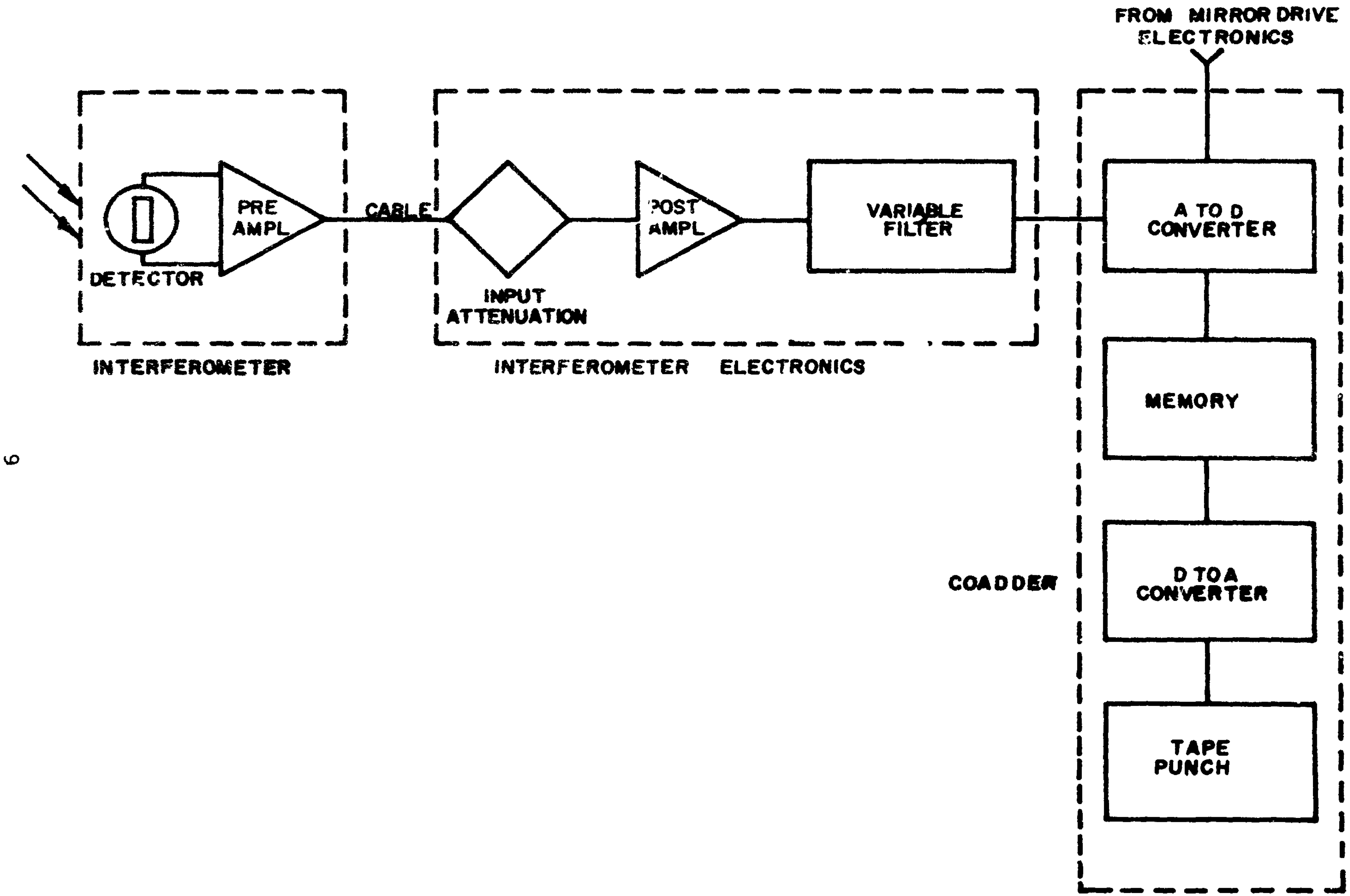

Figure 3: SIGNAL PROCESSING AND DATA REDUCTION ELECTRONICS

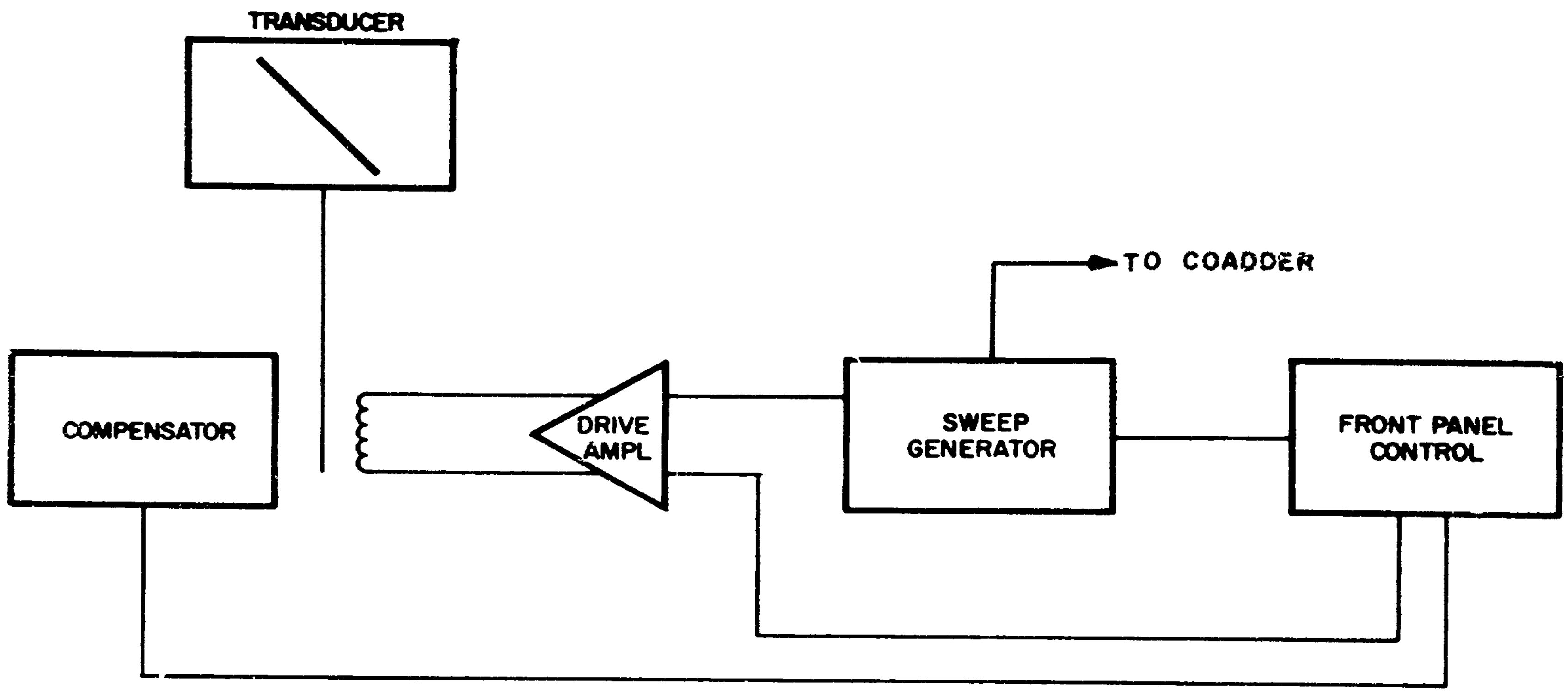

Figure 4: MIRROR DRIVE ELECTRONICS

is initiated by a triggering pulse supplied by the interferogram. Therefore, the samples from successive interferograms correspond precisely in time. Their levels are digitally added in the memory; the coherent signal increases linearly in amplitude with the number of interferograms accumulated.

The noise present as the input accumulates, due to its random character, in such a way that the noise power increases linearly with the number of scans. Its root-mean-square (rms) value therefore increases only by the square root of the number of scans. The resultant gain in the coherent signal relative to the noise is thus, $\sqrt{n}$ where n is the number of times the same signal is sampled. For example, if the Coadder accumulates as few as 16 interferograms, the signal-to-noise ratio will be increased by a factor of four.

The Coadder memory contains 1024 words; a maximum of 1024 sample points may be taken. Each sample is digitized by an 8-bit A-to-D converter that accepts a maximum signal of 9 volts peak-to-peak. Since the capacity of each word in the memory is 16 bits, it is possible to coadd up to 256 interferograms with 9-volt peak-to-peak components. Smaller amplitude interferograms, of course, may be coadded many more times.

C. Calibration

Prior to measurements of fabric emission, three different calibrations were performed on the interferometer. First, the wavelength scale of the instrument was determined. Second, the instrument's effective field-of-view was determined. Third, the spectral responsivity of the instrument was determined over the wavelength region to be used.

1. Wavelength Calibration: The interferometer spectrometer heterodynes the very high electromagnetic frequencies present in the incident radiation down to audio frequencies. If a beam of light of a single frequency, ν, is split and sent over different optical paths and then recombined, the light will constructively or destructively interfere, depending on the difference in path lengths. If this interference is incident on a detector, then the ensuing signal will be a sine function of frequency m, which is directly proportional to the frequency of incident radiation, ν.

The ratio M/ν equals a constant, K, for every point throughout the spectrum. For this calibration, the instrument viewed a known temperature blackbody source, with a 1-mil-thick sheet of polystyrene between the source and the entrance aperture. The resulting spectrum is that of a blackbody with the polystyrene absorption lines present, as shown in Figure 5.

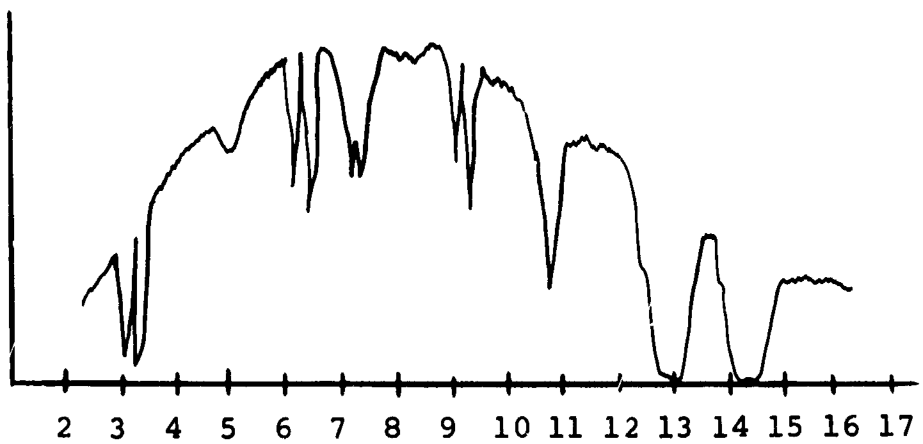

Figure 5: Absorption Spectrum 1 mil. Thick Polystyrene

The absorption lines of polystyrene are well identified,[5] i.e., their exact wavelengths are known and from them the calculation of M/ν can be carried out. The value K determined by this method is accurate to ± 5 cm^{-1}, while the instrument has a resolution of 60 cm^{-1}

The pertinent equation relating audio frequency to wavelength is

$$f = B/T\lambda.$$

f = audio frequency in cps.

B = optical retardation in microns.

T = sweep time in seconds.

λ = wavelength in microns.

The equation can be written as

$$f\lambda = \frac{B}{T} .$$

Since B and T are constant for any given series of measurements, $f\lambda$ must also be constant.

a. Field of View: The effective field of view of the instrument was determined by having the instrument view a chopped collimated source. The optical head was placed on a vernier rotary table capable of controlled movement along both horizontal and vertical axes. The chopped source was viewed and the output recorded for every degree from zero output on one side of the field to zero output on the other side. This was done for both the horizontal and vertical axes, and then plotted as output versus position. The points where the roll-off on either side of center position is reduced by 6 db are marked and the area between is considered to be the effective field-of-view, since the 6 db points are considered to be the half-power points in a uniformly varying field of view, and to describe the effective response of the instrument.

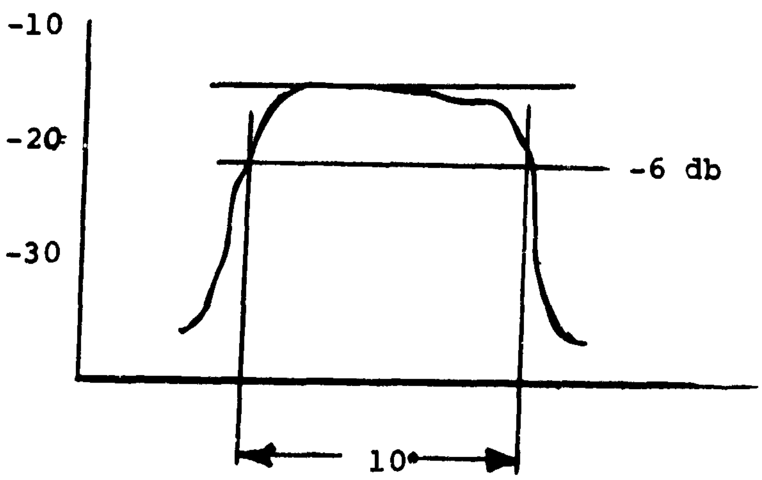

Figure 6: Horizontal Scan Field of View

3. <u>Instrument Responsivity</u>: The responsivity of the interferometer was obtained by focussing it on a blackbody cone and measuring the spectra of the blackbody at a large number of temperatures, both higher and lower than the temperature of the detector. The temperature of the blackbody cone was monitored by thermocouples located on its aluminum surface. Figure 7 portrays the arrangement used. The spectral responsivity of the system is calculated from the formula

$$R_e = \frac{V_\lambda}{Ns_\lambda = Nd_\lambda}$$

where:

V_λ = measured voltage at wavelength λ

Ns_λ = blackbody radiance at wavelength λ

Nd_λ = detector radiance at wavelength λ

The final Re is determined by a least mean square fit using values determined for the different source temperatures. The spectral responsivity curve for the spectrometer is shown in Figure 8.

The computed responsivity of the instrument as a function of wavelength was used as one of the inputs to computer Program B, which corrected the spectra to read out in absolute radiance versus wavelength. The spectrum for each fabric sample is the absolute power spectrum of that sample for the environmental conditions under which the measurements were made.

III. EXPERIMENTAL PREPARATIONS AND PROCEDURES

A. Experimental Procedure

The experimental arrangement used for spectral measurements of the fabric samples is illustrated schematically in Figure 9. The equipment used consisted of the following:

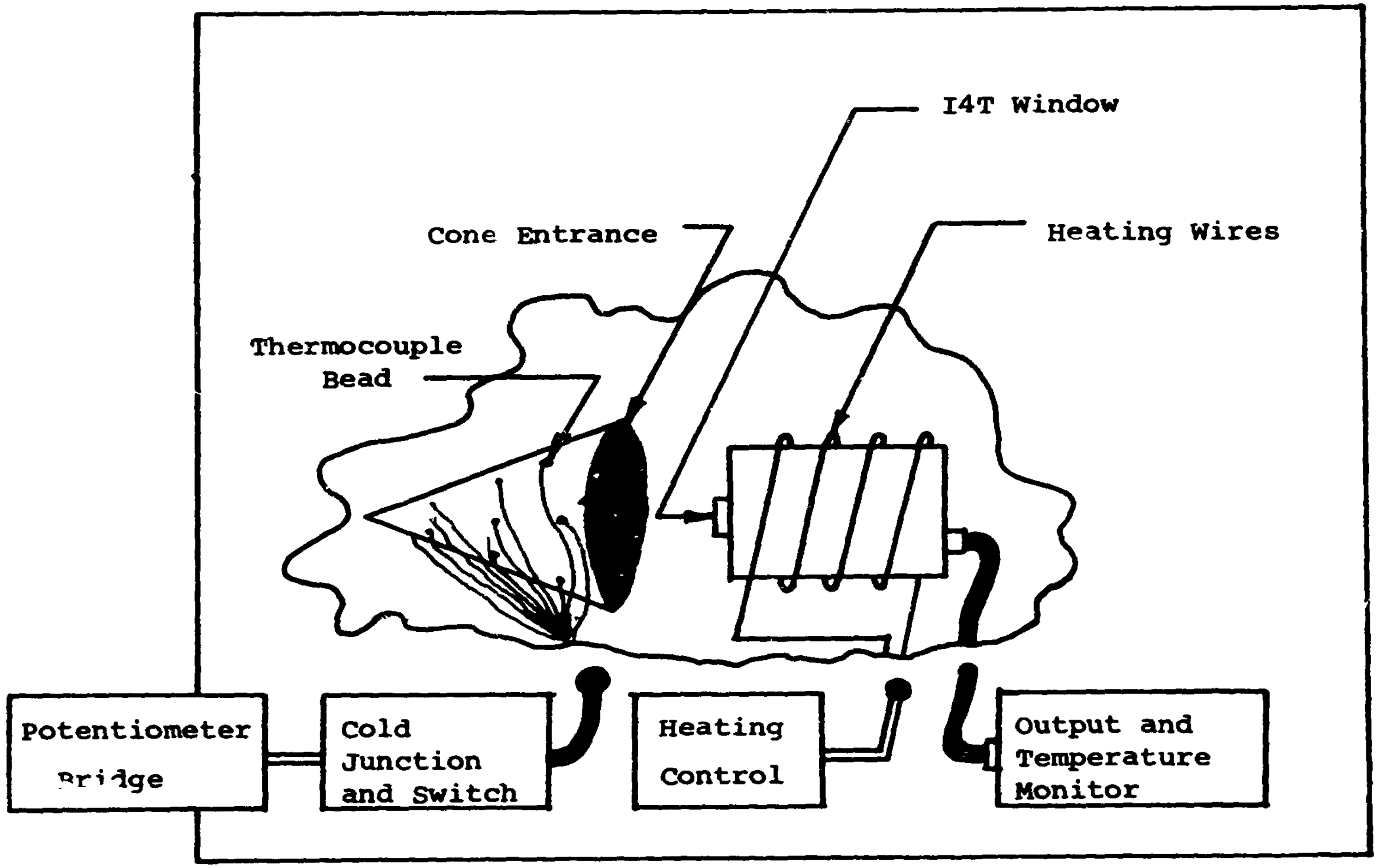

Figure 7: Setup for Response Measurements

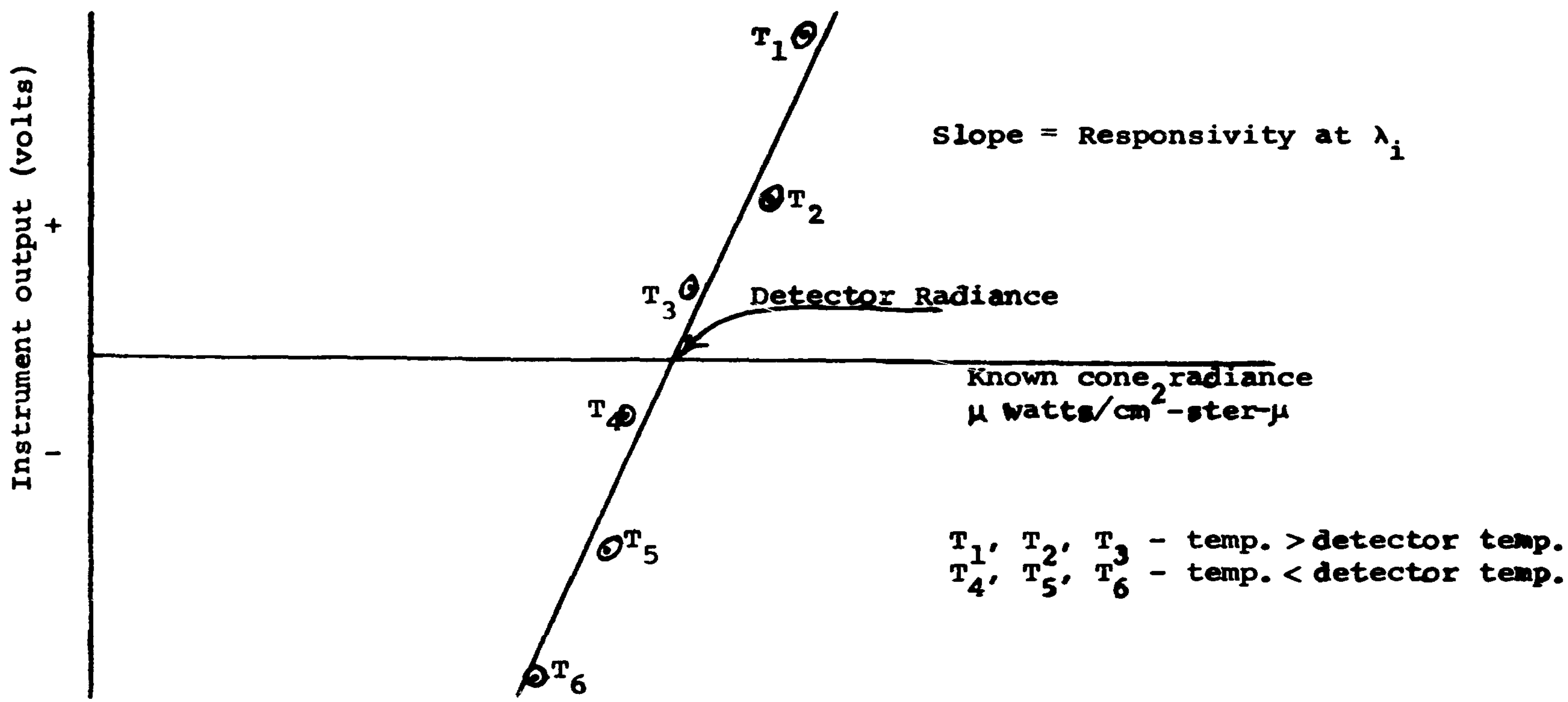

Figure 8: Responsivity Calibration

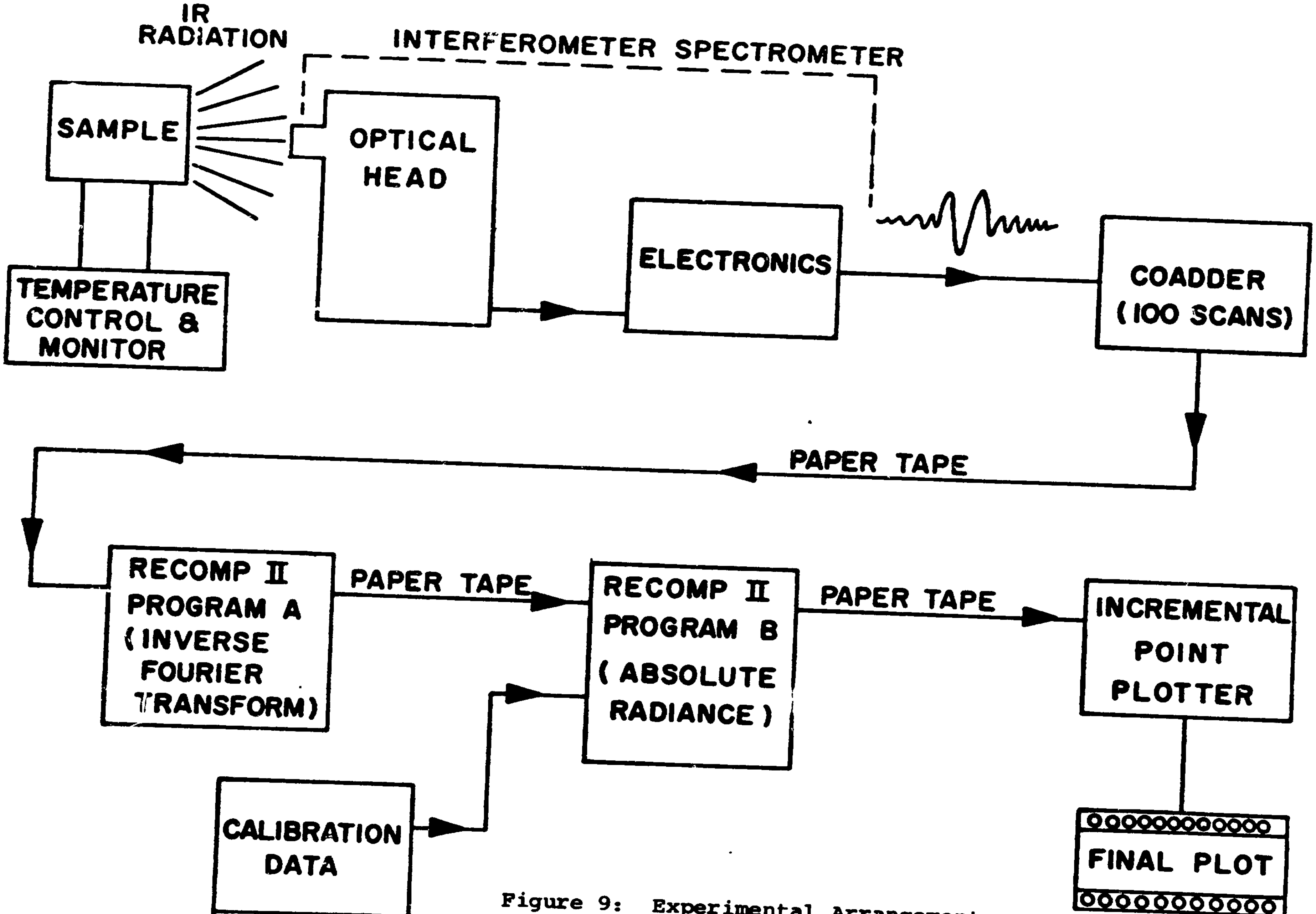

Figure 9: Experimental Arrangement

1. Cold Bo..

2. Hotplate with fabric sample attached

3. Temperature monitoring and controlling unit

4. Interferometer spectrometer

    a. Optical head

    b. Electronics console

5. Time averaging computer unit (Coadder)

6. Digital paper-tape punch unit

The first set of measurements made revealed that observations of samples in a room environment at ambient temperatures obscured any change in emission, thereby blurring any spectral detail in the reduced data. To reduce the effects of a fluctuating background and spurious emission, a "cold box" was constructed. The box consisted of a large thermal mass of copper, a reservoir for dry ice or other coolant, a hotplate for heating samples, a window for the instrument, and temperature-monitoring thermistor beads. Figure 10 shows the construction of the cold box.

If the cold box is used at room temperature, the large thermal mass prevents any fluctuation in temperature. If the box is used with dry ice, then the temperature of the background is lowered to a level that makes background emission negligible. The box is constructed in such a manner as to allow the sample to be heated while the background is at -70°C.

B. Data Processing

For each sample, enough scans were coadded to give an 8-volt peak-to-peak interferogram (see Theory of Operation). The resulting enhanced interferograms were punched on paper tape for computer processing.

Two computer programs were used for the processing of the data. (The processing is schematically diagramed in

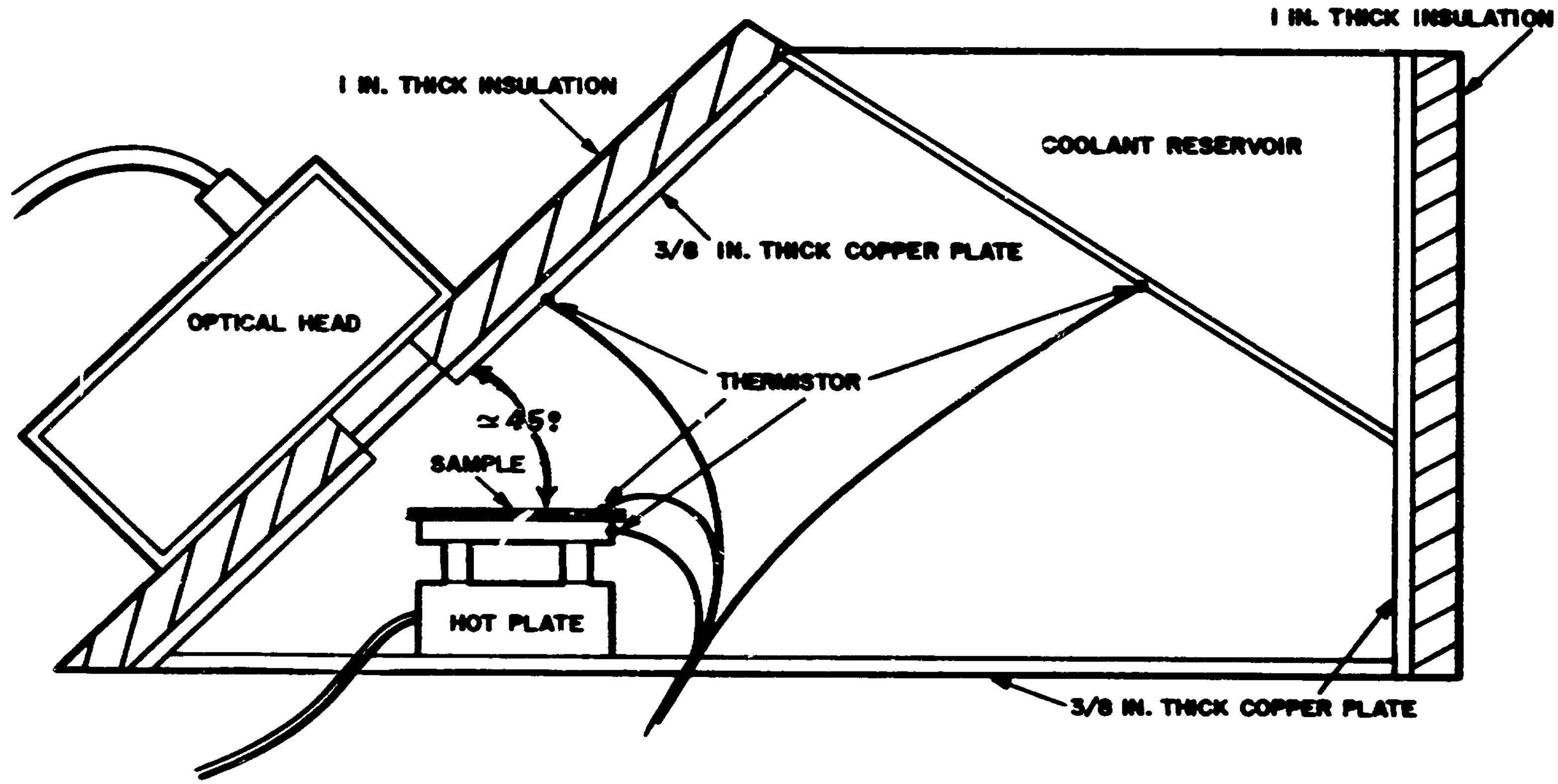

Figure 10: COLD BOX CONSTRUCTION

Figure 3.) The interferogram on paper tape was first processed by Program A, which computed the inverse Fourier transform of the interferogram. The inverse Fourier transform is, in fact, the spectrum of the source uncorrected for the instrument's response function. The output of Program A is also a paper tape.

The output of Program A was processed by Program B, which has an additional input of calibration constants. Program B computes the absolute radiance spectrum of the source corrected for the instrument function and has an output of a paper tape which is used as an input to the incremental point plotter.

An incremental point plotter having an accuracy of 0.01 inch was used to plot the power spectrum of each source on a linear-linear plot. This plot, together with the enclosed blackbody overlay, defines the emissions of the materials in the sense of the fabrics' efficiencies as heat radiators; both also define any identifying spectral structure which may be present due to the composition of the material.

Two basic computer programs were used to process the test data. (See Appendix B for complete programs). Program A converts the interferograms into the raw spectra by taking the inverse Fourier transform of the interferograms. Program B corrects the raw spectra for the instrument function yielding absolute power spectra.

Program A computes a spectrum from an interferogram by taking the real part of the Fourier integral of the interferogram signal as a function of time. That is:

$$A(m) = \text{Real Part} \int_{-\tau}^{\tau} I(t)\, e^{-2\pi imt}\, dt$$

A(m) = intensity of source as a function of audio frequency, m

τ = one-half the sweep time

$I(t)$ = the interferogram signal as a function of time

m = audio frequency ($m = K\nu$ where ν = wave number of incident radiation)

The spectrum produced by Program A is uncorrected for the instrument function and is linear in audio frequency, m, hence, it is also linear in wave number.

Program B uses as inputs the uncorrected spectra computed by Program A (punched on paper tape), and the previously determined calibration information for the instrument.

The responsivity of the instrument as a function of audio frequency, m, is defined:

$$Re_m = \frac{A(m)}{\left| N_s - N_d \right|_m}$$

N_s = radiance of the blackbody source

N_d = radiance of the detector

$A(m)$ = the response of the instrument

N_s and N_d were computed by measuring the temperatures of the source and detector, and A(m) was directly measured. From these values, the responsivity, Re, as a function of m was determined.

For the first group of sample spectra, the detector is cooler than the source and its temperature is recorded. Hence, the absolute radiance is calculated by Program B, using the following relationship:

$$(N_s)_m = \frac{A(m)}{Re_m} + (N_d)_m \, .$$

Program B also converts the audio frequency to its corresponding wavelength, λ, in microns by the relationship

$$\lambda = \frac{K}{m} .$$

The output of Program B is a punched paper tape which contains the radiance of the source as a function of wavelength. The plot has a linear-vertical scale in micro-watt/cm^2-ster-μ versus a linear-horizontal scale in microns.

