NATIONAL BUREAU OF STANDARDS REPORT

9433

E - EQUIPMENT CALIBRATION

by L. Chernoff

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Prepared for

Department of the Air Force
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Washington, D. C.

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1. Material Tested.

An E-equipment birefringent (BRF) photometer was received from the Air Force in January, 1966 in accordance with AFTAC Project Authorization No. T/6340/NBS(E 57). The photometer was assembled by Air Force personnel in the basement of the East Building of the National Bureau of Standards.

The BRF photometer contains a BRF filter assembly consisting of a BRF filter and four interference filters which are used on measurements of four spectral lines. Three such BRF filter assemblies were measured in turn on the BRF photometer as indicated in Table I.

Table I

Filter Position	Spectral Line Wavelength		
	BRF Filter Assembly S/N 902 (A°)	BRF Filter Assembly S/N 106 (A°)	BRF Filter Assembly BF 101 -1-203-0001 (A°)
#1	6708	6708	6708
#2	4554	4554	4554
#3	5535	5535	5535
#4	6127	6127	4607

2. Test Procedure.

2.1 Line Sources

The spectral line sources used in these tests were hollow-cathode tubes manufactured by the Westinghouse Electric Corporation. See Appendix A. The tubes were mounted in a special holder. Power for the lamps was obtained from a well regulated, 1,000-volt dc power supply connected in series with a 40,000- ohm load resistor. The current through the hollow-cathode tube was measured with a milliammeter. The position of the tube was adjusted so that the optical axis between the photometer head and the tube passed perpendicularly through the center of the face of the tube. The hollow-cathode tubes used to obtain the necessary spectral lines are given in Table II.

Table II

Spectral Line Wavelength (A°)	Hollow-Cathode Tube Designation	Cathode Material	Gas Filler
6708	WL-22825	Lithium	Argon
4554	WL-22874	Barium	Neon
5535	WL-22874	Barium	Neon
6127	WL-22914	Zirconium	Argon
4607	WL-22835	Strontium	Neon

These tubes have been marked "NBS" on their bases.

Measurments made on two successive days of the line strengths produced by the hollow-cathode tubes for the specified spectral lines agreed to within ±2%. Successive measurements made of these line strenghts while the tube was operated continuously for periods up to 20 minutes after warm-up showed a precision within ±1.5%. These results are in accordance with the manufacturer's specifications.

2.2 Modulation Efficiency

The BRF photometer produces an ac signal in proportion to the irradiance of the spectral line and a dc signal in proportion to the irradiance of the continuum. The modulation efficiency (ME) is defined as

$$\text{ME } (\%) = \frac{\text{ac peak signal (volts)}}{\text{dc signal (volts)}} \times 100$$ when the source is a spectral line.

The ME was measured with the line sources operated at different currents and at different distances from the photometer in order to produce a range of irradiances. Some measurements were made with a diffuser placed over the opening of the photometer in order to reduce the effects of internal reflections within the photometer. When distances longer than ten feet from the photometer were used, the differences in the ME measured with and without the diffuser were insignificant.

Although the BRF photometer contains its own signal read-outs, all measurements were made with external voltmeters which were connected at the output of the photomultiplier tube preamplifier. The dc signal was measured with an electrometer amplifier, and the ac signal was measured with an electronic root-mean-square voltmeter whose reading is in rms volts. These readings were multiplied by 1.414 to convert them to ac peak voltage readings. Background noise and dark current corrections were obtained by taking voltmeter readings with the spectral line source covered and the BRF photometer shutter open.

2.3 Continuous Modulation

Continuous modulation (CM) is defined as

$$CM(\%) = \frac{\text{ac peak signal (volts)}}{\text{dc signal (volts)}} \times 100$$

for a continuous-spectrum source.

The continuous-spectrum source was a special low-level light source which attenuates the light of a tungsten filament lamp by means of apertures and a diffuser. A range of irradiances was produced by varying the distance from the photometer, the size of the aperture of the low-level light source, and the lamp voltage.

2.4 Absolute Calibration

Two-inch diameter interference filters were obtained to isolate the desired spectral lines. See Appendix B. For the case of the 6127 A° line, the neighboring lines of the 6127 A° line were so close that an interference filter to isolate this line would have been too costly and would have caused too much attenuation of the line strength. An estimation of the effect of irradiances from the neighboring spectral lines on the BRF photometer would have been so uncertain that a meaningful absolute calibration at 6127 A° was not feasible. Therefore, absolute calibrations at this spectral line were not undertaken.

The hollow-cathode tube holder was modified to hold an interference filter in front of the face of the tube perpendicular to the path of most of the emitted light. The irradiances from spectral lines, other than the desired one, which might be transmitted at the edge of the interference filter are small enough to be ignored.

For each BRF photometer filter position, the tube-filter combination was placed in position at various distances from the photometer. The distance to the photometer always exceeded ten feet. The tube was covered with black cloth so that it emitted light only through its face.

For the absolute calibrations, the hollow-cathode tubes were operated at a current of 20.0 mA, and measurements were made after a warm-up period of fifteen minutes. The voltage output of the photometer was measured at several distances, and by using the inverse-square law, these measurements were converted for convenience to the condition of the photometer irradiated by the tube at a distance of 10 feet.

The absolute radiance of the hollow-cathode tube-filter combinations was determined by comparison with an NBS standard of spectral irradiance by using a spectrophotometer. From the value of the radiance, the irradiance produced by the tube-filter combinations at a distance of 10 feet was computed.

2.5 Field of View

A parallel beam of light was obtained from the lithium source by means of a small aperture and two lenses. The field of view of the photometer was measured by rotating the photometer head about the azimuth while noting the ac signal resulting from the parallel beam.

2.6 Spectral Response of Photomultipliers

Two EMI #9558A photomultiplier tubes were measured for relative spectral response. The tube marked S/N 8236 was the one used in the BRF photometer for all of the above tests; the tube marked S/N 8512 is a spare.

In the tests of the spectral response, the first dynode-cathode potential was kept at a constant 150 volts by means of a Zener-diode. This procedure maintains the focus of the photo-electrons, thus stabilizing the relative spectral response for all settings of the total high-voltage applied to the hybrid-dynode voltage divider.

