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FINAL REPORT

Research, Studies, and Investigations on Spectral Reflectance and Absorption Characteristics of Camouflage Paint Materials and Natural Objects

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Contract No. DA-44-009 ENG-1447

Department of the Army Project No. 8-31-03-012

Placed by

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FINAL REPORT

RESEARCH, STUDIES AND INVESTIGATIONS ON SPECTRAL REFLECTANCE AND ABSORPTION CHARACTERISTICS OF CAMOUFLAGE PAINT MATERIALS AND NATURAL OBJECTS.

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Director of Research Division

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I. ABSTRACT

This Final Report covers the studies and investigations on the spectral reflectance and absorption characteristics of camouflage paint materials and natural objects in the spectral region between 0.4 and 15.0 microns.

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The report discusses the development of an instrument for the spectral reflectance measurements and presents spectral reflectance data of both camouflage paint materials and natural backgrounds. It is shown that a considerable degree of perfection was achieved in the instrumentation and the method for the measurement of the "total diffuse" infrared reflectance of camouflage materials.

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A special study was also conducted on sulfur to determine its suitability as a reflectance standard in the infrared.

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The effect of pigment particle shape on the water absorption of a paint and the resultant effect on the paint's infrared reflectance was studied and the results are shown by spectrophotometric curves. The hiding power of selected pigments and paints was studied as a function of wavelength.

The report concludes that:

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a) A satisfactory instrument together with a method has been developed for the measurement and evaluation of the infrared reflectance of camouflage materials.

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b) A form of sulfur has been found as a suitable standard for comparing its infrared reflectance with that of diffusely reflecting camouflage materials. This sulfur may be described as a finely divided form containing

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at least 30% or more carbon disulfide-insoluble sulfur, [illegible] in Flowers of Sulfur or in a vaporized and quenched sulfur.

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c) The water penetration of camouflage paints of the alkyd and emulsion types is dependent upon the pigment selection and the particle shape of the pigment.

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d) Generally the spheroidal, hexagonal or platy pigments showed higher resistance to water penetration than the acicular or cubical shapes.

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e) The effect of water immersion of 4 to 24 hrs. had very little effect on the reflection spectrum of alkyd resin and of acrylic resin emulsion paints. Only slight lowering in reflectance was noted after 72 hrs. of immersion.

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f) The hiding power of the camouflage paints and pigments tested is definitely a function of wavelength and must be considered for camouflage purposes in the infrared to 15 microns.

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g) No colored paint tested accomplished complete hiding when applied in approximately 1 mil dry film thickness on a highly reflecting aluminum surface and tested in all wavelengths to 15 microns.

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h) Very low reflectance in the infrared region, especially beyond 3.0 microns, can be achieved by applying camouflage paints over a black primer which will approach the low reflecting characteristics of most background materials beyond 3.0 or 4.0 microns.

It is recommended that:

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a) The information contained in the reports of this contract be used as a basis for camouflage purposes in the infrared region of the spectrum.

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b) Consideration be given to a two-coat system, where applicable, to utilize the transparency in the infrared of the outer camouflage coating.

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c) Primer materials be utilized which combine good rust inhibiting qualities with the desired infrared reflecting characteristics.

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II. PURPOSE AND SCOPE

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This project is concerned with

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1. The development of suitable instrumentation for the measurement of the reflectance and absorption characteristics of camouflage paint materials and of certain groups of natural materials generally considered as background to camouflage paint applications, in the spectral region between 0.4 and 15 microns. A study not provided in the original program was found to be necessary; that is, determination of a reliable standard for the infrared reflectance of diffusely reflecting surfaces.

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2. The study of a selected group of natural background materials such as certain leaves, barks, grasses, sands and soils. The spectra obtained are compared with those of paints and pigments obtained in later paragraphs of the studies.

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3. The comparison of the changes in the reflectance spectra of camouflage paints caused by a change in the particle shape of the pigmentation, by exposure of the paint to water, and by the re-drying of the paints. In some selected instances, the water immersion was supplemented by salt water immersion.

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4. The study of a group of eight pigments and paints with reference to the relation between their hiding power (in the visible range) and their reflectance characteristics to 15 microns. The hiding power was therefore determined, to 15 microns for each of these paints, as the ratio between their reflectance on black and on polished aluminum.

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Based on the results of this investigation it has been possible to present a group of conclusions and recommendations for the application and further development of the findings of this work.

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The scope of the investigation was extensive, and it required great effort and enthusiasm on the part of each one connected with the work for its completion. The project was under the direction of Dr. Max Kronstein, Research Associate. The instrumental development and its application was done by Mr. Robert J. Kraushaar, Research Assistant. The preparation of the test samples and the supervision of the work on the Beckman Spectrometer was in the hand of Mr. Robert Roper, who was assisted by Mr. Max Rehfeld. The work of assembling the data and the preparation of the reports was done by Mrs. Marion Ward Kronstein.

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The group wishes to express their sincere appreciation at this time to Mr. Robert E. Deecle, Project Advisor, for his continued cooperation and counsel throughout the many phases of the development.

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For assistance in the instrumental development, we wish to thank also Mr. A. R. Dennett of The Eppley Laboratory, Inc., manufacturer of the Golay Detectors used on the project; and Mr. Paul A. Wilks and the engineer group of The Perkin-Elmer Corporation, manufacturer of the Model 12-C and Model 112 Spectrometers which were used on the project.

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We wish to thank those who assisted in special aspects of the work as they arose; namely, Mr. Fred A. Behr of North American Philips Company, Inc. for his experimental assistance in the x-ray diffraction studies of sulfur, and Mr. James A. Amick of the R.C.A. Laboratories in Princeton, New Jersey for his assistance on the same problem.

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In conclusion, the group expresses the hope that the results will be found to be of practical use for the problems for which the work has been undertaken.

III. FACTUAL DATA AND OBSERVATIONS

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1. INSTRUMENTATION

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A. DEVELOPMENT OF AN INSTRUMENT FOR SPECTRAL REFLECTANCE MEASUREMENTS.

a. STATEMENT OF THE PROBLEM.

In a preceeding project (Contract No. DA-44-009 eng-652) an attachment was developed for use on a single beam Perkin-Elmer Infrared Spectrometer whereby a system of mirrors directed the beam from the exit slit of the monochromator through an entrance hole of a Coblentz Hemisphere to the test sample. Here that beam of known wavelength positions was used for the illumination of a test sample mounted in the hemisphere; and with a Golay Detector the total diffuse reflectance of the sample under the illumination by the beam of known wavelength was measured. The Golay Detector was connected with the recorder of the Perkin-Elmer instrument and an instrument chart reading was thus obtained.

In order to compere the infalling illuminating energy with the total reflected energy and in order to calculate accordingly the percent reflectance at each wavelength, the detector was modified in a manner to permit its movement alternately with the position of the sample. Hereby two curves were obtained: first the Golay Detector was set into the position of the specimen and the spectrum curve of the illuminating beam was determined; the detector was then moved to its alternate position, which is the same distance as the sample from the center of the hemisphere, and the reflected energy of the test sample was determined on the recorder chart.

Certain correction factors were applied in the evaluation of the ratio between the two charts, point by point, which took into consideration certain errors which prevailed in that test set-up.

The aspects of that earlier instrumentation which required im-

provement are noted below:

1) The illuminating beam passed through an air space from the spectrometer to the hemisphere.

2) The illuminated area on the test sample was slit-shaped, while the window of the receiving Golay Detector was round.

3) The sample table, as well as the detector, was not sufficiently rigid. This caused a higher noise level than was desirable in the readings.

4) The spectrometer was not mounted as rigidly as was desirable.

5) The Golay Detector required a number of dry batteries as well as a wet battery. This resulted in variation in energy, due to the decay of the batteries, during a working day and caused a continuous drift of the zero line in the charts.

6) All correction factors had been based on the comparison with the reflectance of a first surface rhodium mirror as standard. It was felt that the reflection from a flat first surface mirror was much more unidirectional at the wavelengths under consideration than that from irregular surfaces such as those of pigment powders, pigmented paints, sands, leaves and barks of trees. Therefore, it was necessary to find a more suitable standard which reflects diffusely in a manner more nearly like that of the samples which were to be compared. Such a standard was necessary to minimize errors which would be caused by large differences between the goniometric properties of the standard and those of the samples.

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b. NEW DEVELOPMENT

Work was undertaken to correct these aspects of the earlier set-up.

A new reflectance attachment was built of heavy steel and screwed onto the spectrometer in such a manner that the nitrogen filling the spectro-

meter filled the reflectance attachment also. (Figure 35, Second Technical Report). In this manner readings were made under nitrogen. The spectrometer itself was bolted to a heavy steel base-plate which was mounted solidly on a footing of cement building blocks. (Figures 57 and 58 on pages 8 and 9).

A new Golay Detector was obtained having a window the same shape as the slit in the hemisphere. (Figure 34, Second Technical Report).

A new model amplifier for the Golay Detector, which required a wet battery only, was obtained. Hereby, two wet batteries were used in rotation, with one battery being recharged while the other was in use. The strength of the signal of the Golay Detector was tested after each run, and it was determined that no error was introduced due to the drop in voltage as a function of time. Furthermore the background, or the spectrum of the infalling illuminating beam, is determined for a limited wavelength range of a few microns only. Then the reflection spectrum is determined for the same wavelength range. The procedure is repeated for the next ranges, a few microns at a time, until the entire range of 15 microns has been covered. In this manner the zero drift, due to battery life decay, was largely eliminated.

Certain types of sulfur have been studied and evaluated as a standard for diffusely reflecting materials. This research group feels that the question of the standard to be used in the evaluation of the ratios is of much greater importance than had generally been assumed, and that the use of the rhodium mirror in the determination of the calculation factor will cause figures which are too low when applied to diffusely reflecting materials. The use of sulfur as a standard is discussed in detail in this report on pages 18 ff .

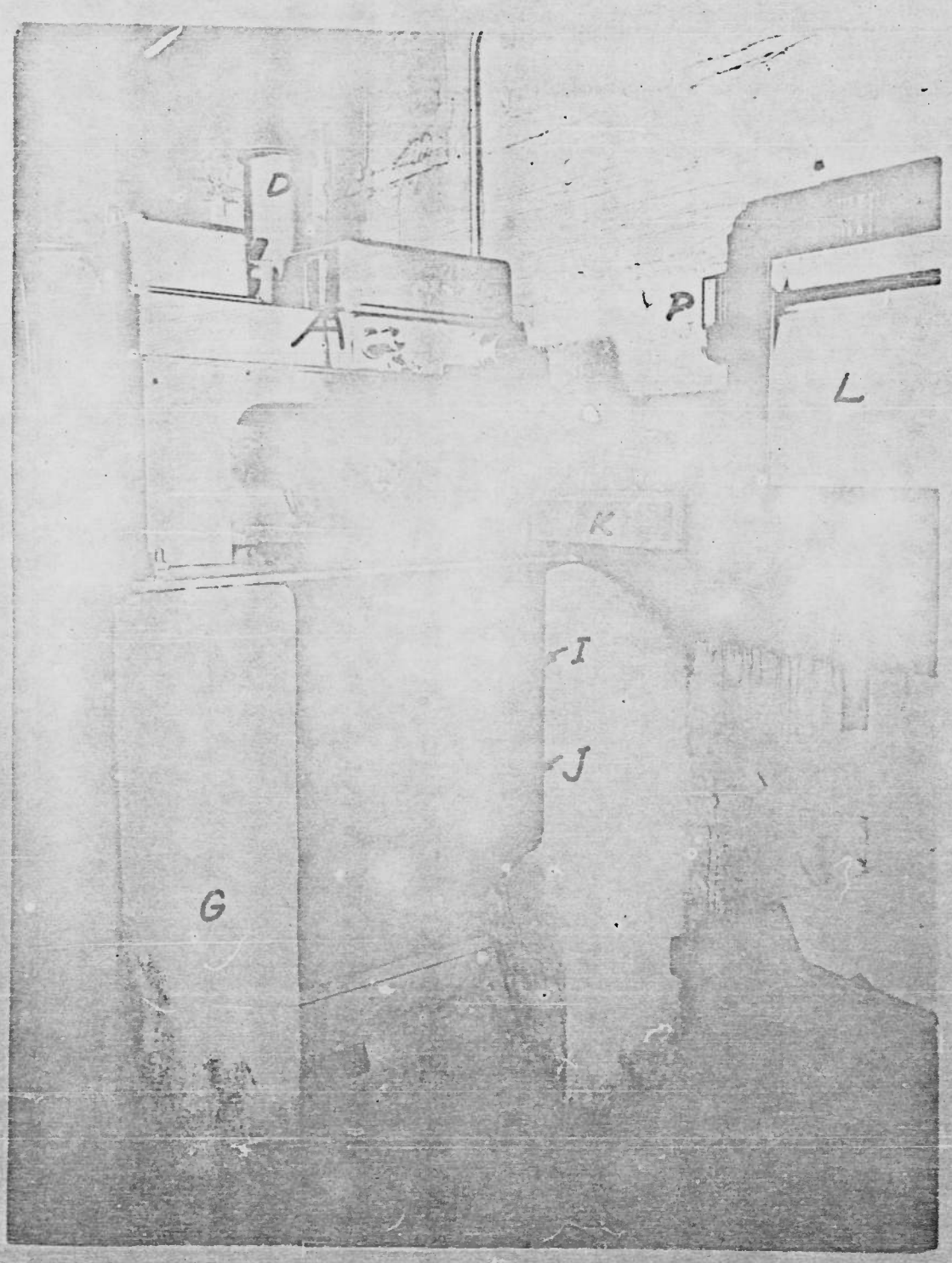


FIGURE 57

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A - Spectrometer
B - Light source
D - Reflection/mirror system housing
G - Concrete foundation
H - Power supply
J - Amplifier for detector
K - Control panel
L - Recorder
O - Chopper
P - Hydrometer/thermometer

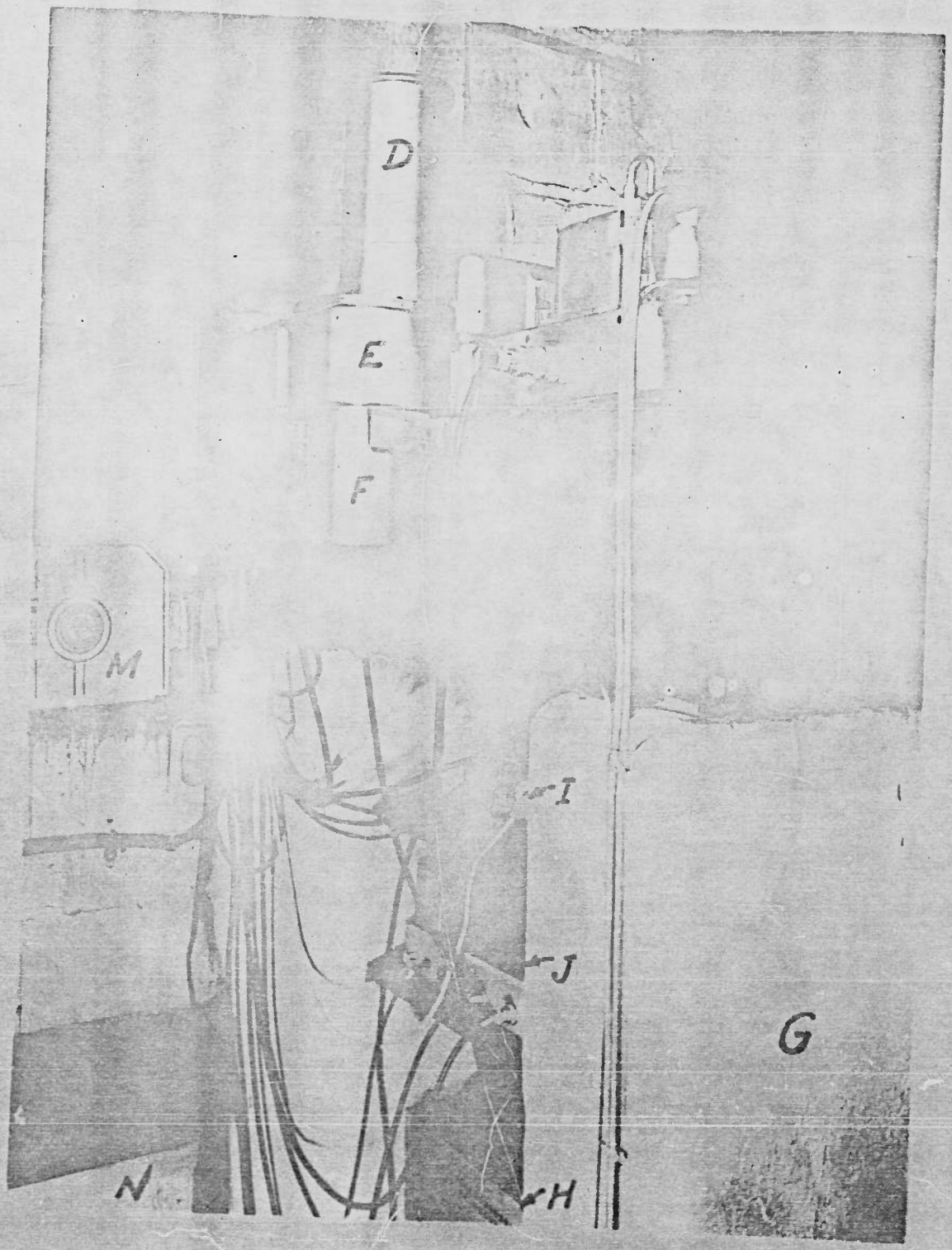


FIGURE 58

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A - Spectrometer
B - Light source
C - Location of exit beam
D - Reflection/mirror system housing
E - Hemisphere casing
F - Detector housing
H - Power supply
I - Amplifier for spectrometer
J - Amplifier for detector
M - Battery charger
N - Battery box

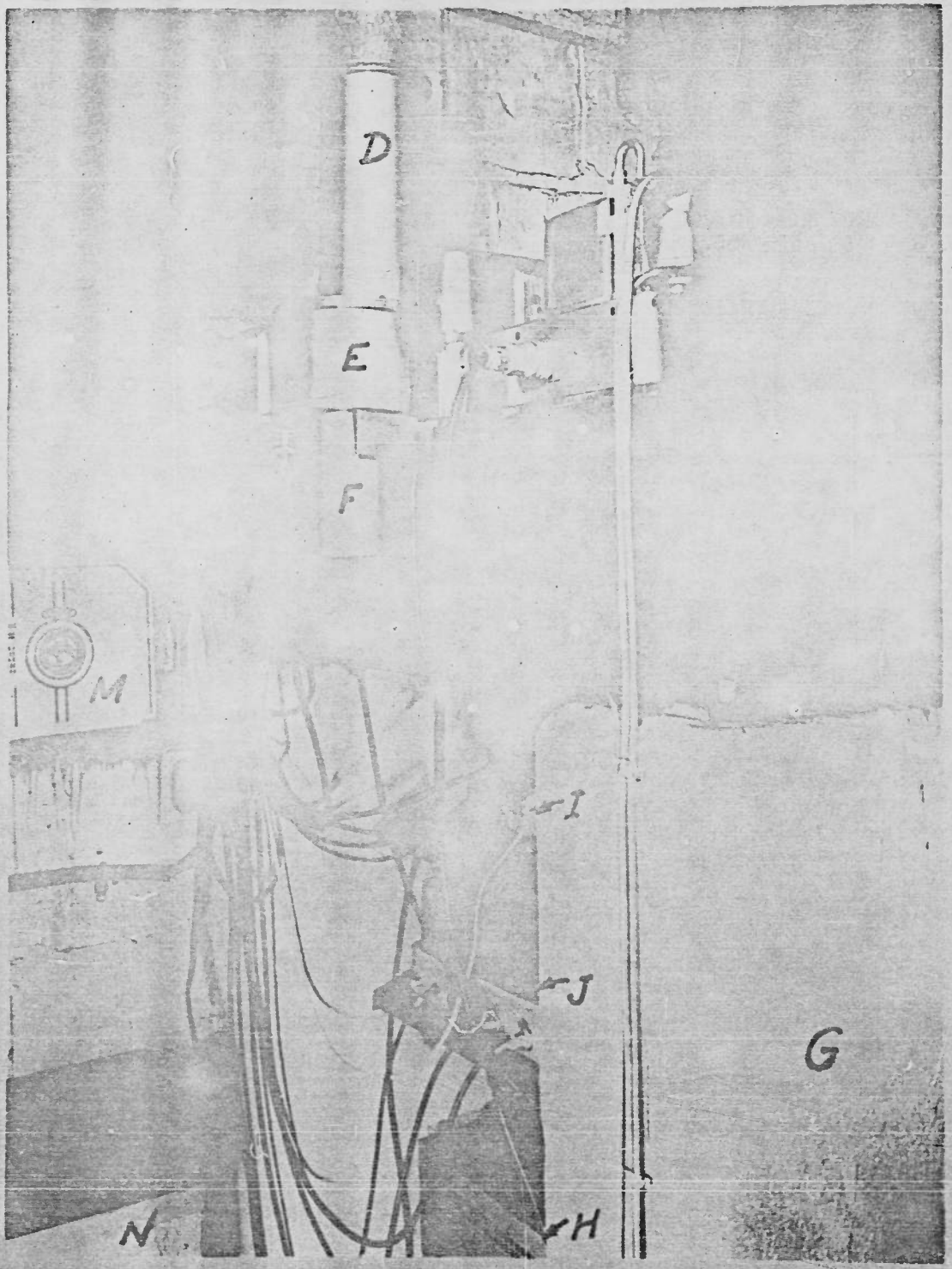


FIGURE 58

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A - Spectrometer
B - Light source
C - Location of exit beam
D - Reflection/mirror system housing
E - Hemisphere casing
F - Detector housing
G - Concrete foundation
H - Power supply
I - Amplifier for spectrometer
J - Amplifier for detector
M - Battery charger
N - Battery box
Q - Tubing for nitrogen

During the course of the contract work it became necessary, due to an accident, to replace the Model 12-C single beam, single pass spectrometer,- with the approval of the sponsor,-with the Model 112 single beam, double pass Perkin-Elmer Spectrometer. The comparative specifications for these two instruments are given in TABLE 50, page 11.