IV. RESULTS

A. Experimental Results

The first group (Group I) of emission measurements was obtained from fabric samples maintained at temperatures in the 50°C to 60°C range. Table II lists the fabrics which were tested in a 20°C dry room environment, without use of the "cold box" and shows the sample temperature during measurement.

TABLE II

FABRIC TYPES

Spectrum	Fabric	Temperature (°C)
1	Cotton Towel, reactive dye	51
2	Cotton towel, reactive dye	51
3	Cotton towel, reactive dye	51
4	Cotton towel, reactive dye	52
5	Wool/nylon shirting, 16 oz; 0154-58	58
6	Wool/nylon shirting, 16 oz; 0154-58	58
7	Wool/nylon shirting, 16 oz; 0154-58	58
8	Wool/nylon shirting, 16 oz; 0154-58	60

Table II - Fabric Types Continued

Spectrum	Fabric	Temperature (°C)
9	Fiber 6-sateen, 8.5 oz., OG-106, 37 VEE-1545A	59
10	Fiber 6-sateen, 8.5 oz., OG-106, 37 VEE-1545A	58
11	Fiber 6-sateen, 8.5 oz., OG-106, 37 VEE-1545A	60
12	Wool flannel, OG-108, vat dyed	57
13	Wool flannel, OG-108, vat dyed	58
14	Wool flannel, OG-108, vat dyed	56
15	Nylon oxford acid dyes	60
16	Nylon oxford acid dyes	59
17	Nylon ballistic cloth, OG-106 (std)	57
18	Nylon ballistic cloth, OG-106 (std)	57
19	Nomex twill, VEE-166-2A	56
20	Nomex twill, VEE-166-2A	58
21	Wool serge, 18 oz. 85-0717	58
22	Wool serge, 18 oz. 85-0717	55
23	Wool serge, 18 oz. 85-0717	57
24	Cotton sateen, 9 oz., RBP topped, OG-107 w/Permel	59
25	Cotton sateen, 9 oz., RBP topped, OG-107 w/Permel	56
26	Nylon oxford, acid metallized	59
27	Nylon oxford, acid metallized	60
28	Nomex, 5419, 8.9 oz. duck, coated on 1 side	58
29	Nomex, corduroy, aluminized	56

From these fabrics, the following four were selected for study in the second part of the program:

1. Nylon, oxford, acid metallized

2. Nomex, twill Vee-166-2A

3. Wool serge, 18 oz. 85-0717

4. Fiber 6-sateen, 8.5 oz. OG-106, 37 Vee-1545A

In addition, cotton poplin, 4 oz. OG107, vat was added at the suggestion of the Project Officer. These fabrics were placed in the "cold box" and the effects of variation of the following parameters on the spectra were measured.

A. Temperature

 1. 20°C

 2. -40°C

 3. 60°C

B. Humidity

 1. Low humidity

 2. High humidity

C. Infrared Background

D. Insulation-Effect on Spectrum

The reduced spectra for these samples are presented as groups II through VII. The following is an outline of the procedure for recording each group.

GROUP II - Cloth Surface and Ambient 20°C - The "cold box" was used with the interior slightly below room temperature (20°C). Each of the material samples was placed in the box, allowed to reach equilibrium with the interior of the box, and then the spectrum was recorded.

GROUP III - Cloth Surface and Ambient -44°C - The cold box coolant reservoir was filled with dry ice and the temperature was allowed to reach equilibrium. The temperature of the walls of the box, the sample holder, and the sample was -44°C. The spectra show that there was very little total emission from the sample at this temperature.

GROUP IV - Cloth Surface 20°C Ambient (background) -44°C - With the walls still at -44°C, the temperature of the sample and sample holder was raised to 20°C. There was negligible emission from the background at this temperature, and any spectral detail would be real.

GROUP V - Cloth Surface 60°C Ambient -40°C - The temperature of each material sample was allowed to reach +60°C and its spectrum was recorded.

GROUP VI - Cloth Surface 60°C Ambient 13°C - Variation of Humidity The floor of the "cold box" was lined with damp absorbent material. Using a humidity gauge that was placed in the chamber, the humidity was recorded and the spectral information was gathered at several different relative humidities.

GROUP VII - Hotplate 65°C Ambient -40°C - Fabric Insulated - The hotplate was heated to 65°C. Five-eighths of an inch of foam insulation was placed between the cloth surface and the hotplate. Each material was left in this condition for 25 minutes before the spectrum was recorded.

By using the enclosed blackbody overlay with the resultant spectra, the emission spectrum of each fabric can be compared to the emission spectrum of the blackbody at the sample temperature, thus indicating the fabric emissivity.

B. Sources of Error

The radiation reaching the detector of the instrument from the source is actually the superposition of radiated and reflected radiation from many sources. Figure 11 shows the phenomena quite graphically: radiation is emitted from the source; scattered and absorbed by the atmosphere; mixed with radiation emitted and reflected from background objects; modified by the transmission characteristics of the windows, lenses, beamsplitters in the instrument; further mixed with emitted radiation from the inner surfaces of the instrument; and finally, altered by the instrument and the interpretation of the reduced data[6]. In the case of the measurements made for this report, all the sources of error due to the instrumentation were corrected by a computer program. Therefore, only the background characteristics are of concern. There

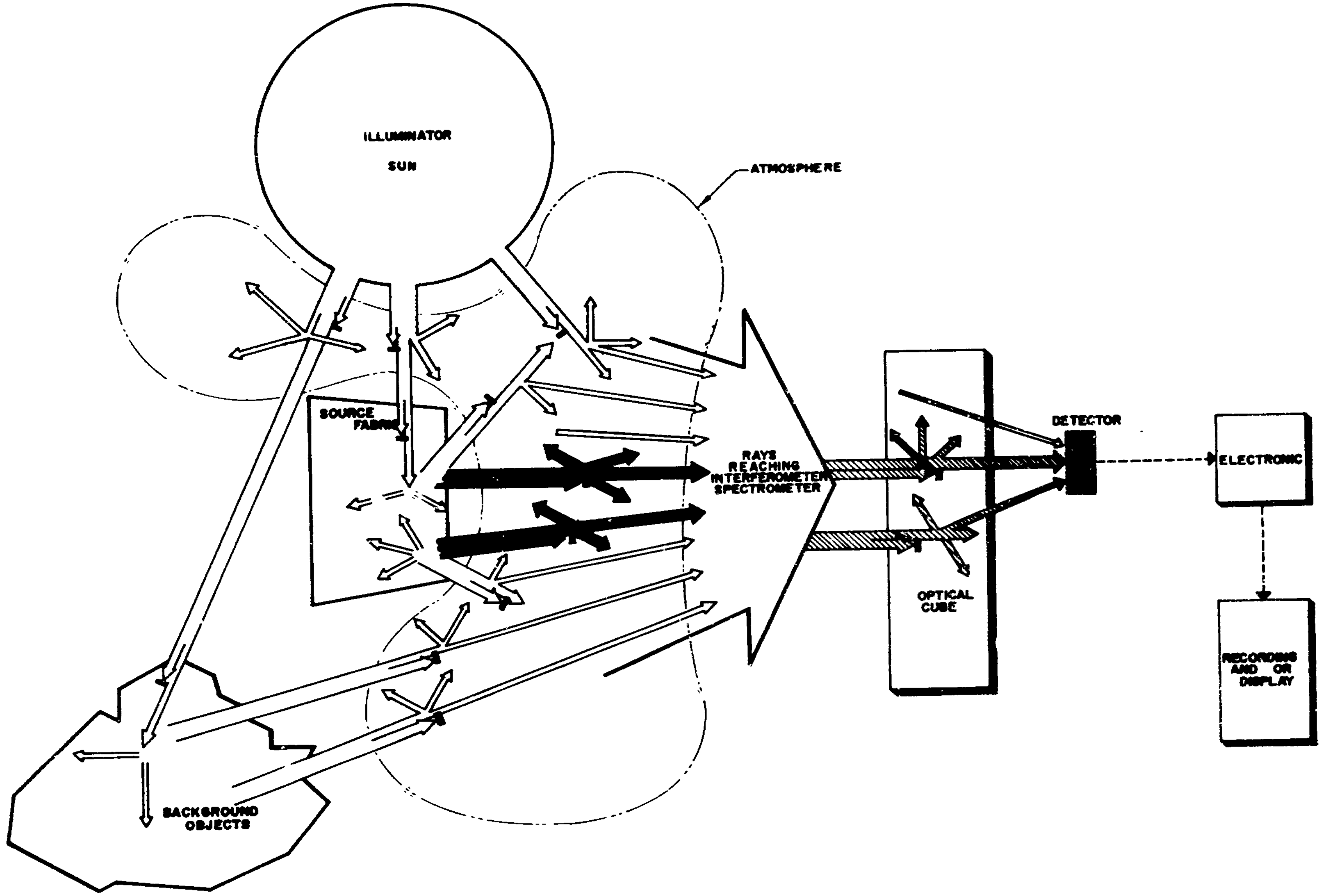

Figure 11: THE EFFECTS OF BACKGROUND AND ATMOSPHERE ON RADIOMETRIC MEASUREMENTS

are two means of working with background interference: one is to eliminate it as much as possible, and the other is to understand it and let it be a factor in interpreting the data. Both of these methods are used in this report.

For example, if the background is cooled so that it radiates considerably less than the source of interest, then the radiation and reflection due to the background is lessened, making more accurate measurements possible. Figure 12 illustrates this effect more fully. In the description of the experimental procedure, the construction of a "cold box" is detailed. This box is used for the reduction of background radiation. Much of the data used in this report were taken inside the chamber.

For analysis of the data, it was important for the temperature of the source, fabric, background, and instrument to be known exactly, for an error of a few degrees in source of instrument temperature can significantly change the total emission characteristics of the reduced spectrum. This error occurs when the parameters of the experiment are put into the computer.

C. Terrain Features

Terrain features are defined as all objects other than the source of interest that contribute to the radiant flux reaching the instrument. This includes earth, grass, trees, water, sky, clouds, and atmosphere. The spectra of certain terrain features were taken by Block Engineering independently of this study. These terrain features were sand and dirt, trees, a river, and a brick building.

Sand and dirt have a high emissivity and, due to their granular nature, act as good blackbody radiators. A fabric sample at the same temperature as sand and dirt would have about the same spectral chacteristics, and the total emissivity from each would be equal. The spectrum of a group of trees shows structure at 10.8μ and 11.5μ. Aside from this, there is nothing to differentiate the spectrum of trees from the spectrum of a fabric sample. The spectrum taken of a river shows mostly radiation reflecting from other sources, and could be called a continuum. The spectrum of a building shows structure at 6μ, 7μ, and 12μ. This spectrum is also a composite of reflected and emitted

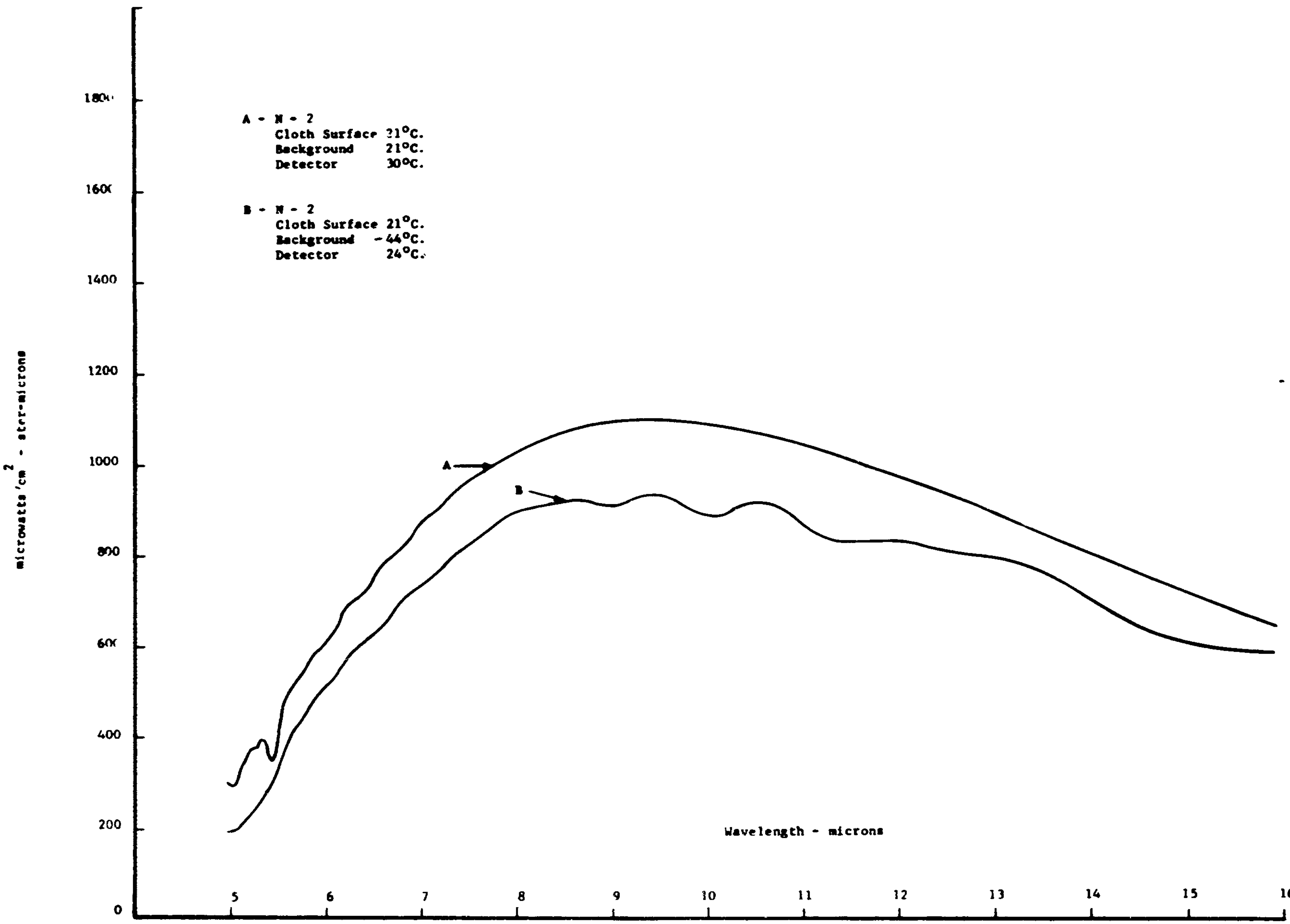

Figure 12: Effects of Spurious Relection

radiation, and differs very little from the other terrain features.

In Section V, (Conclusions), the effect of background feature reflection and radiation on the source is discussed and related to the fabric spectra. This spurious reflection and radiation causes the same spectral masking and blending of terrain features as it does of the fabric samples, so that terrain measurements made in the field will vary with changing ambient conditions. A change in the ambient temperature, cloud cover, or sun position may all change the spectral characteristics of the source.

With measurements made, either in the field or in the laboratory, it is almost certain that a portion of the optical path will be exposed to the air. The atmosphere absorbs and scatters radiation from the source. Figure 13 shows the transmission of a 1000-foot path through the atmosphere.[3] However, in measurements for this report, the main concern would be the H_2O and CO_2 absorption bands at 2.7 , 4.2 , and 6.5 , due to the relatively short path lengths of air experienced in the experiment.

The same parameters that affect the total emission measurements of fabrics would affect total emission of terrain features.

V. CONCLUSIONS

Owing to the number of spectra taken, and the wide variety of conditions under which they were taken during the course of these tests, it is felt that the data presented here are conclusive. There are two basic physical reasons for the lack of spectral detail in these measurements. The first reason is that the small variations in the weave of the cloth act as blackbody radiators, thus masking spectral detail. Second, the observation of the samples in a room environment gave rise to spurious reflection of radiation from walls, ceiling, light, etc. Kirchoff's law states:

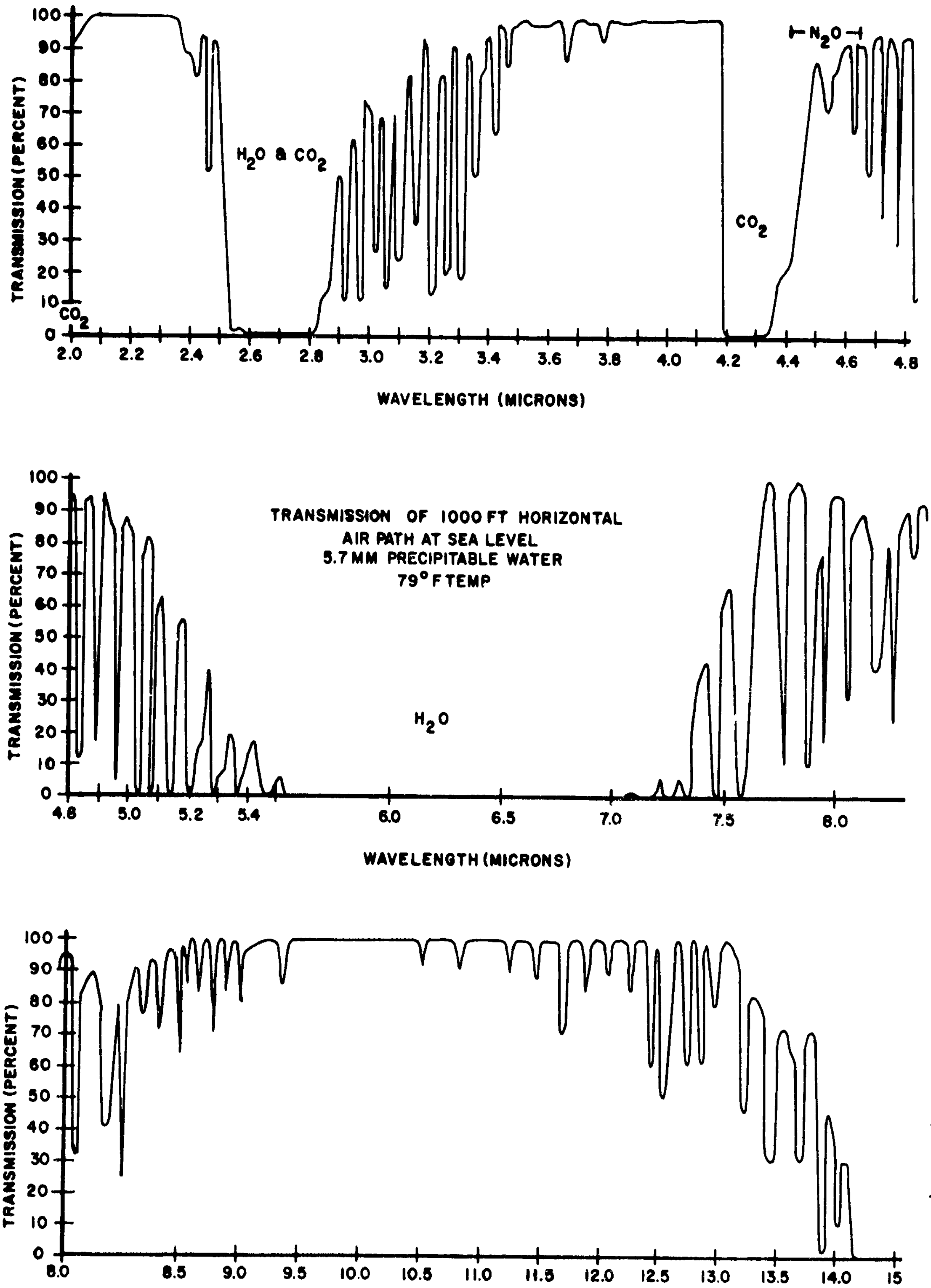

Figure 13: SPECTRAL TRANSMISSION OF THE ATMOSPHERE

$$\epsilon + \tau + \rho = 1$$

where ϵ = emissivity

τ = transmissivity = 0

ρ = reflectivity

Since the sum of emissivity and reflectivity equals a constant (1) a rise in reflectivity means a corresponding decrease in emissivity[8]. The use of the cold box largely eliminates spurious emission and reflection.

Figure 21 shows two superimposed spectra of the same fabric at the same temperature. The only difference in the two measurements is that the background of A was at room (and sample) temperature while the background of B was at -44°C. The difference in the maximum heights of A and B is the reduction in reflection resulting from cooling the background. It can also be seen that certain detail appearing in spectrum B is almost totally masked in spectrum A. This increase in reflectivity, brought about by the sample being at the same temperature as the surroundings, is the largest deterrent to taking significant spectra in the field. To show that the amount of spectral detail is an ambient condition dependent phenomenon, consider the following.

On a clear day, the radiant emittance from the sky has the spectral distribution as shown in Figure 14 below[9].

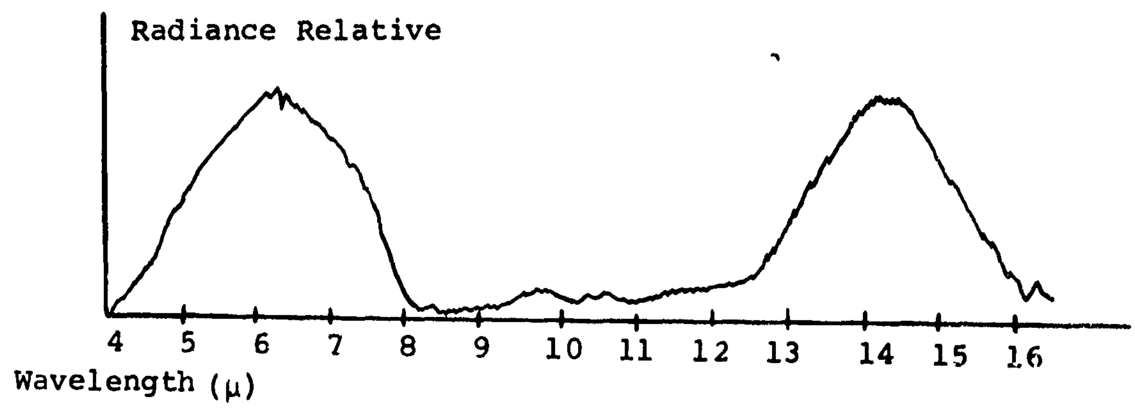

Figure 14: Radiance of Clear Sky

If a sample were observed under clear sky conditions, the 8μ to 12.5μ region of its spectrum would show very little reflected radiation, and largely true sample spectrum; however, on an overcast day, the sky spectrum has the shape[9] shown in Figure 15.

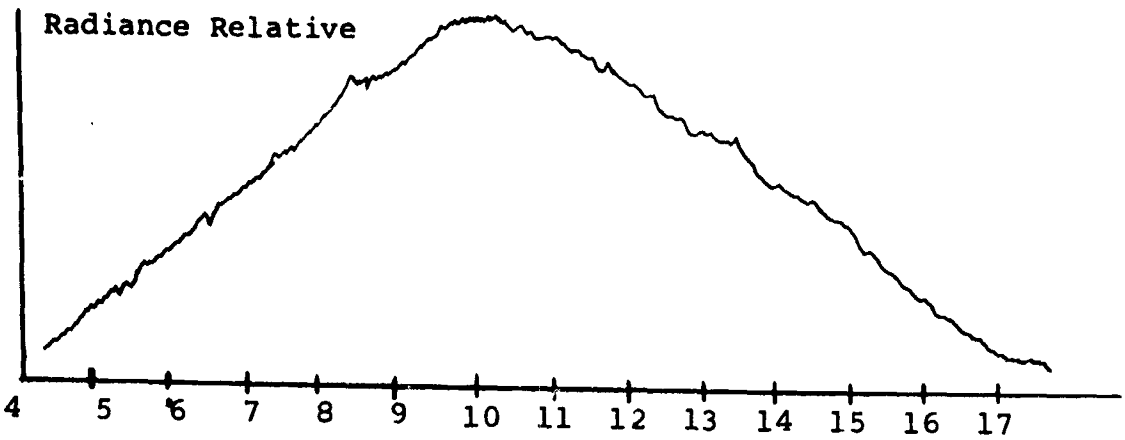

Figure 15: Radiance of Cloudy Sky

It can be seen that the emission in the 8μ to 12μ portion of the spectrum is much greater, and hence, the radiance reflected by the sample would be greater in this region, giving a false total emission measurement. Add to this effect the reflected radiance from trees, grass, water, and rocks and it can be seen that the resultant spectrum could be an ambiguous representation of the sample.

The spectra taken under conditions of varying humidity show that the change in humidity affects the spectrum much less than changing the background. For significant path lengths between the source and the instrument, the water-absorption bands would increase in strength with an increase in humidity, but the other portions of the spectrum would remain unchanged.

The spectra taken with insulation placed between the hotplate and the sample show that the radiance from the cloth surface is less when insulation is present than when insulation is absent. It can be concluded that the rate of radiation exchange between the hotplate and the cloth surface is slower through insulation than it is when the cloth and hotplate are in direct contact. The spectrum of the insulated cloth cannot be distinguished from the spectrum of cloth at room temperature.

VI. RECOMMENDATIONS FOR FURTHER WORK

The data presented in this report comprise a fairly rigorous measurement program directed towards the determination of the complete emission characteristics of fabric samples under laboratory conditions. It is concluded that terrain features and ambient conditions have a very large effect on any measurements taken under field conditions. Therefore, it will be difficult to correlate laboratory emission studies to field conditions because of the many variables involved. More work in the total emission of fabrics should now be performed in a field environment, and a better understanding of the exact difference between the emission of fabrics and the emission of terrain may be derived. Such work could lead to the development of fabrics, methods of treating fabrics, or methods of utilizing fabrics so that fabrics cannot be differentiated from background features. It is further recommended that no further laboratory work be undertaken. Field measurements should be the next extension of this work.

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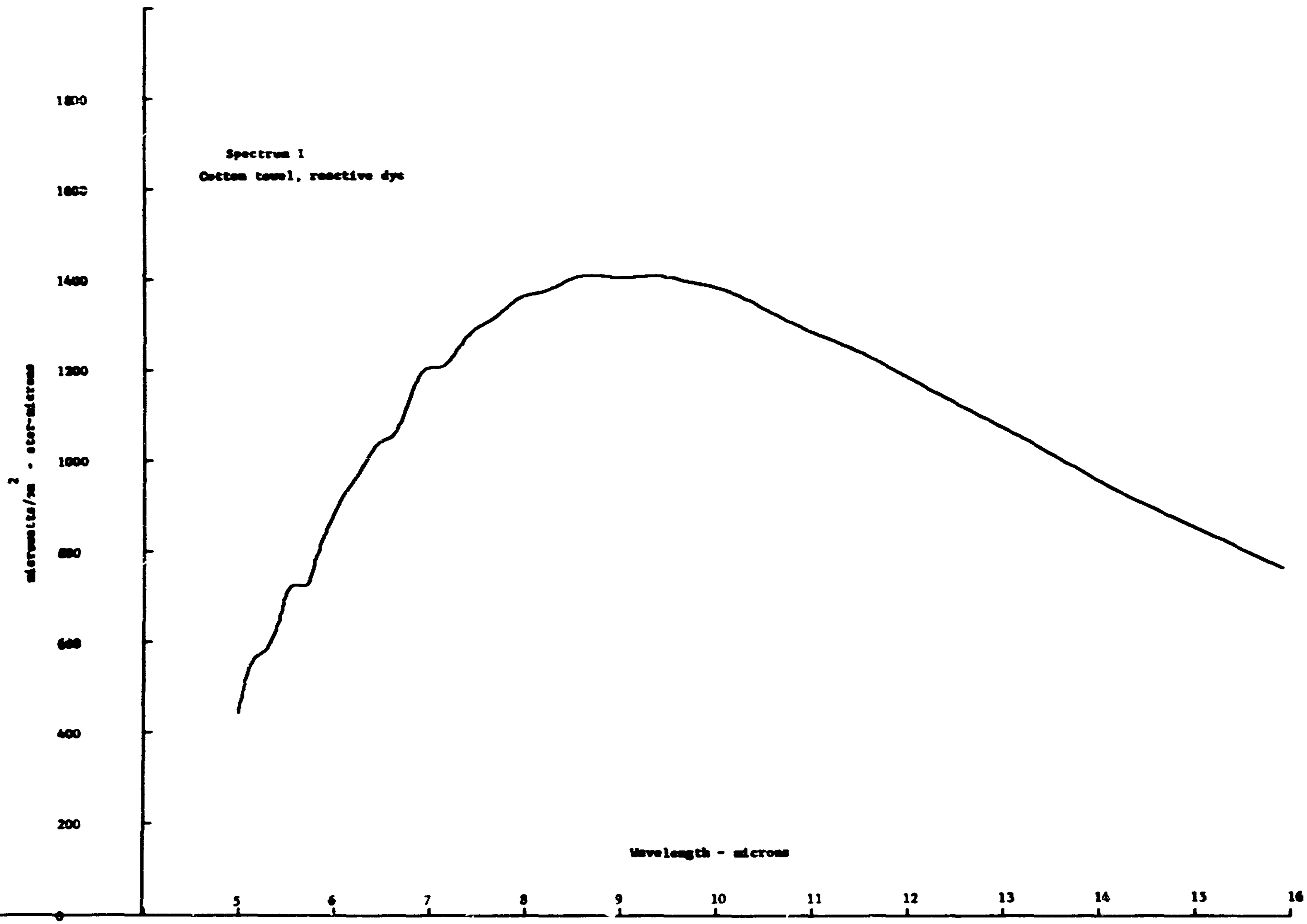
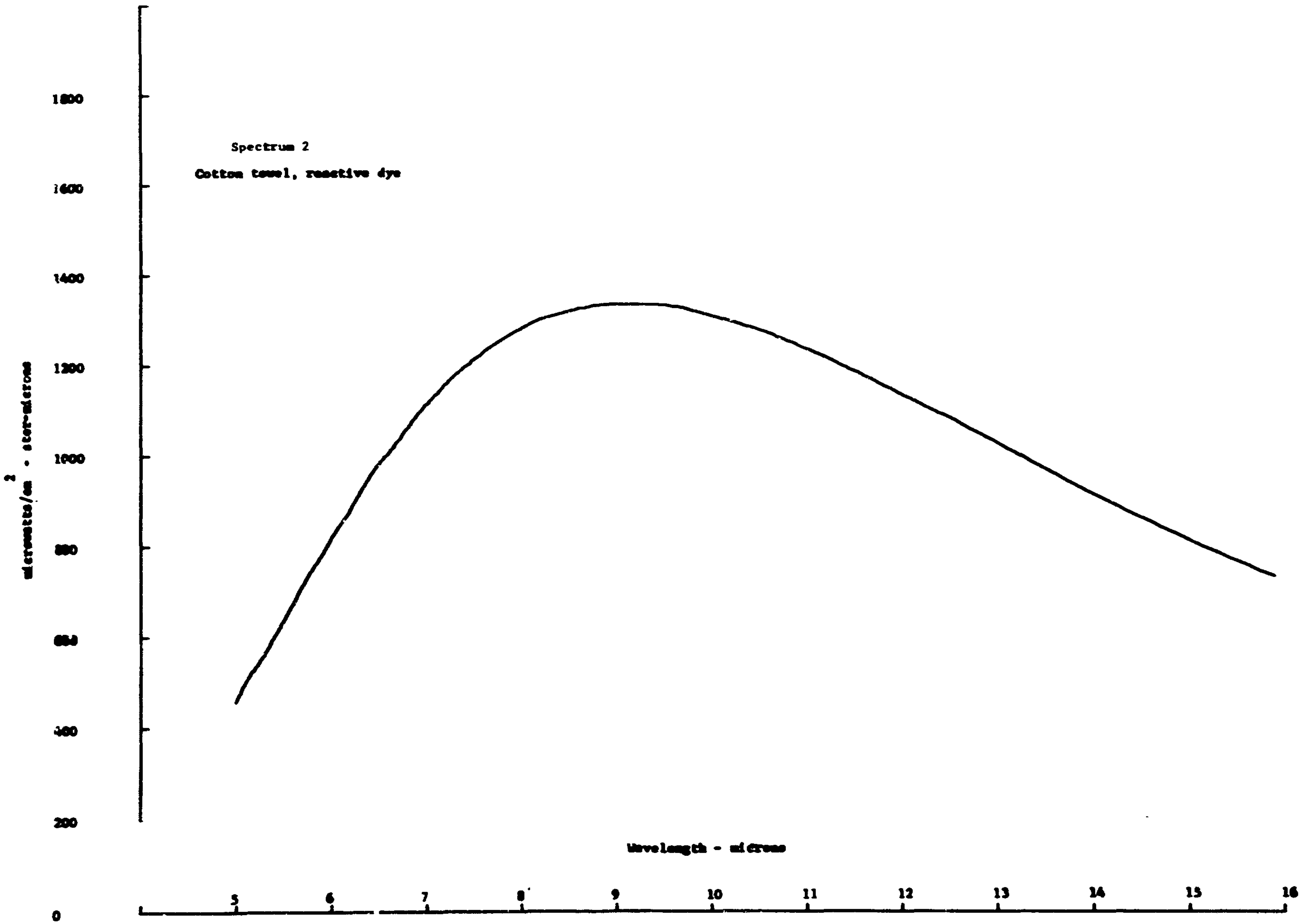
GROUP I SPECTRA