3. Results.

3.1 Modulation Efficiency

The results of the ME measurements are given in Table III.

Table III

Filter Position	Modulation Efficiency		
	BRF Filter Assembly S/N 902 (%)	BRF Filter Assembly S/N 106 (%)	BRF Filter Assembly BF 101-1-203-0001 (%)
#1	54	23	54
#2	35	20	34
#3	53	24	47
#4	15	28	36

3.2 Continuous Modulation

It would be expected that the CM would be a constant independent of the level of irradiance for each filter position of the BRF photometer. It was observed, however, that the CM increased as the level of irradiance decreased. No explanation for this was found.

The BRF photometer automatically switches gain or scale factor (SF) in order to adjust the sensitivity of the photomultiplier tube in accordance with the level of irradiance. There are four SF settings. An increase in the SF of one step indicates an increase in gain by a factor of 10 from the previous SF setting.

The results of the CM measurements are given in Table IV. These values represent an average within an SF setting for a given filter position. Since the dependence of CM on the irradiance level was not verified until BRF filter Assembly S/N 902 was no longer available for testing, results for this BRF filter assembly are not complete. In addition, some levels of irradiance low enough to produce readings at SF4 were too low to differentiate from background noise.

3.3 Absolute Calibration

Absolute calibration data are given, for convenience in future checks, at a distance of 10 feet from the target cathode of the hollow-cathode tube to the cover glass of the photometer head. The actual photometric distance in this case is the distance between the target cathode and the face of the first internal lens of the BRF optical system, a distance of 149.5 inches.

BRF sensitivity data are given in terms of $(\mu W/cm^2)/\ mV_{ac\text{-}rms}$, for SF 1. In order to convert to $\mu W/mV_{ac\text{-}rms}$, these values are multiplied by the surface area of the lens of the optical system, 198 cm^2. In order to convert to SF settings other than SF 1, these values must be divided by a factor of $10^{(SF-1)}$.

The results of the absolute calibration measurements are given in Table V.

Table IV

Filter Position	SF	Continuous Modulation BRF Filter Assembly S/N 902 (%)	BRF Filter Assembly S/N 106 (%)	BRF Filter Assembly BF 101-1-203-0001 (%)
#1	1	1.8	9.6	2.4
	2	3.4	11	6.2
	3	14	15	16
	4	25	19	25
#2	1	*	13	2.1
	2	3.0	13	4.8
	3	*	16	12
	4	*	21	24
#3	1	1.5	12	2.3
	2	4.4	13	5.6
	3	16	19	11
	4	*	*	33
#4	1	1.5	9	2.2
	2	*	10	5.2
	3	14	17	13
	4	*	*	25

* Not measured

Table V

BRF Filter Assembly	Filter Position	Sensitivity ($\mu W/cm^2$) $/mV_{ac-rms}$ for SF 1	Reading (mV_{ac-rms}) at 10 feet	SF
S/N 902	#1	2.69×10^{-7}	364	2
	#2	3.45×10^{-7}	416	2
	#3	1.43×10^{-7}	456	1
S/N 106	#1	6.94×10^{-7}	142	2
	#2	1.09×10^{-6}	132	2
	#3	4.11×10^{-7}	159	1
BF 101-1-203-0001	#1	5.40×10^{-8}	182	1
	#2	5.80×10^{-8}	249	1
	#3	3.61×10^{-8}	1,810	1
	#4	4.03×10^{-8}	1,080	1

The estimated uncertainty of these results is ±15%.

3.4 Field of View

The field of view was found to be 9.5° between points where the ac reading fell to 10% of the maximum.

3.5 Spectral Response of Photomultipliers

The relative spectral responses of the two photomultiplier tubes are given in Table VI. These results have been normalized to a value of 1.00 at 4250 A° (approximately the point of maximum sensitivity).

Table VI

Wavelength (A°)	Relative Spectral Response of Photomultiplier Tube S/N 8236	S/N 8512
4250	1.00	1.00
4500	.99	.97
5000	.85	.81
5500	.66	.65
6000	.51	.50
6500	.38	.34
7000	.25	.20

4. Field Check of Photometer Calibration.

A field check of the BRF photometer calibration can be accomplished by using the hollow-cathode tube-filter combinations described in section 2.4 and the procedure given below.

1. Place the hollow-cathode tube in the tube holder leaning about one quarter inch space between the face of the tube and the front edge of the holder.

2. Place the appropriate interference filter into the filter holder between the two teflon rings with the uncolored side of the interference filter facing the hollow-cathode tube. Attach the filter holder containing the filter firmly against the front of the tube holder, and secure it with the screws.

3. Place the hollow-cathode tube filter combination at a distance of 10 feet from the cover glass of the BRF photometer head and the target of the tube.

4. Adjust the tube holder so that the optical axis between the photometer head and the tube passes perpendicularly through the center of the face of the tube. This can be accomplished by:

a. leveling the photometer head,

b. placing the tube at same height as the center of the cover glass of the photometer head,

c. while sighting down the barrel of the tube holder, adjusting its position until the tube holder and the image of its reflection in the cover glass are sighted in a line.

5. Mask with black cloth around the tube holder so that light is emitted only through the interference filter and not through the side walls of the tube.

6. Operate the hollow-cathode tube at 20.0 mA. Use a warm-up period of 15 minutes occasionally checking the current.

7. Read the ac-rms output of the BRF photometer with the hollow-cathode tube uncovered and covered. Keep the same scale factor for both readings. Subtract the reading with the tube covered (which provides a correction for background light) from the reading obtained with the tube uncovered.

The corrected reading is then compared with the corresponding reading listed in the last column of Table V. If the comparison shows a difference of more than 15%, further instructions are to be obtained from headquarters.