With this new model, the operation of the two choppers required for the monochromator and for the Golay Detector was improved by having the axle which operated the chopper of the monochromator extended and attaching the chopper of the Golay Detector on the same axle.

Much greater energy in the source of radiation was obtained by the effective use of the Stupakoff Glower instead of the Globar. In earlier work the Glower had had an average "life" of only 20 hrs. and about 2 ignitions. This was appreciably lower than the rated 100 hrs for this device. Tests were made which showed the cause of the failure of the Glowers to be thermal shock at the connection points of the glower. To alleviate this, a Variac was placed in the electrical circuit and used in the following manner:

1) The Variac was set to apply approx. 50 volts across the transformer.

2) A gas torch was applied to the Glower element until a light orange color was observed.

3) The Variac voltage was increased slowly until the Glower burned without benefit of the gas torch.

4) The Variac voltage was increased, in 5 volt increments over a 20 min. period until 110 volts were applied to the transformer.

TABLE 50.

SPECIFICATIONS FOR THE TWO PERKIN-ELMER SPECTROMETERS
(Data of the Manufacturer)

	MODEL 12-C	MODEL 112
PRINCIPLE	Modulated single beam.	Modulated single beam.
MONOCHROMATOR	Single pass, f/4.5	Double pass, Littrow mounting, 27 cm focal length, effective aperture f/4.5, prism face 60 x 75 mm, effective prism base 300 mm (4 traversals).
SCANNING SPEEDS	8 min. to 4 hrs for rock salt region. (average time-16 min.) Automatic speed change wavelength drive.	Average is 22 min. for NaCl region. The normal speeds are 1, 2, and 4 min. per revolution of the wavelength drum. Change gears mounted on the back panel of the drive may be used to multiply these speeds by factors of 2, 4, $\frac{1}{2}$ or $\frac{1}{4}$.
RESPONSE TIME	2, 4, 8 or 16 sec., 90 percent response.	2, 4, 8 and 12 sec., 90 percent response.
RESOLUTION	1.5 cm^{-1} at 10μ (rock salt prism)	Better than 1 cm^{-1} at 850 cm^{-1} (NaCl).
WAVELENGTH REPRODUCIBILITY	0.003 μ.	0.01 microns at 2 microns; 0.003 microns at 15 microns with NaCl optics.
STRAY RADIATION	Less than 5 percent at 15μ with grating filter.	(SCATTERED RADIATION): Less than 0.1 percent throughout its range.
TRANSMITTANCE ACCURACY	$\pm$.25 percent	0.2 percent
TRANSMITTANCE REPRODUCIBILITY	$\pm$.25 percent	0.2 percent

- - - - - -

5) Operation was then continued normally until completion of the tests.

6) To extinguish the Glower, the Variac voltage was lowered gradually until the Glower was of such a color/temperature that the current was insufficient to maintain the temperature. This generally occurred at about 40 volts across the transformer, and the time required was approximately 5 min.

Using this procedure the following operational results were obtained: Glower #1 operated approx. 130 hrs and ignited approx. 20 times; Glower #2 operated approx. 220 hrs. and ignited approx. 35 times. Glower #2 was still in good condition at the end of the tests. The electric circuit and the mounting of the Stupakoff Glower are shown in FIGURE 59 on page 13 .

With this source of greater energy it was possible to use the spectrometer over a wider effective range . Also the new model Golay Detector had a wider effective range of sensitivity than the earlier Golay Detector. The manufacturer specifies that the detector has "uniform sensitivity from the ultraviolet through the visible and the infrared to the micro-wave region". The improvement of the slit-width in operation is shown in TABLE 51, page 14 . The resolution of the instrument is shown in TABLE 52, page 15.

With these improved conditions it was possible to make measurements from about 0.7 to 15 microns without the change in prisms which had caused difficulties in operation in the work of the earlier contract.

The calculation of the drum readings into microns is shown in TABLE 53. pages 16. and 17.

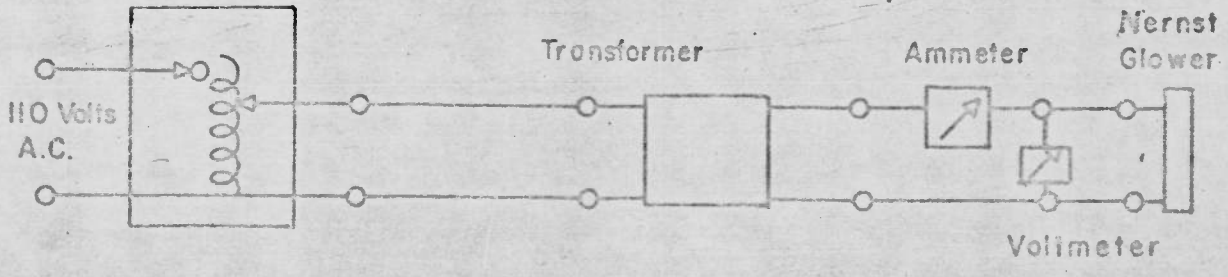
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c. RECOMMENDATION

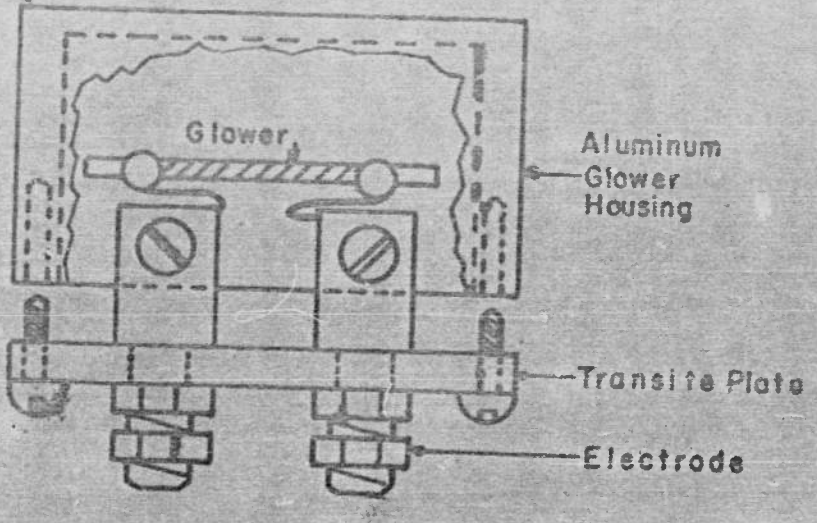
In looking ahead to possible further improvements it might be noted that the instrument might be easier to operate with the new constant energy drive system which Perkin-Elmer Corporation has brought to the market. This came too late to be included in the experimental work of the contract.

- - - - -

Fig. 59



ELECTRIC CIRCUIT OF STUPAKOFF GLOWER



MOUNTING OF THE STUPAKOFF GLOWER

TABLE 51.

SLIT WIDTHS USED WITH THE INSTRUMENTS

OPERATING WITH MODEL 12-C (SINGLE PASS)			WITH MODEL 112(DOUBLE PASS) AND WITH STUPAKOFF GLOWER	
WAVELENGTH MICRONS	EARLIER DEVELOPMENT: SLIT,MICRONS	I.MODEL OF THIS CONTRACT SLIT:MICRONS	WAVELENGTH-RANGE: MICRONS	FINAL MODEL: SLIT:MICRONS
0.5	----	200	----	-----
0.6	------	----	0.545 - 0.6 0.600 - 0.7	200 140
0.7	--------	100	0.7 - 0.85	90
0.8	--------	60	0.85 - 0.9	55
0.9	--------	---	0.9 - 1.02	35
1.0	---------	55	1.02 - 2.4	25
1.5	35	18		
2.0	35	18	2.4 - 2.9	25
3.0	35	18	2.9 - 4.0	29
4.0	65	23	4.0 - 4.5	38
5.0	90	55	4.5 - 5.5	49
6.0	250	72	5.5 - 6.45	70
7.0	350	94		
8.0	350	130	6.45 - 7.95	90
9.0	600	175	7.95 - 9.7	130
10.0	900	175		
11.0	900	240	9.7 -12.6	200
12.0	1400	330		
13.0	2000	550	12.6 - 13.7	400
14.0	2000	950	13.7 - 14.4	650
15.0	2000	2000	14.4 - 15.0	1400

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TABLE 52.

COMPARISON OF THE RESOLUTION OF THE INSTRUMENTS

WAVELENGTH (MICRONS)	BAND PASS OF THE SPECTROMETERS			
	MODEL 12 C		MODEL 112 T	
	MICRONS	ANGSTROMS	MICRONS	ANGSTROMS
1.0	---	---	0.00038	3.8
1.5	0.00895	89.5		
2.0	0.01625	162.5	0.0030	30.0
3.0	0.0260	260	0.00498	49.8
4.0	0.0520	520	0.00615	61.5
5.0	0.0630	630	0.00625	62.5
6.0	0.1190	1190	0.0062	62.0
7.0	0.1243	1243	0.00624	62.4
8.0	0.1020	1020	0.00635	63.5
9.0	0.1365	1365	0.0064	64.0
10.0	0.1720	1720	0.0072	72.0
11.0	0.1540	1540	0.0092	92.0
12.0	0.2195	2195	0.0130	130.0
13.0	0.2692	2692	0.0128	128.0
14.0	0.2490	2490	0.0212	212.0
15.0	0.2289	2289	0.0217	217.0

The Band Pass $\Delta\lambda$. was calculated using the following equation taken from the Instruction Manual for the Perkin Elmer Infrared Equipment Vol. I FIG 8B :

$$\Delta\lambda = \Delta\lambda_p + \Delta\lambda_{0.1} \times \text{Slit width}/0.1$$

Hereby is $\Delta\lambda_p$ the prismatic resolution for infinitely narrow slits

and $\Delta\lambda_{0.1}$ the incremental resolution for 0.1 MM slit width (Half energy spectral slit width)

The slit width used for the different wavelength ranges is given in TABLE 51, on page 14 of this report.

TABLE 53.

CALIBRATION OF THE PERKIN-ELMER MODEL 112 SPECTROMETER AT THE END OF WORK

DRUM READING	WAVELENGTH (MICRONS)	DRUM READING	WAVELENGTH (MICRONS)	DRUM READING	WAVELENGTH (MICRONS)
2480	0.412	2010	0.940	1540	7.55
2470	0.433	2000	0.975	1530	7.65
2460	0.446	1990	1.005	1520	7.75
2450	0.457	1980	1.050	1510	7.85
2440	0.465	1970	1.095	1500	7.95
2430	0.473	1960	1.140	1490	8.05
2420	0.480	1950	1.200	1480	8.15
2410	0.486	1940	1.285	1470	8.25
2400	0.492	1930	1.360	1460	8.35
2390	0.497	1920	1.450	1450	8.40
2380	0.501	1910	1.560	1440	8.50
2370	0.506	1900	1.690	1430	8.60
2360	0.511	1890	1.860	1420	8.70
2350	0.516	1880	2.040	1410	8.75
2340	0.520	1870	2.210	1400	8.85
2330	0.524	1860	2.420	1390	8.95
2320	0.529	1850	2.670	1380	9.00
2310	0.537	1840	2.870	1370	9.10
2300	0.545	1830	3.020	1360	9.15
2290	0.553	1820	3.210	1350	9.25
2280	0.560	1810	3.620	1340	9.35
2270	0.566	1800	4.01	1330	9.40
2260	0.572	1790	4.05	1320	9.50
2250	0.578	1780	4.18	1310	9.60
2240	0.583	1770	4.30	1300	9.70
2230	0.588	1760	4.50	1290	9.80
2220	0.593	1750	4.70	1280	9.85
2210	0.597	1740	4.95	1270	9.95
2200	0.601	1730	5.10	1260	10.00
2190	0.605	1720	5.25	1250	10.10
2180	0.609	1710	5.38	1240	10.20
2170	0.612	1700	5.50	1230	10.30
2160	0.616	1690	5.63	1220	10.40
2150	0.619	1680	5.78	1210	10.45
2140	0.621	1670	5.93	1200	10.50
2130	0.624	1660	6.05	1190	10.60
2120	0.680	1650	6.20	1180	10.70
2110	0.710	1640	6.33	1170	10.75
2100	0.725	1630	6.45	1160	10.80
2090	0.740	1620	6.58	1150	10.90
2080	0.760	1610	6.68	1140	11.00
2070	0.780	1600	6.80	1130	11.10
2060	0.800	1590	6.93	1120	11.15
2050	0.820	1580	7.05	1110	11.25
2040	0.845	1570	7.18	1100	11.30
2030	0.870	1560	7.28	1090	11.40
2020	0.900	1550	7.33	1080	11.45

(Continued on next page)

TABLE 53. (Continued)

DRUM READING	WAVELENGTH (MICRONS)
1070	11.55
1060	11.60
1050	11.65
1040	11.75
1030	11.80
1020	11.90
1010	11.95
1000	12.00
990	12.10
980	12.15
970	12.20
960	12.30
950	12.35
940	12.40
930	12.50
920	12.55
910	12.60
900	12.70
890	12.75
880	12.80
870	12.85
860	12.90
850	12.95
840	13.00
830	13.10
820	13.15
810	13.20
800	13.25
790	13.30
780	13.35
770	13.40
760	13.45
750	13.50
740	13.55
730	13.60
720	13.65
710	13.70
700	13.75
690	13.80
680	13.80
670	13.85
660	13.90
650	13.95
640	14.00
630	14.00
620	14.05
610	14.10
600	14.15
590	14.20
580	14.25
570	14.30
560	14.35
550	14.40
540	14.45
530	14.50
520	14.55
510	14.60
500	14.70
490	14.80
480	14.90
470	15.00

B. A STANDARD FOR DIFFUSELY REFLECTING SURFACES. UNCLASSIFIED

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a. STATEMENT OF THE PROBLEM

The instrumental procedure produces two instrumental curves on the recorder. One is for the infalling or illuminating beam which impinges on the Golay Detector and the other for the radiation reflected from the sample. Hereby, the detector window first is in position to receive the infalling beam; the position of the detector in the hemisphere is then rotated in such a manner that the sample attached to the detector receives the infalling beam, at the same angle, and the detector window collects the reflected radiation. (See Figure 60 below and Figures 34 and 35 in the Second Technical Report.) It is therefore possible to determine by calculation the ratio between these two curves for all wavelengths.

But in view of the limitations inherent in the use of the Coblentz Hemisphere in collecting what is expected to be the "total diffuse reflectance", it is necessary to compere the measured reflectance with a known standard of reflectance. In this manner a correction factor is established,



Figure 60. UNCLASSIFIED

a. Detector in position to receive the infalling beam.

b. Detector in position to receive the reflected beam from the sample or the standard.

for this particular set-up, by which the "total diffuse reflectance" may be calculated from the measured reflectance. The problem of the instrumental limitations have been discussed in the Second Technical Report, page 9 ff, and the question of errors has also been discussed on page 52 of the same report.

Therefore, it was necessary to provide for means of calculating from these ratio values the data which can be assumed to be the true percentual reflectance values of any given test specimen at the various wavelengths. This requires the determination of a "correction factor" for each wavelength based on the instrumental limitations as well as the difference between specularly reflecting surfaces and diffusely reflecting surfaces.

In the visible and very near-infrared range it has been the practice to compare the specular reflectance of a specimen with that of a rhodium mirror and to compare the diffuse reflectance of a specimen with the reflectance of freshly smoked magnesium oxide. At longer infrared wavelengths the use of magnesium oxide was not practical because of its low reflectance beyond approx. 2.7 microns. It was necessary, therefore, to find a different material which would provide a usable degree of constant and sufficiently high infrared reflectance in the range of the determinations which were in the scope of this project.

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b. STUDY OF SULFUR AS INFRARED REFLECTANCE STANDARD.

In the Fall of 1953, Agnew (1) pointed out this need for a diffuse reflectance standard for comparative measurements. He postulated that, for a radiation incident to the normal at an angle i, an ideal diffusely reflecting substance would approach a circular distribution of reflected

(1) Agnew, J.T. and McQuistan, R.B., JOSA, Vol. 43, p.999 (November 1953).

energy according to the relation:

$$I_{obs} = I_o \cos i \cdot \cos j$$

where the angle between the line of observation and the normal to the surface is j.

He made some measurements using for the angle i the constant angle of 45° and varying the angle j from +75° to -70°, except the range from 40° to 50°. Some metallics were studied, such as finely divided aluminum (up to 100-mesh), brass and small tin pellets. They were found to be more desirable than sandblasted aluminum, which has been considered under this current project. Some semi-metallics were studied, such as germanium powder, dark powder of lead (up to 100-mesh), lead oxide, selenium and tellurium. Of these the selenium appeared to be the most promising. Of the non-metallics, powdered sodium chloride, powdered glass and finely divided sulfur were tested. Of these, sulfur and sodium chloride had the most promising characteristics. Agnew concluded that the chemical nature and crystal structure have a pronounced effect on the diffuse reflectance characteristics of a given substance, even of the powdered materials; and he suggested that for further investigation the use of combinations of materials such as a layer of sulfur backed by a flat, highly reflecting surface such as polished aluminum should be studied.

In our current project a non-metallic standard appeared to be the most desirable one because of the non-metallic nature of the materials to be studied. Of the non-metallic materials it appeared most suitable to use a material which would not depend on its individual preparation, such as powdering, for its constant behavior. As a standard, it was desirable to

use a material which, under comparable conditions, would produce the same reflectance when applied at different times and by different operators. If variations of any important order should occur, it would be necessary to know the cause of these variations and how to avoid them.

Under the current contract the use of sulfur as a diffusely reflecting standard was investigated further. It was soon observed that two types of finely powdered sulfur had completely different reflectance characteristics. The Flowers of Sulfur showed desirable stability in reflectance during preliminary tests, while the colloidal sulfur dropped in reflectance to a considerable degree at 2.2 microns. A study was made to determine why this difference in reflectance between the two different forms of sulfur existed. First, three different forms of sulfur were considered. These were 1) a natural grown crystal of mineral sulfur, 2) colloidal sulfur (Fisher,Cat. No. S-597), and 3) sulfur flowers (Fisher,Cat. No. S-591). Of these , only the Flowers of Sulfur appeared to provide the necessary characteristics for a comparative reflectance standard.