Spectrum 1
Cotton towel, reactive dye
microwatts/cm² - ster-microns
Wavelength - microns
0
200
400
600
800
1000
1200
1400
1600
1800
5
6
7
8
9
10
11
12
13
14
15
16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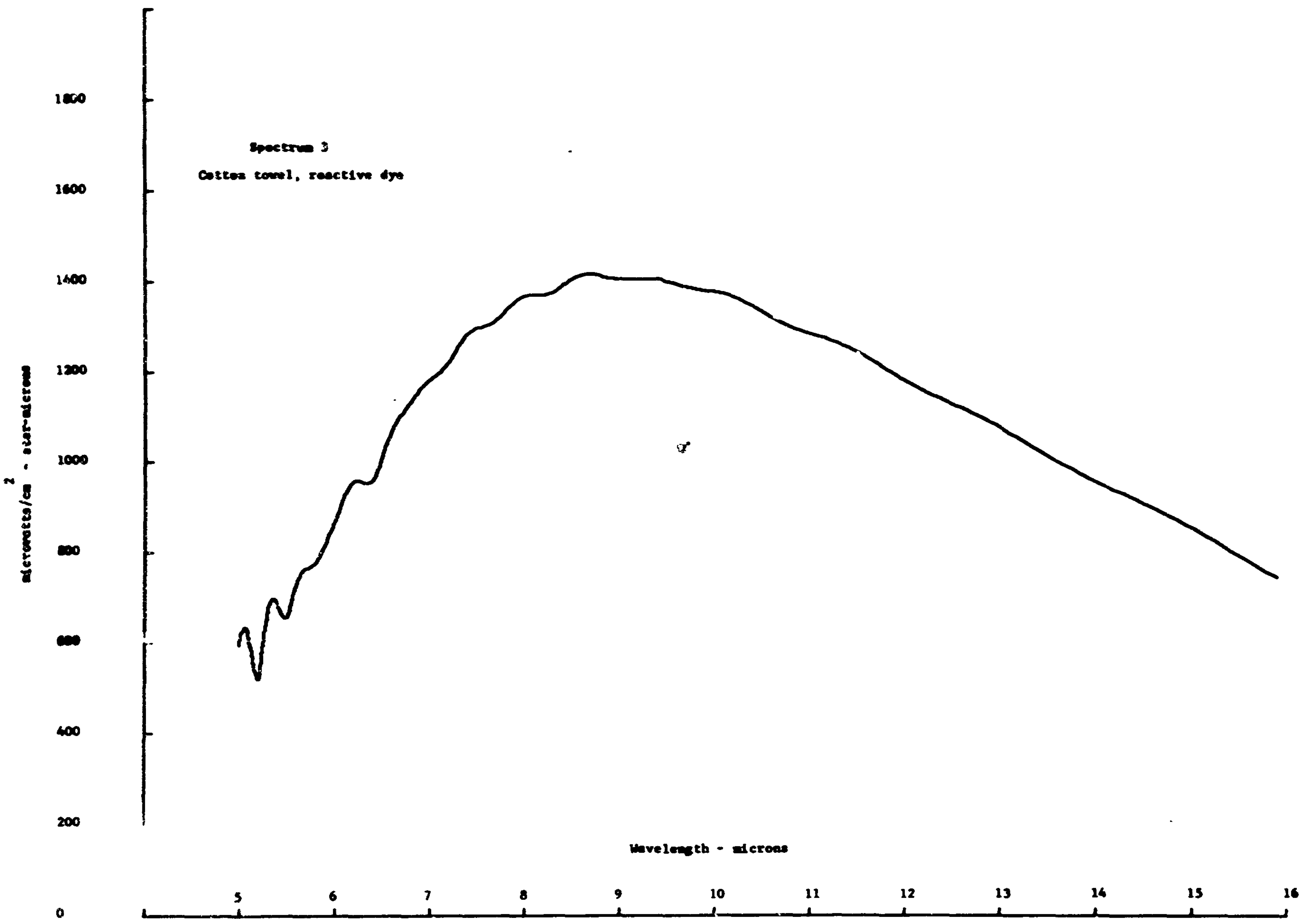
Cotton towel, reactive dye
microwatts/cm² - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16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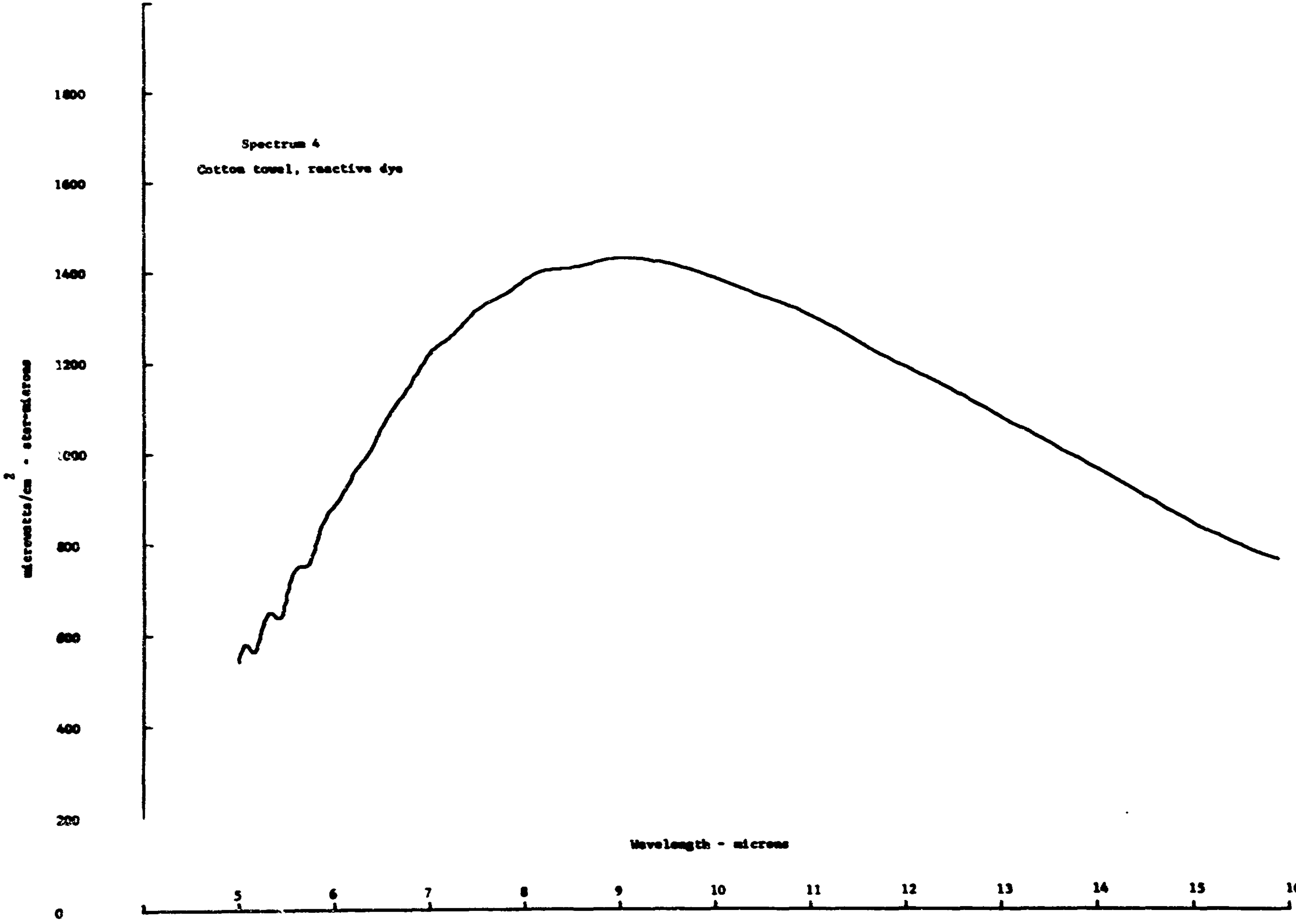
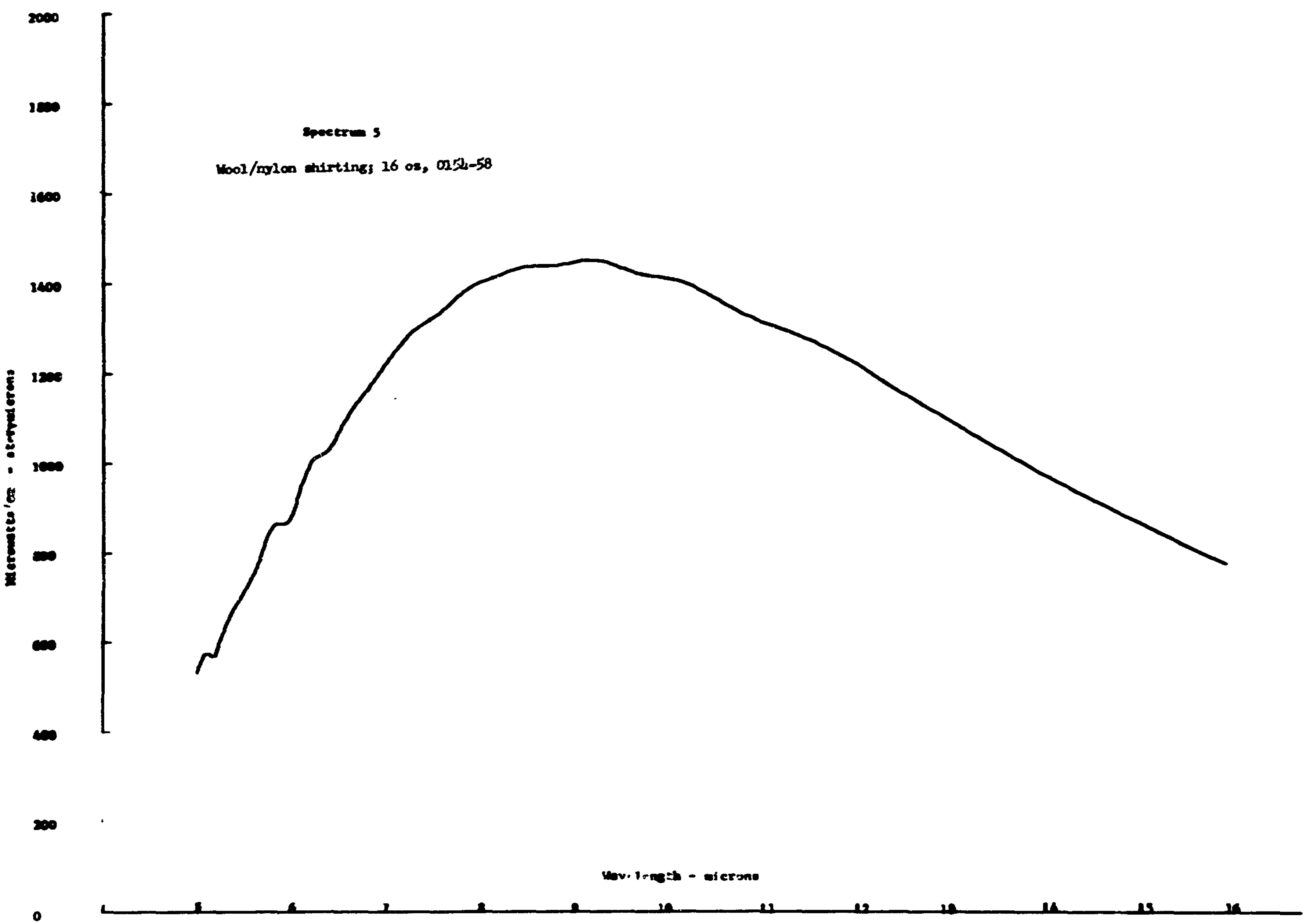
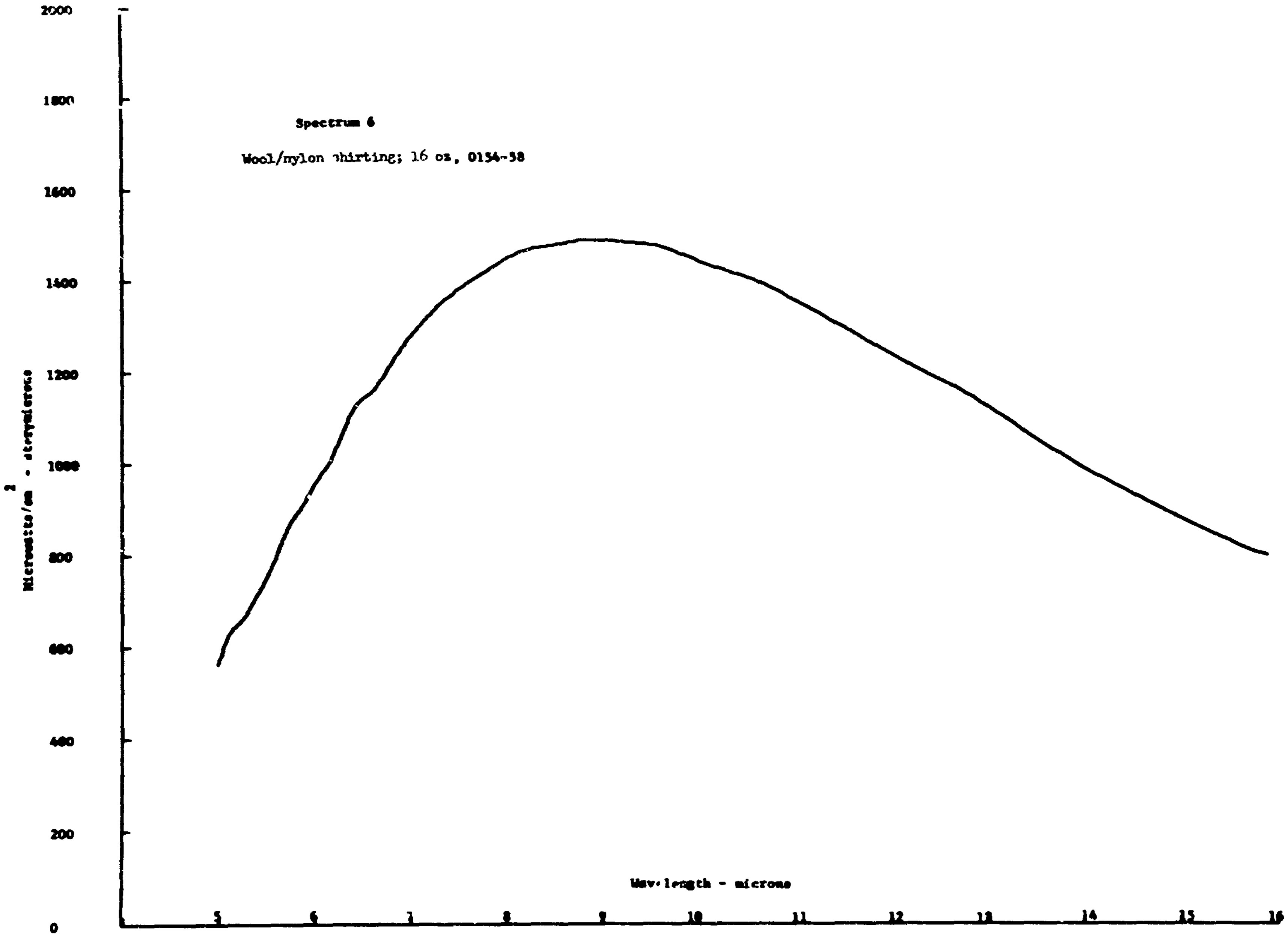
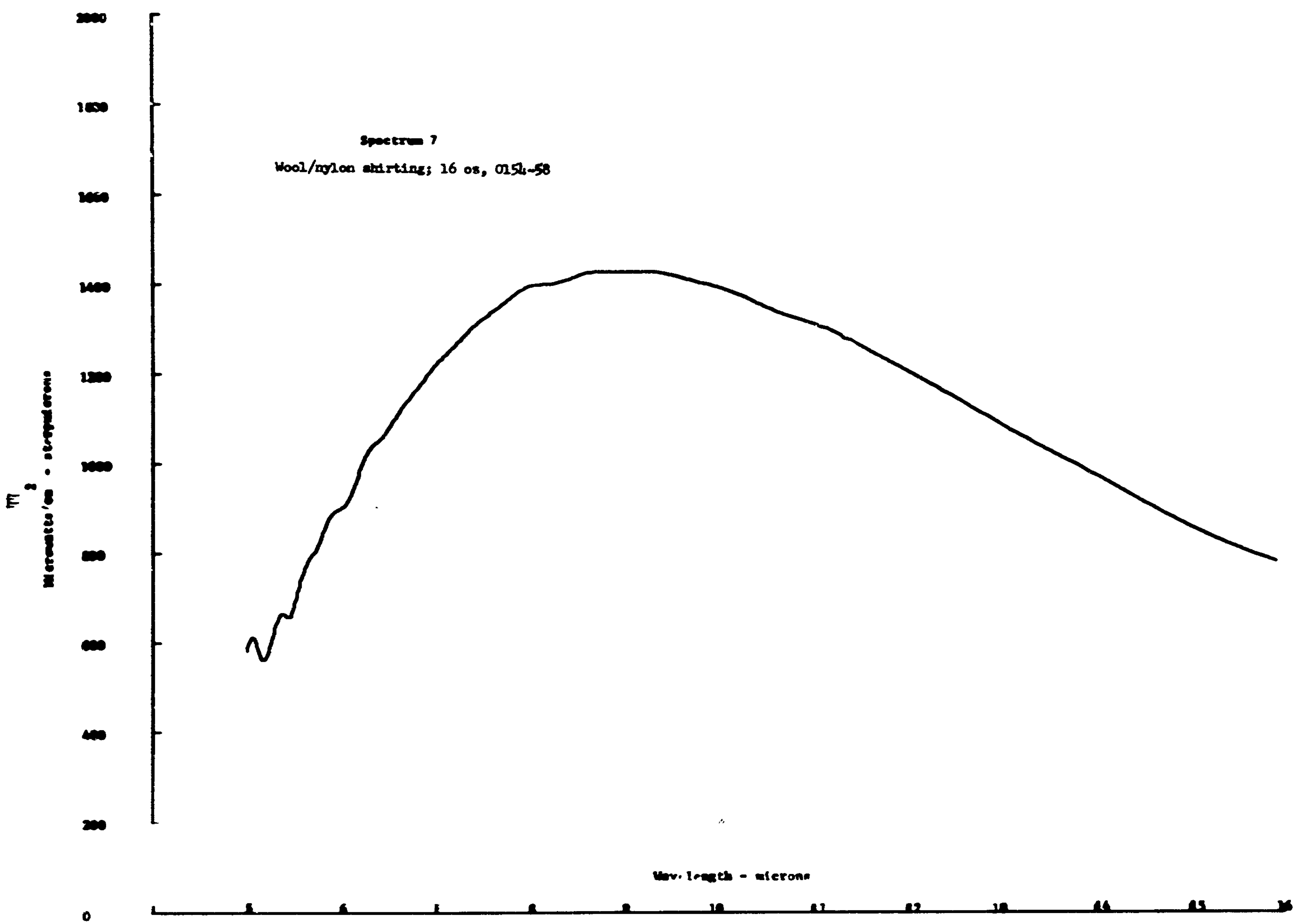
Cotton towel, reactive dye
microwatts/cm² - ster-micron
1800
1600
1400
1200
1000
800
600
400
200
0
5
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns

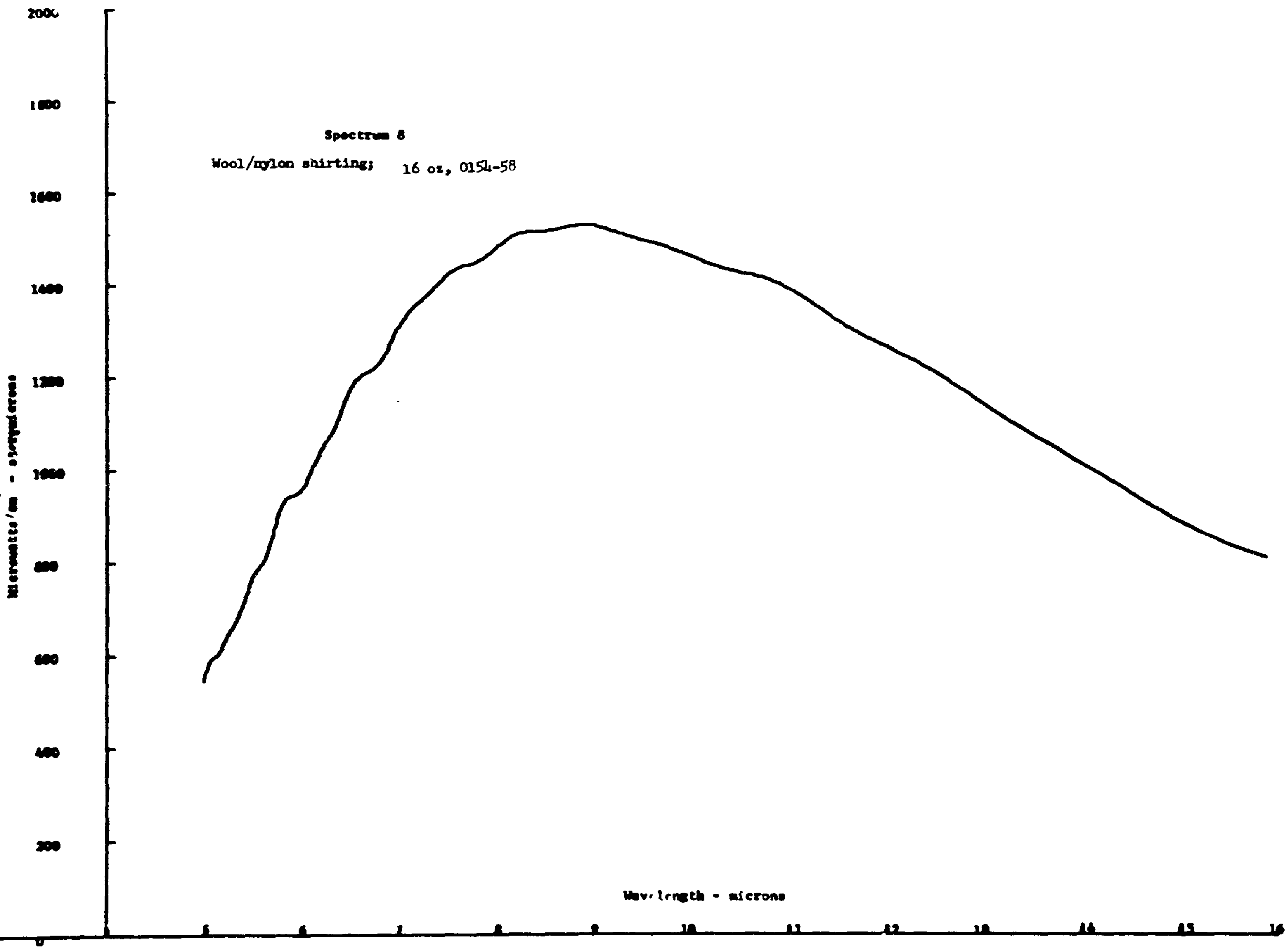


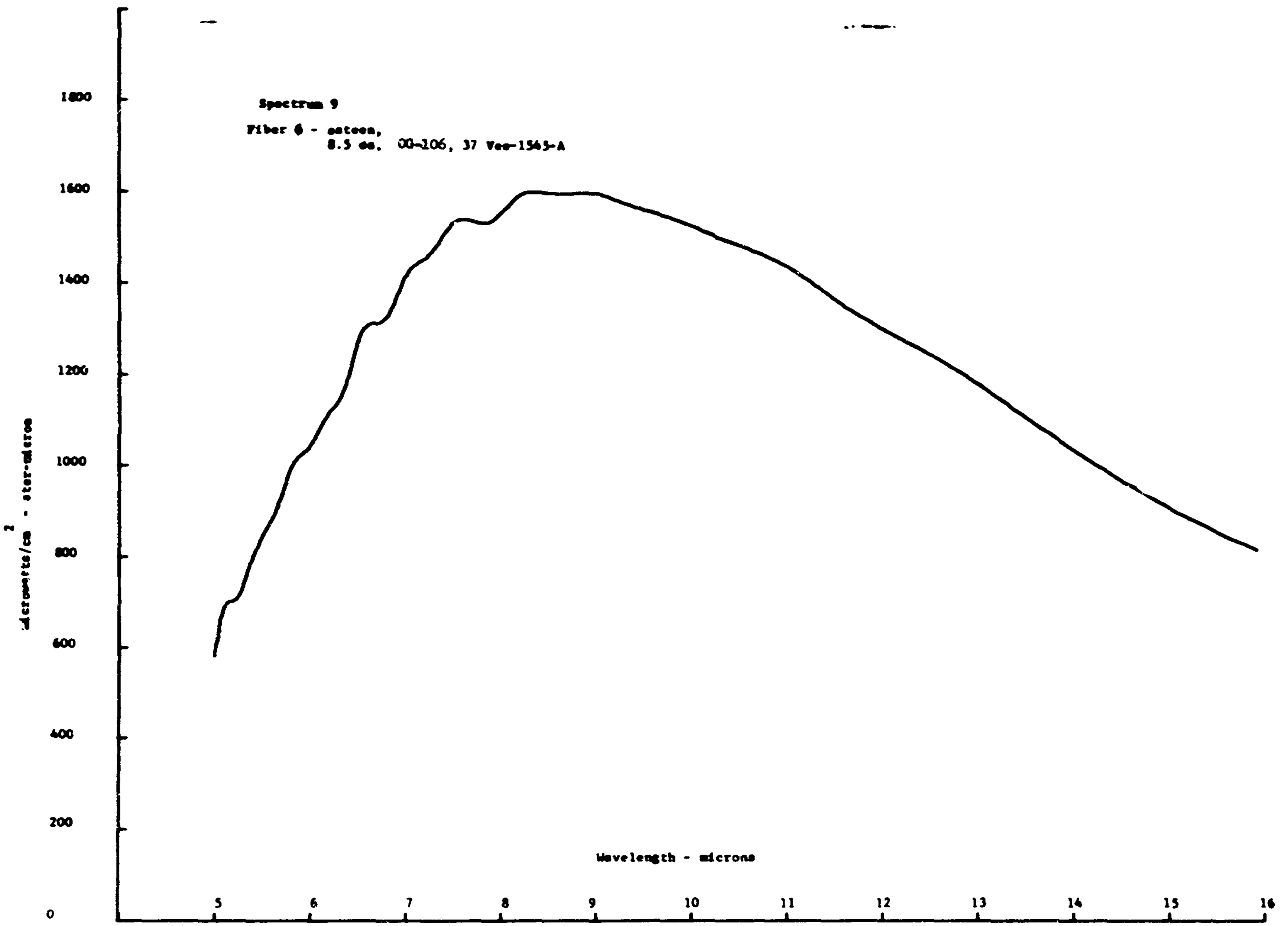
Spectrum 4
Cotton towel, reactive dye
microwatts/cm² - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16

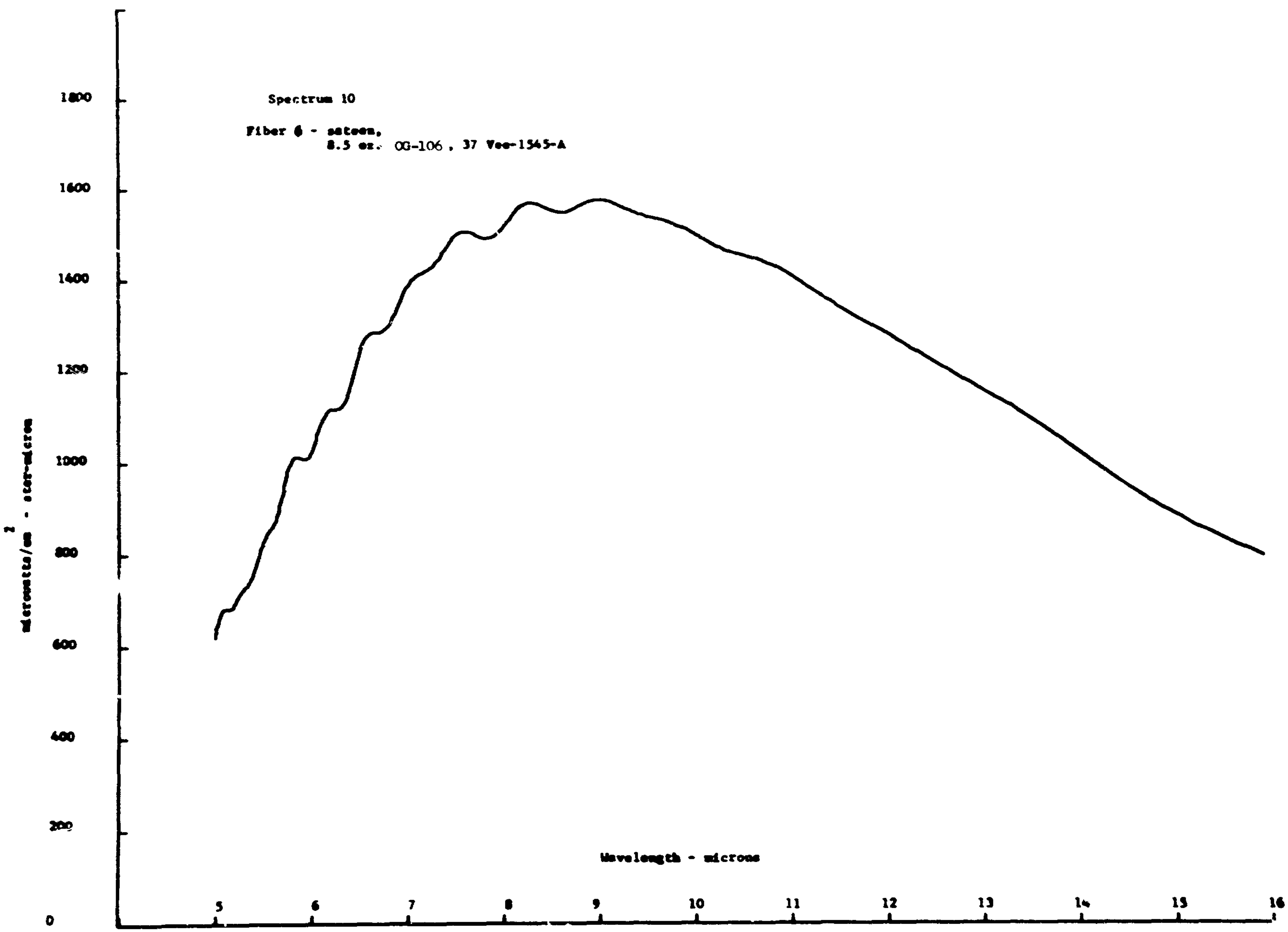

Spectrum 5
Wool/nylon shirting; 16 oz, 0154-58
2000
1600
1400
1200
1000
600
400
200
0
Wavelength - microns
5
6
7
9
10
11
12
14
15
16

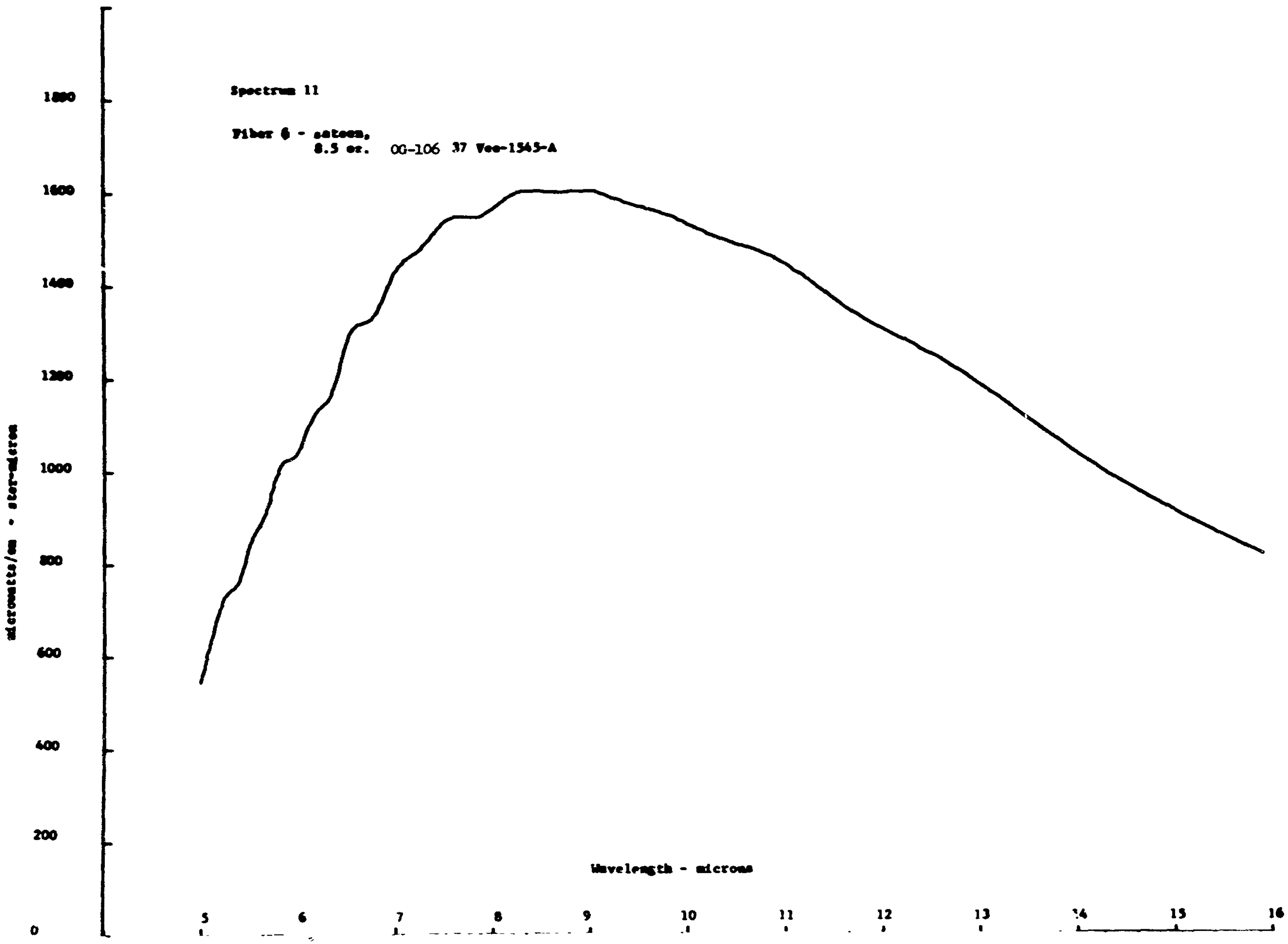

Spectrum 6
Wool/nylon shirting; 16 oz, 0154-58
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Microwatts/cm² - steradian
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16