5. Discussion.

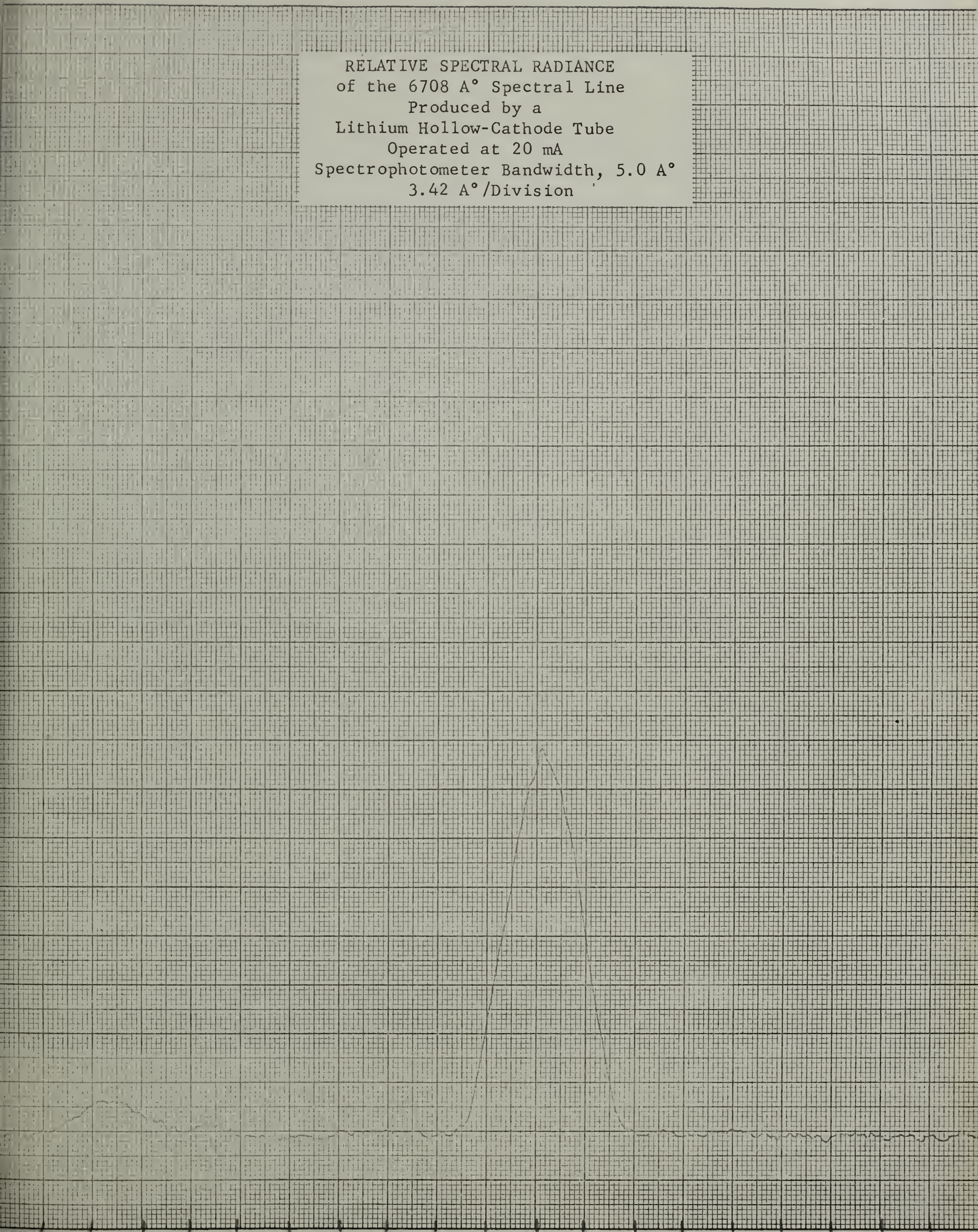
The primary reason for inaccuracy in the absolute calibration was inconsistency of the BRF photometer readings. Occasional readings differed widely from the mean. Readings which differed by more than 20% from the mean were discarded, although the cause of these differences could not be determined.

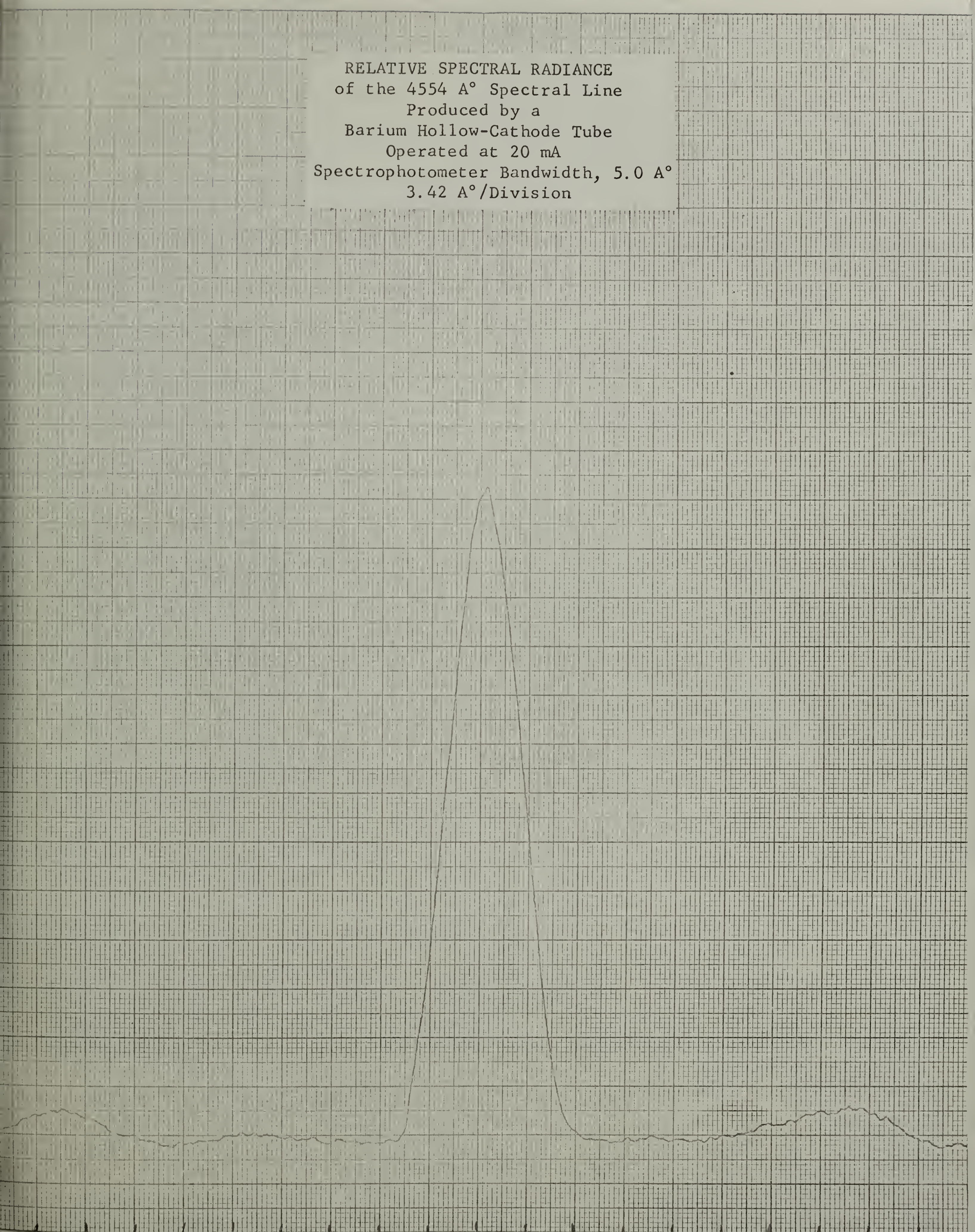
Some of the tasks requested under AFTAC Project Authorization No. T/6340/NBS (E57) were not accomplished. There are at present no facilities at the National Bureau of Standards for measuring the transmittance of complicated optical systems such as the birefringent photometer or the birefringent filter assemblies (part of Task a. and Task f.). The equipment available for measuring reflectance and spectral transmittance will not accomodate elements as large as the cover glass and interference filters of the BRF photometer (Tasks c. d. and e.).