The production methods of these three sulfurs were considered in an effort to better understand their behavior:

a. The sulfur crystal is the natural orthorhombic mineral having the following chemical and physical properties:

Hardness	1.5-2.5
Specific Gravity	2.05-2.09
Refractive Index	2.038
Fusible at	108°C.
Soluble in	CS_2

X-ray pattern shows normal symmetry.

b. The colloidal sulfur can be produced either by very fine powdering of sulfur or by chemical precipitation from certain sulfide solutions with subsequent purification.

c. Flowers of Sulfur is produced by heating sulfur to a point of sublimation. The sulfur vapor is allowed to expand into a large chamber in an atmosphere of sulfur dioxide and nitrogen. Here it cools rapidly and condenses into fine droplets which solidify to a product known as Flowers of Sulfur.

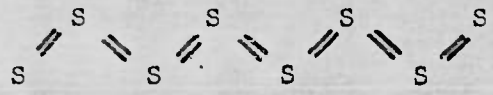
To understand this development chemically, the following approach has been taken (2). The natural crystalline sulfur is assumed to be the stable form of rhombic sulfur, or the Alpha sulfur. This term for the stable rhombic sulfur, which is soluble in carbon disulfide, differentiates it from the monoclinic crystalline Beta sulfur into which the Alpha sulfur changes at about 95°C. This too is soluble in carbon disulfide. If the solution is cooled below about 43°C, however, a portion of the sulfur becomes insoluble and seperates as Lambda sulfur, whereby Pi sulfur remains in solution at that temperature.

Amorphous metasulfur is a variety which is insoluble in carbon disulfide. It is obtained by rapidly cooling very hot molten sulfur or sulfur vapor to normal temperature and by then removing the soluble varieties by extraction with carbon disulfide. At normal temperatures the metasulfur remains stable, but at about 104°C. it changes quite quickly into the monoclinic form.

If sulfur is near its melting temperature, it is assumed to be primarily in a Lambda form or the molecular weight S_8 and in the molecular configuration of a ring.

(2) Tuller, W.N., "The Sulphur Data Book", McGraw-Hill Book Co., Inc, New York (1954)

In heating sulfur above 160°C, this S_8 ring opens up in quantity to form an open chain metasulfur, such as (3):



With rising temperature a polymerization of these open chains occurs and they reach their maximum length at about 187°C. ("viscous sulfur"). Beyond 187°C., depolymerization prevails increasingly with rising temperature until the boiling point is reached. At about 510°C. in the vapor state the value n in S_n represents an average of 6; at 700°C, the value S_n is S_2.

The vapor phase in the production of Flowers of Sulfur consists therefore of a mixture of short open-chain sulfur (principally S_8 and S_6) together with S_8 rings, H_2S and SO_2. Upon condensation to the liquid phase, the open-chain fragments polymerize rapidly as in viscous sulfur. Hereby, the presence of H_2S and other impurities causes chain terminating reactions with these impurities. Simultaneously another part of the substance matter crystallizes into the stable 8-membered ring of rhombic sulfur and, under the moderate temperature condition in the chamber, the long chain sulfur crystallizes into the mixed from of sulfur known as Flowers of Sulfur.

This made it understandable that the difference in infrared reflectance between colloidal or unsublimed sulfur and Flowers of Sulfur was caused by a true chemical difference. Since this difference resulted from the difference in production method, that is, by the one being heated into a vapor phase during production and the other being produced either by very fine powdering of sulfur or by chemical precipitation from certain sulfide solutions with subsequent purification, it appeared desirable to include a fourth sulfur specimen in the study, whose heating procedure and recovering method might cause an even more uniformly heated sulfur than

(3) Gee, G., TRANSACTIONS FARADAY SOCIETY, Vol.48,p.515-526 (1952).

had been available in the sulfur flowers. This sulfur was obtained as a material where the sulfur vapors are quenched by dissolving them in carbon disulfide. Hereby, the short open-chain fragments of the vapor polymerize in solution to a size sufficient to produce insolubility. The material of this kind which was taken for our experimental work was obtained as pure grade "Crystex" from the Stauffer Chemical Company, Research Division, in Chauncey, New York.

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2. THERMODYNAMICS

It is necessary here to point out the meaning of the term "amorphous" sulfur. Lange (4) described amorphous sulfur as a material with the formula S and having a molecular weight of 32.06. Monoclinic or rhombic sulfur is given as S_2 with a weight of 256.48.

Macaluso (5) describes vaporized sulfur as an amorphous sulfur in a highly polymerized form, having a molecular weight of approx. 200,000; while amorphous, insoluble sulfur is described as polydisperse, highly polymeric, straight-chain elastomers of sulfur atoms with chain endings of other elements. These may range from simple hydrogen to sulfuric acid groups, or even alkyl groups or their carbonates and related groupings. This sulfur, named R_2S_n, is chemically and thermally metastable and thermodynamically instable at ordinary temperatures.

Lange (4) defines normal sulfur, in a similar manner, as a "reversibly stable group of polymeric molecular compounds of sulfur atoms, namely S_8 rings and S_n chains, whose equilibrium composition is a function of temperature and pressure".

Since ring sulfur in the liquid phase is defined as Lambda sulfur, the term Mu sulfur has been introduced for the insoluble sulfur.

(4) Lange, N.A., "Handbook of Chemistry", 8th Ed., Handbook Publishers, Inc. Sandusky, Ohio.
(5) Macaluso, P., "The Chemistry of Sulfur", Report No. 25, (Sept. 26, 1951) Stauffer Chemical Co., Res. Department, Eastern Div., Chauncey, New York.

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d. SULFURS USED

Using now this terminology, the test specimens in our experimental work comprised the following:

1) A natural crystalline rhombic sulfur.

2) A "colloidal" sulfur which, inspite of its very small particle size, was primarily a rhombic sulfur.

3) Heat-transformed sublimed sulfur (Flowers of Sulfur), which contain up to 30% in the insoluble Mu form by the heat transformation.

4) Heat-vaporized and quenched high-polymer sulfur consisting of about 99.5% sulfur with 85% to 93% in the insoluble Mu form. These percentual limitations cover the difference between the commercial grades and the pure grade obtained for this study.

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e. X-RAY DIFFRACTION STUDIES

In further attempts to understand the sulfurs better some X-ray diffraction studies were made. The instrument which was used was the NORELCO X-ray Diffraction Spectrometer. (Appreciation is expressed here to Mr. Fred Behr of North American Philips Company, Mount Vernon, New York and to Mr. James A. Amick of the R.C.A.Laboratories in Princeton, New Jersey for their instrumental assistance in the question of defining the standard material.) The x-ray diffraction spectra are shown in Figures 61 to 65, p.26-30.

Here the colloidal sulfur (Fig. 61,p.26)and the sublimed sulfur (Figure 63, page 28) had similar spectra; but, in agreement with the chemical facts mentioned earlier, the Flowers of Sulfur showed a slight deviation from the spectrum of the colloidal sulfur in that some of the lines had less intensity than was the case with the specimen of colloidal sulfur.

Colloidal Sulfur

Cu Ka 50 Kv - 20 ma

Fig. 61.

X Ray Diffraction Spectrum X-1

Fig. 62.
X Ray-Diffraction Spectrum
X-2

Colloidal Sulphur
Preheated.

Cu Ka 50Ky -20 ma
2°/min 1°div - .006 rng.

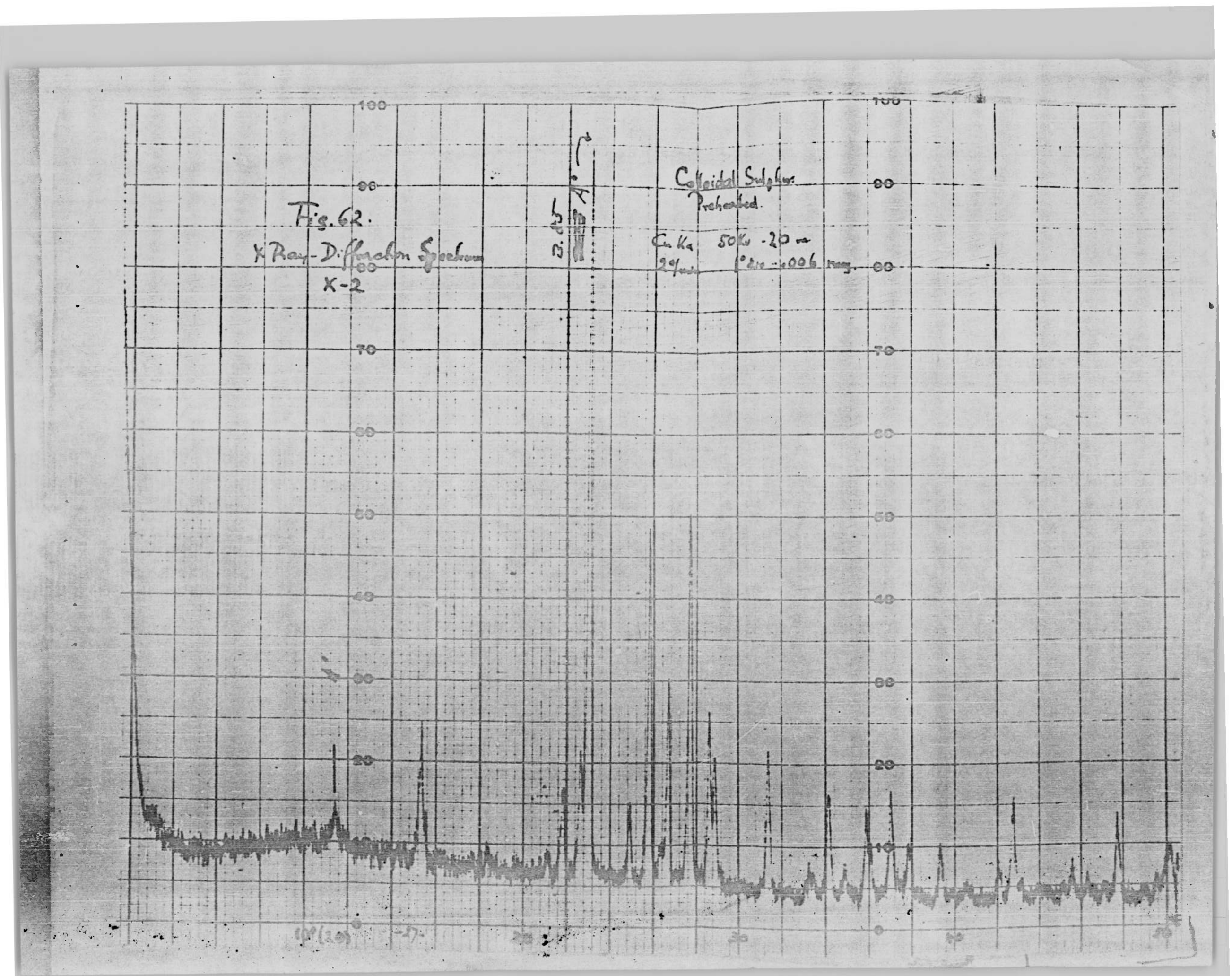


Fig 63

X Ray-Diffraction Spectrum of

Sulfur Sublimed N.F

(Sulfur flowers)

Circulation - Ka 35% · 20 ma

Scanning speed: 2° ... 1° ...

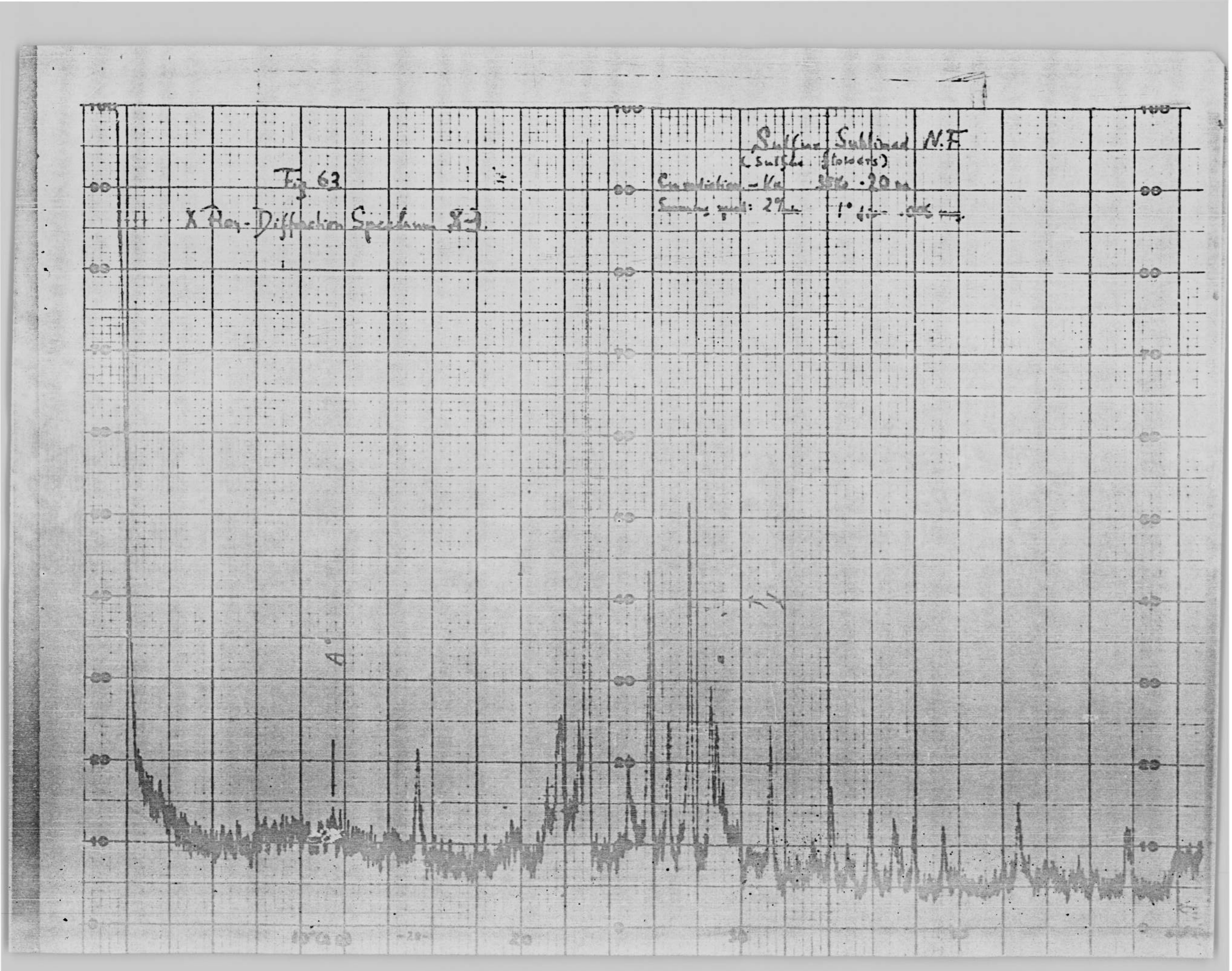


Fig 64

X Ray - Diffraction Spectrum

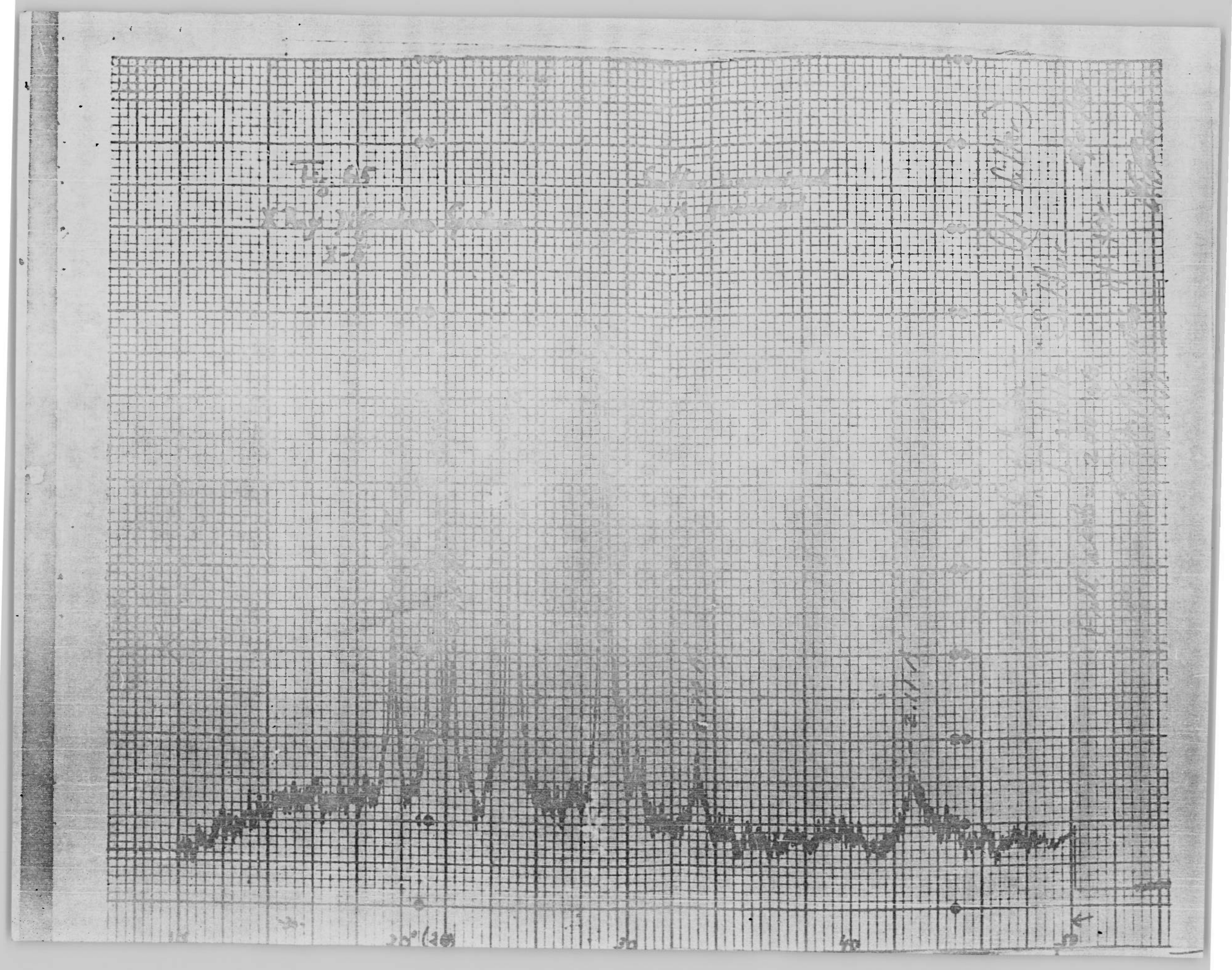
X-H

Sulphur Sublimed N.F.

(Sulphur flowers) - Precipitated

Cu K$_\alpha$ - 50 K$_v$ - 20 ma - 2°/min

1°/in - .006 rad.



An additional specimen had been produced by slowly heating the colloidal sulfur to a temperature just approaching the melting point of sulfur or to about 110°C. This was done because at around 96°C. the rhombic sulfur is being progressively transformed into the monoclinic sulfur. The specimen was then allowed to cool very slowly to room temperature. Its spectra (Figure 62.) showed a definite indication of broadening at the line appearing at 11.4 degrees. Otherwise, this specimen remained the same as the colloidal sulfur.

The same test was made on the sublimed sulfur. The spectrum is shown as Figure 64.

Proceeding to the insoluble Mu form sulfur (the vaporized and quenched form), the intensity relation between lines in the colloidal or in the sublimed sulfur and the lines in the insoluble sulfur were different. (Figure 65.). The Mu form sulfur showed strong lines in the spectrum which had not been present in the spectra of the other specimens. The meaning of the results have been expressed as follows: that"if sulfur of the insoluble type were present in the other samples, it was to a relatively small percent, less than 5% or so,and may not have been present at all". This corresponds to the fact that the "insoluble sulfur" specimen was one consisting of 85% to 93% of the Mu form. The colloidal sulfur in the original form and the one heated gradually to about 110°C. was not expected to contain the Mu form at all. The Flowers of Sulfur,with its estimated 30% Mu form sulfur content,had shown certain differences in intensity. Here the full content of Mu form had not shown up clearly enough in the X-ray diffraction spectrum to permit a quantitative estimate of the Mu form content to be made.

In connection with the X-ray diffraction study, the attempt was made to use electron diffraction methods also, by cooperation of R.C.A.; but here the finely divided sulfurs had the tendency of evaporating under the test conditions. Electron micrographs were taken, but they were not conclusive.