Spectrum 7
Wool/nylon shirting; 16 os, 0154-58
2000
1800
1600
1400
1200
1000
800
600
400
200
0
5
6
7
8
9
10
11
12
13
14
15
16
Wave length - microns

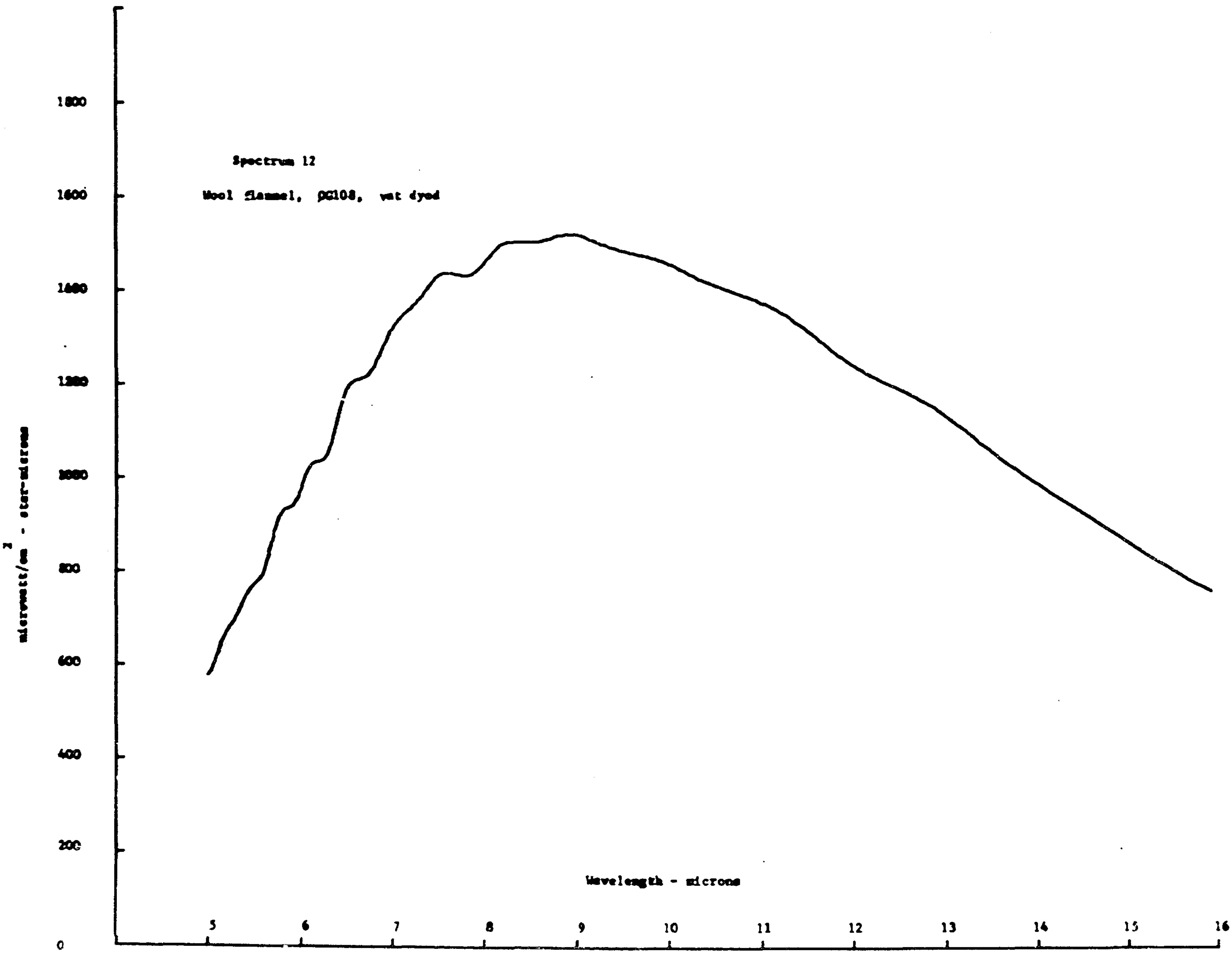

Spectrum 8
Wool/nylon shirting; 16 oz, 0154-58
2000
1800
1600
1400
1200
1000
800
600
400
200
0
5
6
7
8
9
10
11
12
13
14
15
16
Wave length - microns

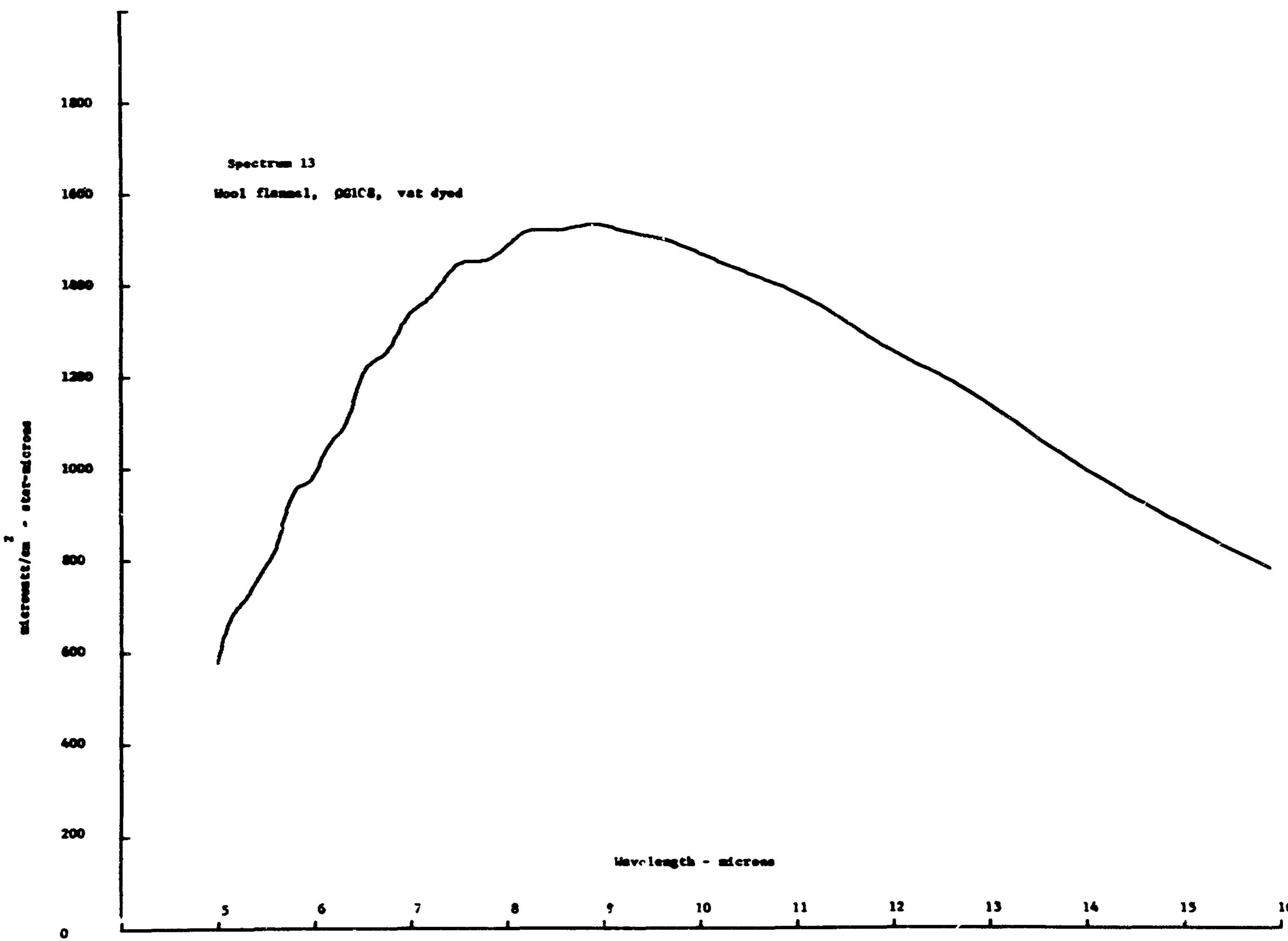

Spectrum 9
Fiber 6 - sateen,
8.5 oz. OD-106, 37 Vee-1545-A
1800
1600
1400
1200
1000
800
600
400
200
0
microwatts/cm^2 - ster-micron
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16


Spectrum 10
Fiber 6 - sateen, 8.5 oz. OG-106, 37 Vee-1545-A
1800
1600
1400
1200
1000
800
600
400
200
0
microwatts/cm² - ster-micron
5
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns



Spectrum 11
Fiber 6 - sateen,
8.5 oz. OG-106 37 Vee-1545-A
microwatts/cm² - ster-micron
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16


Spectrum 12
Wool flannel, ρG108, vat dyed
1800
1600
1400
1200
1000
800
600
400
200
0
microwatt/cm² - ster-microns
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16



Spectrum 13
Wool flannel, OG108, vat dyed
microwatt/cm² - ster-micron
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
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10
11
12
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14
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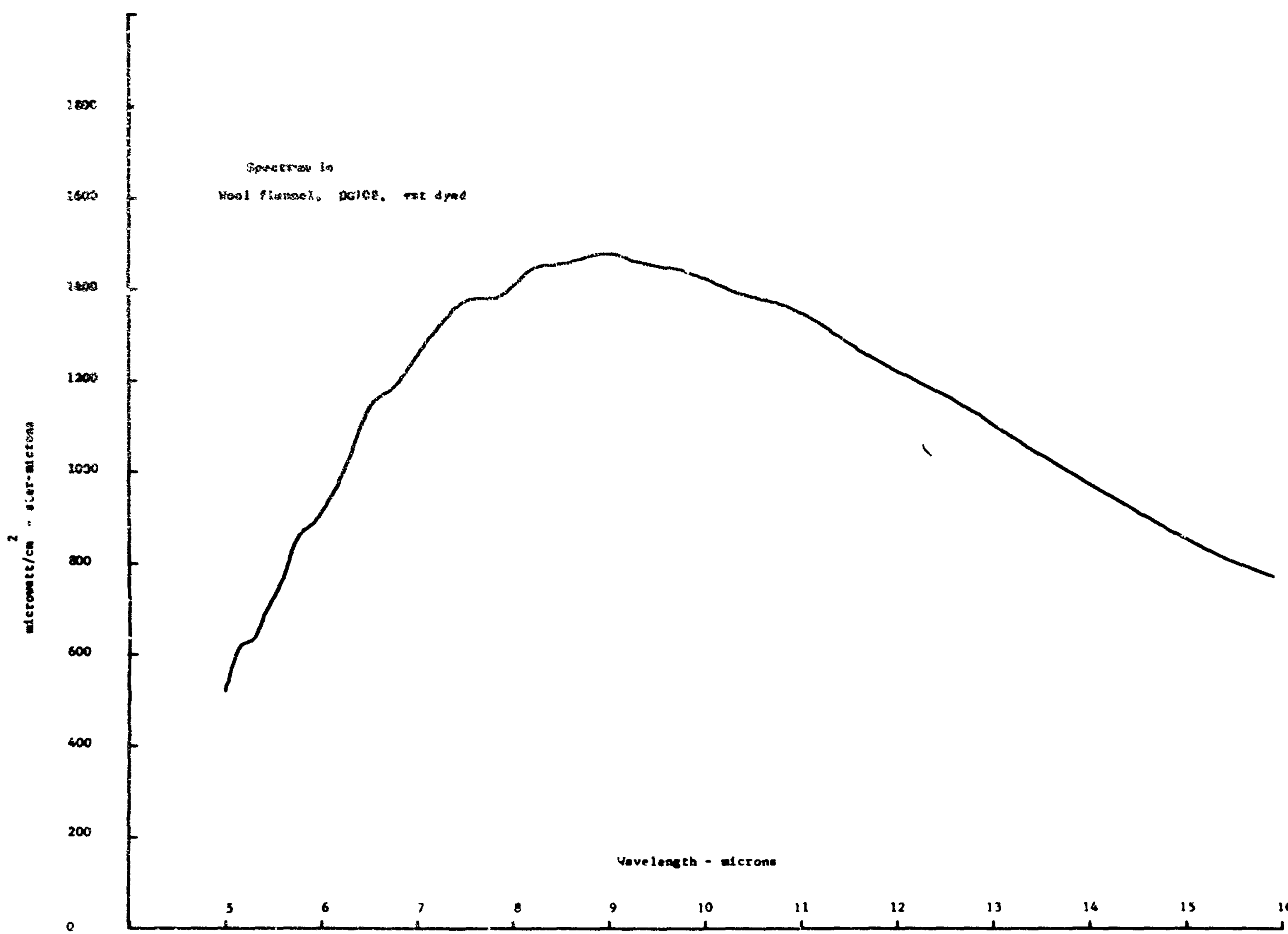
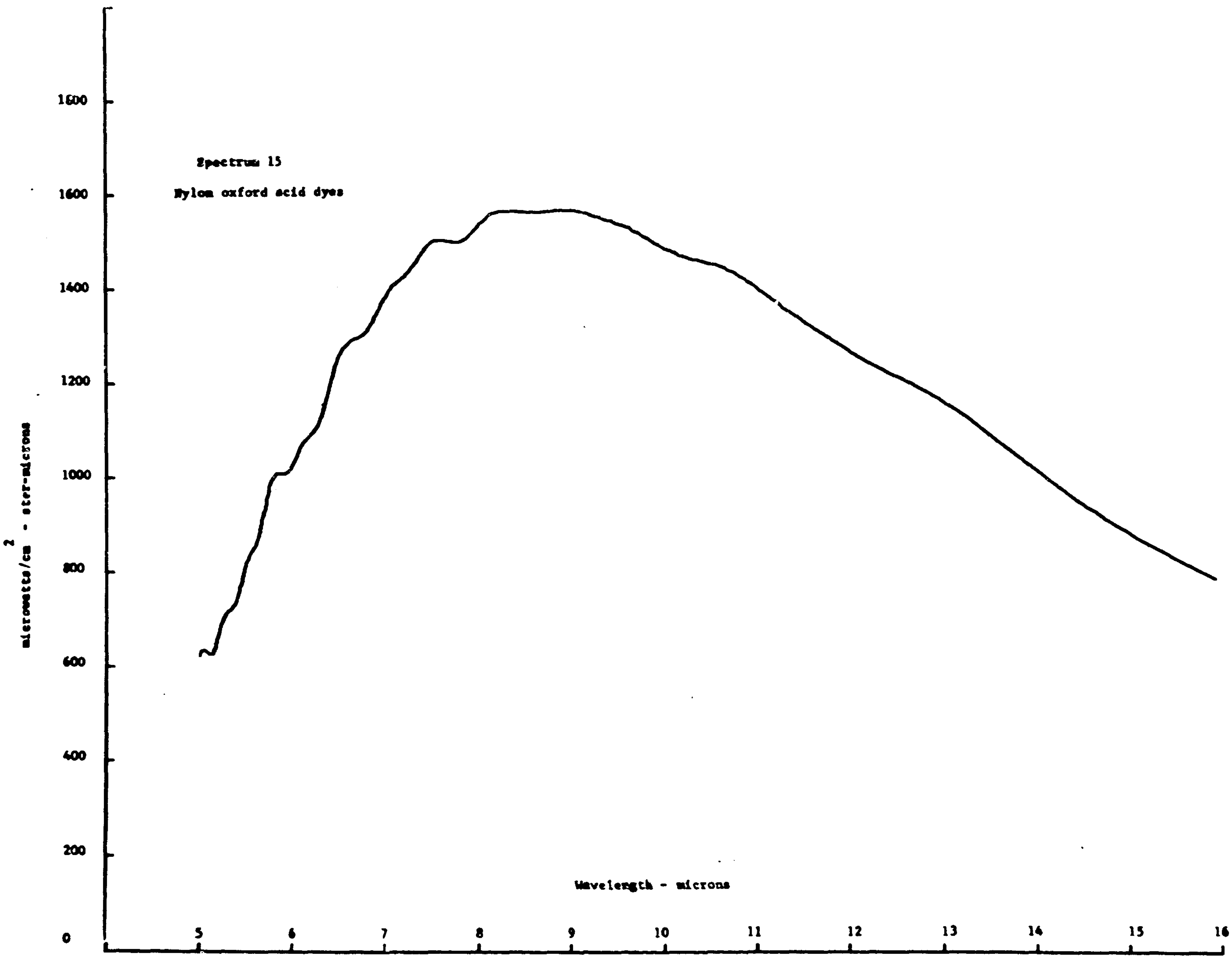
16


Spectrum
Wool flannel, vat dyed
1800
1600
1400
1200
1000
800
600
400
200
0
microwatt/cm^2 - ster-microns
5
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns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Nylon oxford acid dyes
microwatts/cm^2 - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
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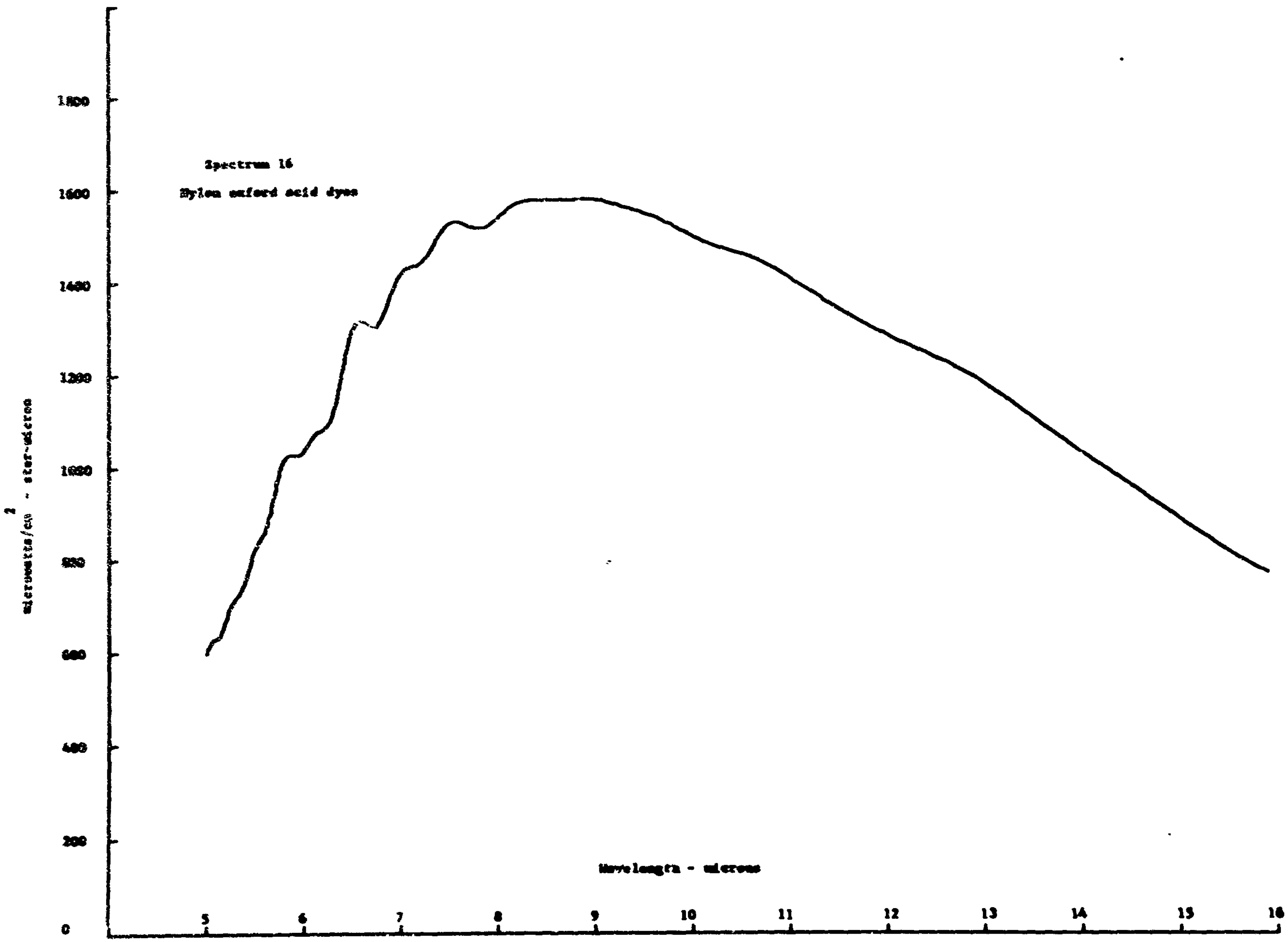
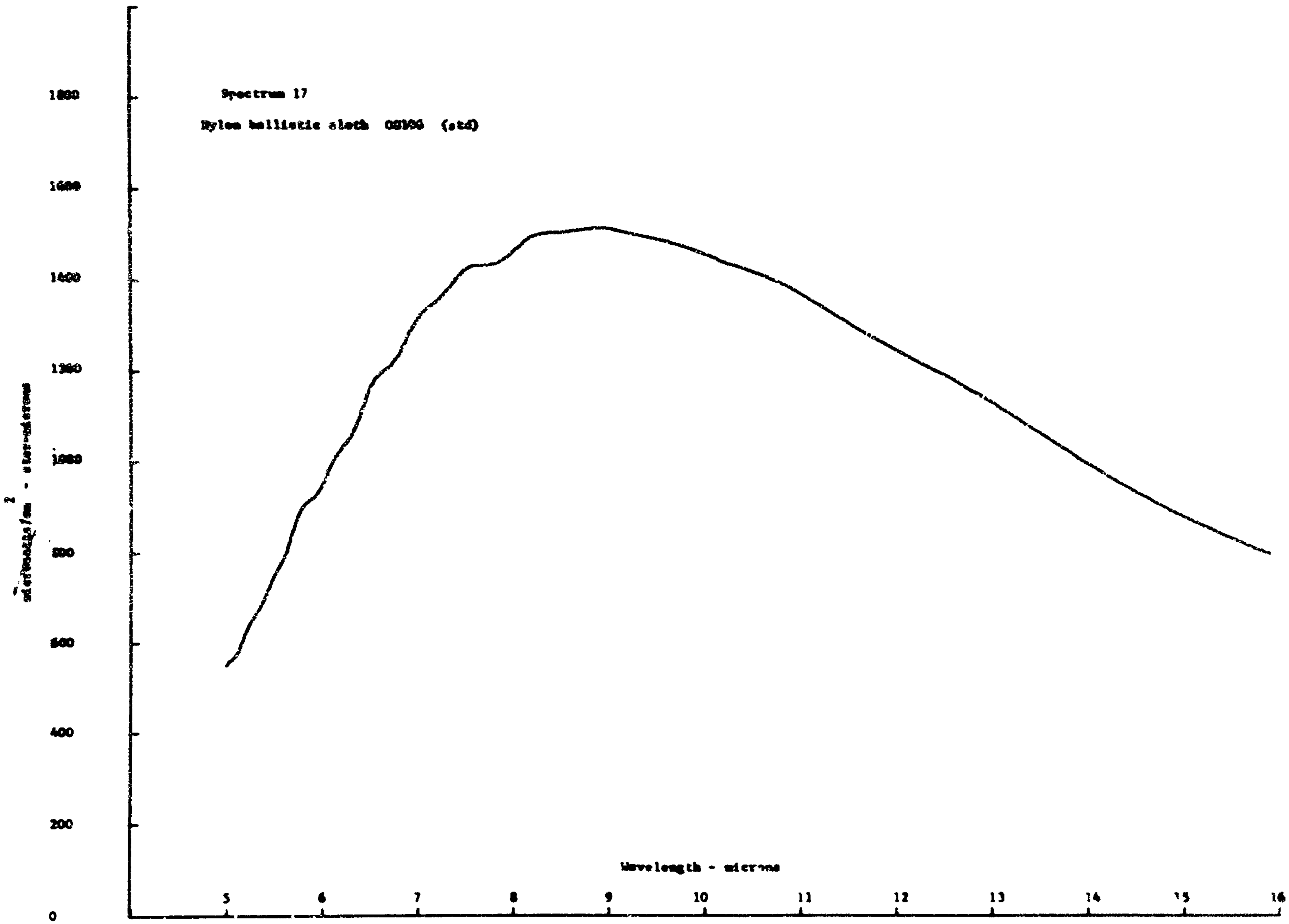
16


Spectrum 16
Nylon oxford acid dyes
microwatts/cm² - ster-micron
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16


Spectrum 17
(std)
Wavelength - microns
0
200
400
600
800
1000
1200
1400
1600
1800
5
6
7
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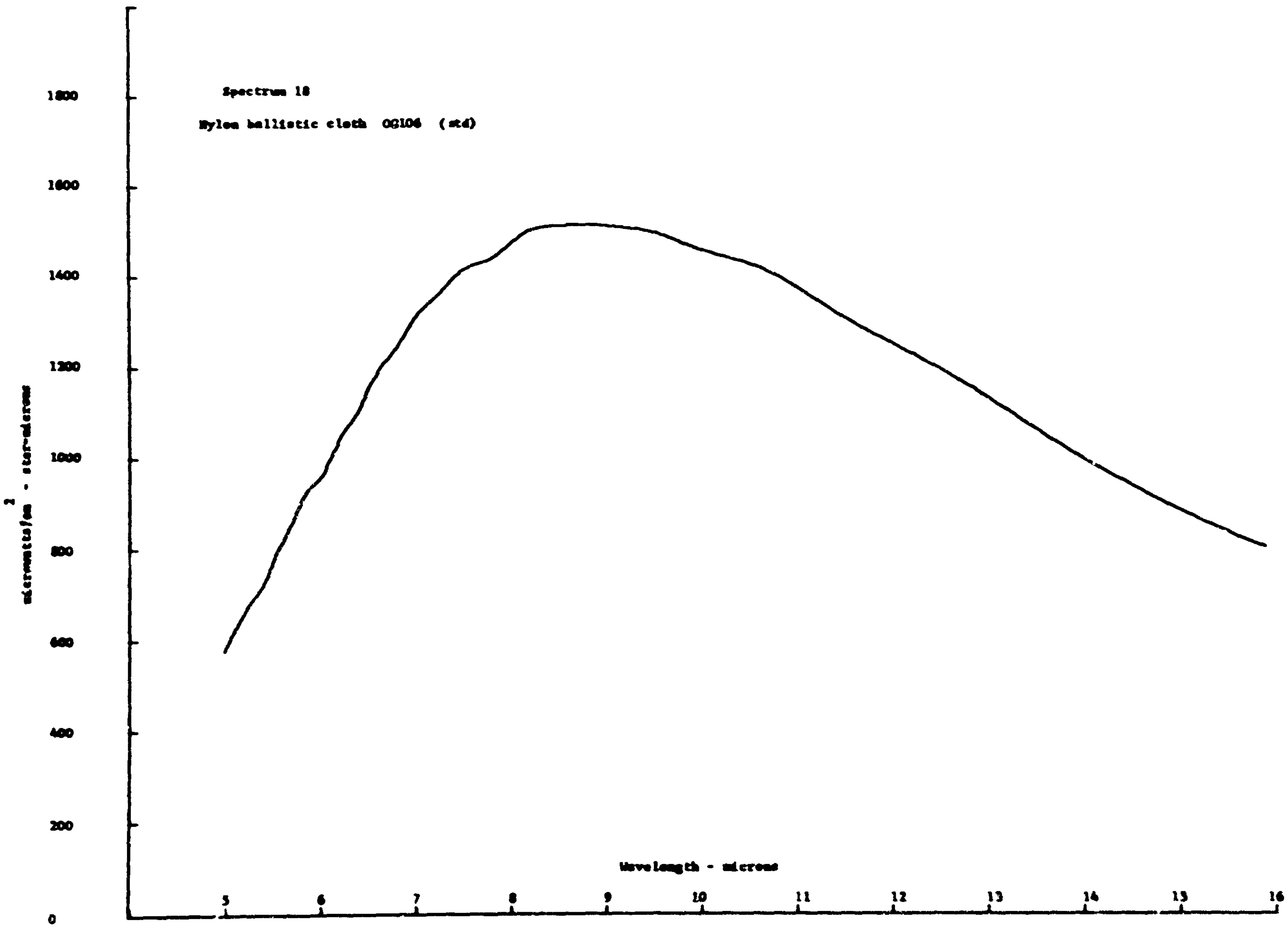
12
13
14
15
16


Spectrum 18
Nylon ballistic cloth OG106 (std)
1800
1600
1400
1200
1000
800
600
400
200
0
microwatts/cm² - ster-microns
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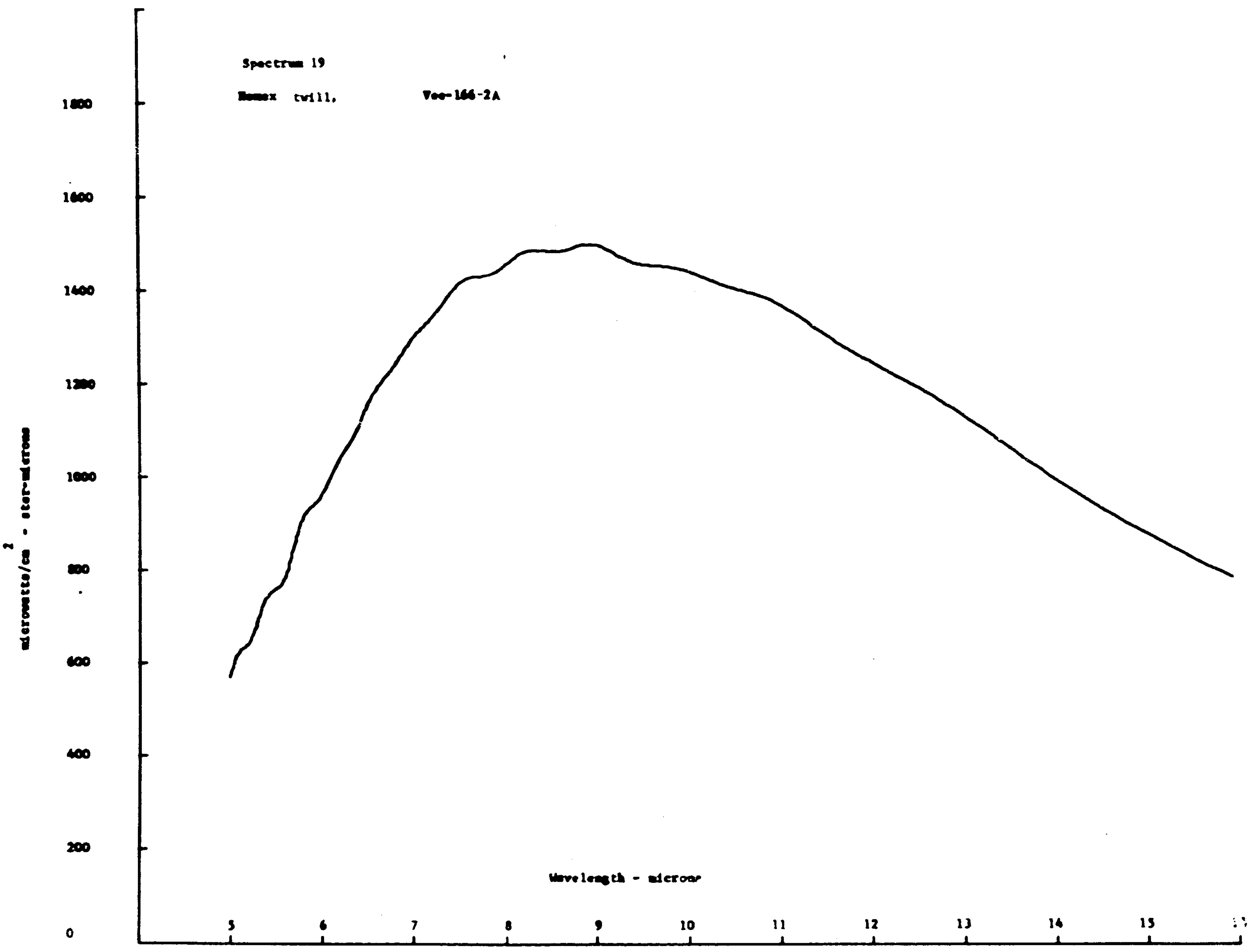
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns