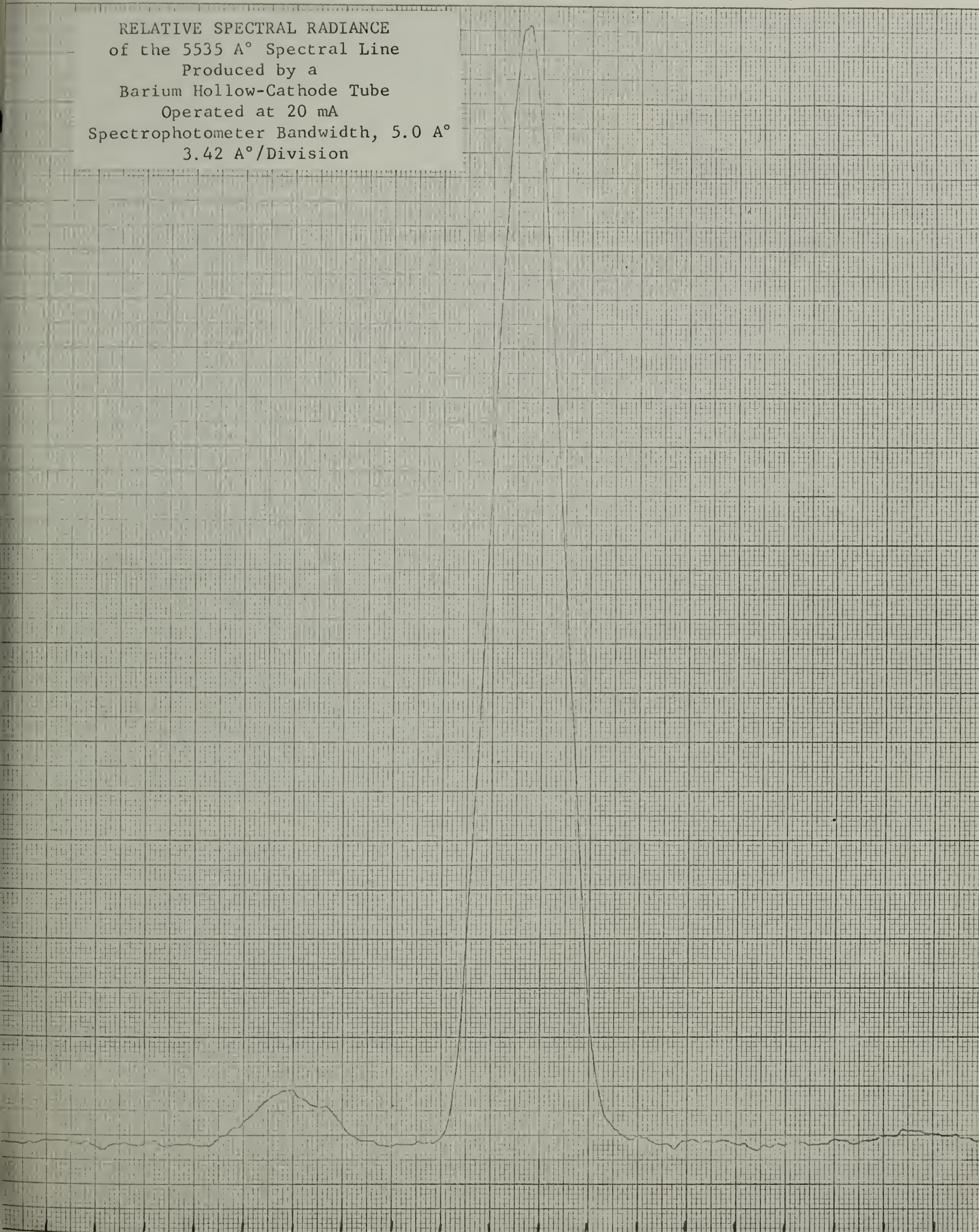
Appendix A

The following curves show measurements of the relative spectral radiance of the hollow-cathode tubes at each of the spectral lines used. The spectrophotometer used in these measurements has a bandwidth of 5.0 A°. The actual bandwidth of spectral lines produced by hollow-cathode tubes ranges from 0.2 to 0.5 A°.