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C. THE CORRECTION FACTOR FOR DIFFUSELY REFLECTING SURFACES BASED ON THE SULFUR STANDARD.

Each of the four sulfurs was inserted in the sample holder next to the Golay Detector in the same manner as test specimens. The reflectance of each was determined, in the same manner as with other samples; and the ratio between values for the infalling beam and the reflected beam was determined.

Since the sublimed Flowers of Sulfur appeared to be especially suitable for our work, a series of four determinations were made; and the average taken. From these values, the curve "Flowers of Sulfur, average of 4 curves before correction factor" was obtained. This is shown in Figure S-1 at the end of this report.

The spectrum of the rhodium mirror was obtained and plotted before the application of any correction factor, as shown in Figure S-2.

Both of these curves were used in establishing the correction factors which were used on the applicable instrumental reflectance curves of the samples. The correction factors were obtained in order that they could be applied to all instrumental curves to obtain a final value that is more representative of a "total diffuse reflectance" measurement.

The rhodium mirror curve was used for determining a correction factor for materials which were of a similar type of specular reflectance

as the mirror. These were metal surfaces, application of unpigmented varnishes, etc. This factor was determined by comparing the curve shown for the rhodium mirror, point by point, with values obtained by the cooperation of the sponsoring agency and given in TABLE 54, page 34.

In the wavelength range to 2.7 microns, the rhodium mirror was measured relative to magnesium oxide.

In the same range, Flowers of Sulfur was measured also against magnesium oxide and the rhodium mirror (TABLE 55, pages 35 and 36.).

The measurement against magnesium oxide was calculated against the data for the absolute reflectance of magnesium oxide of Sanders and Middleton (6) (TABLE 56). The values obtained here were used as "total diffuse" reflectance values for the sulfur.

From the data on the rhodium mirror and the sulfur, two correction factors were determined: one for specularly reflecting specimens based on the ratio between the known reflectance data of the rhodium mirror of Table 54 and the measured reflectance data of the rhodium mirror shown in Figure S-2.

The resulting ratio data are given in TABLE 57 and were used as the correction factor for specimens of similar character.

The other factor was used for diffusely reflecting surfaces and was obtained as the ratio between the "total reflection of sulfur" in TABLE 55 and the measured average of four determinations given in FIGURE S-1.

The absolute data of the sulfur was not available over the entire range to 15 microns; but, since the ratio remained constant in the entire range except between 0.845 microns and 3 microns, the factor of 1.80 was applied to the wavelength region from 3 to 15 microns. This factor is

(6) Sanders, C. and Middleton, E.E.K., JOSA, Vol.43, p.58 (Jan 1953).

TABLE 54.

THE CALCULATION OF THE CORRECTION FACTORS I.

SPECTRAL REFLECTANCE OF THE RHODIUM MIRROR, AS USED IN THE CALCULATIONS.

WAVELENGTH IN MICRONS	REFLECTANCE IN %
0.4	72.5
0.6	76.3
0.8	81.0
1.0	82.0
1.2	84.6
1.4	86.4
1.6	87.6
1.8	98.4
2.0	90.5
2.4	91.4
3.0	92.0
3.5	92.5
4.0	93.0
5.0	94.1
6.0	94.5
7.0	94.8
8.0	95.1
9.0	95.3
10.0	95.5
11.0	95.5
12.0	95.5
13.0	95.5
14.0	95.5
15.0	95.5

THE DATA FROM 0.4 TO 2.0 MICRONS WERE OBTAINED FROM THE NATIONAL BUREAU OF STANDARDS, THE DATA FROM 5 TO 15 MICRONS FROM ERDL . (THE ERDL DATA FROM 0.4 TO 4 MICRONS DIFFERED NO MORE THAN 0.7% FROM THE NBS DATA).

TABLE 55. UNCLASSIFIED

THE CALCULATION OF THE CORRECTION FACTORS II.

(SPECTRAL REFLECTANCE MEASUREMENTS ON THE ERDL SPECTROPHOTOMETER WITH GLASS HEMISPHERE)

WAVELENGTH MICRONS	RHODIUM REL.MgO	FLOWERS OF SULPHUR REL. MgO	SULPHUR REL.RHOD.	SULPHUR:TOTAL DIFFUSE REFLECTANCE (USING ABSOLUTE MgO DATA OF SANDERS)
0.70	84.4	90.7	107.5	
0.72	84.8	91.2	107.5	88.1
0.74	85.2	91.5	107.2	
0.76	84.	91.0	106.5	87.7
0.78	84.3	91.4	107.	
0.80	85.2	91.8	107.	88.2
0.82	85.5	91.7	107.1	
0.84	85.	91.7	109.8	
0.86	85.9	92.3	107.3	88.4
0.88	86.4	92.7	107.1	
0.90	86.7	93.4	107.8	89.4
0.92	86.4	93.	107.8	
0.94	86 4	92.4	107.0	
0.96	86 8	93	107.2	88.7
0.98	86.5	92.	107.2	
1.00	87.	93.	107.	89.1
1.05	87.6	93.7	107.	89.6
1.10	88.4	94.1	106.3	90.1
1.15	88.8	94.4	106.2	
1.20	89.4	94.2	105.5	
1.25	90.	94.6	105.	
1.30	90.7	95	104.8	90.3
1.35	91.5	96.5	105.	
1.40	92.	95.8	104.1	
1.45	92.2	95.8	104.	
1.50	92.4	95.8	103.5	91.0
1.55	92.8	96.1	103.5	
1.60	93.2	96.1	103.	
1.65	94.5	97.1	102.5	
1.70	93.4	96.6	104.4	
1.75	95.8	97.5	101.8	
1.80	96.8	97.6	100.8	
1.85	97.7	99.1	101.5	
1.90	99.2	99.2	100	
1.95	100	100	100	94.1
2.00	100	100	100	94.2
2.05	99.2	99.2	100	
2.10	99.2	100	101	
2.15	99	100	101	
2.20	101	101.2	100.3	95.4
2.25	101.2	102.8	101.2	
2.30	102.5	103.8	101.2	

TABLE 55.(Continued)

THE CALCULATION OF THE CORRECTION FACTORS II(CONTINUED)

WAVELENGTH MICRONS	RHODIUM REL MgO	SULPHUR REL MgO	SULPHUR REL.RHODIUM	SULPHUR:TOTAL DIFFUSE REFLECT.
2.35	103.3	105.2	101.8	
2.40	103.2	105.	102.	
2.45	103.	105.8	102.2	99.5
2.50	103.7	106.5	102.8	
2.55	105.	107	101.8	
2.60	106.8	108.5	101.8	
2.65	112.8	114	101.2	

TABLE 56.

THE CALCULATION OF THE CORRECTION FACTORS III.

THE "ABSOLUTE" REFLECTANCE OF MAGNESIUM OXIDE ACCORDING TO THE DATA OF SANDERS AND MIDDLETON IN THE JOURNAL OF THE OPTICAL SOCIETY, JANUARY 1953:

(AVERAGE OF THREE SPECIMENS ONE DAY OLD).

WAVELENGTH (MICRONS)	REFLECTANCE %	WAVELENGTH (MICRONS)	REFLECTANCE %
0.60	97.1	1.87	94.2
0.64	96.9	1.91	94.0
0.68	96.7	1.95	94.1
0.72	96.6	2.00	94.2
0.76	96.4	2.04	94.2
0.80	96.2	2.08	94.2
0.85	96.1	2.12	94.2
0.89	96.1	2.16	94.2
0.93	96.0	2.20	94.2
0.97	95.9	2.24	94.0
1.01	95.75	2.28	93.6
1.05	95.7	2.32	93.3
1.09	95.6	2.37	93.2
1.13	95.5	2.41	93.3
1.17	95.4	2.45	94.0
1.22	95.3		
1.26	95.3		
1.30	95.2		
1.34	95.1		
1.38	94.9		
1.42	94.9		
1.46	95.0		
1.50	95.1		
1.55	95.1		
1.59	95.0		
1.63	94.9		
1.67	94.9		
1.71	94.9		
1.75	94.9		
1.79	94.6		
1.83	94.5		

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TABLE 57.

THE CALCULATION OF THE CORRECTION FACTORS IV

THE CORRECTION FACTORS FOR A SPECULARLY REFLECTING SURFACE (BASED ON THE RHODIUM MIRROR STUDIES).

DRUM READING	WAVELENGTH IN MICRONS	FACTOR
UP TO 2160	0.616	1.00
2150	0.619	1.01
2140	0.621	1.01
2130	0.624	1.03
2120	0.680	1.04
2110	0.710	1.05
2100	0.725	1.05
2090	0.740	1.06
2080	0.760	1.06
2070	0.780	1.06
2060	0.800	1.07
2050	0.820	1.07
2040	0.845	1.06
2030	0.870	1.06
2020	0.909	1.06
2010	0.940	1.05
2000	0.975	1.04
1990	1.005	1.03
1980	1.05	1.02
1970	1.095	1.02
1960	1.14	1.01
1950	1.20	1.01
1940	1.285	1.01
1930	1.36	1.01
1920	1.45	1.00
1910	1.56	1.00
1900	1.69	1.00
1890	1.86	1.00
1880	2.04	1.00
1870	2.21	1.01
1860	2.42	1.01
1850	2.67	1.02
1840	2.87	1.02
1830	3.02	1.03
1820	3.21	1.03
1810	3.62	1.03
1800	4.01	1.04
1790	4.05	1.04
1780	4.18	1.04
1770	4.30	1.05
1760	4.50	1.05
1750	4.70	1.05
FROM 1740 ON	4.95	1.06

tabulated in TABLE 58, page 40.

Applying the factor for diffusely reflecting media to the reflectance curve of sulfur shown in FIGURE S-1 and to the other sulfurs studied, the corrected reflectance curves are obtained as shown in FIGURES S-3 to S-6. FIGURE S-3 gives the sublimed sulfur (Flowers of Sulfur) and FIGURE S-4 the vaporized"insoluble" sulfur; that is, the two sulfurs which contain the Mu type sulfur.

FIGURE S-5 shows the colloidal sulfur, which is microrhombic sulfur; and FIGURE S-6 shows the natural sulfur crystal, which is quite uniform in reflectance throughout the test range but low in reflectance value and difficult to reproduce the surfaces in view of the character of the sulfur crystals.

As comparative standard in studies on diffusely reflecting surfaces, the sulfurs which contain the Mu form are quite constant until past 10 microns with a typical absorption band between 10.5 and 12.5 microns and with a dropping off beyond 13.4 microns. As the Mu type sulfur becomes more readily available in great purity, it might later replace the Flowers of Sulfur, which is used as comparative standard in the present study. But as FIGURES S-3 and S-4 show, such a change between the two sulfurs will have little effect on the various determinations given in this report.

For comparison, FIGURE S-7 shows the spectrum of the magnesium oxide powder with its sharp drop between 2 and 3 microns. This curve has been made from chemically pure magnesium oxide because it was not feasible to use the area close to the salt window of the Golay Detector for producing freshly smoked magnesium oxide without possible damage to the window. It was also impractical to produce the freshly smoked magnesium oxide outside the instru-

TABLE 58.

THE CALCULATION OF THE CORRECTION FACTORS V.

THE CORRECTION FACTORS FOR A DIFFUSELY REFLECTING SURFACE (BASED ON THE SULPHUR STUDIES .)

DRUM READING	WAVELENGTH IN MICRONS	FACTOR
UP TO 2040	to 0.845	1.81
2030	0.870	1.80
2020	0.900	1.79
2010	0.940	1.76
2000	0.975	1.74
1990	1.005	1.70
1980	1.050	1.69
1970	1 095	1.68
1960	1.140	1.67
1950	1.200	1.67
1940	1.285	1.67
1930	1.360	1.67
1920	1.450	1.66
1910	1.560	1.66
1900	1.690	1.66
1890	1.860	1.67
1880	2.040	1.67
1870	2 210	1.68
1860	2.420	1.69
1850	2 670	1.70
1840	2.870	1.72
FROM 1830 ON	3.020	1.80

ment and then insert it into the small area without damage to the uniformity of the surface.

The question remained which of the two correction factors would apply to certain surfaces which might have a slight semi-gloss and would appear to be between the specular and the diffusely reflecting substances.

For comparison, studies were made using the Beckman Spectrometer with Reflection Attachment on these surfaces. Its characteristics are well known and have been discussed in the Supplement , page 3 , of the Final Report of the preceeding contract (DA-44-009-eng-652). Where an agreement between the Beckman and the Perkin-Elmer was to be expected, both factors were applied and showed the following:

a) To pigmented finishes of some degree of hiding power, the diffuse reflection factor is to be applied. The diffuse reflection factor applied also to such complex matter as leaves of trees where the beam penetrating the specimen surface is entering a network of substance matter which gives them the diffusely reflecting characteristic.

b) In cases where the hiding power is so low that the film is transparent in the visible range, and where the specimen is applied on a specularly reflecting surface, such as polished aluminum, the specular factor had to be applied. This refers, for instance, to a dispersion of 325-mesh Mica in alkyd resin on polished aluminum or similar materials.

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MEASUREMENT OF BACKGROUND MATERIALS

a. INTRODUCTION

In an evaluation of camouflage materials it is of primary importance to know the reflection spectrum of the background materials studied under corresponding conditions. The number of possible background materials is so great that within the scope of this project a limited number of groups only have been studied in the hope that from these some deductions of a wider scope may be made.

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b. TESTS

The original work program included therefore a number of green leaves, coniferous twigs, dry leaves, dry grass, ten different soils and sands, and three barks of trees. During the course of the work it was necessary to make some seasonal modifications; and it was also necessary to omit some tests on wet leaves because of the proximity of the sample to the salt window of the Golay Detector. In collecting the plant specimens, the project had the cooperation of the New York Botanical Garden; and they were selected as they were available within the scope of the suggestions expressed by the Contracting Officer. The specimens which have been studied are listed in TABLE 59. Their spectrum charts are shown as Figures 2-1 to 2-21 at the end of the report.

c. DISCUSSION OF RESULTS.

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In making two determinations at different times for the various specimens, it became evident that there were variations in the reflectance of leaves of the same branch of a tree ; but in the case of most green leaves this refers only to the region below 3 microns. (Figures 2-1, 2-2, 2-3). At wavelengths beyond 3 microns, these differences are of a minor order . An exception to this was the pressed, dormant maple leaf where there were some variations beyond 4 microns (Figure 2-5). This variation, however, is assumed to result from variations in the pressure applied on different

TABLE 59.

LIST OF BACKGROUND MATERIALS TESTED

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CONTRACT POSITION	MATERIAL	SPECTRUM CHART NO.
# 2 a	YOUNG WILLOW LEAF (SALIX FRAGILIS), DRY TOP SIDE	FIG 2-2
# 2 b	GREEN MAPLE LEAF (ACER RUBRUM, EASTERN NORTH AMERICA) WET TOP SIDE	NOT FEASIBLE
# 2 c	HOLLY LEAF DRY. (ILEX ALTACLARENSIS) TOP SIDE	FIG 2-3
	SAME BOTTOM SIDE	FIG 2-4
# 2 d	GREEN MOUNTAIN LAUREL (KALMIA LATIFOLIA) DRY TOP SIDE	FIG 2-1
# 2 e	GREEN OAK LEAF WET	NOT FEASIBLE
# 2 f	GREEN CONIFEROUS TWIGS (JACK PINE, PINUS BANKSIANA), NORTHEASTERN AMERICA DRY	FIG 2-7
# 2 g	SAME WET	NOT FEASIBLE
# 2 h	PRESSED DORMANT MAPLE LEAF DRY (ACER RUBRUM) EASTERN NORTH AMERICA	FIG 2-5
# 2 i	OAK LEAF, WINTER COLOR, DRY, TOP SIDE (QUERCUS BOREALIS MAXIMA, EASTERN NORTH AMERICA)	FIG.2-6
# 2 j	GRASS. DRY (MEADOW FESCUE)	FIG.2-8
# 2 k	SOIL, SAND # 18 (MAINAMANU SILT LOAM, HAWAII)	FIG 2-9
	# 70 (BARNES FINE SILT LOAM, S.D.)	FIG.2-10
	# 72 (GOOCH FINE SILT LOAM, ORE.)	FIG.2-11
	# 89 (VEREENIGING, AFRICA)	FIG.2-12
	# 113 (MAURY SILT LOAM, TENN.)	FIG.2-13
	# 115 (DUBLIN CLAY LOAM, CALIFORNIA)	FIG.2-14
	# 117 (GRADY SILT LOAM, GEORGIA)	FIG.2-16
	# 186 (FULLMAN LOAM, N.M.)	FIG.2-15
	# 195 (COLTS NECK LOAM, N.J.)	FIG.2-17
	B (MESITA NEGRA-LOWER TEST SITE)	FIG.2-18
# 2 l	BARK: RED OAK (QUERCUS BOREALIS MAXIMA)	FIG.2-19
	BARK: JACK PINE (PINUS BANKSIANA)	FIG.2-20
	BARK: COLORADO SPRUCE (PINUS PONDEROSA)	FIG.2-21

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areas of the leaf surface due to the veins.

Certain differences were also observed on different specimens of the same sand (Figures 2-9, 2-14). Some tests were made to determine the reason for this; and it was found that this is caused by differences in the particle size distribution in different samples taken from a sand. This was concluded from the following observations:

1) Different sands react to slight differences in packing of the sample to a different degree (See Figures 20, 21, 22 in the Second Technical Report).

2) Sieving a sand, that is, changing its particle size distribution, also affects its reflectance.

The differences were in the percent reflectance in certain wavelength ranges and not in the general course of the curve. The curve was therefore plotted as the medium between the determinations.

The barks of trees followed the same general reflection pattern as the leaves.

Measurements were made on absorption by attaching the leaves to the entrance slit of the monochromator. Here, the transmitted energy was so low that the results were within the error limits of the instrument; and the results are not shown in the Figures. In the case of the coniferous twigs and barks, it was not possible to obtain any useable results.

Table 59 shows that measurements on wet leaves were infeasible. This was because the distance between the sample and the salt window in the Golay Detector is only one-sixteenth of an inch and the wetness might easily interfere with the use of the salt window.

d. CONCLUSION

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In comparing all the reflection spectra of these background materials

with the paints and pigment dispersions in Paragraphs 3 and 4 of the contract, it is evident that these background spectra do not correspond to any of the paints on polished aluminum because of the high reflection peaks of the paints on aluminum in the 3 to 6 micron region.

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3. THE EFFECT OF PIGMENT PARTICLE SHAPE ON THE WATER PENETRATION AND THE RESULTING CHANGES ON THE INFRARED REFLECTANCE OF A CAMOUFLAGE PAINT.

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a. INTRODUCTION

Paint chemists have brought up the question repeatedly whether or not certain pigment particle shapes can influence the water penetration characteristics of an applied pigmented paint. It has been pointed out especially that platy pigments can orientate themselves in a paint film with their flat surfaces parallel to the paint surface, thus forming a moisture barrier in the paint. In this respect, platy mica has been introduced as a part of the pigmentation in house paints, in transformer coatings and in other applications. It was therefore of interest to study whether or not the particle shape of pigments in general will have an influence on the camouflage characteristics of pigmented paints when their reflectance in the infrared is measured in dry, in wet, and in recovered condition.

b. WORK PROGRAM

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The contract provided, therefore, for a study of the effect of pigment particle shape on the water penetration and the resulting changes in the infrared characteristics of a camouflage paint. Hereby, each selected shape was used as 100% pigment in the vehicle; and the paint was applied on aluminum and on black background. The paints were then studied with respect to their infrared characteristics under the following conditions:

a) The dry paint.

b) The paint after 4 hrs. water immersion (increased to 72 hrs.).

c) The paint after 24 hrs. water immersion (increased to 72 hrs).

d) The paints which showed the greatest resistance to water immersion

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in b) and c) should be immersed also in 5% NaCl for 24 hrs SECRET spectral reflectance curve determined again.

e) All immersed panels allowed to dry at 30°C. for 24 hrs. and then tested again.

f) The two coatings with pigment particle shapes showing the highest and the lowest moisture penetration mixed 1:1 with chromium oxide in a coating employing the same vehicle as used before and the coating tested in similar manner as before.

g) The two pigments of different particle shape which showed the greatest resistance to moisture penetration in the vehicle used before used again as 100% pigment content in a second vehicle which belongs to the group of water emulsion type camouflage paints.