Spectrum 19
twill,
1800
1600
1400
1200
1000
800
600
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200
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microwatts/cm² - ster-microns
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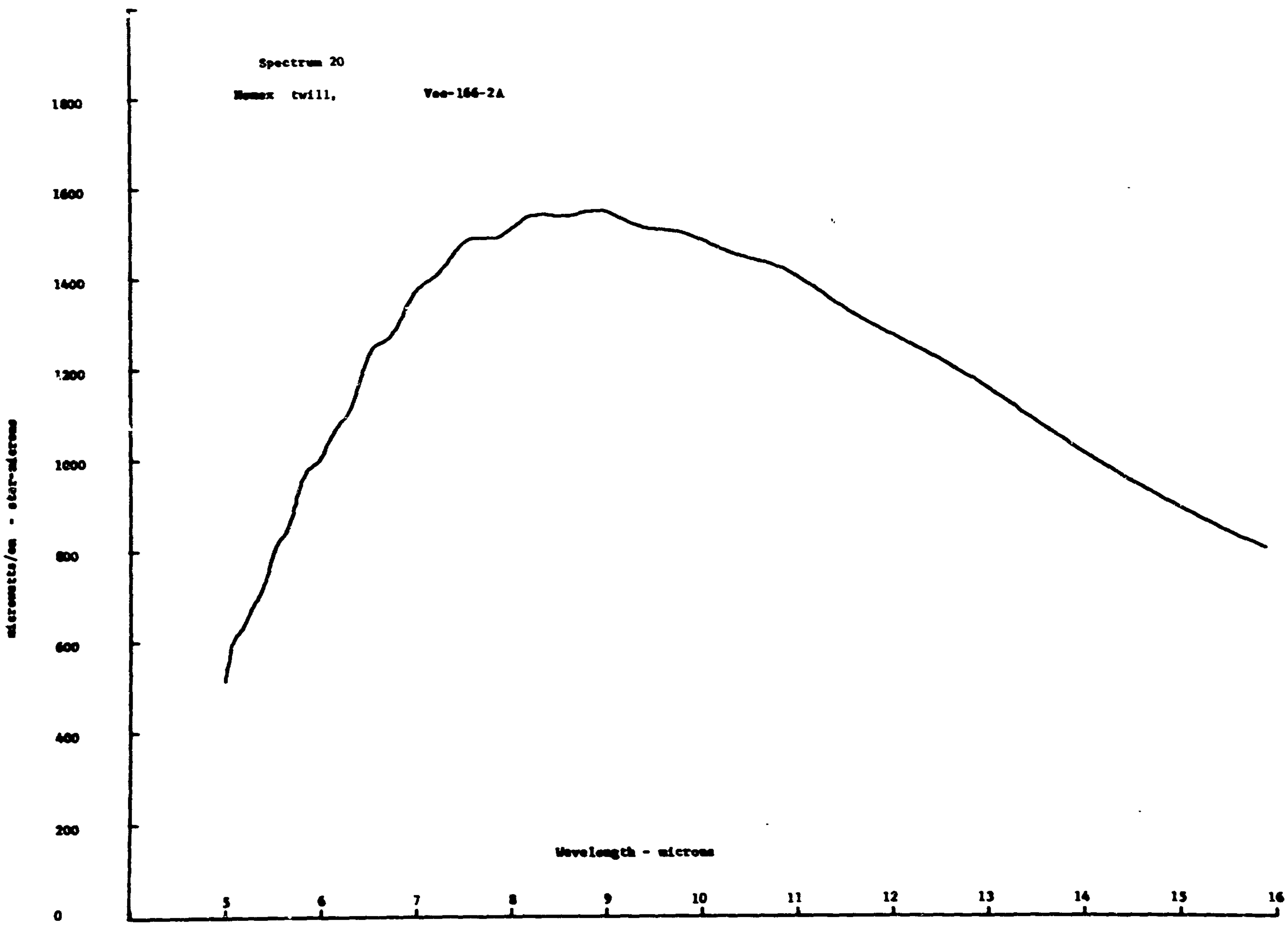
6
7
8
9
10
11
12
13
14
15
Wavelength - microns



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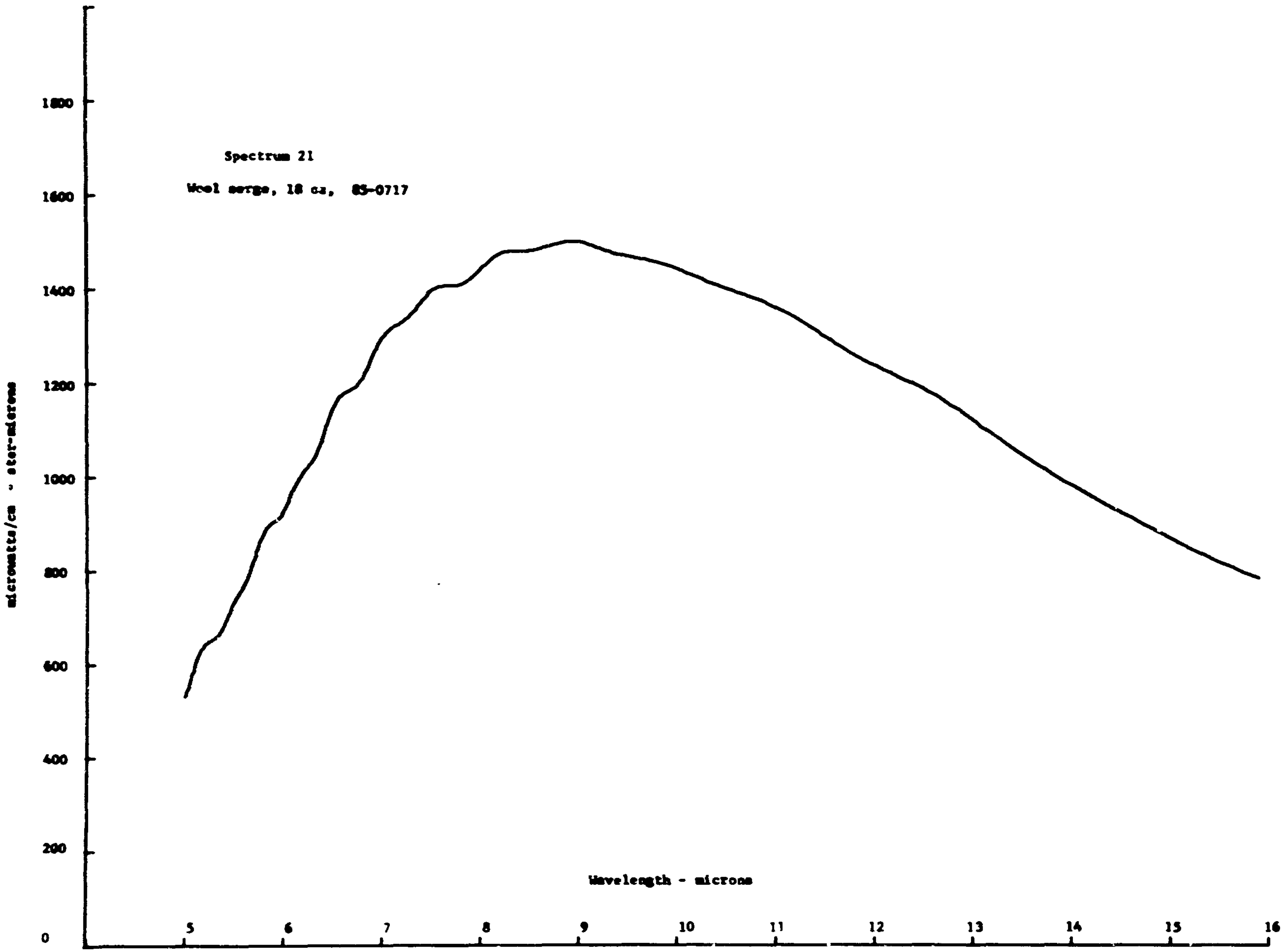
Nomex twill, Vee-166-2A
microwatts/cm² - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16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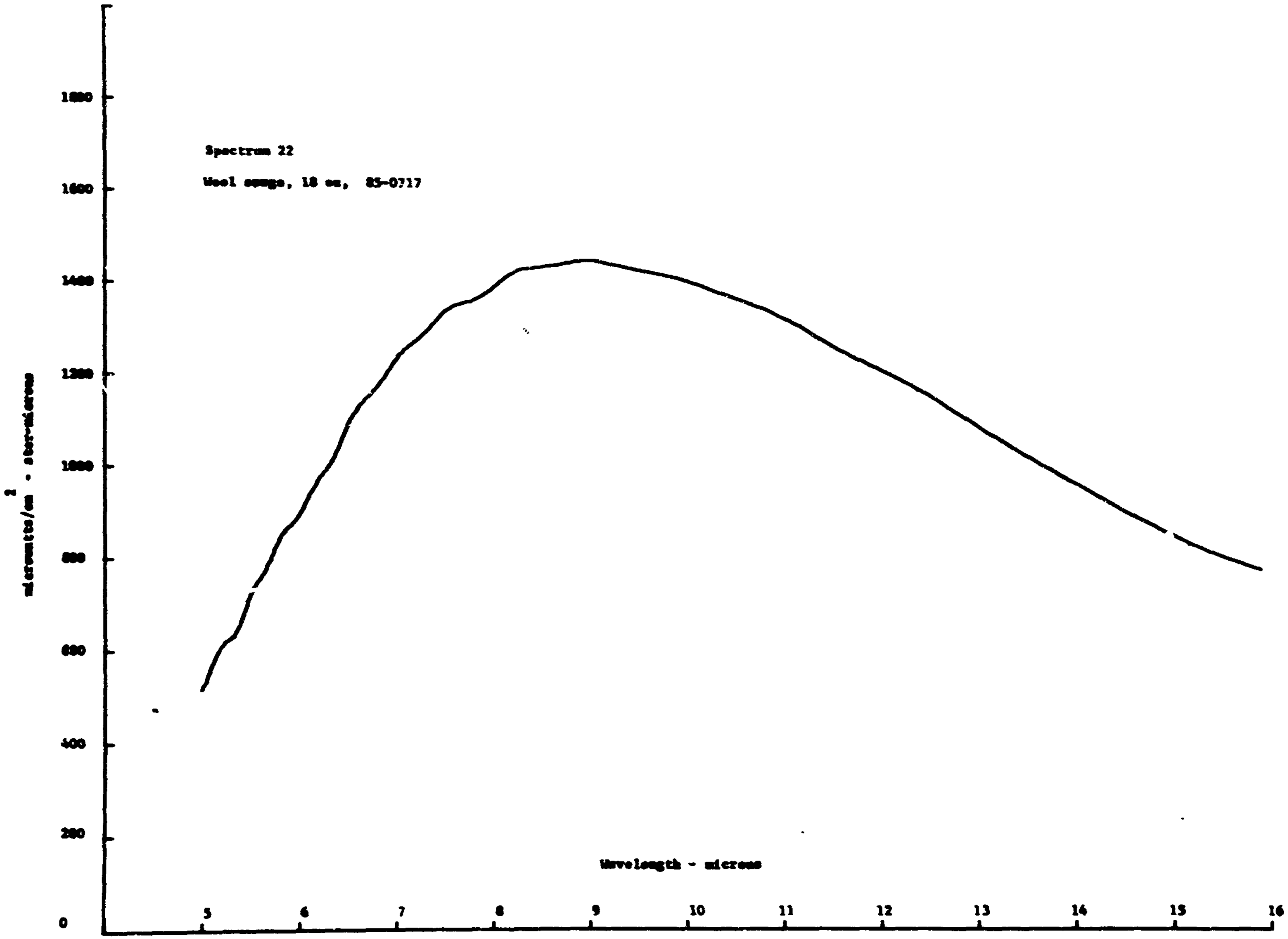
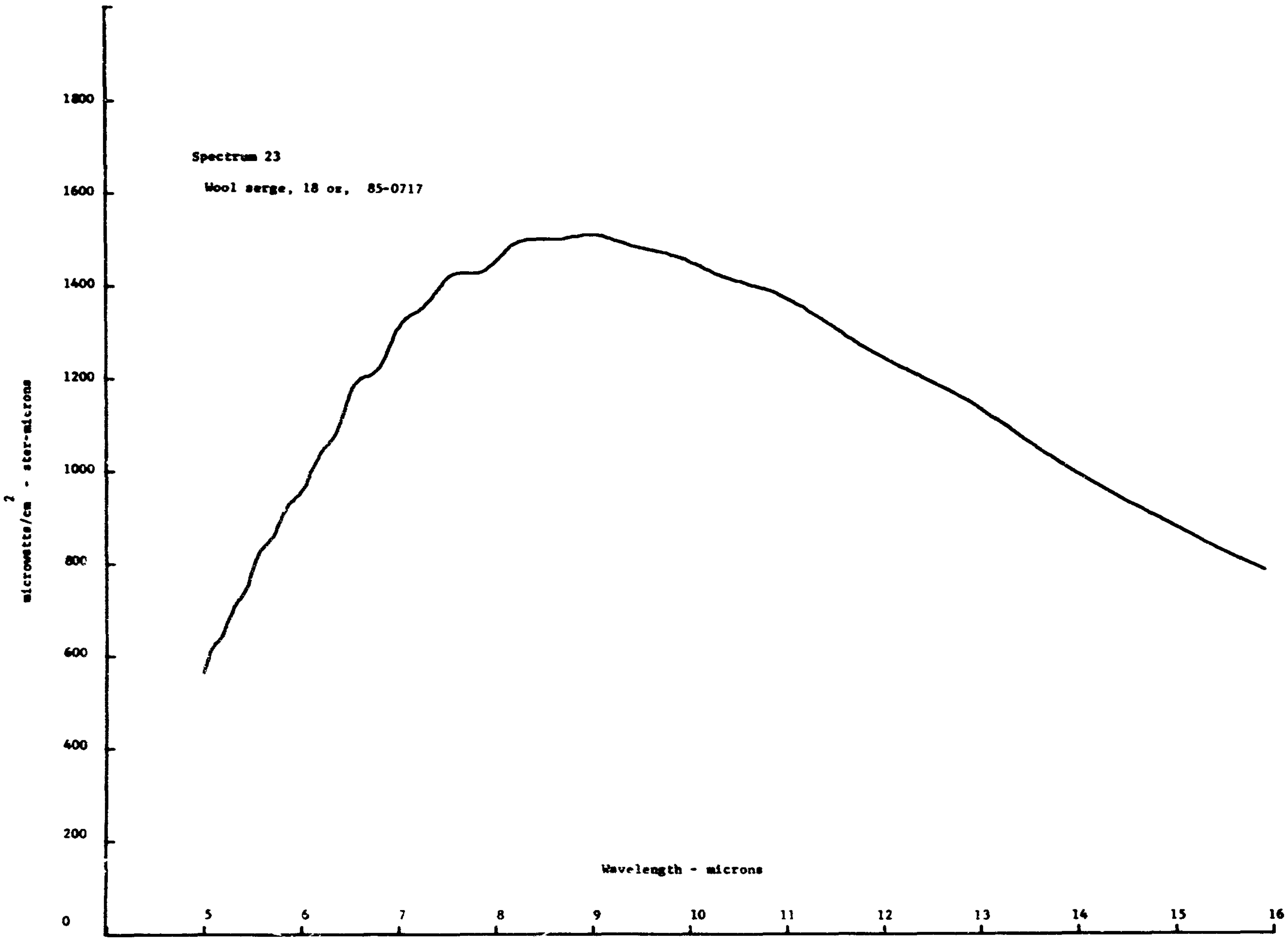
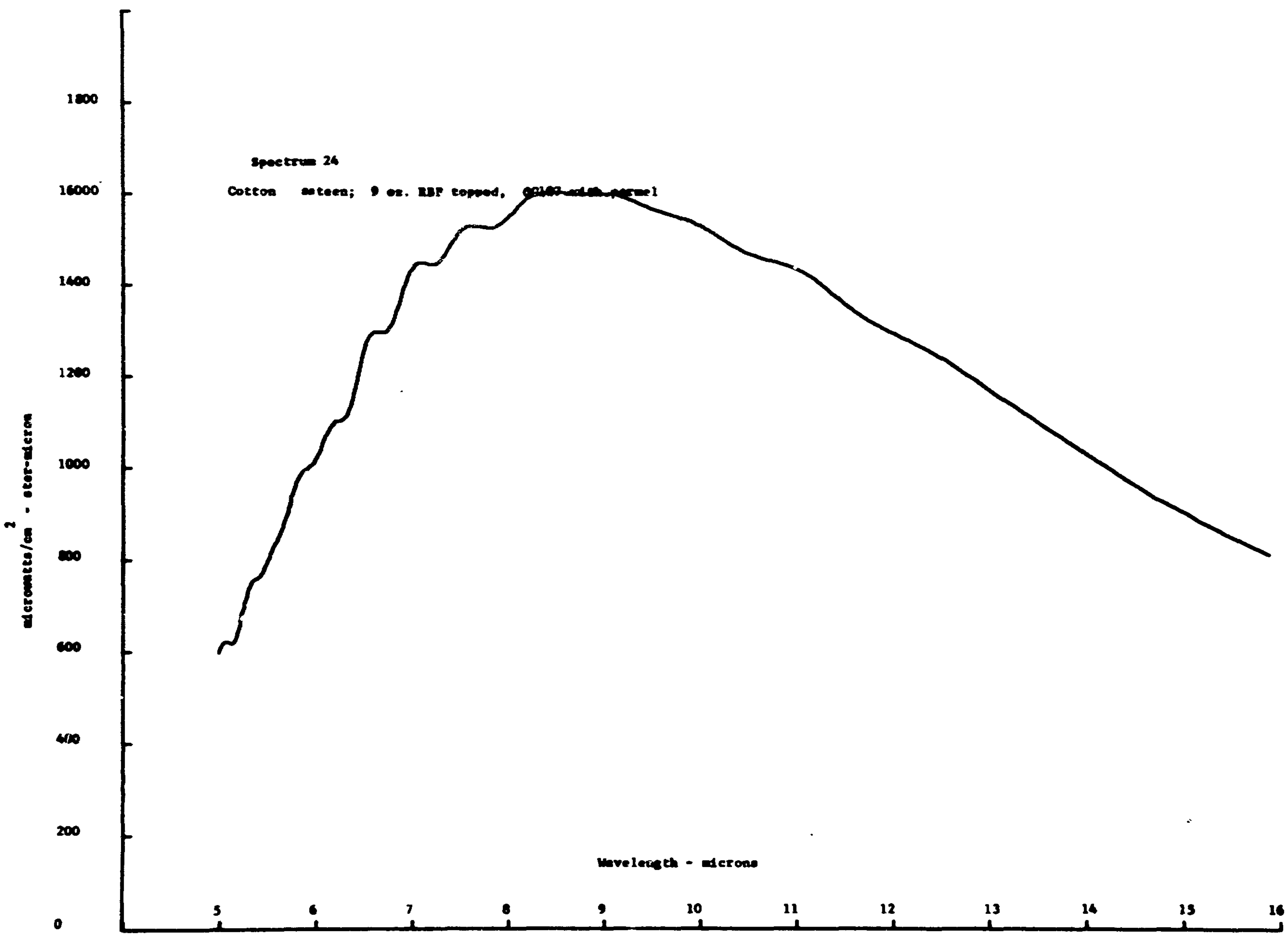
Wool serge, 18 oz, 85-0717
microwatts/cm² - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16

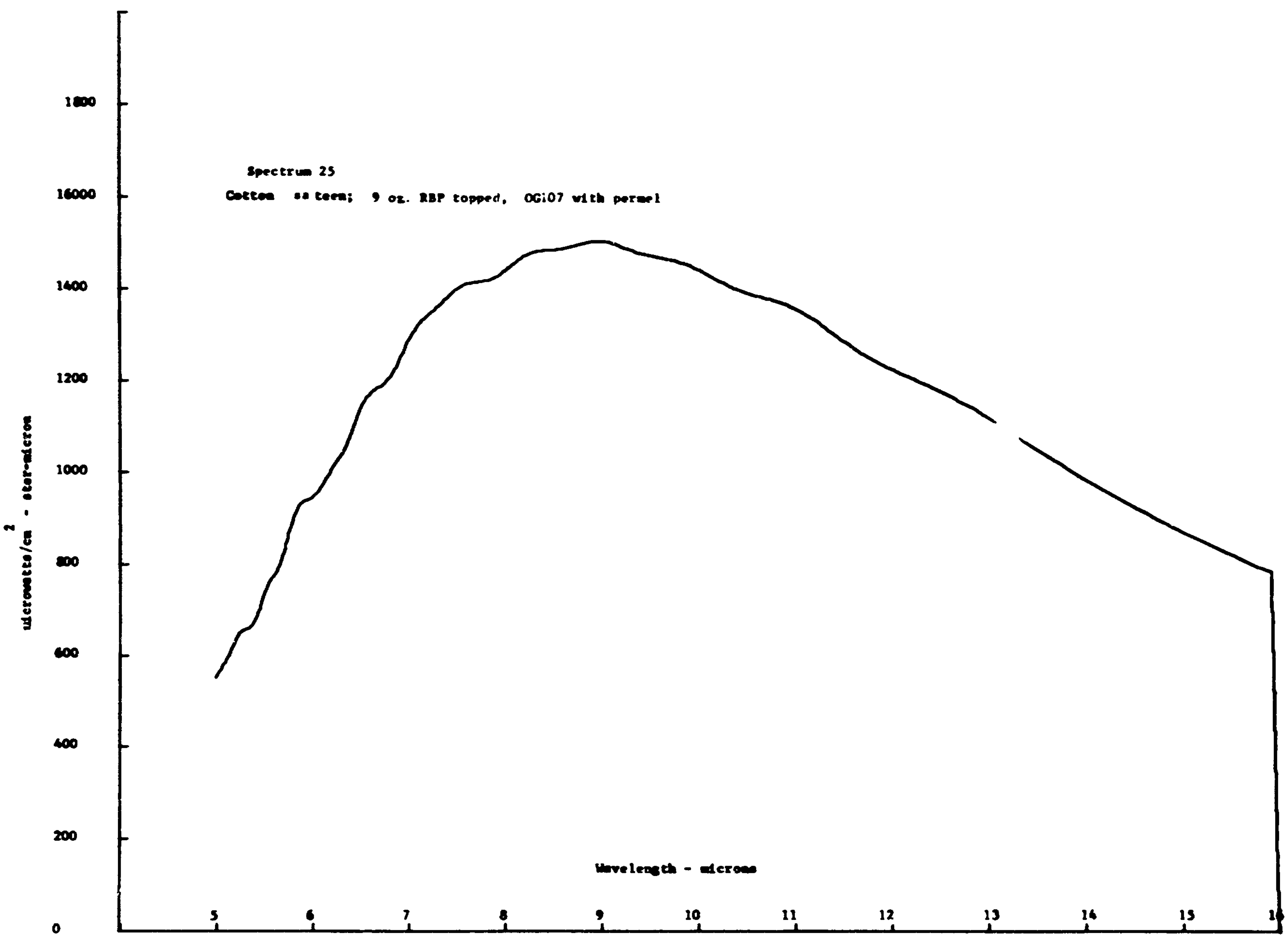

Spectrum 22
Wool sponge, 18 oz, 85-0717
1800
1600
1400
1200
1000
800
600
400
200
0
microwatts/cm² - ster-micron
5
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns

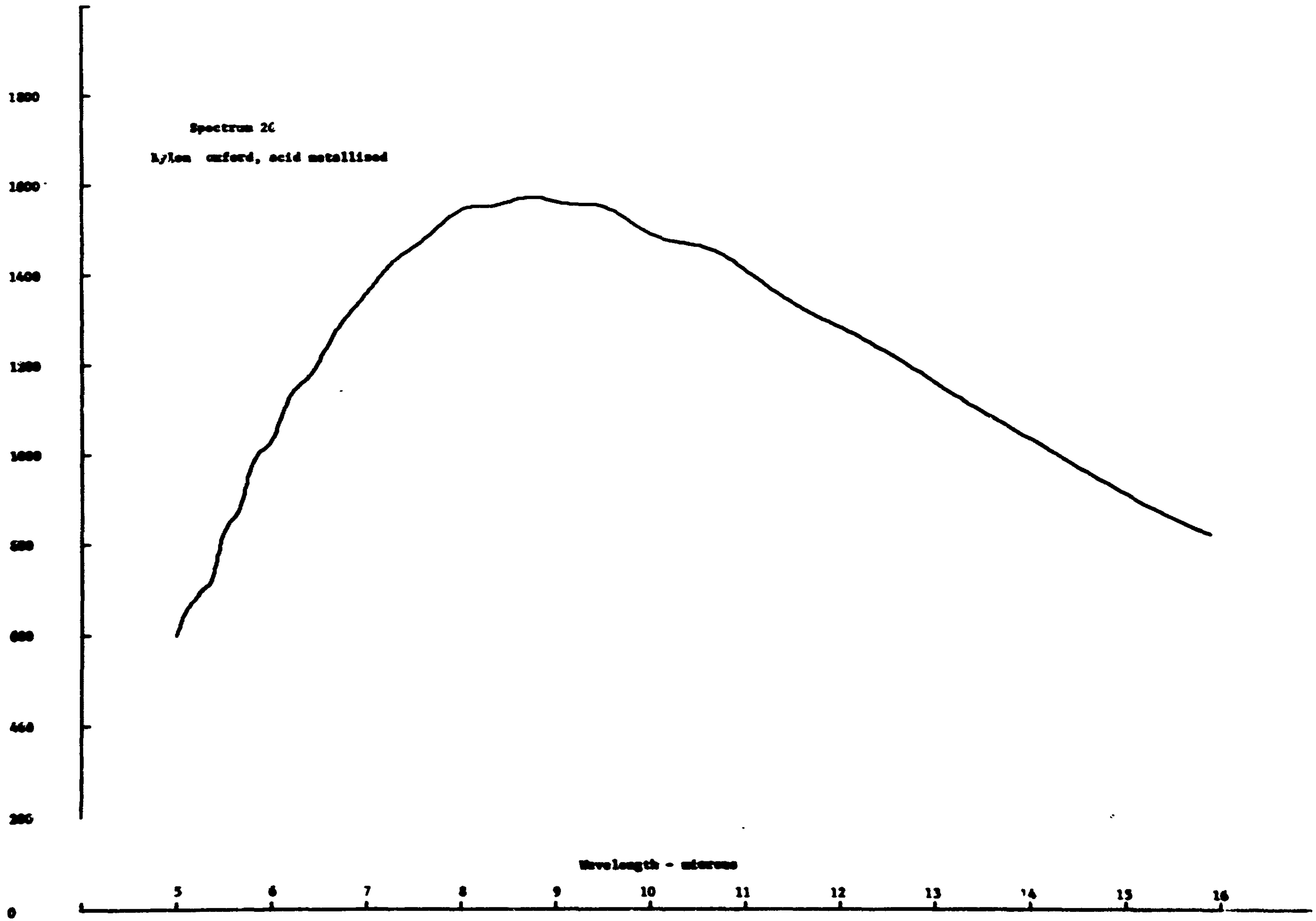


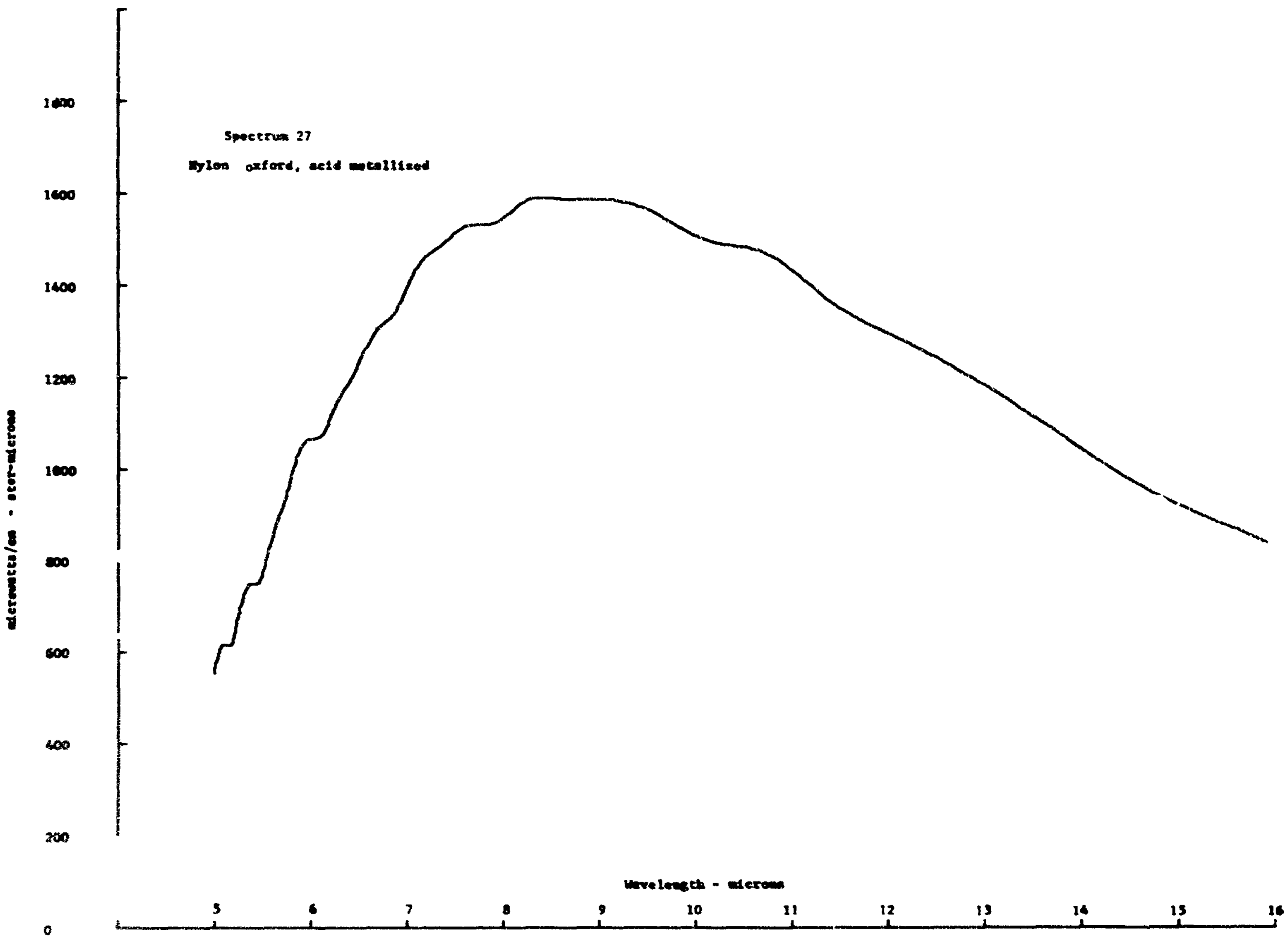
Spectrum 23
Wool serge, 18 oz, 85-0717
1800
1600
1400
1200
1000
800
600
400
200
0
microwatts/cm² - ster-microns
5
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns