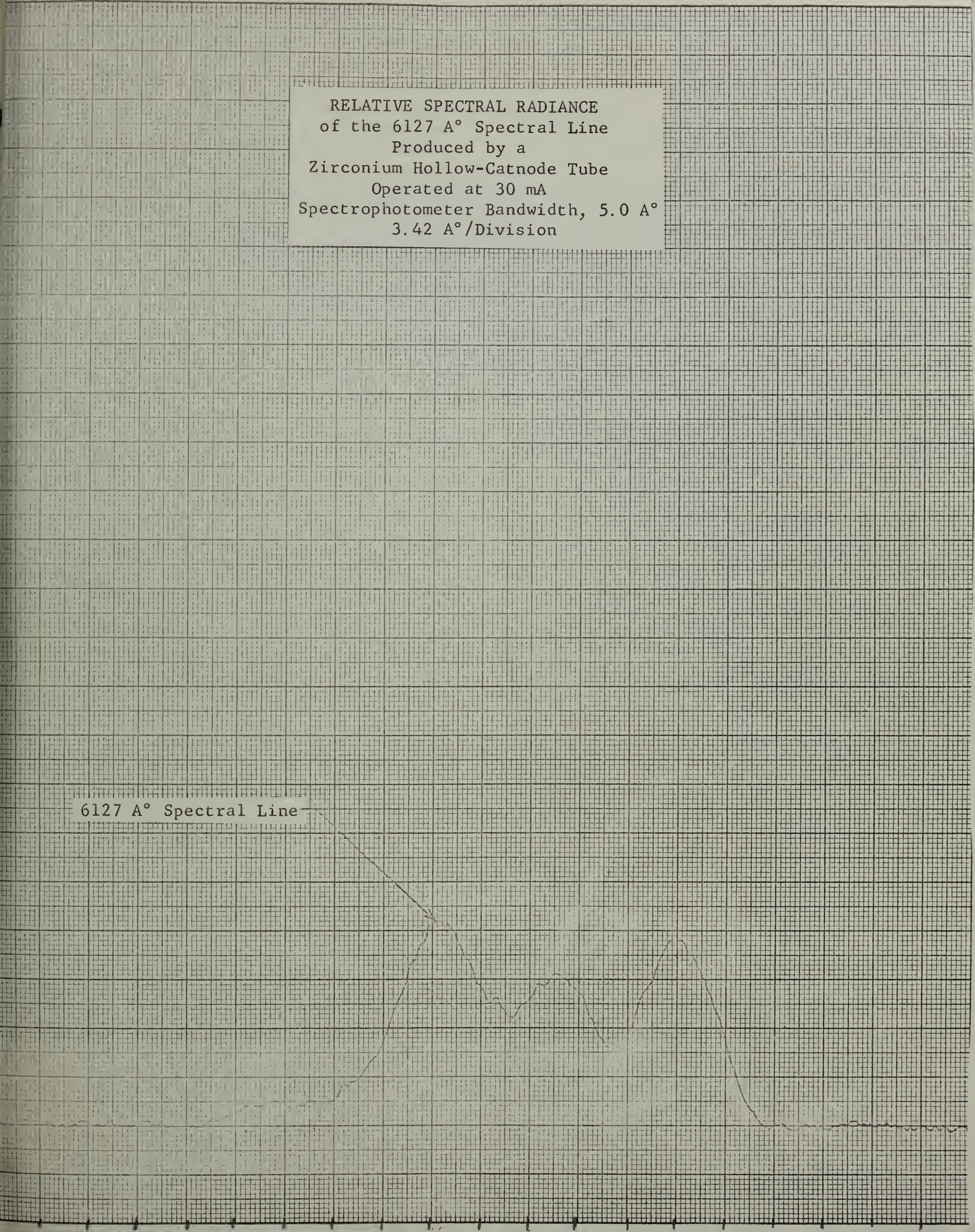
The wavelength scale for these curves is 3.42 A°/ division. Because of the low level of radiance of the zirconium 6127 A° spectral line, the tube providing this lens was operated at 30 mA. Operating the tube at 30 mA instead of 20 mA will not significately change the relative spectral radiance.