As the work progressed, it became evident that with respect to b) and c) the influence of the 4 hr. and the 24 hr. water immersion on the reflectance of dried paints was of a very minor order. The period of water immersion was increased therefore to 72 hrs. With respect to d) test results showed that the attack of the salt water in 24 hr. immersion was not as great as had generally been expected.

Furthermore, it became evident that it is not enough to compare two pigments with respect to their particle shape alone. Where possible, pigments under comparison should be of similar hiding power or chemical characteristics. For this reason, the number of pigments studied was increased. The index of the spectra obtained is given in TABLE 60, pages 48-50. The paint composition is given in TABLE 61, pages 51 and 52.

c. DISCUSSION OF RESULTS

SECRET CONFIDENTIAL In comparing the various curves to the pigments studied under Paragraph 3 of the contract, it is evident that no paint tested eliminated

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TABLE 60.

INDEX OF SPECTRUM CHARTS

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CONTRACT POSITION	PARTICLE SHAPE	PIGMENT	BINDER	PAINT	TESTED ON		FIGURE No.
Par. 3(1)	SPHEROIDAL	RED SYNTHETIC IRON OXIDE(MAPICO RED #347)(IRON OXIDE II)	ALKYD RESIN (REZYL #387)	2	ALUMINUM	DRY	3-1
						IMMERSED 72 HRS.	3-1
						RECOVERED	3-1
					BLACK	DRY	3-2
						IMMERSED 72 HRS.	3-2
	SPHEROIDAL	ZINC OXIDE II (XX 503)	ALKYD RESIN (REZYL #387)	15		RECOVERED	3-2
					ALUMINUM	DRY	3-3
						IMMERSED 72 HRS.	3-3
						RECOVERED	3-3
					BLACK	DRY	3-4
						IMMERSED 72 HRS.	3-4
						RECOVERED	3-4
Par. 3(2)	HEXAGONAL	ALUMINUM SILICATE (ASP 100)	ALKYD RESIN (REZYL #387)	10	ALUMINUM	DRY	3-5
						IMMERSED 72 HRS.	3-5
						RECOVERED	3-5
					BLACK	DRY	3-6
						IMMERSED 72 HRS.	3-6
						RECOVERED	3-6
	HEXAGONAL	WHITE LEAD SPECIAL TYPE	ALKYD RESIN (REZYL #387)	16	ALUMINUM	DRY	3-7
						IMMERSED 72 HRS.	3-7
						RECOVERED	3-7
						IN SALTWATER(3-d)	3-7
					BLACK	DRY	3-8
						IMMERSED 72 HRS	3-8
						RECOVERED	3-8
		THIS MATERIAL HAS BEEN USED ALSO IN a)MIXED COMPOSITION b)WITH AN EMULSION BINDER.				IN SALTWATER(3-d)	3-8

TABLE 60. (CONTINUED)

CONTRACT POSITION	PARTICLE SHAPE	PIGMENT	BINDER	P/V	TESTED ON		FIGURE No.
Par. 3(3)	PLATY	WET GROUND MICA 325-MESH	ALKYD RESIN (REZYL #337)	9	ALUMINUM	DRY	3-9
						IMMERSED 72 HRS.	3-9
						RECOVERED	3-9
					BLACK	DRY	3-10
						IMMERSED 72 HRS.	3-10
						RECOVERED	3-10
	PLATY	IT IS TO BE NOTED THAT THE HEXAGONAL ALUMINUM SILICATE (FIGURES 3-5 and 3-6) IS IN A PLATY CONDITION ALSO, BUT THE PARTICLES ARE MORE IRREGULAR IN THICKNESS THAN THOSE OF WET GROUND MICA (FIGURES 3-9 and 3-10).					
Par. 3(4)	ACICULAR	RED SYNTHETIC IRON OXIDE (MAPICO #516 DARK)	ALKYD RESIN (REZYL #337)	1	ALUMINUM	DRY	3-11
						IMMERSED 72 HRS.	3-11
						RECOVERED	3-11
					BLACK	DRY	3-12
						IMMERSED 72 HRS.	3-12
						RECOVERED	3-12
	ACICULAR	ZINC OXIDE I (XX 601)	ALKYD RESIN (REZYL #337)	8	ALUMINUM	DRY	3-13
						IMMERSED 72 HRS.	3-13
						RECOVERED	3-13
					BLACK	DRY	3-14
						IMMERSED 72 HRS.	3-14
		THIS ACICULAR ZINC OXIDE I HAS BEEN USED IN MIXED PIGMENTATION ALSO.				RECOVERED	3-14
Par. 3(5)	CUBICAL	RED SYNTHETIC IRON OXIDE (MAPICO#110-A) (IRON OXIDE I)	ALKYD RESIN (REZYL #337)	3	ALUMINUM	DRY	3-15
						IMMERSED 72 HRS.	3-15
						RECOVERED	3-15
					BLACK	DRY	3-16
						IMMERSED 72 HRS.	3-16
		THIS PIGMENT WAS USED IN AN EMULSION BINDER ALSO.				RECOVERED	3-16
Par. 3-f(6)	MIXED PIGMENTATION I.	ACICULAR ZINC OXIDE I (XX 601) WITH CHROME OXIDE X1134	ALKYD RESIN (REZYL/337)	17	ALUMINUM	DRY	3-17
						IMMERSED 72 HRS.	3-17
						RECOVERED	3-17
					BLACK	DRY	3-18
						IMMERSED 72 HRS.	3-18
						RECOVERED	3-18

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TABLE 60. (CONCLUDED)

CONTRACT POSITION	PARTICLE SHAPE	PIGMENT	BINDER	PAINT	TESTED ON		FIGURE No.
Par. 3-f(6)	MIXED PIGMENTATION II.	HEXAGONAL WHITE LEAD WITH CHROME OXIDE X 1134	ALKYD RESIN (REZYL #387)	18	ALUMINUM	DRY	3-19
						IMMERSED 72 HRS.	3-19
						RECOVERED	3-19
					BLACK	DRY	3-20
						IMMERSED 72 HRS.	3-20
						RECOVERED	3-20
Par. 3-g	IN ACRYLIC RESIN EMULSION I.	RED SYNTHETIC IRON OXIDE (MAPICO 110-2)	ACRYLIC RESIN EMULSION (RHOPLEX AC-33)	19	ALUMINUM	DRY	3-21
						IMMERSED 72 HRS.	3-21
						RECOVERED	3-21
					BLACK	DRY	3-22
						IMMERSED 72 HRS.	3-22
						RECOVERED	3-22
Par. 3-g	IN ACRYLIC RESIN EMULSION II	HEXAGONAL WHITE LEAD	ACRYLIC RESIN EMULSION (RHOPLEX AC-33)	20	ALUMINUM	DRY	3-23
						IMMERSED 72 HRS.	3-23
						RECOVERED	3-23
					BLACK	DRY	3-24
						IMMERSED 72 HRS.	3-24
						RECOVERED	3-24

FOR COMPARISON THE FOLLOWING WERE ADDED:

REFLECTANCE OF THE POLISHED ALUMINUM PANELS (WASHED WITH ETHYL ACETATE)	3-25
REFLECTANCE OF AN ALKYD COATING ON BLACK (SHOWING THE EFFECT OF THE BLACK UNDERCOAT ON AN UNPIGMENTED FILM).	3-26
REFLECTANCE OF AN ALKYD COATING ON ALUMINUM	3-27

COMPOSITION OF THE BLACK UNDERCOAT (A LINSEED-ALKYD BASED BLACK PAINT)

PIGMENTATION:	CARBON BLACK	41.2%
	MAGNESIUM SILICATE	58.8%
VEHICLE:	LINSEED ALKYD RESIN	50.6%
	MINERAL SPIRITS	47.4%
	DRIERS	2.0%

ITS BECKMAN REFLECTANCE READINGS FOR 4 SPECIMENS IS GIVEN IN TABLE 38 OF THE THIRD TECH. REPORT.

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TABLE 61.

TEST PAINTS USED IN THIS REPORT UNCLASSIFIED

PAINT NUMBER	PIGMENT USED	LBS/GAL.	COMPOSITION
1	Acicular red iron oxide: Mapico #516 dark.	37.65	120 parts red iron oxide. 200 parts alkyd resin 55% solids Rezyl resin #387-5 120 parts xylene.
2	Spheroidal red iron oxide: Mapico red #347. (Referred to as Iron Oxide II.)	43.15	120 parts red iron oxide 200 parts alkyd resin 55% solids Rezyl resin #387-5 100 parts xylene.
3	Cubical red iron oxide: Mapico Red 110-2. (Referred to as Iron Oxide I)	41.98	120 parts red iron oxide 200 parts alkyd resin 55% solids Rezyl resin #387-5 105 parts xylene.
4 & 5	Numbers omitted.		
6	Chrome Green I: Vale green A 4444.	33.8	97 parts chrome green. 200 parts alkyd resin 55% solids Rezyl resin #387-5. 90 parts xylene.
7	Chrome Green II: Hudson green A-701.	33.8	97 parts chrome green. 200 parts alkyd resin 55% solids Rezyl resin #387-5 90 parts xylene.
8	Acicular Zinc Oxide: XX 601.	47.0	132 parts zinc oxide. 200 parts alkyd resin 55% solids Rezyl resin #387-5 100 parts xylene.
9	Platy wet ground mica 325-mesh.	23.49	66 parts mica 200 parts alkyd resin 55% solids Rezyl resin #387-5 115 parts xylene.
10	Hexagonal aluminum silicate. ASP 100.	21.5	60.5 pts. aluminum silicate 200 parts alkyd resin 55% solids Rezyl resin #387-5. 86 parts xylene.
11	Colored titanium dioxide I (MP 860-15.)	estimate 35.0	99 parts MP 860-15 200 parts alkyd resin 55% solids Rezyl resin #387-5. 25 parts xylene.
12	Colored titanium dioxide II. (MP 860-13)	35.0	99 parts MP 860-13 200 parts resin 55% solids Rezyl resin #387. 70 parts xylene.

(Continued on next page)

TABLE 61 (Concluded)

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PAINT NUMBER	PIGMENT USED	LBS/GAL.	COMPOSITION
13	Colored zinc oxide I. Y-1784	46.0	131 parts colored zinc oxide I. 200 parts alkyd resin 55% solids Rezyl resin #387 85 parts xylene.
14	Colored zinc oxide II. D-31	46.0	101 parts colored zinc oxide II. 154 parts alkyd resin 55% solids Rezyl resin #387 55 parts xylene.
15	Spheroidal zinc oxide. XX 503	47.0	132 parts zinc oxide. 200 parts alkyd resin 55% solids. Rezyl resin #387 100 parts xylene.
16	Hexagonal white lead.	56.0	156 parts hexagonal white lead. 200 parts alkyd resin 55% solids. Rezyl resin #387
17	Mixture of Acicular zinc oxide XX601 and Chrome oxide X 1134.	- -	66 parts zinc oxide * 49 parts chrome oxide 200 parts alkyd resin 55% solids Rezyl resin #387.
18	Mixture of Hexagonal white lead and Chrome oxide X 1134.	- -	79 parts hexagonal white lead. * 49 parts chrome oxide. 200 parts alkyd resin 55% solids Rezyl resin #387.
19	Cubical red oxide (110-2) in emulsifiable paint.	41.98	80 parts iron oxide 140 parts acrylic resin emulsion Rhoplex AC-33) 50 parts water.
20	Hexagonal white lead in emulsifiable paint.	56.0	92 parts hexagonal white lead. 121 parts acrylic resin emulsion Rhoplex AC-33) 20 parts water.

* Mixed 50:50 by volume.

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fully the differences in the reflectance of the background in [illegible] range to 7 microns. In all cases the reflectance on aluminum was greater than the reflectance on black. It is especially clear that none of the paints was capable of eliminating the higher reflectance area between 3.5 and 5.8 microns on polished aluminum.

The differences between the pigment groups are summarized as follows:

(1) Spheroidal red iron oxide and spheroidal zinc oxide II on aluminum and on black (FIGURES 3-1 to 3-4): In all tests for the dry paints, the paints after 72 hrs. water immersion, and for the recovered paints after 24 hrs. air drying, the variations caused by the water immersion were of minor order.

(2) Hexagonal aluminum silicate (a pigment extender without any practical hiding power) and hexagonal white lead (a pigment having a high degree of hiding power) (FIGURES 3-5 to 3-8): The water penetration effect on the diffuse reflectance curves was of minor order. However, the great difference in hiding power of these two pigments is evident from the fact that the alkyd paint with aluminum silicate on aluminum has such a high specular reflectance, which is caused from the reflectance of the aluminum background, that the correction factor for specular surfaces (based on the rhodium mirror) was applied. With the white lead pigmented paints, the diffuse reflection factor was used.

(3) Platy mica extender (FIGURES 3-9 and 3-10): The hiding power of this material was of such a low order that the specular correction factor had to be applied. The platy mica and the hexagonal aluminum silicate behaved differently from the other pigments in that they showed practically no hiding power. It is to be pointed out that the hexagonal aluminum silicate has a

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tendency to break into [illegible] but these aluminum silicate fragments are more irregular in thickness than the mica particles. Therefore, it could have been expected that the mica pigmented paint would show a measurable higher degree of moisture penetration than the aluminum silicate paint; but in both cases the moisture resistance was so great that 72 hrs. immersion in water did not produce differences in the reflectance of the two immersed paints.

(4) Acicular iron oxide and acicular zinc oxide I: (FIGURES 3-11 to 3-14): These pigments and the cubical pigments tested showed greater effect of the water immersion on the reflectance spectra than the pigments of (1), (2), and (3), especially when tested on polished aluminum. With acicular iron oxide, the recovered paint appears as a lowered reflectance in the 1.5 to 2.7 micron area where it drops from about 80% reflectance to about 60%; and in the 4 to 5 micron region it drops from about 65% reflectance to about 50%. Between 2.9 and 3.2 microns and 5.7 and 7.0 microns, the reflectance remained unchanged. The acicular zinc oxide II on aluminum shows a flattening of the reflectance peaks below 2.7 microns, but the recovery characteristics around 4 and 5 microns are considerably better than for the acicular iron oxide.

(5) Cubical iron oxide (FIGURES 3-15 and 3-16): This pigment showed the greatest change between the dry and the wet paint of any of the pigments which were studied. The dry paint had a large reflection peak between 3.3 and 5.8 microns which reached its maximum at 4.9 microns. After 72 hrs. water immersion, this peak was not there; but it appeared again after the paint was dried for 24 hrs.as a lower peak. The peak dropped from 77% reflectance for the dry paint before water immersion to 62% reflectance for the recovered paint.

(6) Mixed pigments: The contract provided that one pigment of the group which shows considerable water effect and one pigment which shows little effect from water should be mixed with chromium oxide and used as mixed pigmentation. For this, acicular zinc oxide was selected as being most affected by moisture; and hexagonal white lead was selected as being least affected by moisture penetration. In this selection, only pigments of good hiding power were considered. The curves are shown in FIGURES 3-17 to 3-20). The acicular zinc oxide with chromium oxide and alkyd binder shows a drop in reflectance between 4.5 and 5.2 microns from 80% for the dry paint to about 70% for the paint after 72 hrs. water immersion. The recovered paint shows 62% reflectance in the same wavelength region. The hexagonal white lead with chromium oxide and alkyd binder shows negligible variation in reflectance. The paints on black background show less variation in these tests than the paints on polished aluminum.

(7) Acrylic resin emulsion paints: The reflectance levels are lower for these paints than for the other paints studied; and therefore the differences in reflectance were less evident. (FIGURES 3-21 to 3-24). Nevertheless, the cubical iron oxide in acrylic resin emulsion dropped in reflectance in the wavelength region between 4.5 and 5.5 from around 50% to 40% reflectance. The reflectance of the wet paint was lower and did not show greater reflectance after 24 hrs. drying . In the case of hexagonal white lead in acrylic resin emulsion, the hiding power in this region is so great that the reflectance on aluminum remained below 21% beyond 3.2 microns. This paint loses reflectance during immersion and recovery in the 1.0 to 2.0 micron region where the maximum reflectance drops from about 75% to below 70%. Generally, the emulsion paints tested were affected very little in their

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reflectance spectra by the 72 hr. immersion test.

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SECRET The study of the effect of pigment particle shape on water penetration and the resulting changes in the infrared reflectance of a camouflage paint has shown:

a) That reflectance measurements can be used in comparing the effect of water immersion on paints.

b) That the water resistance of the paints differed with different particle shapes.

Since these studies had to be made on paints on aluminum or some other solid base, it was not possible to measure in these cases the changes in absorption also, because the painted panels were not suitable for use as absorption samples in the Perkin-Elmer Spectrometer. Some studies on absorption were made on free paint films (See pages 62 ff.); but it was found that paints having the high pigment /volume concentration required in these studies at the required film thickness of 1 mil have so little transmission (in the case of any of the hiding pigments tested) that the variations caused by water immersion and recovery would fall within the limits of error of the instrument.

To obtain absorption spectra of unsupported films, very thin one-coat paint films had to be selected where it is difficult to measure any variations in film-thickness between different areas of the film. Since the reflection spectra showed the water immersion effect, the fact that the parallel absorption studies were infeasible in these cases was felt to be of no specific importance.

That the paints on black background showed less effect than on aluminum in their infrared reflectance is discussed on page 61 .

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4 A. HIDING POWER AND EFFECTIVE REFLECTANCE OF PIGMENTS AND PAINTS.

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1. STATEMENT OF THE PROBLEM

As originally planned the program included a study of the relationship between the index of refraction , the hiding power, and the reflection characteristics of certain pigments and paints as a function of wavelength. A thorough investigation revealed no practical or accurate method for the determination of the index of refraction of the dark pigments, especially in the infrared region of the spectrum. As a result only the hiding power of the paints and pigments was studied.

In industry the hiding power of a paint is measured in the visible range only and the reflectance of an applied paint on a white background and on a black background is determined in one specific angle only. As a light source a lamp of a wide wavelength range is used and no effort is made to select one limited wavelength range for a measurement. From the measurement of the reflectance on white background and on black background, the hiding power is determined as

$$\frac{\text{Percent Reflectance over Black.}}{\text{Percent Reflectance over White.}} \times 100.$$

During the current study the hiding power of the pigments and paints was studied in a similar manner except that a substance of high reflectance in the far infrared was selected. Since white paint has a low infrared reflectance at the longer wavelengths, polished aluminum was used as one background material. A black paint was used for the black background.

The contract required that the studies should be made on

a) Two colored zinc oxides having different hiding power.

b) Two chrome greens having different hiding power.

c) Two iron oxides having different hiding power.

d) Two colored titanium dioxides having different hiding power.

e) One paint using the same vehicle for each of these pigments.

2. EXPERIMENTAL. UNCLASSIFIED

The pigments which were selected are listed in TABLE 62 . The zinc oxides and the titanium dioxides were selected from knowledge about their general hiding characteristics obtained under the previous contract with the Sponsor. The chrome greens and the iron oxides were selected as examples of their groups having different hiding power, according to information from their manufacturers. The work consisted, therefore, in first studying the reflectance of the eight pigments in the infrared range to 15 microns, and then preparing paints of the same pigment/volume concentration and applying them in a thickness of 1 mil on polished aluminum and on a black undercoat.

After making these determinations, the reflectance values obtained using the correction factors for diffusely reflecting surfaces had to be calculated in the point-by-point application of the equation:

$$\text{Hiding Power} = \frac{\text{Percent Reflectance over Black.}}{\text{Percent Reflectance over Aluminum.}} \times 100.$$

Since the change from the Perkin-Elmer Model 12-C to the Model 112 Spectrometer had become necessary during the work, this report gives the spectra charts which were determined with each of these instruments. Also, the rhodium mirror standard was replaced by the new sulfur standard for diffusely reflecting surfaces during the course of the work.

In the curves presented in this report, all measurements which were were made with the single-pass Model 12-c are calculated with the rhodium mirror correction factor. The measurements made with the single-beam, double-pass Model 112 were calculated using the correction factor for diffusely reflecting surfaces. The calculations of the ratio between the reflectance of the paints on black to that on polished aluminum were based on the measurements

TABLE 62.. UNCLASSIFIED

INDEX TO THE CHARTS OF THE PIGMENTS AND PAINTS TESTED UNDER PARAGRAPH 4.