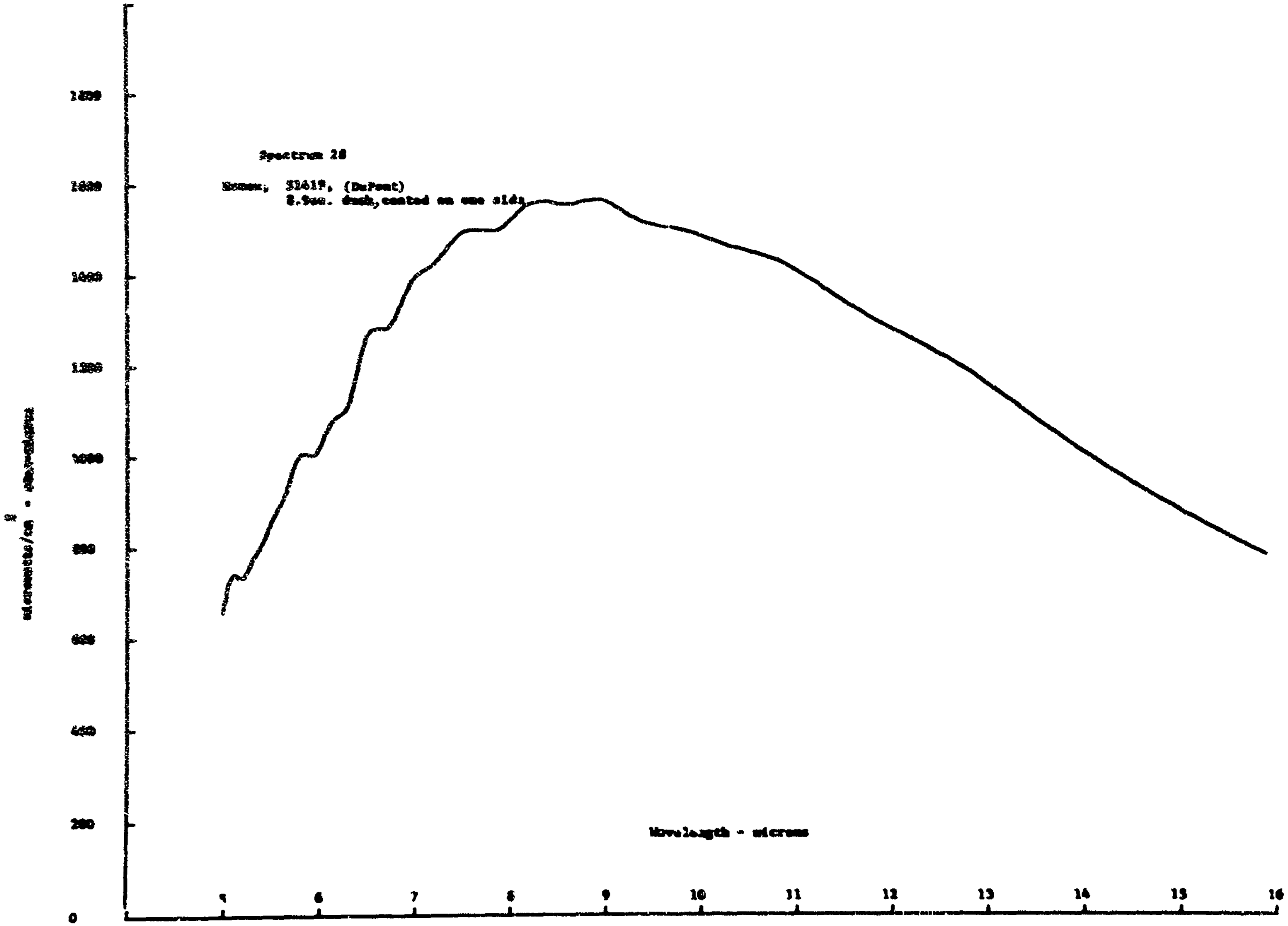


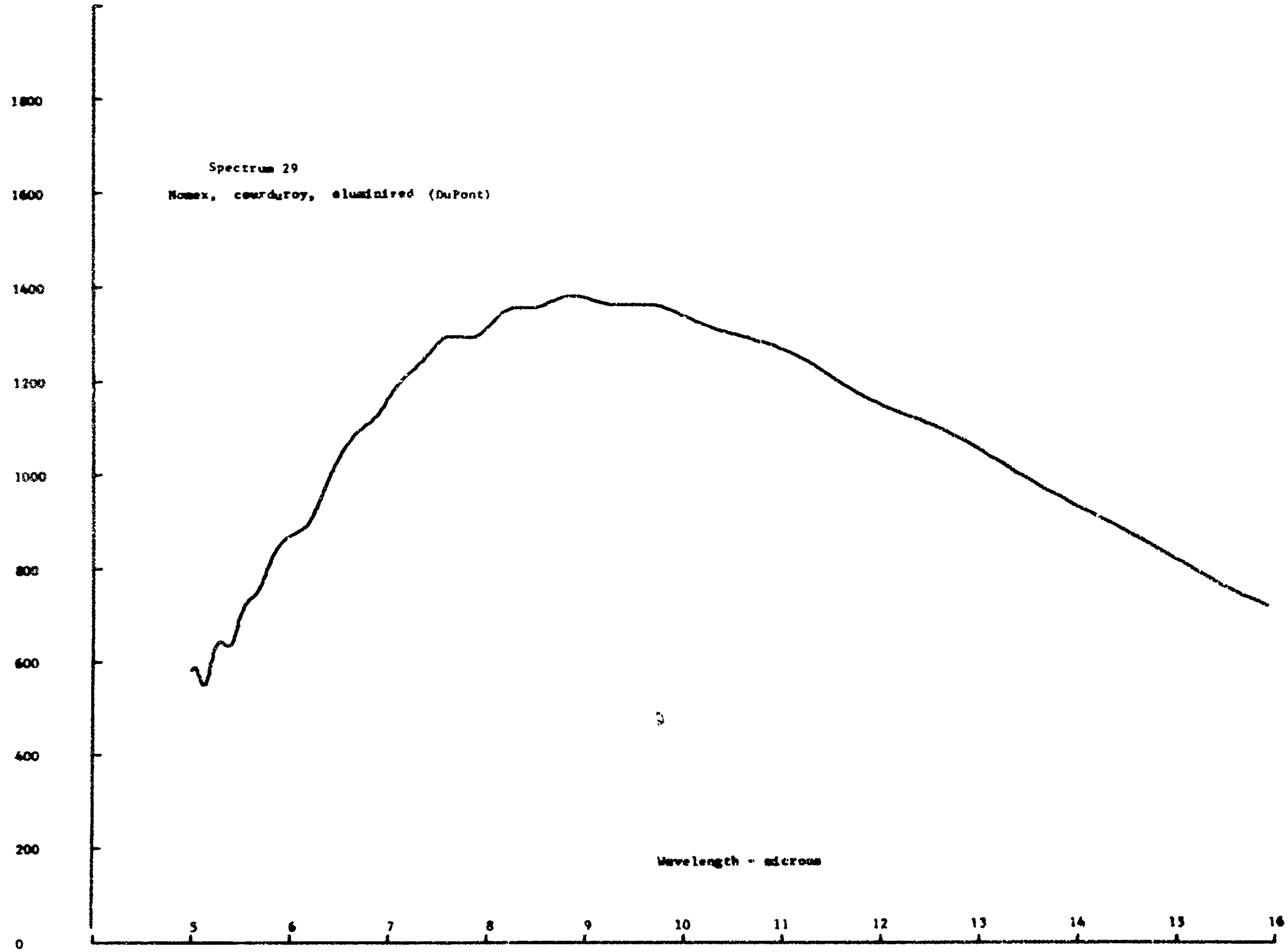
Spectrum 24
Cotton sateen; 9 oz. RBF topped,
1800
16000
1400
1200
1000
800
600
400
200
0
microwatts/cm 2 - ster-micron
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16


Spectrum 25
Cotton sateen; 9 oz. RBP topped, OG107 with permel
microwatts/cm2 - ster-micron
1800
16000
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16


Spectrum 2C
Nylon oxford, acid metallized
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16
1800
1600
1400
1200
1000
800
600
400
200
0

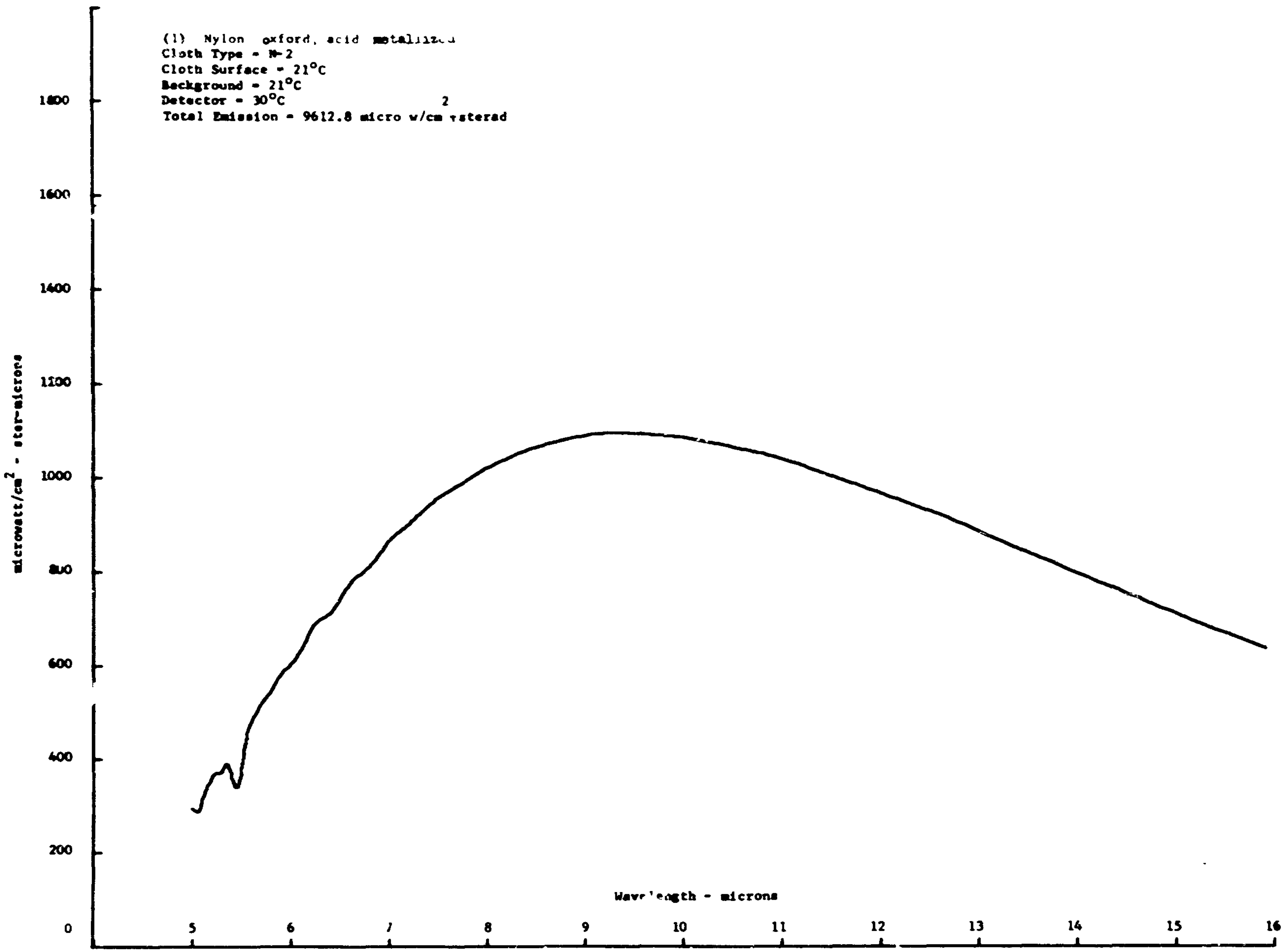

Spectrum 27
Nylon oxford, acid metallized
microwatts/cm² - ster-microns
0
200
400
600
800
1000
1200
1400
1600
1800
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16

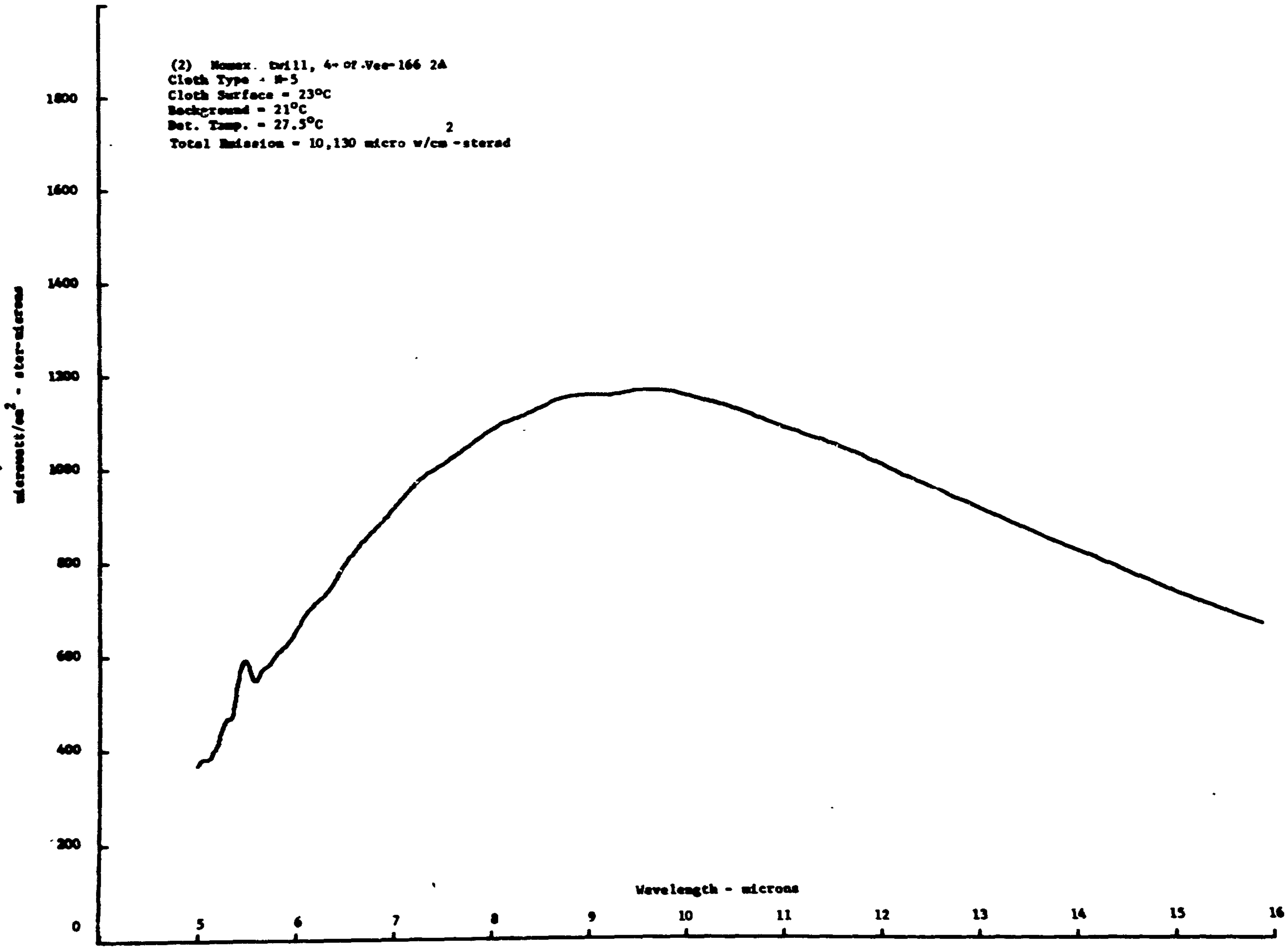

Spectrum 28
(DuPont)
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16
0
200
400
600
800
1000
1200
1400
1600
1800

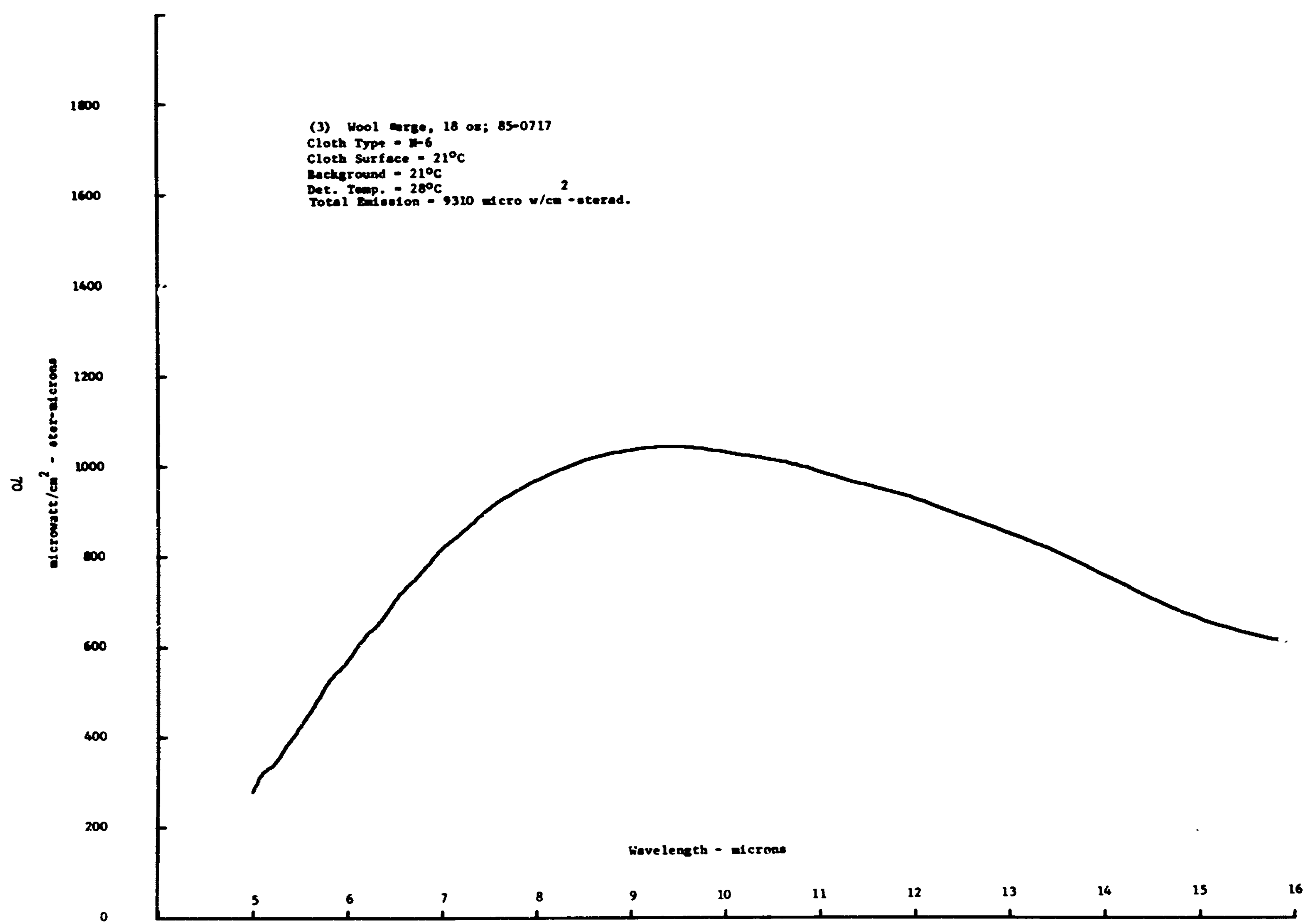


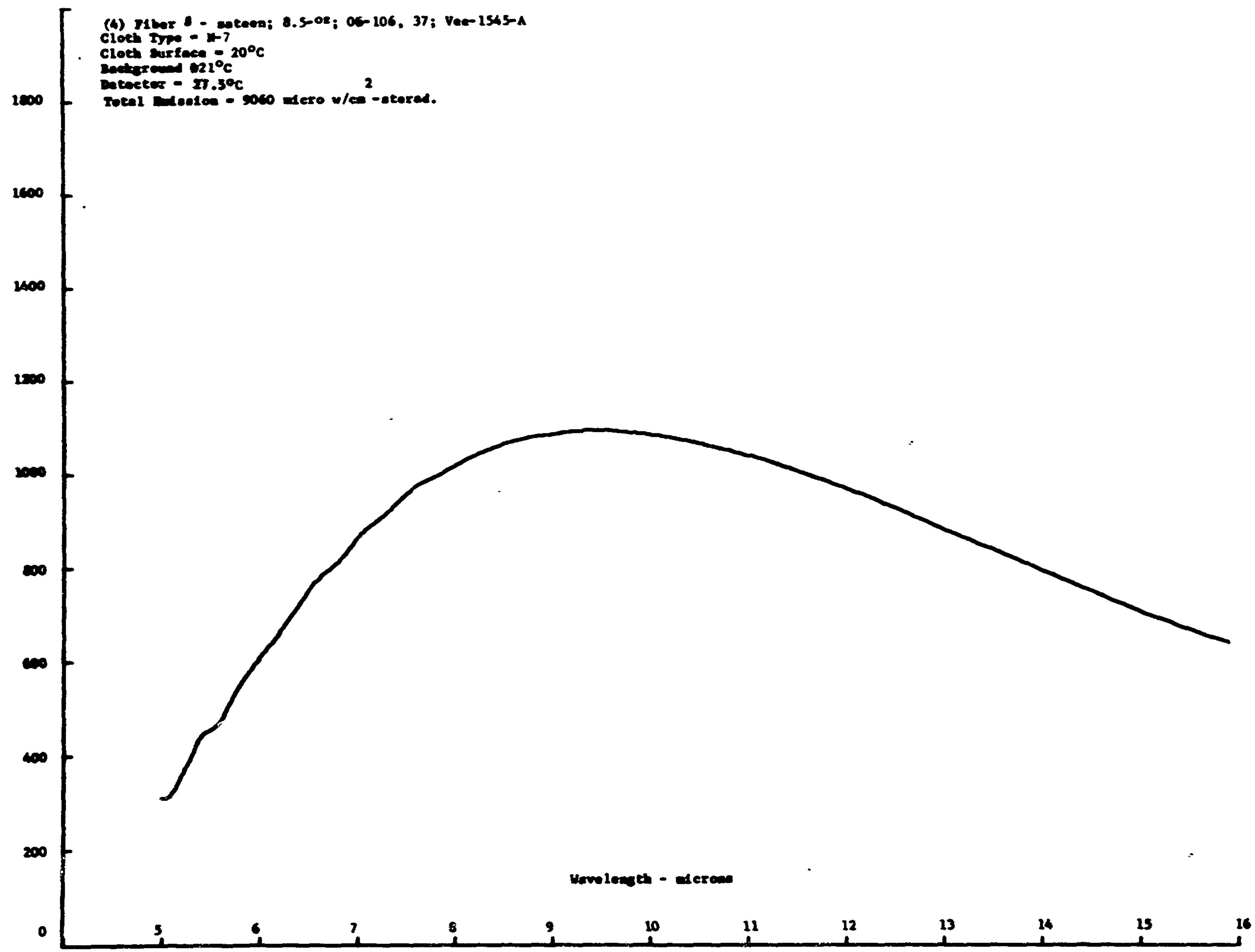
Spectrum 29
Nomex, courduroy, aluminized (DuPont)
1800
1600
1400
1200
1000
800
600
400
200
0
microwatts/cm2 - ster-micro
5
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns

GROUP II SPECTRA

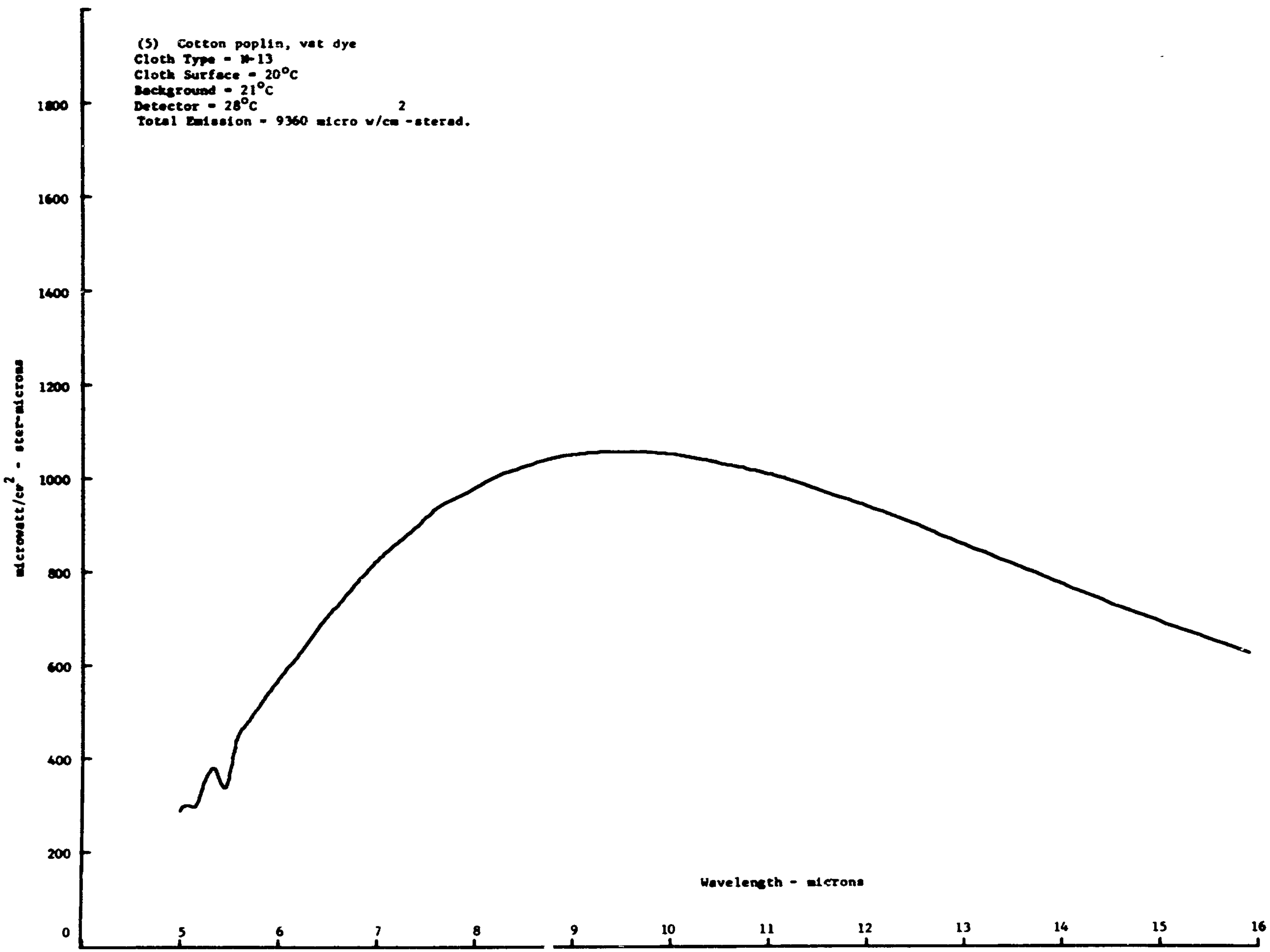

(1) Nylon oxford, acid metalized
Cloth Type - M-2
Cloth Surface - 21°C
Background - 21°C
Detector - 30°C
Total Emission - 9612.8 micro w/cm2 vsterad
1800
1600
1400
1200
1000
800
600
400
200
0
microwatt/cm2 - ster-microns
5
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns


(2) Nomex. twill, 4-oz.Vee-166 2A
Cloth Type - N-5
Cloth Surface = 23°C
Background = 21°C
Det. Temp. = 27.5°C
Total Emission = 10,130 micro w/cm² -sterad
microwatt/cm² - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16

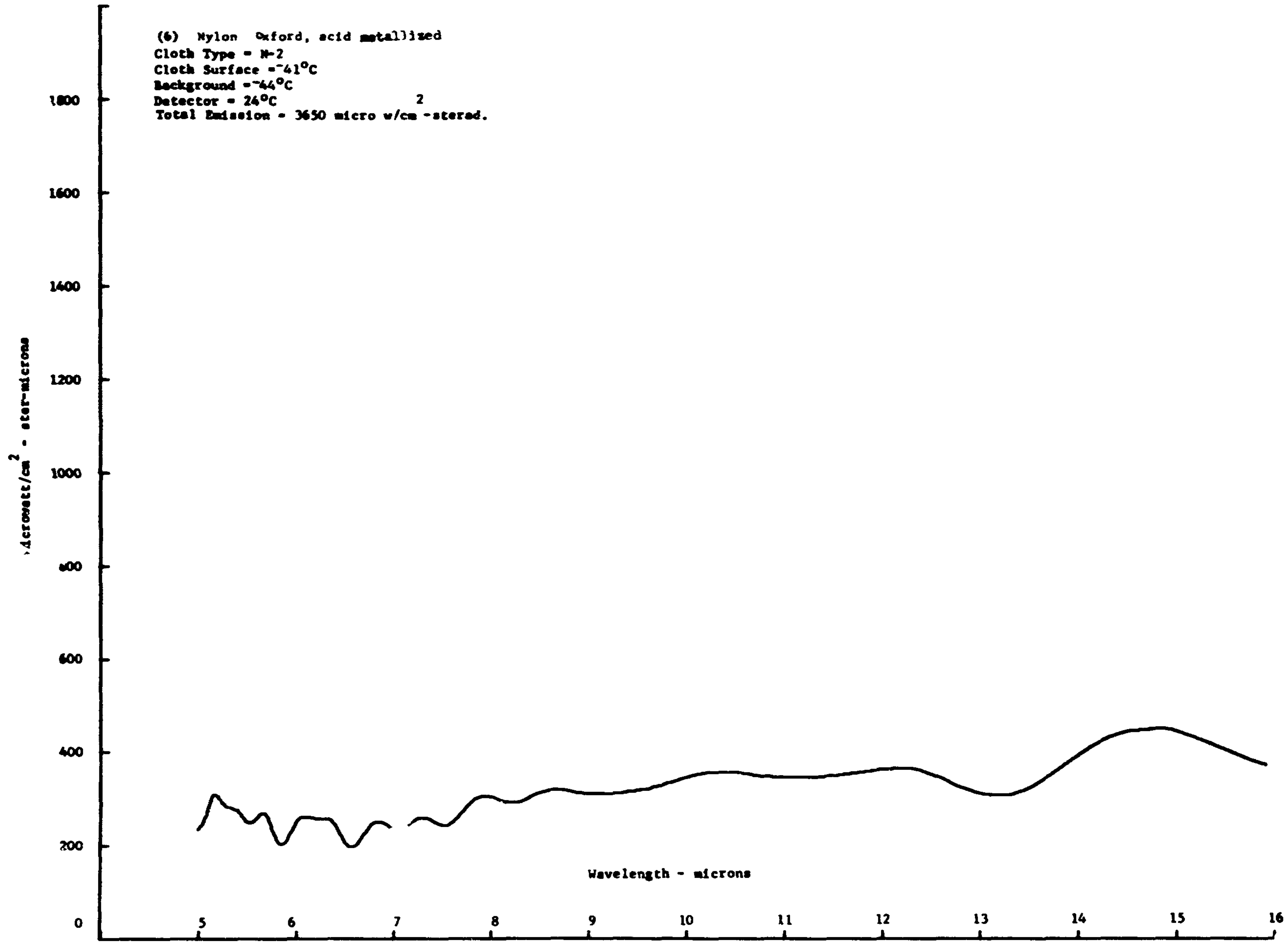

(3) Wool Serge, 18 oz; 85-0717
Cloth Type = N-6
Cloth Surface = 21°C
Background = 21°C
Det. Temp. = 28°C
Total Emission = 9310 micro w/cm² -sterad.
microwatt/cm² - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16