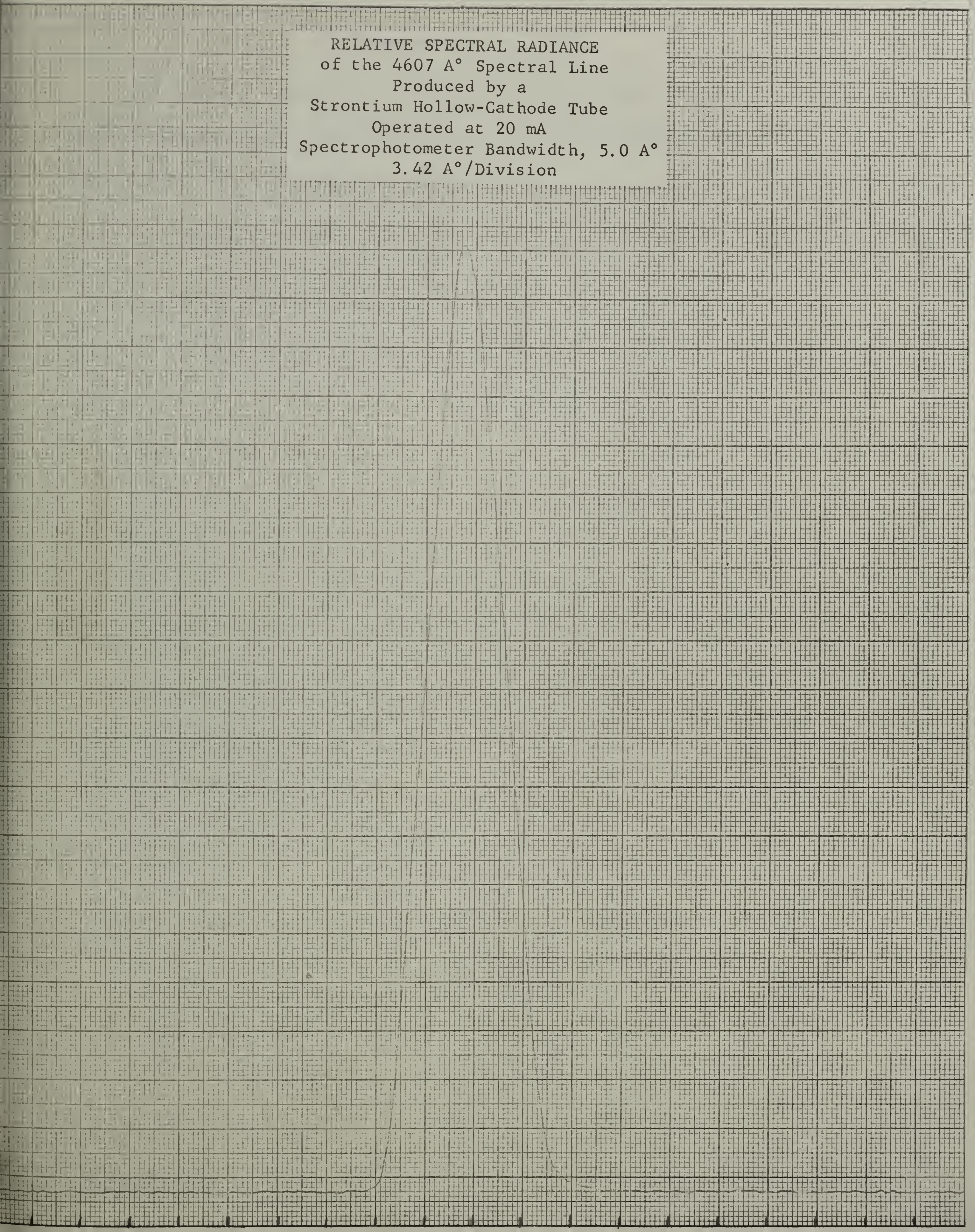

RELATIVE SPECTRAL RADIANCE
of the 6708 A° Spectral Line
Produced by a
Lithium Hollow-Cathode Tube
Operated at 20 mA
Spectrophotometer Bandwidth, 5.0 A°
3.42 A°/Division


RELATIVE SPECTRAL RADIANCE
of the 4554 A° Spectral Line
Produced by a
Barium Hollow-Cathode Tube
Operated at 20 mA
Spectrophotometer Bandwidth, 5.0 A°
3.42 A°/Division



RELATIVE SPECTRAL RADIANCE
of the 5535 A° Spectral Line
Produced by a
Barium Hollow-Cathode Tube
Operated at 20 mA
Spectrophotometer Bandwidth, 5.0 A°
3.42 A°/Division

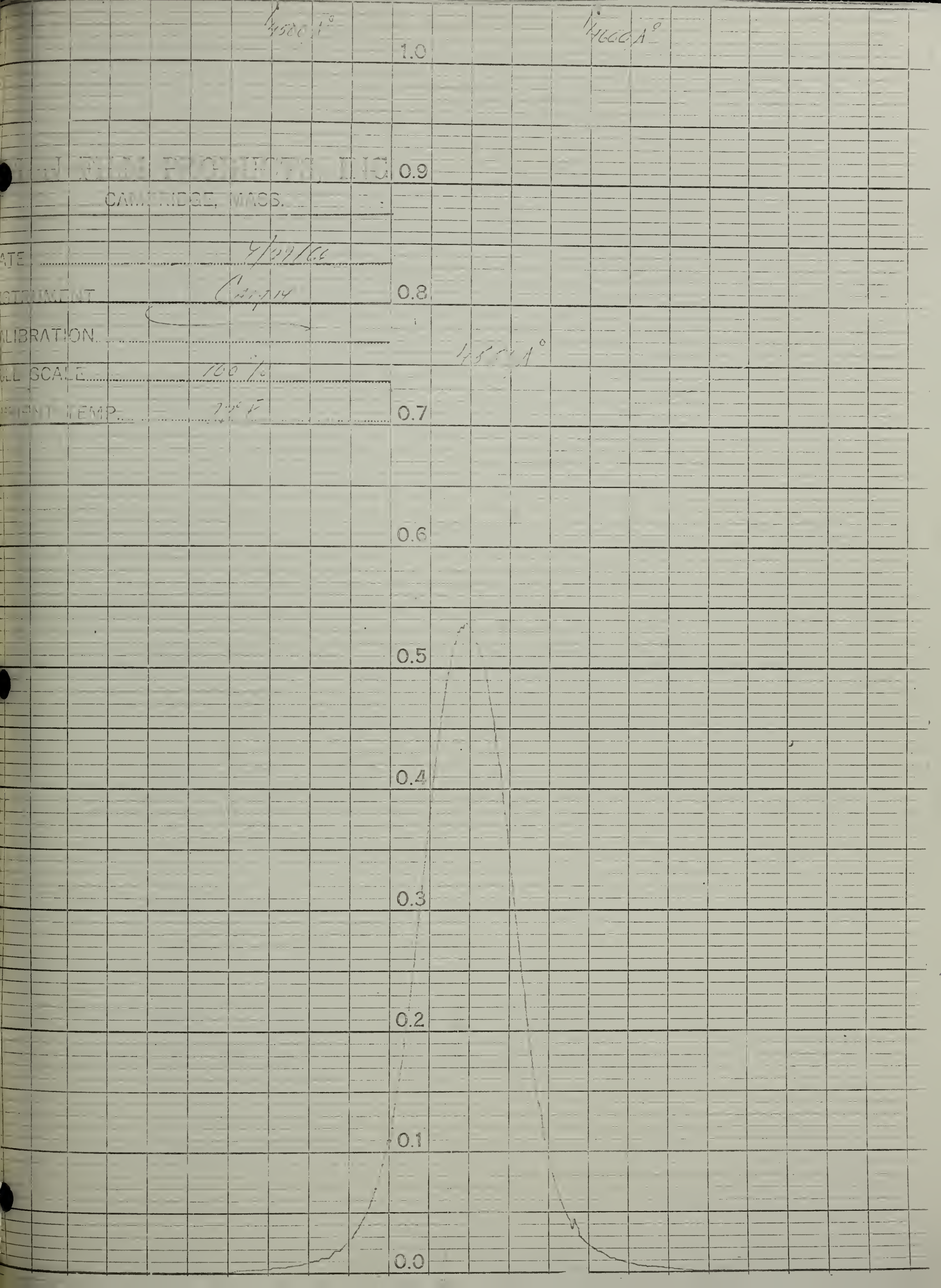

RELATIVE SPECTRAL RADIANCE
of the 6127 A° Spectral Line
Produced by a
Zirconium Hollow-Catnode Tube
Operated at 30 mA
Spectrophotometer Bandwidth, 5.0 A°
3.42 A°/Division
6127 A° Spectral Line