	SINGLE PASS INSTRUMENT AND SPECULAR CORRECTION FACTOR	DOUBLE PASS INSTRUMENT AND DIFFUSE CORRECTION FACTOR.
PIGMENTS:		
COLORED ZINC OXIDE I (Y-1784)	FIGURE 4-1	FIGURE 4-9
COLORED ZINC OXIDE II (D-31)	FIGURE 4-2	FIGURE 4-10
CHROME GREEN I (A 4444)	FIGURE 4-3	FIGURE 4-11
CHROME GREEN II (A 701)	FIGURE 4-4	FIGURE 4-12
SYNTHETIC IRON OXIDE I (MAPICO RED 110-2)	FIGURE 4-5	FIGURE 4-13
SYNTHETIC IRON OXIDE II (MAPICO RED 347)	FIGURE 4-6	FIGURE 4-14
COLORED TITANIUM DIOXIDEI(MP860-15)	FIGURE 4-7	FIGURE 4-15
COLORED TITANIUM DIOXIDE·II (MP 860-13)	FIGURE 4-8	FIGURE 4-16
PAINTS:		
COLORED ZINC OXIDE I (PAINT #13)		
ON BLACK	FIGURE 4-17	FIGURE 4-33
ON ALUMINUM	FIGURE 4-18	FIGURE 4-34
COLORED ZINC OXIDE II (PAINT #14)		
ON BLACK	FIGURE 4-19	FIGURE 4-35
ON ALUMINUM	FIGURE 4-20	FIGURE 4-36
CHROME GREEN I (PAINT #6)		
ON BLACK	FIGURE 4-21	FIGURE 4-37
ON ALUMINUM	FIGURE 4-22	FIGURE 4-38
CHROME GREEN II (PAINT #7)		
ON BLACK	FIGURE 4-23	FIGURE 4-39
ON ALUMINUM	FIGURE 4-24	FIGURE 4-40
IRON OXIDE I (PAINT #3)		
ON BLACK	FIGURE 4-25	FIGURE 4-41
ON ALUMINUM	FIGURE 4-26	FIGURE 4-42
IRON OXIDE II (PAINT #2)		
ON BLACK	FIGURE 4-27	FIGURE 4-43
ON ALUMINUM	FIGURE 4-28	FIGURE 4-44
COLORED TITANIUM DIOXIDE I(PAINT #11)		
ON BLACK	FIGURE 4-29	FIGURE 4-45
ON ALUMINUM	FIGURE 4-30	FIGURE 4-46
COLORED TITANIUM DIOXIDE II(PAINT #12)		
ON BLACK	FIGURE 4-31	FIGURE 4-47
ON ALUMINUM	FIGURE 4-32	FIGURE 4-48

RATIOS BETWEEN REFLECTANCE ON BLACK AND ON ALUMINUM (HIDING POWER):

COLORED ZINC OXIDE I (Y-1784)	FIGURE 4-49
COLORED ZINC OXIDE II (D-31)	FIGURE 4-50
CHROME GREEN I (A 4444)	FIGURE 4-51
CHROME GREEN II (A 701)	FIGURE 4-52
SYNTHETIC IRON OXIDE I(RED 110-2)	FIGURE 4-53
SYNTHETIC IRON OXIDE II (RED 347)	FIGURE 4-54

(Continued on next page)

INDEX TO THE CHARTS OF THE PIGMENTS AND PAINTS TESTED UNDER PARAGRAPH 4.

	SINGLE PASS INSTRUMENT AND SPECULAR CORRECTION FACTOR	DOUBLE PASS INSTRUMENT AND DIFFUSE CORRECTION FACTOR.
RATIOS BETWEEN REFLECTANCE ON BLACK AND ON ALUMINUM (HIDING POWER)(CONT'D):		
COLORED TITANIUM DIOXIDE I (MP 860-15)		FIGURE 4-55
COLORED TITANIUM DIOXIDE II (MP 860-13)		FIGURE 4-56
TRANSMISSION MEASUREMENTS ON THIN FREE FILMS OF THE TEST PAINTS:		
COLORED ZINC OXIDE I (PAINT #13)		FIGURE T-1
COLORED ZINC OXIDE II (PAINT #14)		FIGURE T-2
CHROME GREEN I (PAINT #6)		FIGURE T-3
CHROME GREEN II (PAINT #7)		FIGURE T-4
IRON OXIDE I (PAINT #3)		FIGURE T-5
IRON OXIDE II (PAINT #2)		FIGURE T-6
COLORED TITANIUM DIOXIDE I (PAINT #11)		FIGURE T-7
COLORED TITANIUM DIOXIDE II (PAINT #12)		FIGURE T-8

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with the new Model 112 using the new correction factor for diffusely reflecting surfaces only. The spectra are presented as FIGURES 4-1 to 4-48 at the end of this report.

3. COMMENT. CONFIDENTIAL SECRET Comparing the reflection spectra of two pigment types, each based on the curve obtained with the same instrument and using the same correction factor, group by group, there is no indication that one type of pigment which has a greater hiding power in the visible range than another pigment necessarily has a greater hiding power in the infrared also. Where there are differences, such as between colored zinc oxide I (Figure 4-9) and colored zinc oxide II (Figure 4-10), these differences might just as well be caused by chemical differences between the two pigments. In the case of iron oxide I (Figure 4-13) and iron oxide II (Figure 4-14), the two pigments have comparable chemical characteristics but have different pigment particle shape (cubical and spheroidal), and the influence of these factors might well influence the spectrum differences as well.

Studying the paints based on different pigments of comparable shade but different visible hiding power, the effective hiding power appears clearly as a difference in the degree to which the paint background (aluminum or black) will show through. The study clearly shows that normal paint thicknesses are quite transparent to different infrared wavelengths. For instance, comparing the intensity of reflection on aluminum at 4.8 microns, zinc oxide I paint (Figure 4-34) has about 50% higher reflectance than zinc oxide II (Figure 4-36). Since this reflection peak is not visible on black, this difference is a result of the difference in hiding power, at least at this wavelength. That is, zinc oxide II has twice the capacity to cover the aluminum as zinc oxide I. Similar calculations show the same to be true on other points of the spectrum.

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The same approach can be used on the same wavelength basis on paints based on the two iron oxides and applied on aluminum. In both investigations, the reflectance at 4.5 microns is approximately 20% lower in the case of Iron Oxide I paint (cubical) than with Iron Oxide II paint (spheroidal). That is, Iron Oxide I has 20% more power to cover the reflection of the aluminum than Iron Oxide II (Figures 4-42 and 4-44). Likewise, Titanium Dioxide I paint at the wavelength of 4.8 microns has in both studies between 20% and 22% more capacity to cover the aluminum than the Colored Titanium Dioxide II (Figures 4-46 and 4-48).

Thus different pigments may be compared by comparing the aluminum coverage of their paints at the same wavelength point, such as 4.8 microns or other specific points. This method of measuring the reflectance, wavelength by wavelength, on a highly reflecting background appears to be a better expression of hiding power than the ratio figure for the visible region. These ratios have been determined up to 15 microns and are shown in FIGURES 4-49 to 4-56. This ratio depends on the presence of lines in the spectrum of the paint either on aluminum or on black, and this causes variations between different curve points; but the curves show that the often expressed assumption of a drop in hiding power before 3 microns is not necessarily true for the rest of the infrared spectrum. The calculated ratio curves of Figures 4-49 to 4-56 show good agreement with independent studies on the transmission of unsupported films prepared from the same paints.

B. TRANSMISSION STUDIES ON UNSUPPORTED PAINT FILMS.

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In order to determine the transmission of a paint film independent of a supporting base the following method was used:

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1) Each of the paints of Paragraph 4 of the contract was applied in a film thickness of approx. 1 mil on the gummed surface of brown gummed paper, which was mounted on a glass panel in such a manner that it covered the glass on all sides. In this manner the paint could not run to the uncoated side of the paper.

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2) The paint on the brown paper was then dried in an oven at 50°C. and then at 90°C. for 30 min.

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3) The paper was then removed from the glass and cut into strips which were immersed in lukewarm water.

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4) After the water has penetrated the paper to the film, the film loses its adherence to the paper; and the films were then washed free of any remaining traces of gum with water and soft cotton.

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5) The paint films were then suspended and allowed to dry over night .

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6) The film could then be used in tests by attaching it directly to the entrance slit of the monochromator and the transmitted radiation measured.

When the film thickness of 1 mil was used in the tests, the transmission spectra remained so low that it was generally within the limits of error for the instrumentation. In order to get a measurable degree of transmission, other films were prepared using paint which was thinned; and in this manner a very thin paint film was obtained. Since in these thin layers, any difference in film thickness on different points of the film would amount to a considerable percentage of the total film thickness, an attempt was made to apply a second thin coat over the first coat after it had dried. These specimens were marked in the curves as one-coat or two-coat films (Figures T-1 to T-8). Here, also, the two-coat films have a very low transmission; nevertheless, Titanium Dioxide II (Paint #12) had to be

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shown as a two-coat film (Figure T-8), since the one-coat [illegible] have enough strength to be removed from the gummed paper and handled as an unsupported film.

Generally, it has been found that in testing the paint film in a film thickness of 1 mil, the measurable transmission for the instrument beam is extremely low and remains within the limits of error for the Perkin-Elmer Spectrometer even with the use of the Stupekoff Glower with its high energy . This is in agreement with our attempts to measure the transmission through natural films such as green leaves, grass or bark.

The very thin paint films which were prepared were tested for their transmission and the results were compared with the hiding power curves which had been obtained by calculating the reflection spectra of the same paints in 1 mil thickness ober black and over polished aluminum.

C. COMPARING THE TRANSMISSION AND THE HIDING POWER CURVES.

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In spite of the fact that working with very thin films can cause considerable variation in film thickness and therefore in transmission, the differences in two test runs on two different spots of the film were quite close in this study.

In comparing the transmission curve of Zinc Oxide I (Figure T-1) with the hiding power curve (Figure 4-49) for the same material obtained by determining the ratio of the reflection on black and on aluminum multiplied by 100, the following results were found:

WAVELENGTH	HIDING POWER	TRANSMISSION
3.0 to 5.5 microns	High	Low
5.5 to 6.0 microns	High	Low
Around 9.0 microns	High	Low
Around 12 microns	Low	Increased

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The Red Iron Oxide I shows less transmission (Figure [illegible]) as indicated by the drop in hiding power at around 3.0 microns to 5 microns (Figure 4-53) and again around 12.0 microns. This must be caused by the slightly thicker one-coat film.

The agreement between the calculated hiding power curves (Figures 4-51 and 4-52) and the measured transmission curves for the chrome greens (Figures T-3 and 4) is also close, as shown below:

WAVELENGTH	HIDING POWER	TRANSMISSION
2.0 to 6.0 microns	Low	Increased
6.5 to 13.0 microns	High	Low
13 to 15 microns	Low	Increased

Again the comparison between the hiding power and the transmission curves show how much the transmission reading of such thin films vary with slight variations in film thickness, which can not be controlled at this time.

The Colored Titanium Dioxide I (Figures T-7 and 4-55) shows the following characteristics:

WAVELENGTH	HIDING POWER	TRANSMISSION
3.5 to 7.0 microns	Low	High
13 to 15 microns	High	Low

This manner of agreement between two different and independent methods of determination confirms the finding that the hiding power of these pigments and paints is not of a constant low order, as had often been assumed for the infrared region; and that the hiding power of pigments and paints is definitely a function of wavelength and must be considered for camouflage purposes.

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IV. CONCLUSIONS

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The following conclusions may be made from the work on the project:

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1) A satisfactory instrument together with a method has been developed for the measurement and evaluation of the infrared reflectance of camouflage materials.

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2) A new standard for comparing its infrared reflectance with that of diffusely reflecting camouflage materials has been developed. It is a finely divided form of Mu sulfur and is to be present to at least about 30% or more in the test specimen of the finely divided sulfur used. Two sulfurs have been used successfully, one being Flowers of Sulfur (with about 30% Mu form), the other being a vaporized and quenched sulfur (with 85% -93% Mu form).

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3) The water penetration of camouflage paints of the alkyd and emulsion types is dependent upon the pigment selection and upon the pigment particle shape.

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4) Generally the spheroidal, hexagonal and platy pigments showed higher resistance to water penetration than the acicular and cubical shapes.

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5) The effect of water immersion of 4 to 24 hrs. had very little effect on the reflection spectrum of alkyd resin and of acrylic resin emulsion paints. Only a slight lowering in reflectance was noted after 72 hrs. of immersion.

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6) The hiding power of camouflage pigments and paints tested is definitely a function of wavelength and must be considered so for camouflage purposes in the infrared to 15 microns.

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7) No colored paint tested accomplished complete hiding when applied in approx. 1 mil dry film thickness on a highly reflecting aluminum surface and tested in all infrared wavelengths to 15 microns.

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8) Very low reflectance in the infrared region, especially beyond 3 microns, can be achieved by applying camouflage paints over a black primer which will approach the low reflecting characteristics of most background materials beyond 3 or 4 microns.

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V. RECOMMENDATIONS

It is recommended that

UNCLASSIFIED

1) The information contained in the reports of this contract be used as a basis for camouflage purposes in the infrared region of the spectrum.

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2) Consideration be given to a two-coat system where feasible in order to utilize the transperency in the infrared region of the outer camouflage coating.

UNCLASSIFIED

3) Primer materials be utilized which combine good rust inhibiting qualities with the desired infrared reflecting characteristics.

PIGMENTS USED	SUPPLIER'S DESIGNATION	SUPPLIER
RED SYNTHETIC IRON OXIDE		
Acicular	#516 dark.	Columbian Carbon Co., Mapico Color Division, Trenton, N.J.
Spheroidal	#347	Same.
Cubical	#110-2	Same.
CHROME GREEN		
I. Vale Green	#A 4444	Imperial Paper and Color Corp. Pigment Color Division Glens Falls, N.Y.
II. Hudson Green	#A-701	Same.
ZINC OXIDE (WHITE)		
Acicular type	XX 601	New Jersey Zinc Co., Palmerton, Pa.
Spheroidal type	XX 503	Same.
PLATY WET GROUND MICA	325-mesh	The English Mica Co., Stamford, Conn.
HEXAGONAL ALUMINUM SILICATE	ASP 100	Edgar Brothers Company, Metuchen, N.J.
ZINC OXIDE (COLORED)		
I.	Y-1784	ERDL, Fort Belvoir, Va.
II.	D-31	Same.
TITANIUM DIOXIDE (COLORED)		
I.	MP 860-15	ERDL, Fort Belvoir, Va.
II.	MP 860-13	Same.
HEXAGONAL WHITE LEAD	- -	National Lead Co., Research Laboratories, Brooklyn, N.Y.
CHROME OXIDE	X 1134	Imperial Paper and Color Corp. Pigment Color Division Glens Falls, N.Y.
VEHICLES USED		
Alkyd resin 55% solids. Rezyl Resin #387		American Cyanamid Co., New York 20, N.Y.
Acrylic resin emulsion. Rhoplex AC-33		Rohm and Haas Company, Philadelphia, Pa.

801818

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1827

100
80
60
001
40
20
0
100
002
80
60
40
20

Flowerslot Sulfur
Average of 4 Curves
Before Correction Factor

Fe K$\alpha_{1,2}$

Wavelength, Kilo-rons

Shoulder Peaks
(Uncorrected)

UNCLASSIFIED

003

Sulfur Sublimed M.F.
(Sulfur Flowers)
Avg. of 4 Curves
Corrected Reflectance Curve