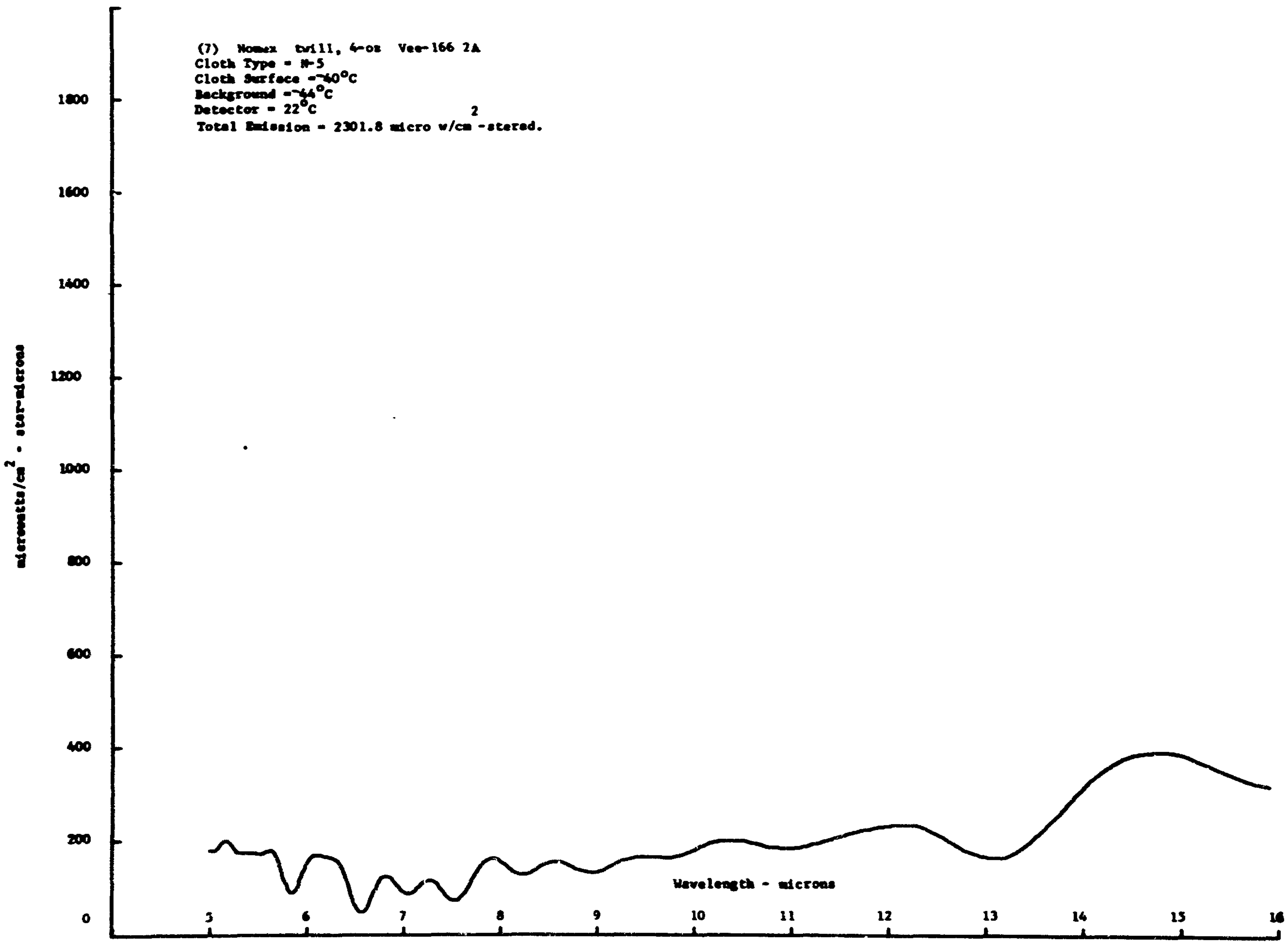


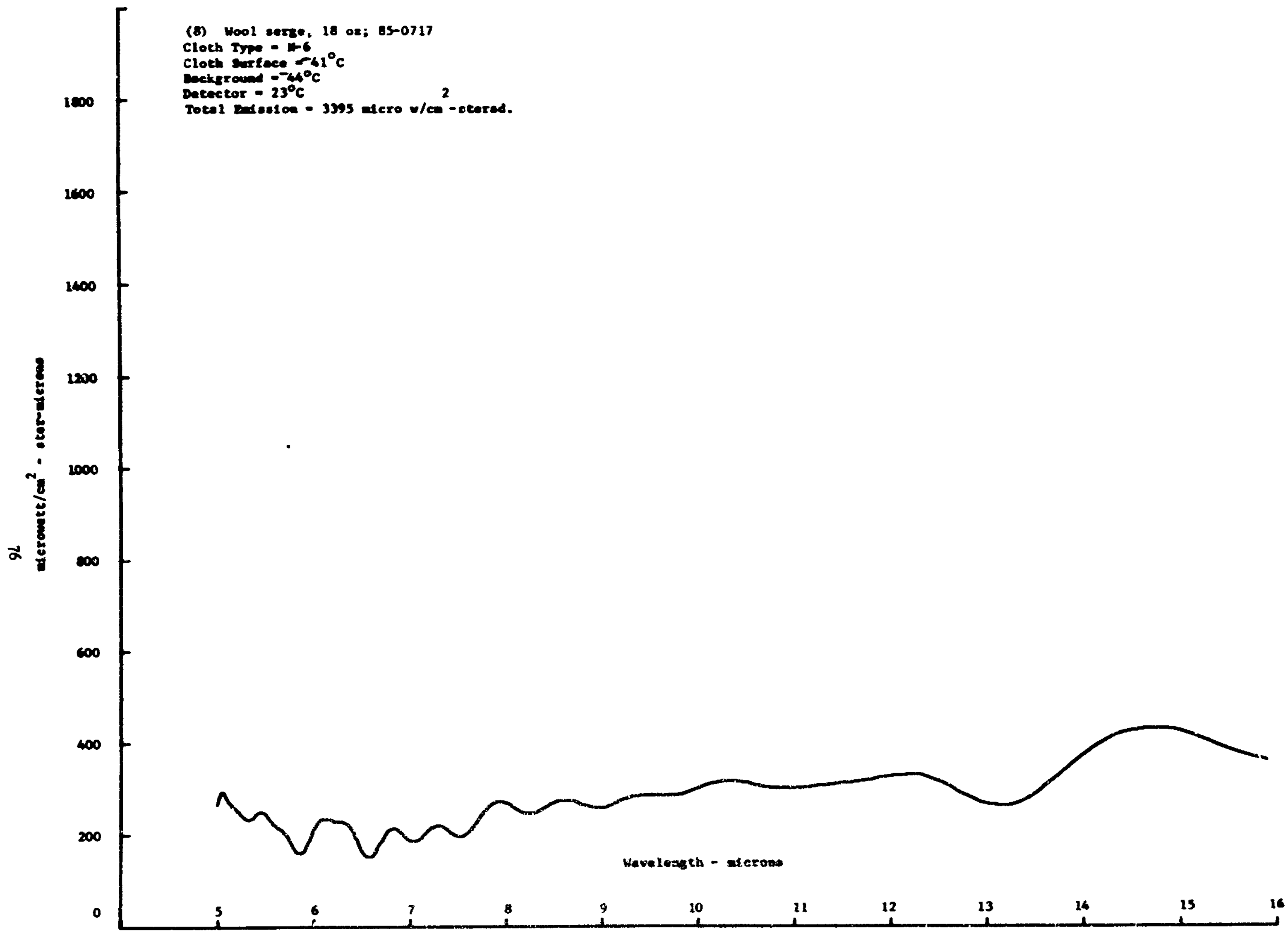
(4) Fiber 8 - sateen; 8.5-oz; 06-106, 37; Vee-1545-A
Cloth Type - N-7
Cloth Surface = 20°C
Background 821°C
Detector - 27.5°C
Total Emission = 9060 micro w/cm² -sterad.
microwatt/cm² - ster-micron
Wavelength - microns
1800
1600
1400
1200
1000
800
600
400
200
0
5
6
7
8
9
10
11
12
13
14
15
16

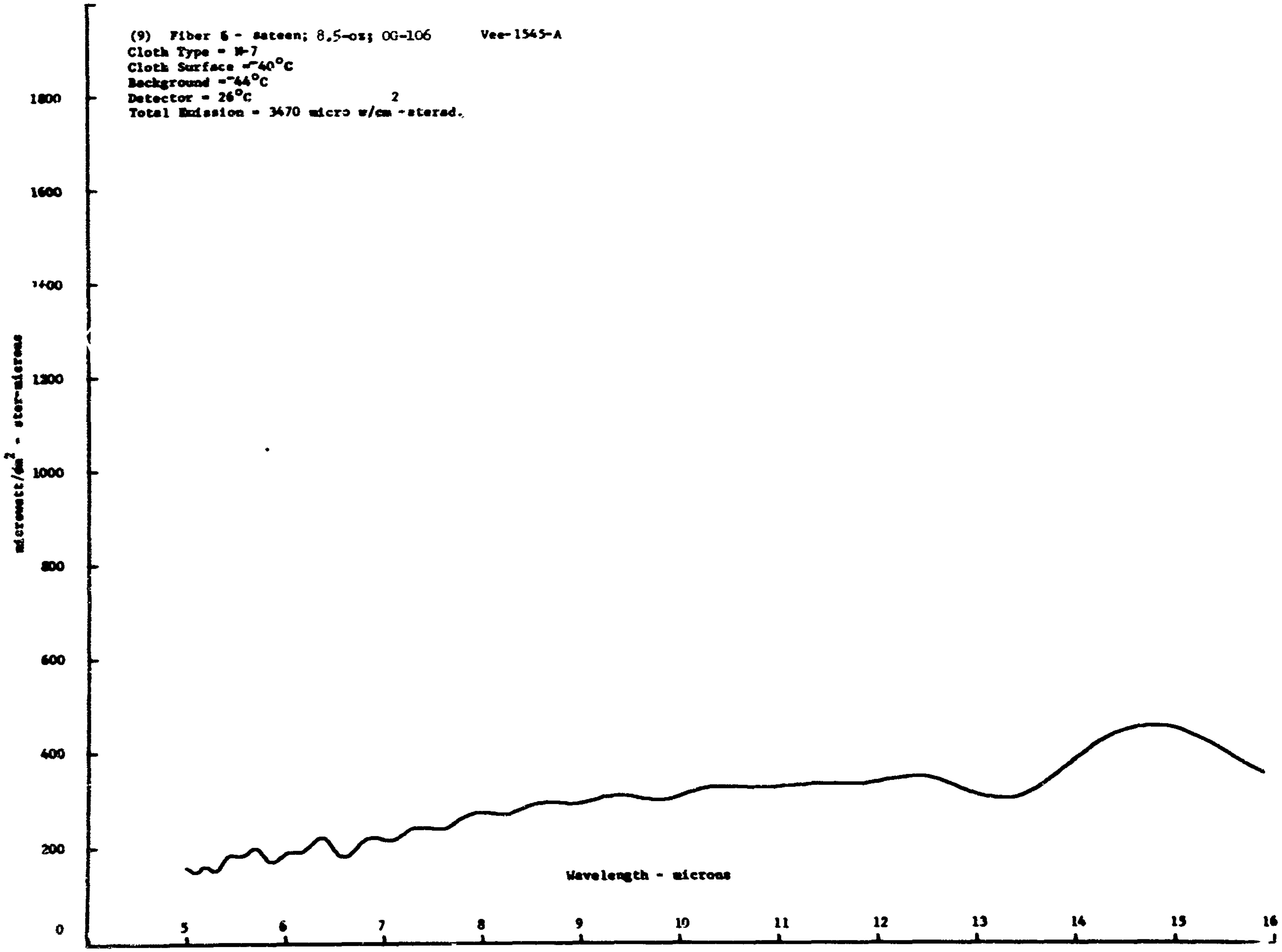

(5) Cotton poplin, vat dye
Cloth Type - N-13
Cloth Surface - 20°C
Background - 21°C
Detector - 28°C
Total Emission - 9360 micro w/cm² -sterad.
microwatt/cm² - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16

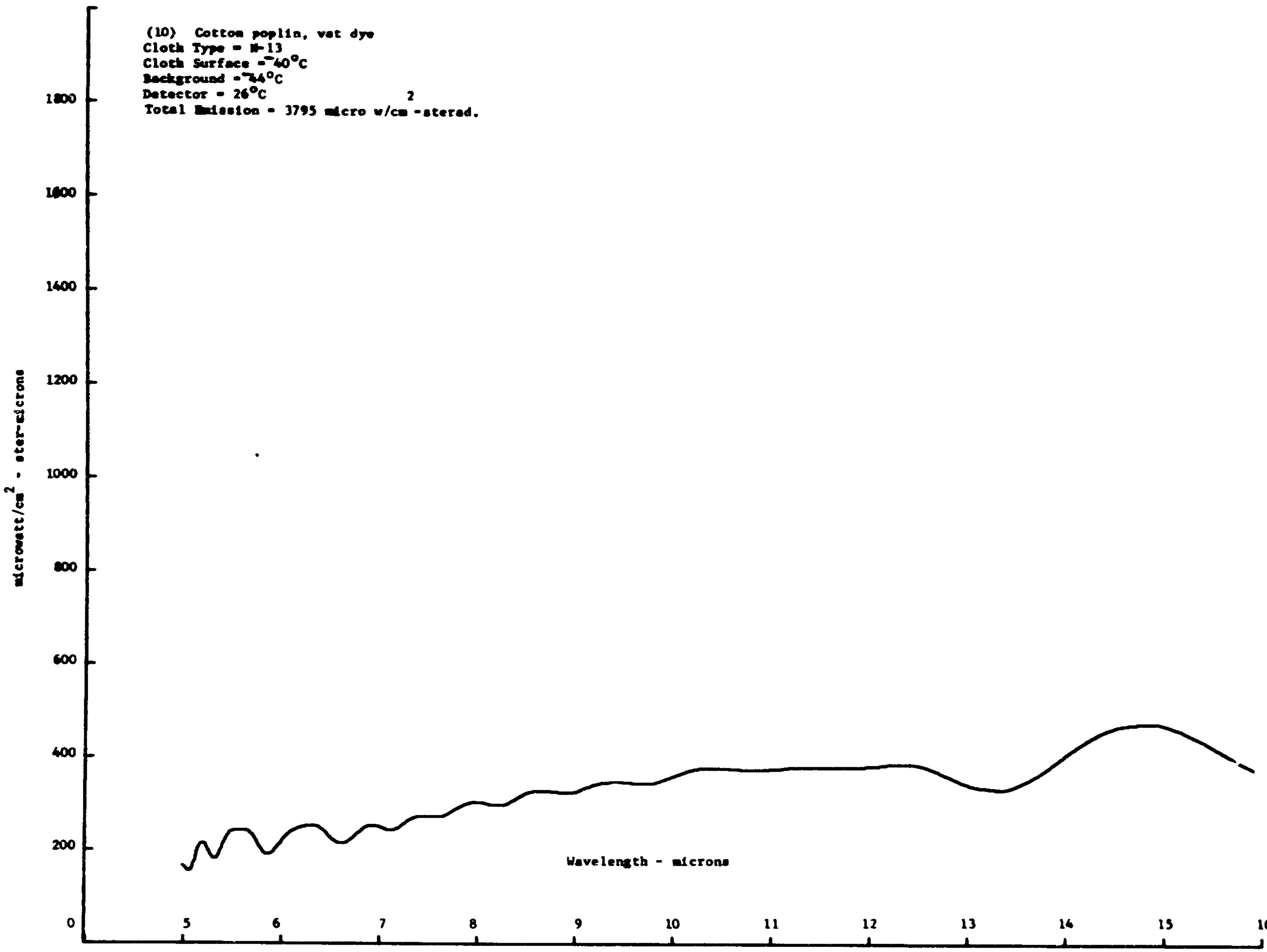
GROUP III SPECTRA


(6) Nylon Oxford, acid metallized
Cloth Type = N-2
Cloth Surface = -41°C
Background = -44°C
Detector = 24°C
Total Emission = 3650 micro w/cm² -sterad.
1800
1600
1400
1200
1000
800
600
400
200
0
Microwatt/cm² - ster-microns
5
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns

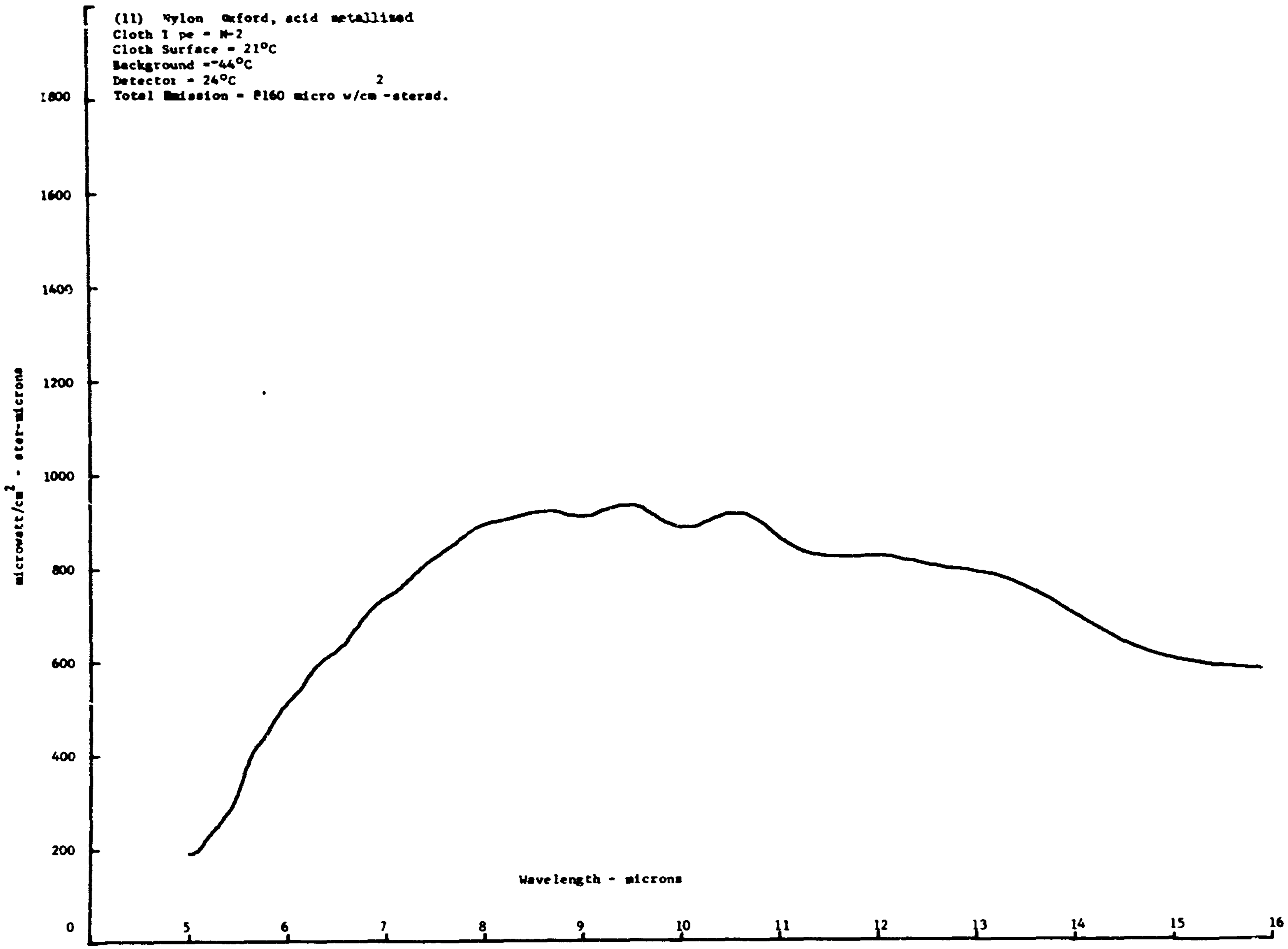

(7) Nomex twill, 4-oz Vee-166 2A
Cloth Type = N-5
Cloth Surface = -40°C
Background = -64°C
Detector = 22°C
Total Emission = 2301.8 micro w/cm²-stered.
microwatts/cm² - ster-microns
Wavelength - microns
1800
1600
1400
1200
1000
800
600
400
200
0
5
6
7
8
9
10
11
12
13
14
15
16

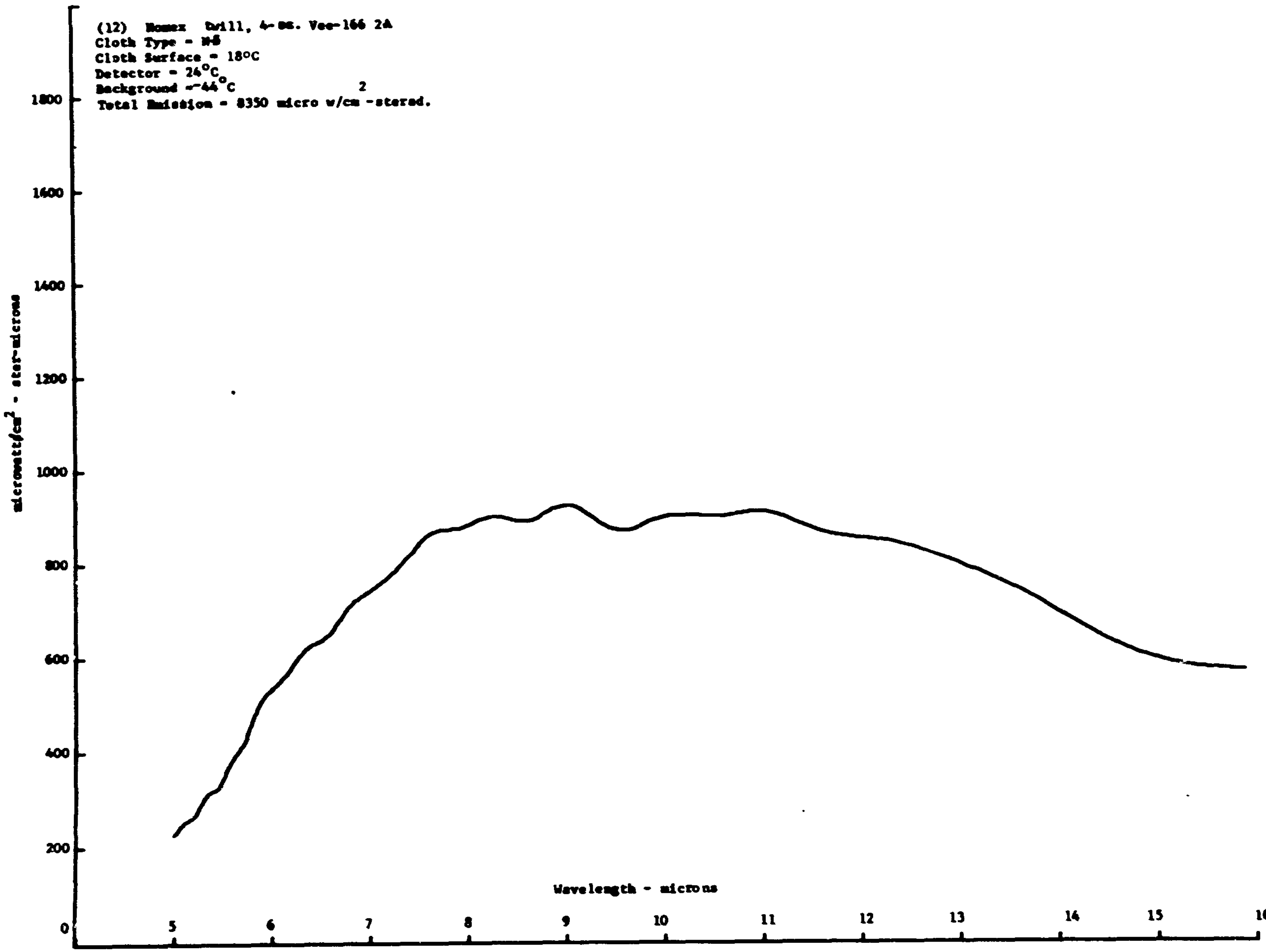

(8) Wool serge, 18 oz; 85-0717
Cloth Type = N-6
Cloth Surface = -41°C
Background = -44°C
Detector = 23°C
Total Emission = 3395 micro w/cm2-sterad.
microwatt/cm2 - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
5
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns

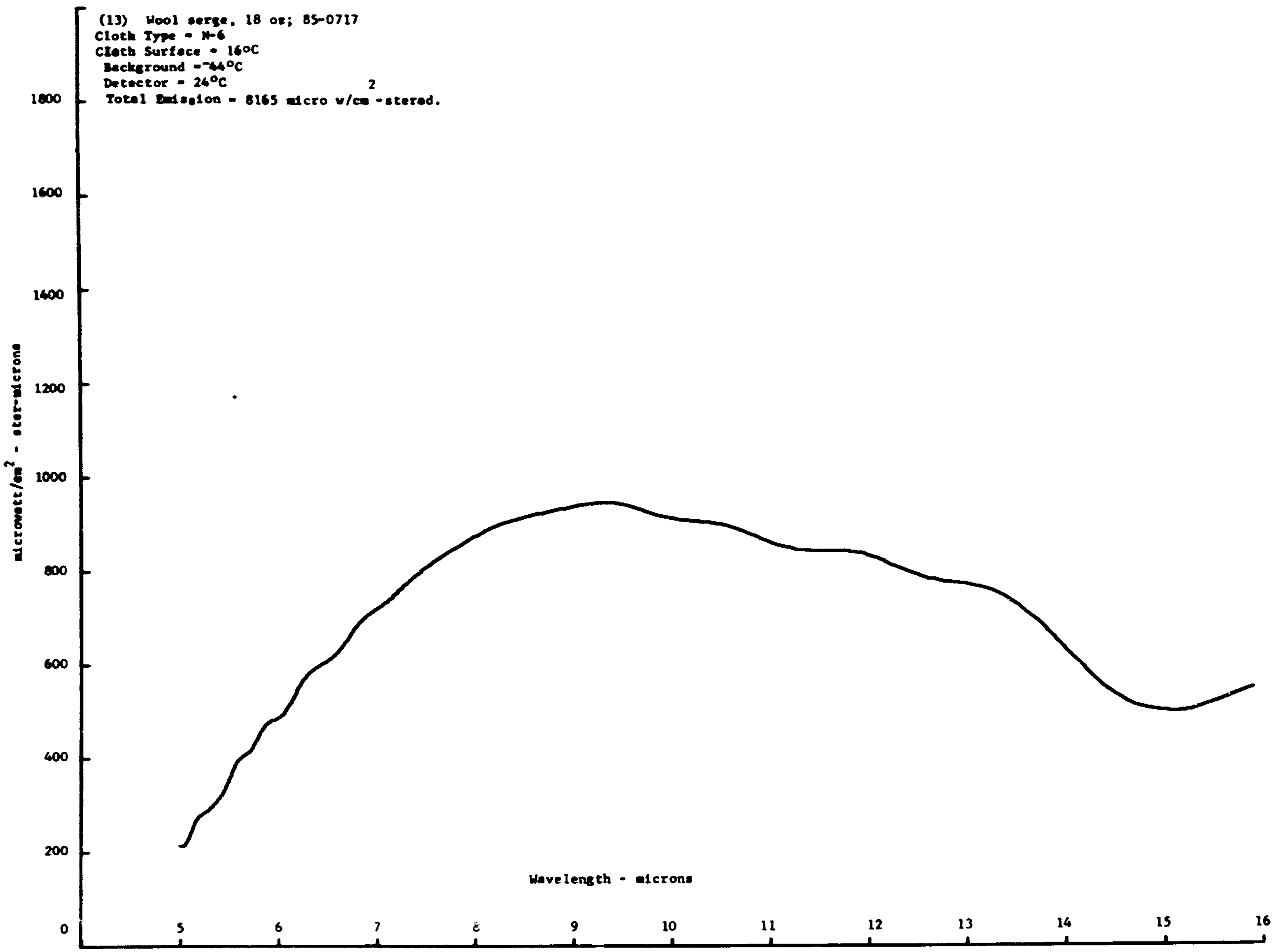

(9) Fiber 6 - sateen; 8.5-oz; OG-106
Vee-1545-A
Cloth Type = N-7
Cloth Surface = -40°C
Background = -44°C
Detector = 26°C
Total Emission = 3470 micro w/cm² -sterad.
microwatt/cm² - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16

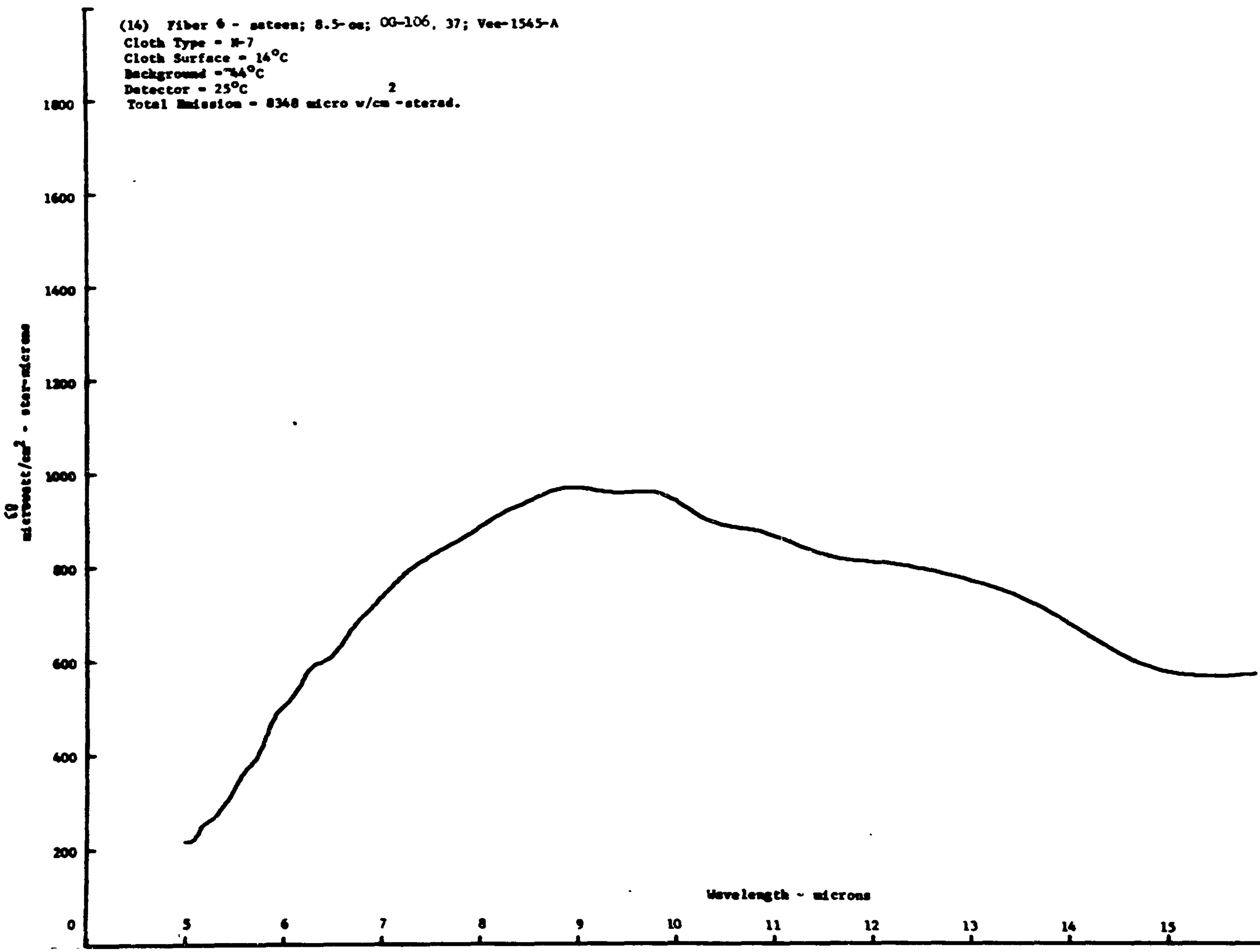

(10) Cotton poplin, vat dye
Cloth Type = N-13
Cloth Surface = −40°C
Background = −44°C
Detector = 26°C
Total Emission = 3795 micro w/cm² -sterad.
1800
1600
1400
1200
1000
800
600
400
200
0
microwatt/cm² - ster-microns
5
6
7
8
9
10
11
12
13
14
15
16
Wavelength - microns

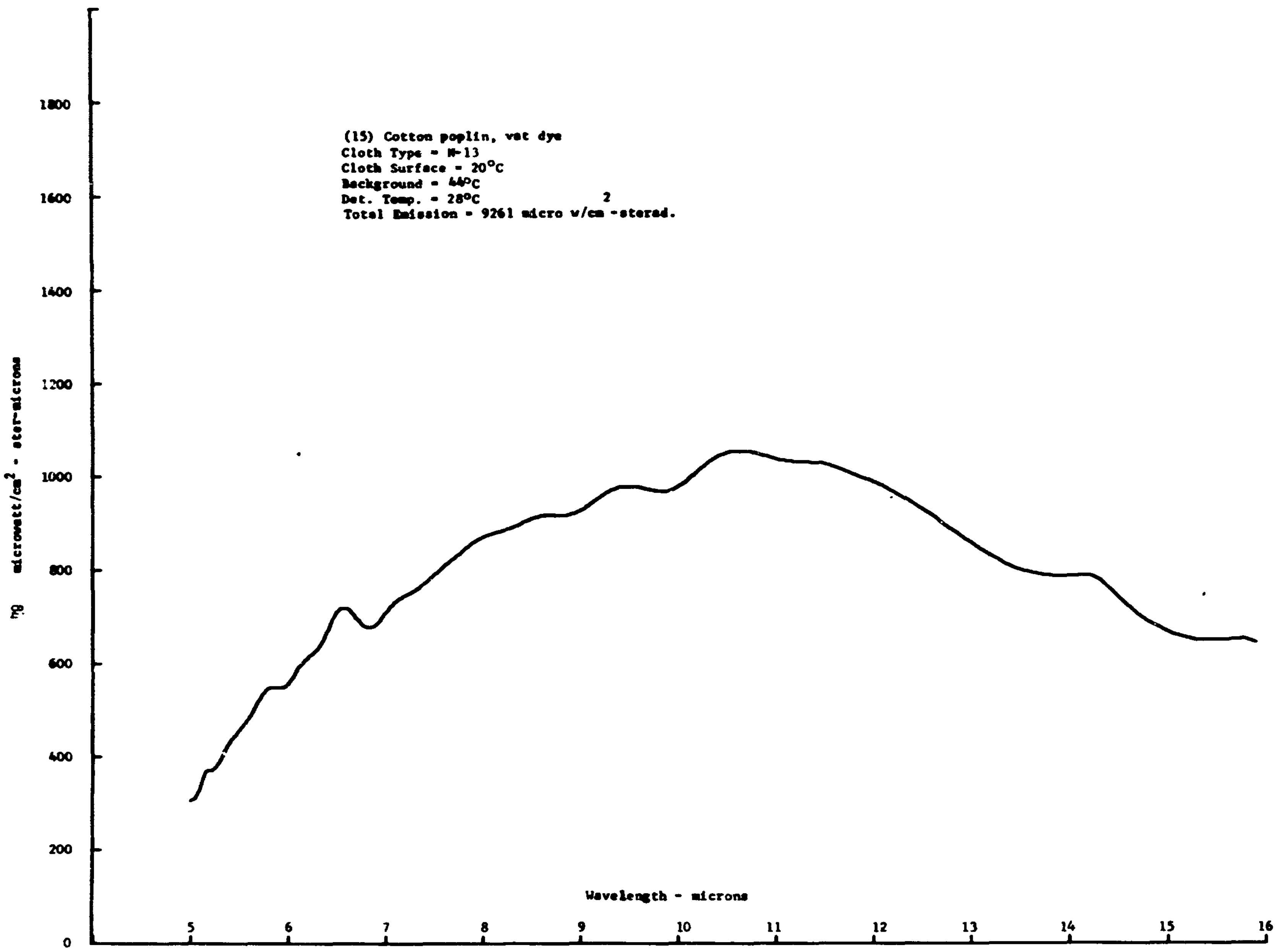
GROUP IV SPECTRA


(11) Nylon Oxford, acid metallized
Cloth Type - N-2
Cloth Surface - 21°C
Background = -44°C
Detector - 24°C
Total Emission - 8160 micro w/cm² -sterad.
microwatt/cm² - ster-microns
Wavelength - microns
0
200
400
600
800
1000
1200
1400
1600
1800
5
6
7
8
9
10
11
12
13
14
15
16