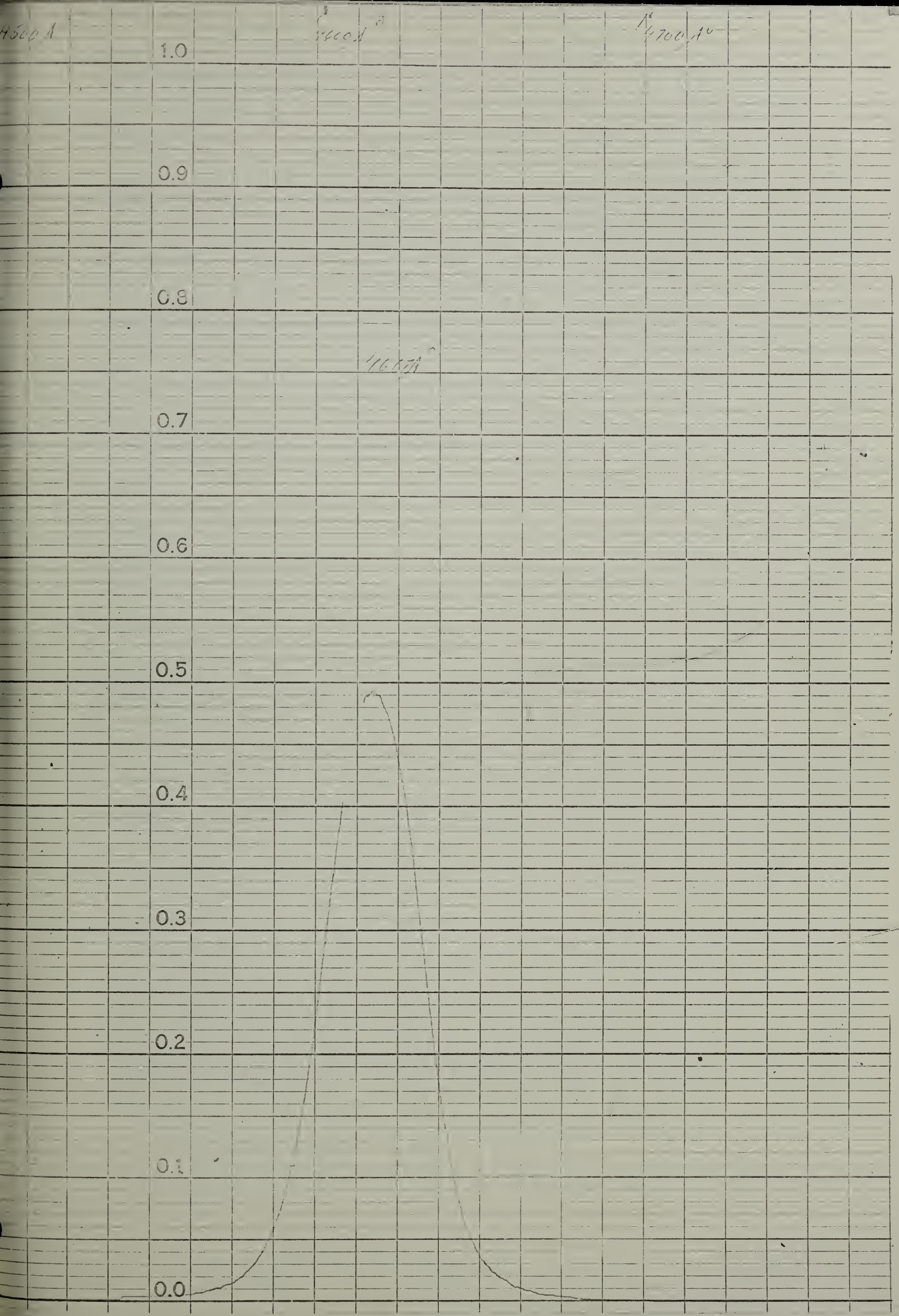
RELATIVE SPECTRAL RADIANCE
of the 4607 A° Spectral Line
Produced by a
Strontium Hollow-Cathode Tube
Operated at 20 mA
Spectrophotometer Bandwidth, 5.0 A°
3.42 A°/Division