100
80
60
40
20
0

Wavelength, Microns

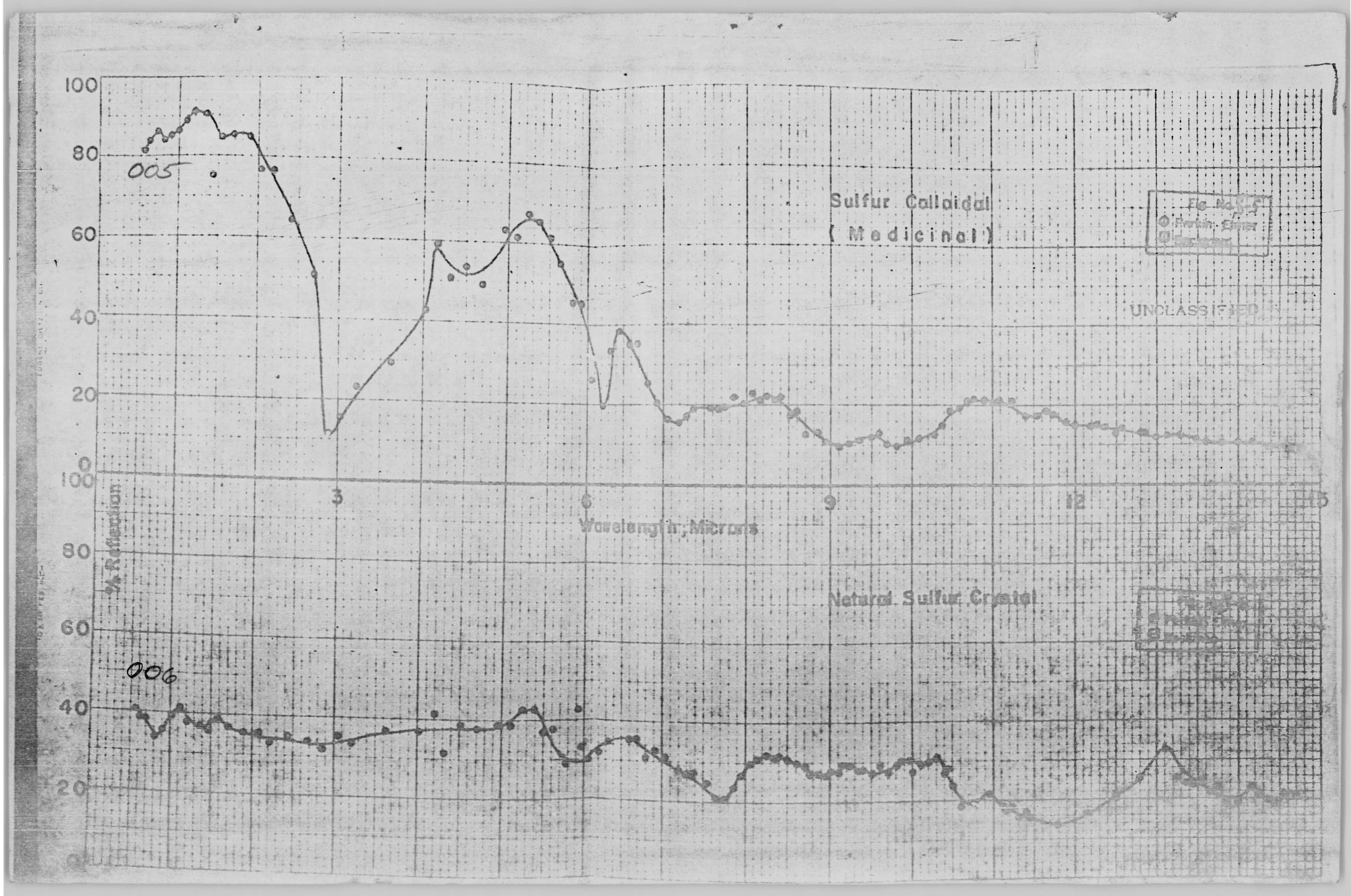
5
6
9
12

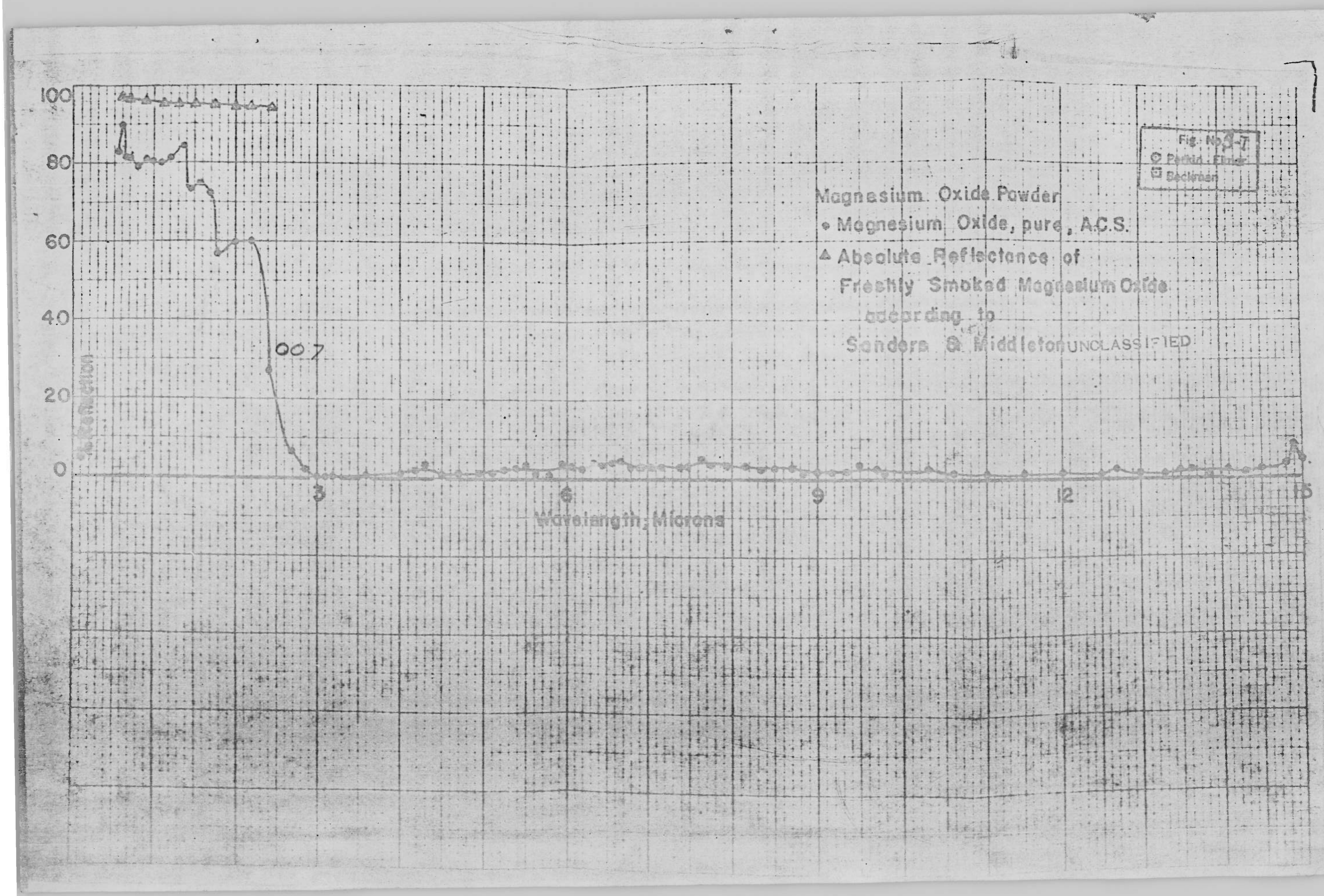
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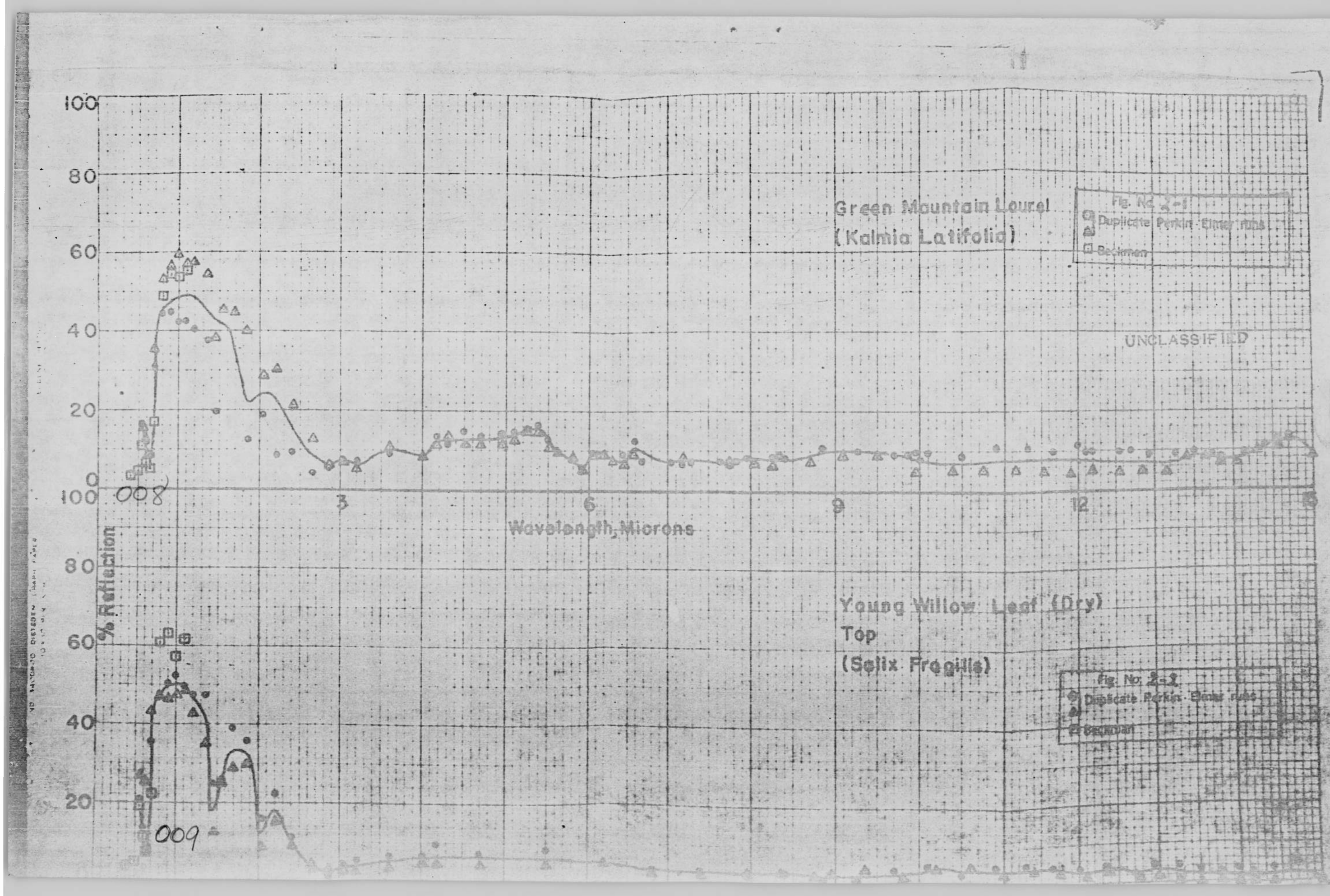
004

Sulfur Vaporized and Quenched
Corrected Reflectance Curve

100
80
60
40
20


100
80
60
40
20
0
005
Sulfur Colloidal
(Medicinal)
UNCLASSIFIED
3
6
9
12
15
Wavelength; Microns
% Reflection
Natural Sulfur Crystal
006


Fig. No. 3-7
© Perkin-Elmer
⊡ Beckman
Magnesium Oxide Powder
• Magnesium Oxide, pure, A.C.S.
△ Absolute Reflectance of
Freshly Smoked Magnesium Oxide
according to
Sanders & Middleton
UNCLASSIFIED
007
100
80
60
40
20
0
% Reflection
3
6
9
12
15
Wavelength, Microns


100
80
60
40
20
0
100
80
60
40
20
% Reflection
3
6
9
12
Wavelength, Microns
Green Mountain Laurel
(Kalmia Latifolia)
Fig. No. 2-1
Duplicate Perkin-Elmer runs
Specimen
UNCLASSIFIED
008
009
Young Willow Leaf (Dry)
Top
(Salix Fragilis)
Fig. No. 2-2
Duplicate Perkin-Elmer runs
Specimen

Holly Leaf (Dry)
Top
(Ilex Altaclarensis)

Fig. No. 1-3
Duplicate Perkin-Elmer (dot)
Beckman

UNCLASSIFIED

100
80
60
40
20
0

010

3
6
9
12

Wavelength, Microns

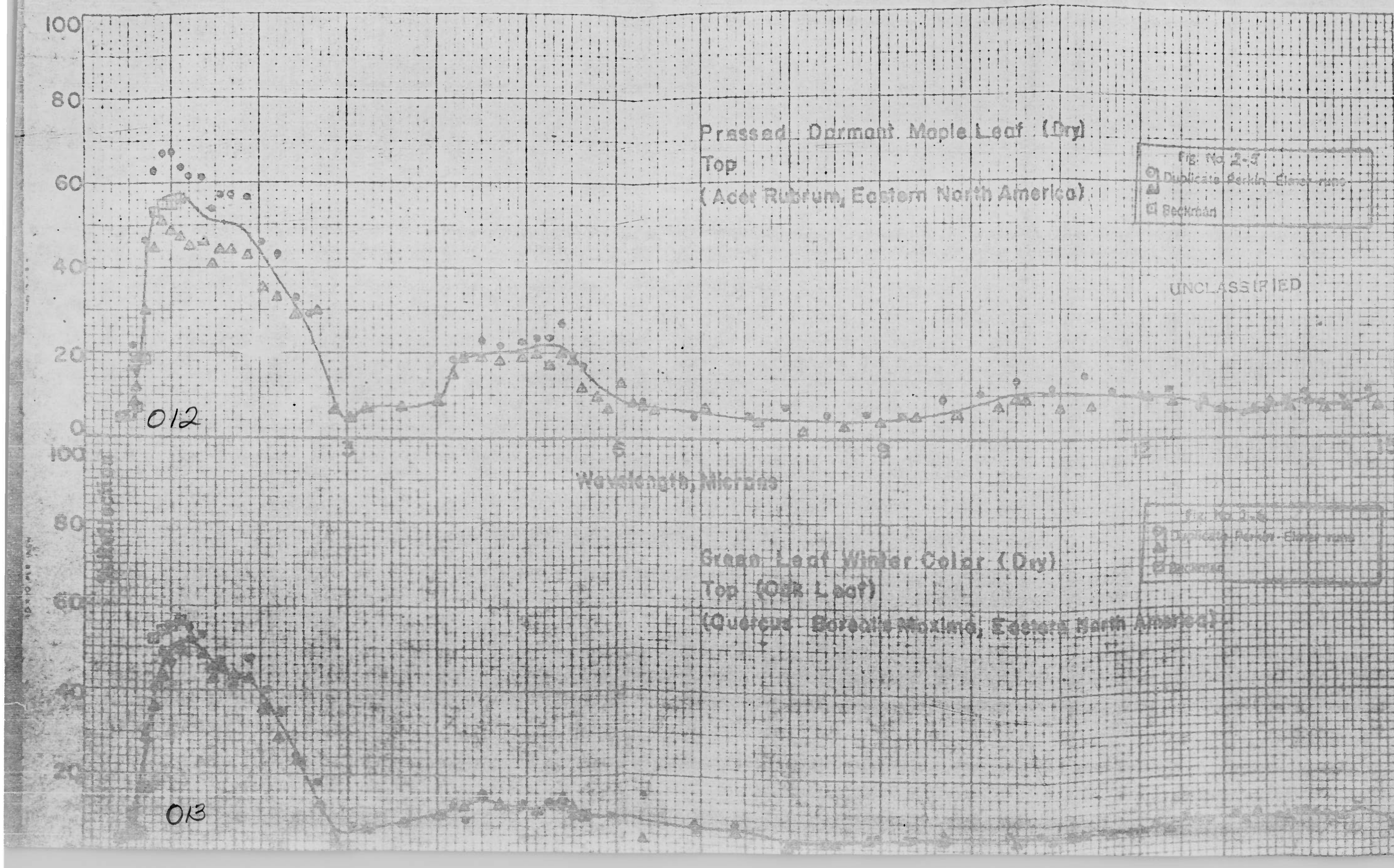
% Reflection

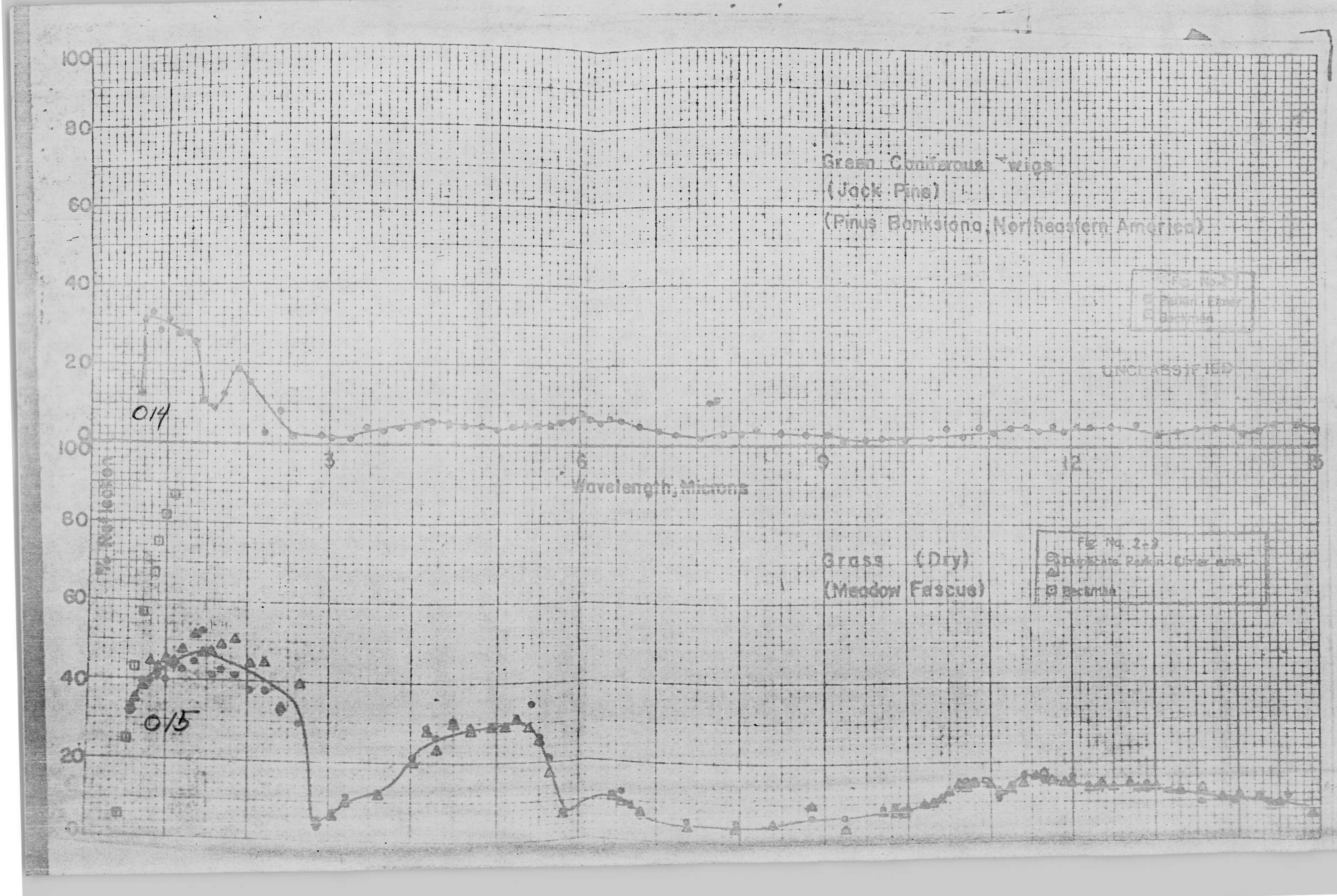
100
80
60
40
20

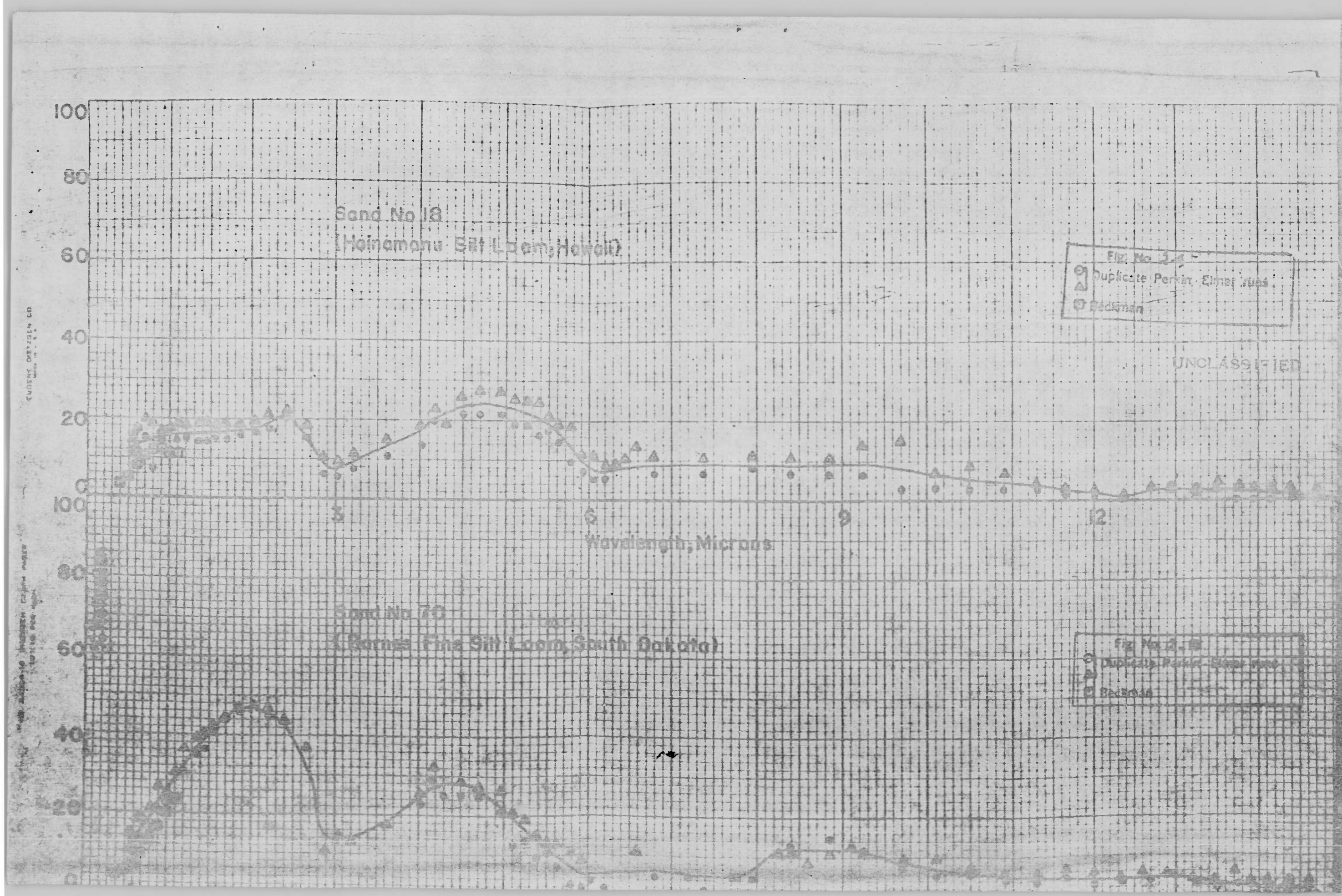
011

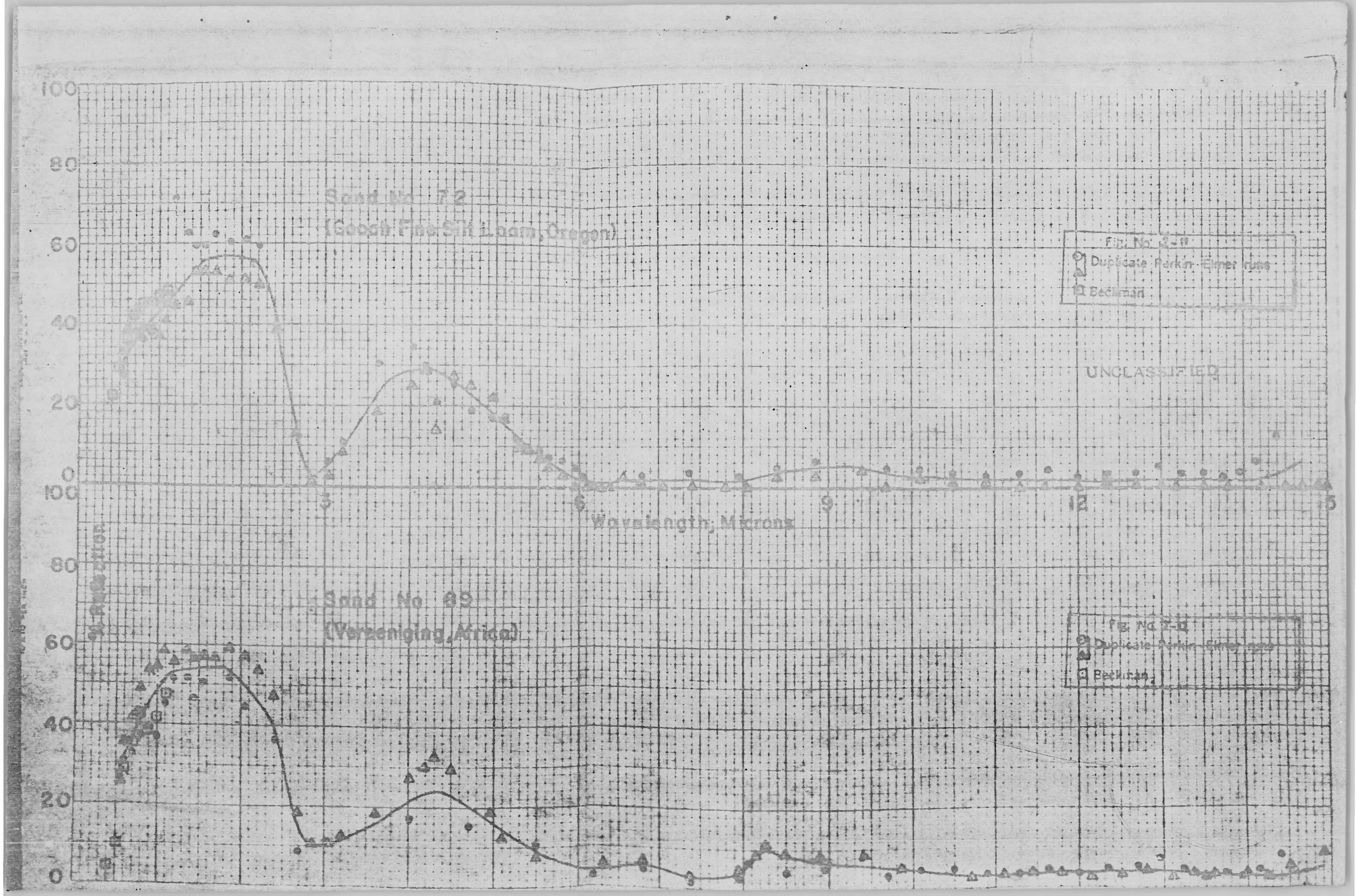
Holly Leaf (Dry)
Bottom
(Ilex Altaclarensis)