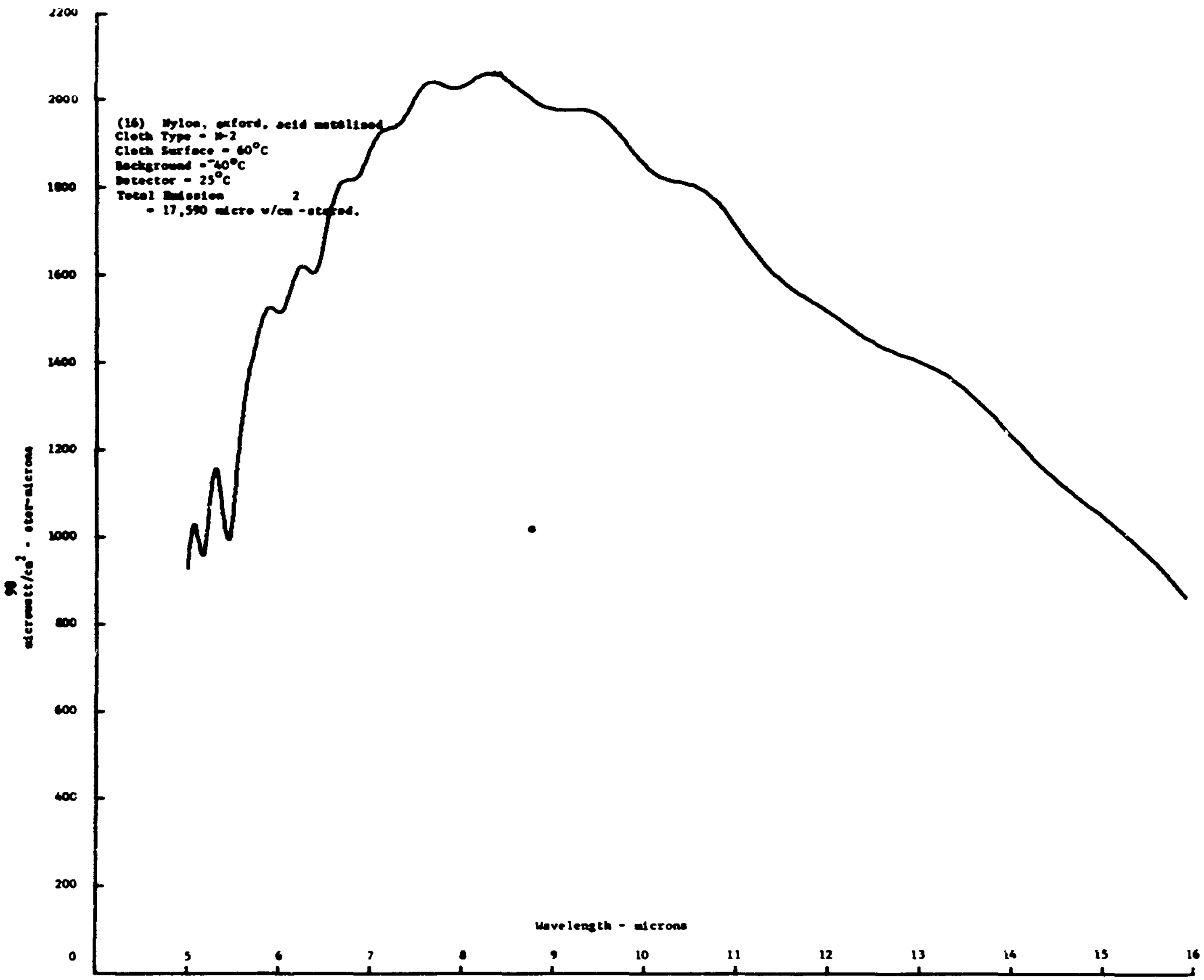

(12) Nomex Twill, 4-oz. Vee-166 2A
Cloth Type -
Cloth Surface - 18°C
Detector - 24°C
Background -44°C
Total Emission - 8350 micro w/cm2-sterad.
microwatt/cm2 - ster-microns
Wavelength - microns
0
200
400
600
800
1000
1200
1400
1600
1800
5
6
7
8
9
10
11
12
13
14
15
16


(13) Wool serge, 18 oz; 85-0717
Cloth Type - N-6
Cloth Surface - 16°C
Background - ~44°C
Detector - 24°C
Total Emission - 8165 micro w/cm2-sterad.
microwatt/cm2 - ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16

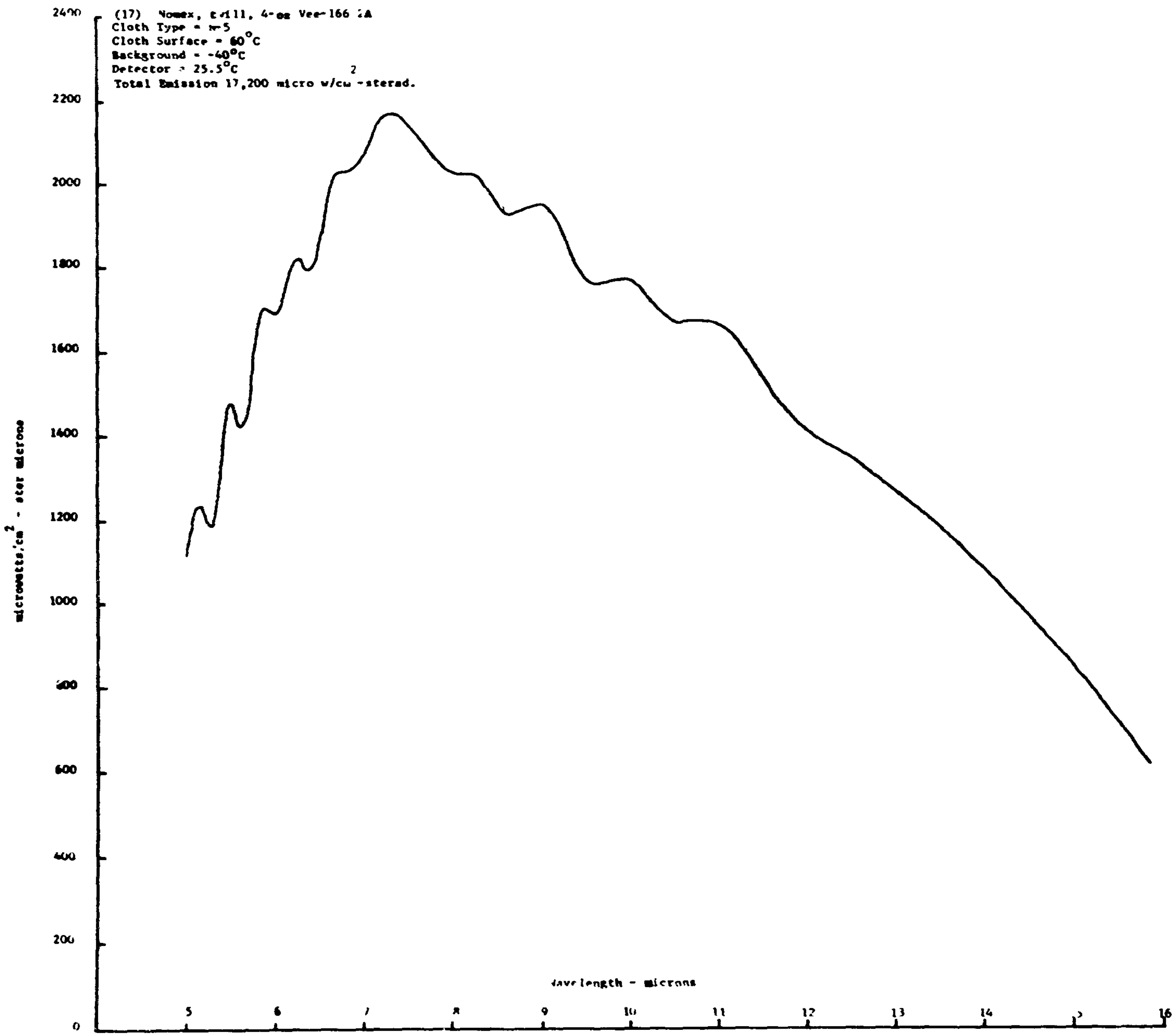

(14) Fiber 6 - sateen; 8.5-oz; OG-106, 37; Vee-1545-A
Cloth Type = N-7
Cloth Surface = 14°C
Background =~14°C
Detector = 25°C
Total Emission = 8348 micro w/cm²-sterad.
microwatt/cm² - ster-microns
Wavelength ~ microns
1800
1600
1400
1200
1000
800
600
400
200
0
5
6
7
8
9
10
11
12
13
14
15
16


(15) Cotton poplin, vat dye
Cloth Type = N-13
Cloth Surface = 20°C
Background = 44°C
Det. Temp. = 28°C
Total Emission = 9261 micro w/cm2-sterad.
microwatt/cm2 - ster-microns
Wavelength - microns
0
200
400
600
800
1000
1200
1400
1600
1800
5
6
7
8
9
10
11
12
13
14
15
16

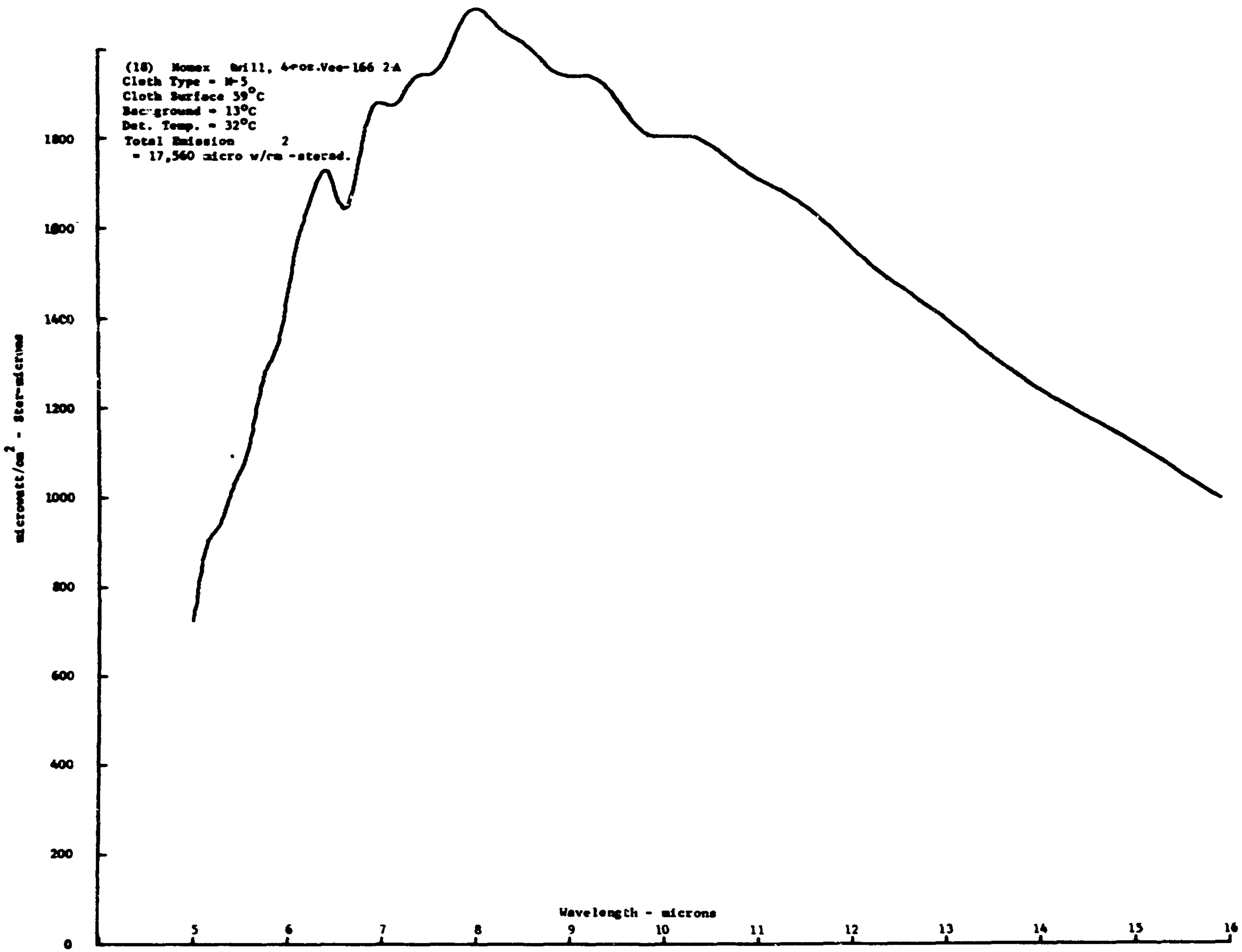
GROUP V SPECTRA

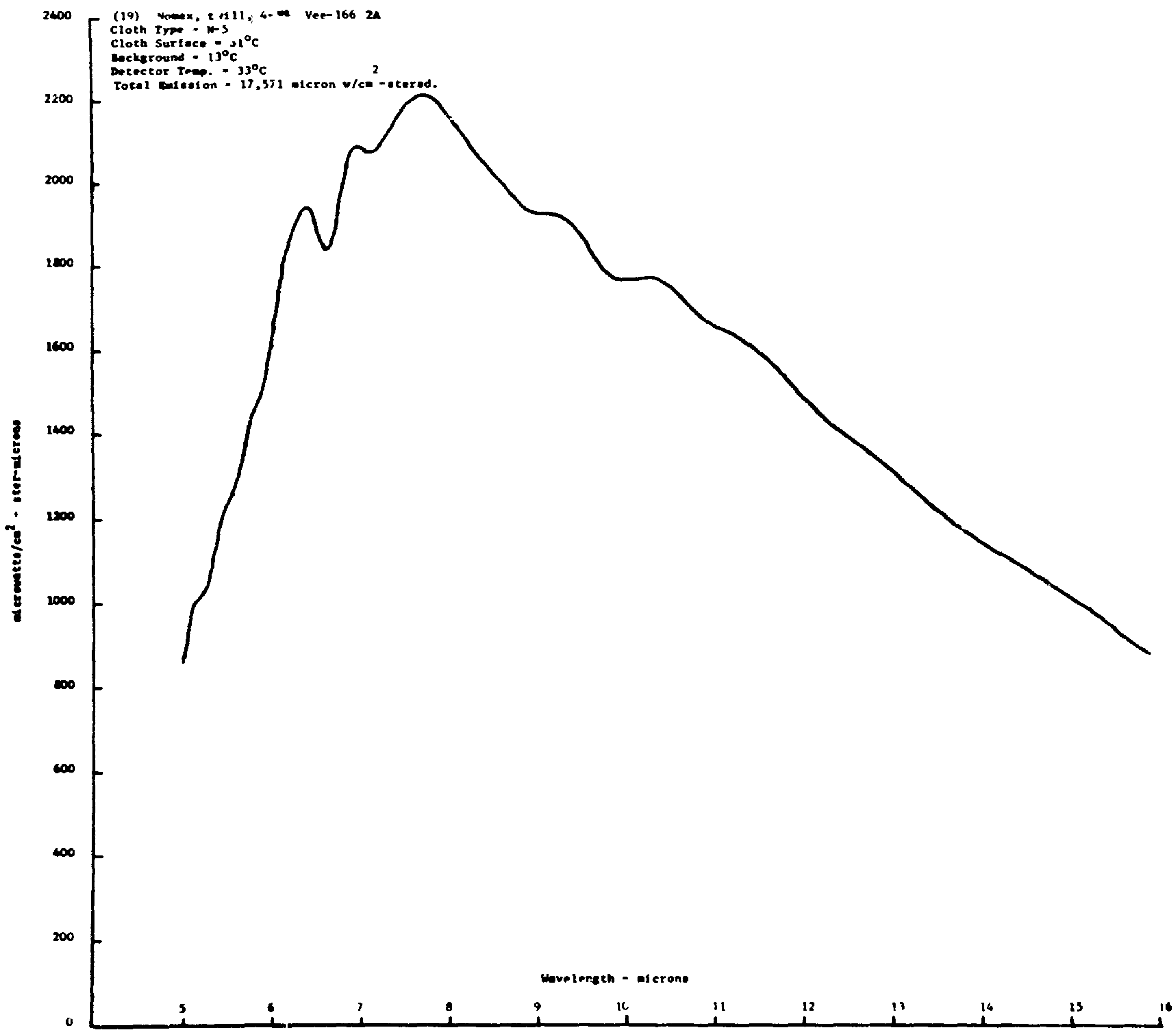


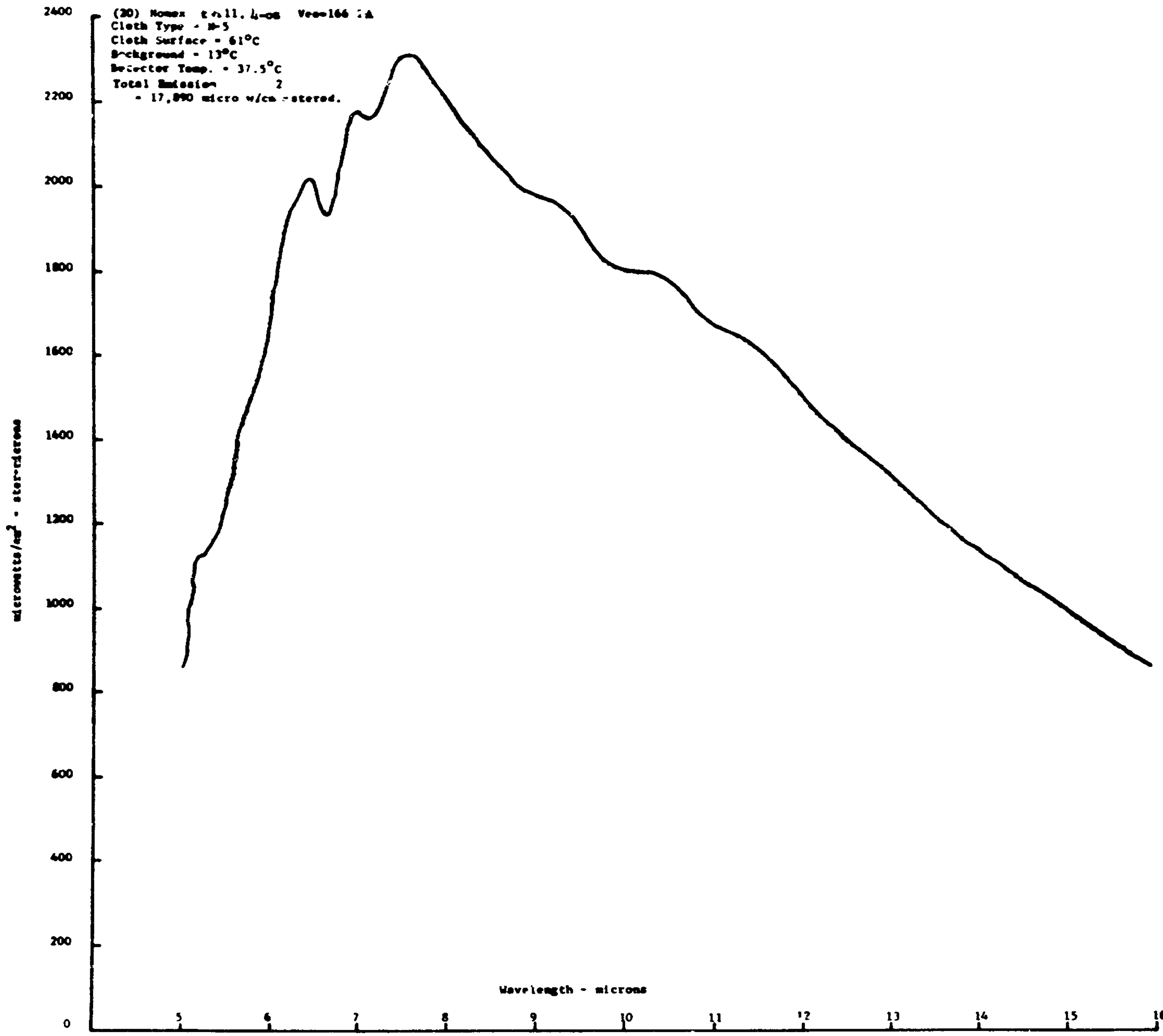
(16) Nylon, oxford, acid metalized
Cloth Type - N-2
Cloth Surface - 60°C
Background - -40°C
Detector - 25°C
Total Emission
= 17,590 micro w/cm² -ster-rad.
micro watt/cm² - ster-microns
Wavelength - microns
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
5
6
7
8
9
10
11
12
13
14
15
16


(17) Nomex, twill, 4-oz Vee-166 ZA
Cloth Type = W-5
Cloth Surface = 60°C
Background = -40°C
Detector = 25.5°C
Total Emission 17,200 micro w/cm² -sterad.
microwatts/cm² - ster microns
Wavelength - microns
2400
2200
2000
1800
1600
1400
1200
1000
600
400
200
0
5
6
7
8
9
10
11
12
13
14
16

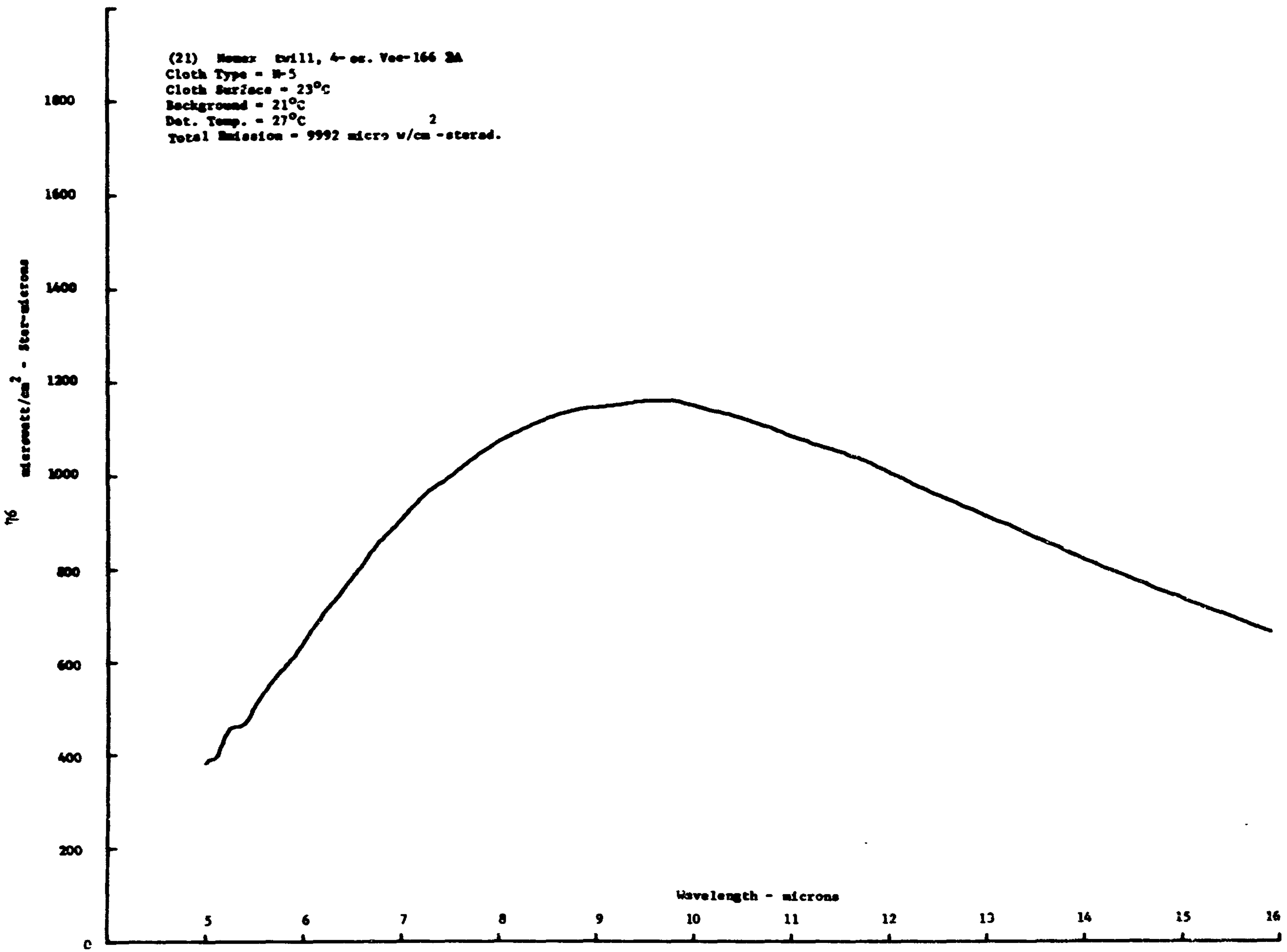
GROUP VI SPECTRA


(18) Nomex Twill, 4-oz.Vee-166 2-A
Cloth Type - N-5
Cloth Surface 59°C
Background - 13°C
Det. Temp. - 32°C
Total Emission 2
- 17,560 micro w/cm -sterad.
microwatt/cm² - Ster-microns
Wavelength - microns
1800
1600
1400
1200
1000
800
600
400
200
0
5
6
7
8
9
10
11
12
13
14
15
16


(19) Nomex, twill, 4- Vee-166 2A
Cloth Type - N-5
Cloth Surface = 31°C
Background = 13°C
Detector Temp. = 33°C
Total Emission = 17,571 micron w/cm² -sterad.
micr825watts/cm² - ster-microns
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16


(20) Nomex
Cloth Type -
Cloth Surface - 61°C
Total
micro w/cm
Wavelength - microns
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
5
6
7
8
9
10
11
12
13
14
15
16

GROUP VII SPECTRA


(21) Nomex twill, 4-oz. Vee-166
Cloth Type - N-5
Cloth Surface - 23°C
Background - 21°C
Det. Temp. - 27°C
Total Emission - 9992 micro w/cm² -sterad.
microwatt/cm² - Ster-microns
1800
1600
1400
1200
1000
800
600
400
200
0
Wavelength - microns
5
6
7
8
9
10
11
12
13
14
15
16

APPENDIX B

COMPUTER PROCESSED SPECTRA DATA

```
NATICK ABSOLUTE RADIANCE
2400 FCA 2454.0
     FST 2456.0
2401 CLA 2404.0
     STA 2422.1
2402 CLA 2405.0
     STA 2424.0
2403 STA 2433.1
     TRA 2410.0
2404 CLA 0000.0
     -00 4200.0
2405 CLA 0400.0
     CLA 5400.0
2406 FDV 2476.0
     FAD 2670.0
2407 FST 2714.0
     TRA 2413.1
2410 CLA 2450.0
     TYA 7760.0
2411 CLA 2451.0
     TYA 7760.0
2412 TRA 2500.0
     TRA 2410.0
2413 TRA 2406.0
     CLA 2452.0
2414 TYA 7760.0
     TRA 2500.0
2415 TRA 2413.1
     FST 2460.0
2416 CLA 2453.0
     TYA 7760.0
2417 TRA 2500.0
     TRA 2416.0
2420 FDV 2460.0
     FST 2462.0
2421 CLA 5000.0
     ARS 0001.0
2422 XAR 0000.0
     CLA 4630.0
2423 FNM 0000.0
     FMP 2462.0
2424 FDV 1456.0
     FST 2464.0
2425 FCA 2456.0
     FMP 2466.0
```

```
2426 FST 2470.0
     FCA 2472.0
2427 FDV 2470.0
     TRA 2700.0
2430 FMP 2472.0
     FDV 2470.0
2431 FDV 2470.0
     TSB 2433.0
2432 FAD 2464.0
     TRA 2433.1
2433 FSB 2464.0
     FST 6456.0
2434 CLA 2422.0
     ADD 2444.0
2435 STO 2422.0
     SUB 2445.0
2436 TZE 0330.0
     CLA 2424.0
2437 ADD 2446.0
     STO 2424.0
2440 CLA 2433.0
     ADD 2447.0
2441 STO 2433.0
     FCA 2456.0
2442 FAD 2474.0
     FST 2456.0
2443 DIS 2433.0
     TRA 2421.0
2444 CLA 0000.0
     -00 0001.0
2445 XAR 0000.0
     CLA 4630.0
2446 CLA 0002.0
     -00 0000.0
2447 CLA 0000.0
     -00 0002.0
```

```
NATICK ABSOLUTE RADIANCE CONT.
2700 FST 2712.0
     FCA 2722.0
2701 FDV 2712.0
     FDV 2714.0
2702 ARS 0000.0
     TRA 0170.0
2703 CLA 7774.0
     HTR 2702.1
2704 FSB 2716.0
     FMP 2712.0
2705 FMP 2712.0
     FMP 2712.0
2706 FMP 2712.0
     FMP 2712.0
2707 FST 2712.0
     FCA 2720.0
2710 FDV 2712.0
     TRA 2430.0
```

NATICK ABSOLUTE RADIANCE CONT.

```
0330 FCA 2750.0
     FST 2456.0
0331 CTV 2770.0
     TRA 0110.0
0332 CLA 2730.0
     TRA 0010.0
0333 CLA 0335.0
     STA 0364.1
0334 TRA 0336.0
     -00 0000.0
0335 HTR 0000.0
     HTR 6454.0
0336 FCA 2770.0
     FST 2754.0
0337 FCA 2764.0
     FST 2762.0
0340 CLA 2731.0
     TRA 0011.0
0341 CLA 2732.0
     PNA 7760.0
0342 CLA 2733.0
     PNA 7760.0
0343 FCA 2754.0
     FAD 2756.0
0344 FST 2754.0
     FSB 2760.0
0345 TPL 0346.0
     TRA 0340.0
0346 CLA 2735.0
     TRA 0010.0
0347 CLA 2736.0
     TRA 0011.0
0350 CLA 2737.0
     PNA 7760.0
0351 CLA 2740.0
     PNA 7760.0
0352 FCA 2762.0
     FSB 2474.0
0353 FST 2762.0
     FSB 2752.0
0354 TMI 0355.0
     TRA 0347.0
0355 FCA 2746.0
     FMP 2466.0
```

NATICK ABSOLUTE RADIANCE CONT.

```
0356 FST 2470.0
     FMP 2470.0
0357 FMP 6456.0
     FDV 2472.0
0360 FST 2460.0
     FCA 2472.0
0361 FDV 2470.0
     FST 2462.0
0362 CLA 2741.0
     TRA 0010.0
0363 FCA 2456.0
     FMP 2466.0
0364 FST 2470.0
     FMP 5376.0
0365 FMP 2470.0
     FDV 2472.0
0366 FST 2460.0
     FCA 2472.0
0367 FDV 2470.0
     FST 2462.0
0370 CLA 2741.0
     TRA 0011.0
0371 FCA 2456.0
     FSB 2474.0
0372 FST 2456.0
     CLA 0364.0
0373 SUB 2447.0
     STO 0364.0
0374 SUB 2734.0
     TZE 0376.0
0375 TRA 0363.0
     -00 0000.0
0376 CLA 2735.0
     TRA 0010.0
0377 HTR 6454.0
     -00 0000.0
```

NATICK ABSOLUTE RADIANCE CONT.

```
2730 +00 2752.0
     +00 2770.0
2731 +00 2752.0
     +00 2754.0
2732 +12 2451.0
     +12 2451.0
2733 +06 1430.1
     +06 1430.1
2734 +35 2470.0
     +07 5376.0
2735 +00 2764.0
     +00 2770.0
2736 +00 2762.0
     +00 2770.0
2737 +43 0614.0
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13. Abstract (continued)

field, there is inter-reflection between the terrain features and the sample, sky radiance, atmospheric absorption, and reflection from background objects of the fabric, giving a spectrum that is not representative of the sample.

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26 March 1965 to 26 March 1966

5. AUTHOR(S) (Last name, first name, initial)
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13. ABSTRACT

Laboratory measurements of the total and spectral infrared radiation emitted by textile materials, as applicable to the outer layer of a uniform, were made with an interferometer spectrometer. The effects of changes in the environmental parameters of the fabric, such as background temperature, fabric temperature, and humidity, were studied. For this report twelve different fabrics with a diversity of weaves and surface roughnesses were studied. The fifty-five spectra of these fabrics, which are published in this report, cover a wide range of fabric temperature, background temperature, and humidity.

It was found that the weave of the fabric acts as many small blackbody radiators and tends to mask any spectral detail that may be present. Further masking of detail is done by reflected background radiation. It was found that a fluctuation in background temperature, fabric temperature, or humidity caused a change in the spectral characteristics of the fabric.

Spectra of terrain features are presented and are compared to the spectra of the fabrics. It is shown that there is a spectral similarity between the fabric and terrain features because both are subject to spectral masking by background and sample characteristics. In the

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Measurement	8					
Infrared Radiation	9		7			
Fabrics	9		6,7			
Temperature			6			
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