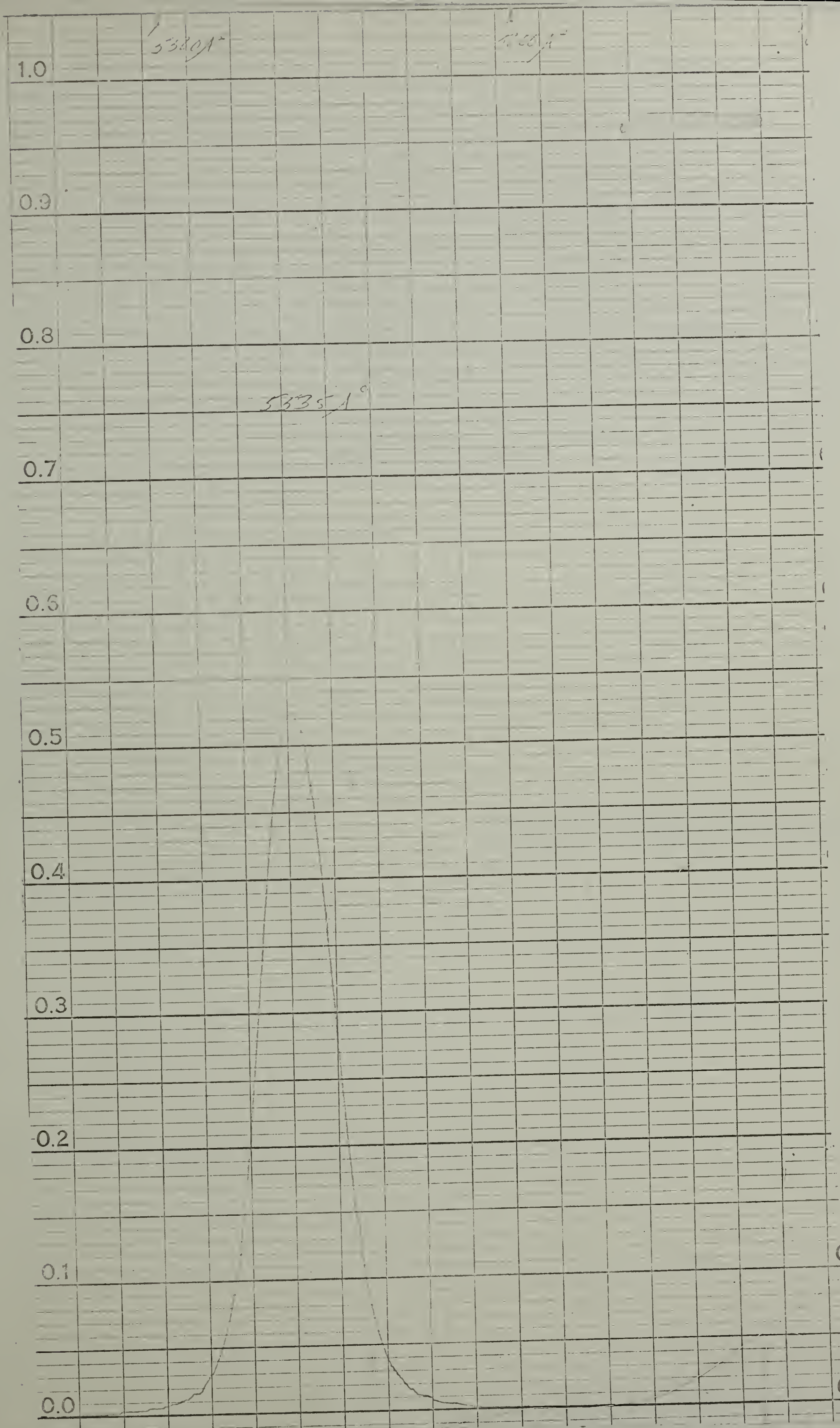
Appendix B

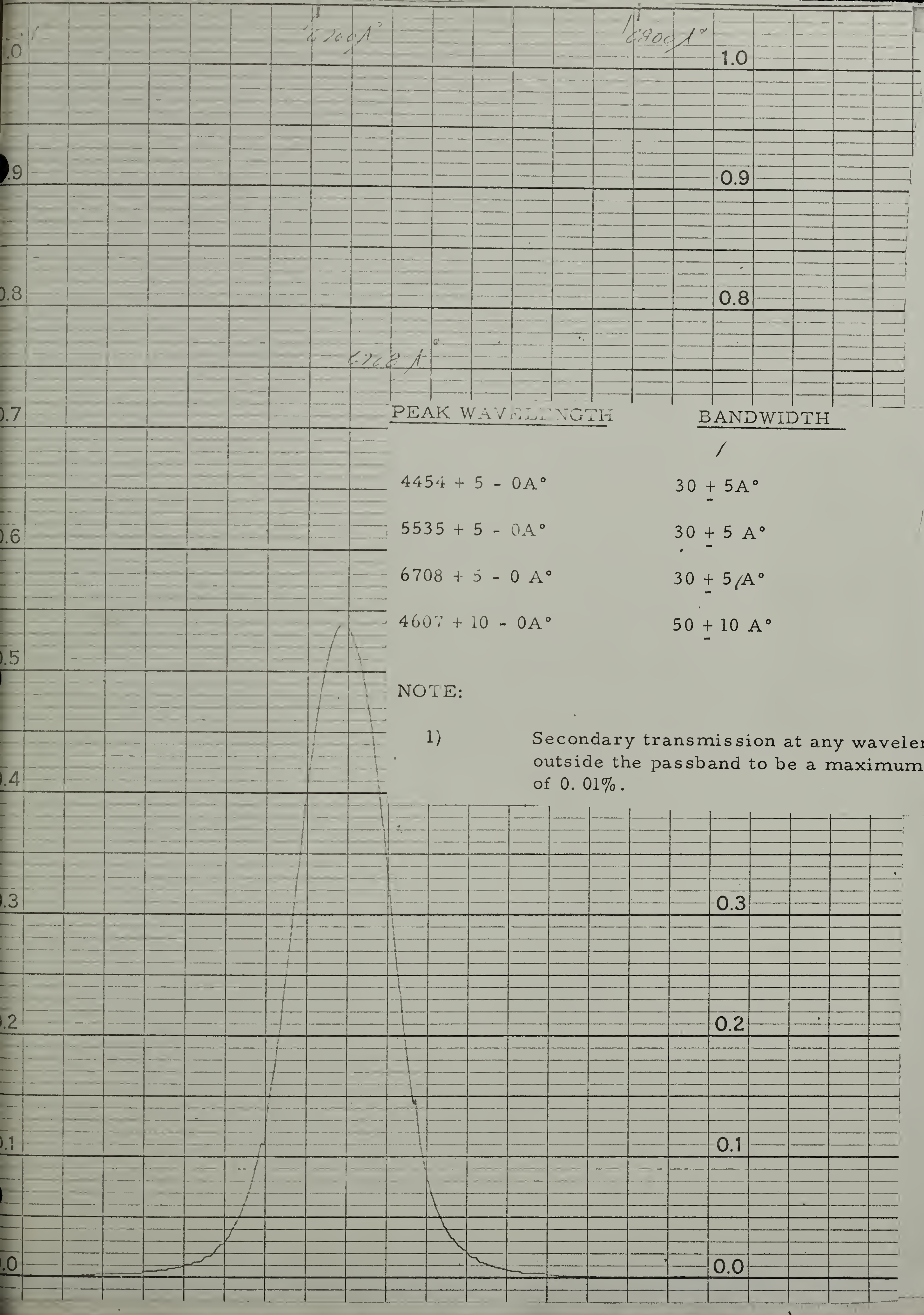
The following curves show the spectral transmittance of the interference filters used in the absolute calibration of the BRF photometer. These curves were supplied by the manufacturer.



4500 A°
4600 A°
1.0
0.9
CAMBRIDGE, MASS.
4/29/66
Cary 14
0.8
LIBRATION
SCALE 100 %
4550 A°
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0



PEAK WAVELENGTH	BANDWIDTH
4454 + 5 - 0A°	30 ± 5A°
5535 + 5 - 0A°	30 ± 5 A°
6708 + 5 - 0 A°	30 ± 5 A°
4607 + 10 - 0A°	50 ± 10 A°

NOTE:

1) Secondary transmission at any wavelength outside the passband to be a maximum of 0. 01%.

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