Fig. No. 1-4
Duplicate Perkin-Elmer (dot)
Beckman

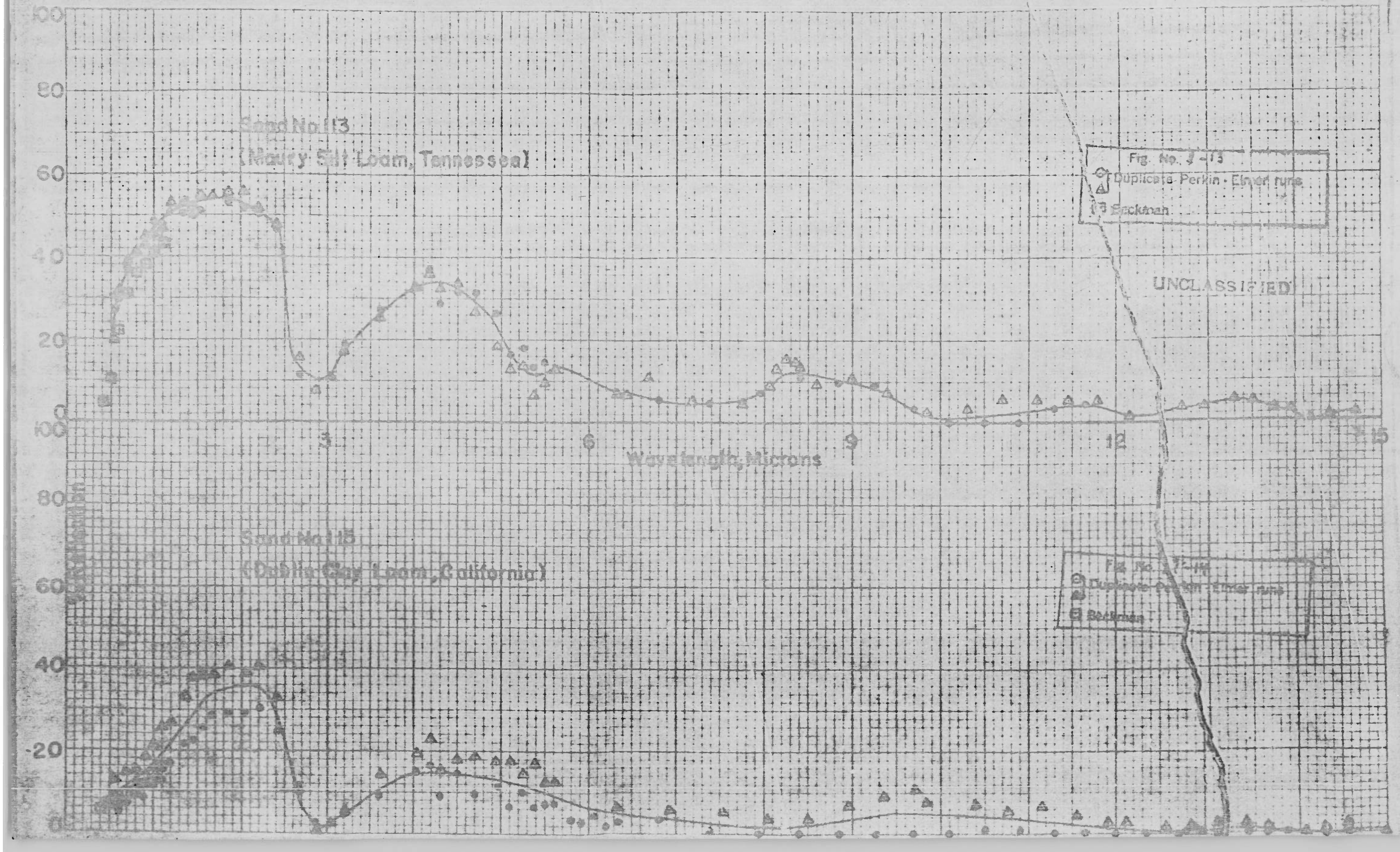

100
80
60
40
20
0
Pressed Dormant Maple Leaf (Dry)
Top
(Acer Rubrum, Eastern North America)
Fig. No. 2-3
Duplicate Perkin Elmer runs
Beckman
UNCLASSIFIED
012
Wavelength, Microns
Green Leaf Winter Color (Dry)
Top (Oak Leaf)
(Quercus Borealis Maxima, Eastern North America)
013


100
80
60
40
20
0
100
80
60
40
20
0
% Reflection
3
6
9
12
15
Wavelength, Microns
Green Coniferous Twigs
(Jack Pine)
(Pinus Banksiana, Northeastern America)
Grass (Dry)
(Meadow Fescue)
014
015
UNCLASSIFIED

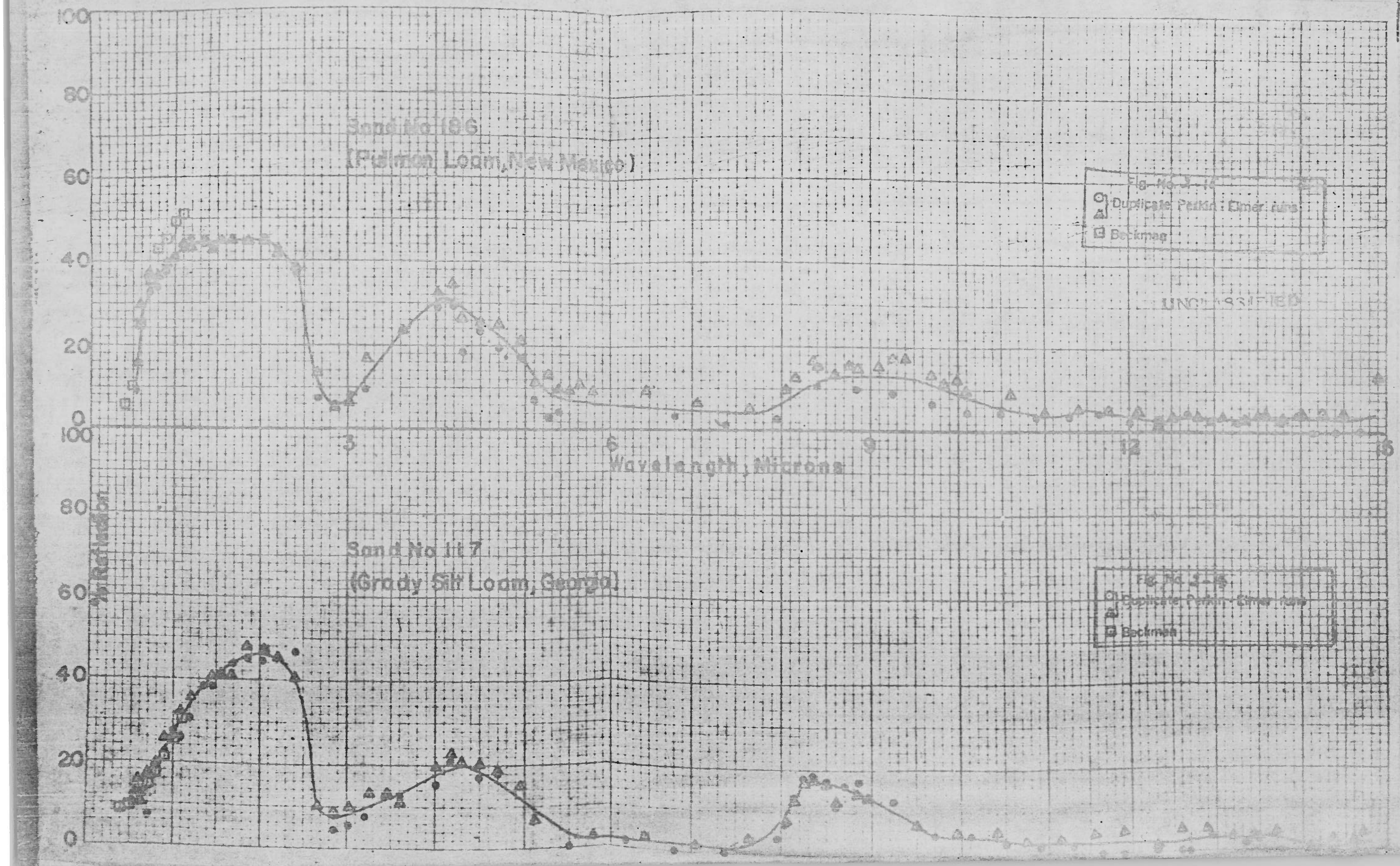

Sand No 18
(Holmamonu Silt Loam,Hawaii)
Fig. No. 3-4
Duplicate Perfect Einzel Ives
Reddman
UNCLASSIFIED
100
80
60
40
20
0
3
6
9
12
Wavelength, Microns
Sand No 70
(Barnes Fine Silt Loam, South Dakota)
Fig. No. 3-5
Duplicate Perfect - Single Pass
Beckman

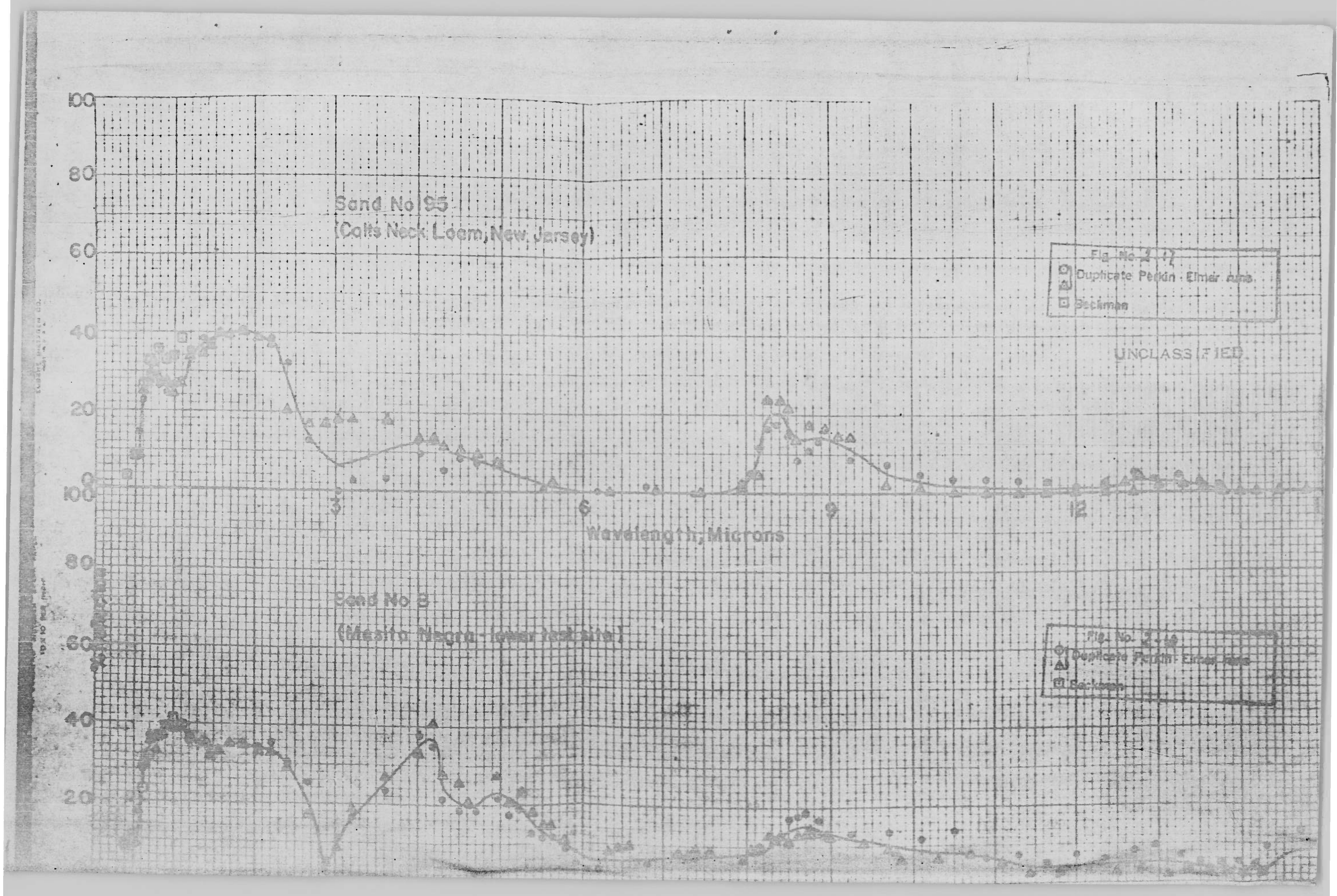

Sand No. 72
(Gooch Fine Silt Loam, Oregon)
Fig. No. 7-11
Duplicate Perkin-Elmer runs
Beckman
UNCLASSIFIED
Sand No. 69
(Vereeniging, Africa)
Fig. No. 7-12
Duplicate Perkin-Elmer runs
Beckman
Wavelength, Microns
Reflectance, Percent
100
80
60
40
20
0
3
6
9
12
15

UNCLASSIFIED



UNCLASSIFIED




Sand No 85
(Colts Neck Loam, New Jersey)
Fig. No. 2-17
Duplicate Perkin-Elmer runs
Beckman
UNCLASSIFIED
100
80
60
40
20
0
3
6
9
12
Wavelength, Microns
Sand No 8
(Mesilla Negra - lower test site)
Fig. No. 2-18
Duplicate Perkin-Elmer runs
Beckman

Bark:
Northern Red Oak
(Quercus Borealis Maxima)

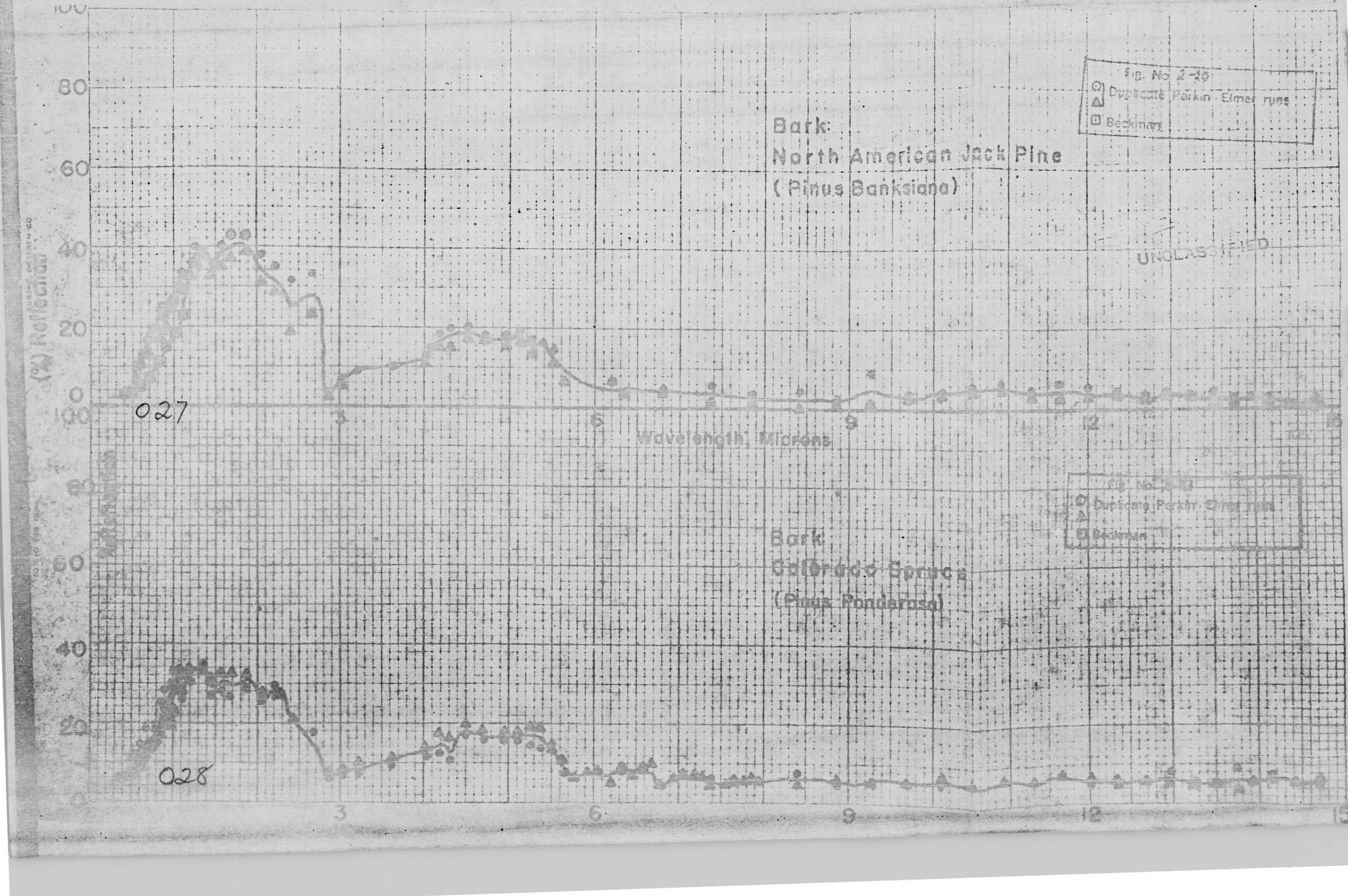
Fig. No. 2 (?)
Duplicate Periods Three Times
Declination

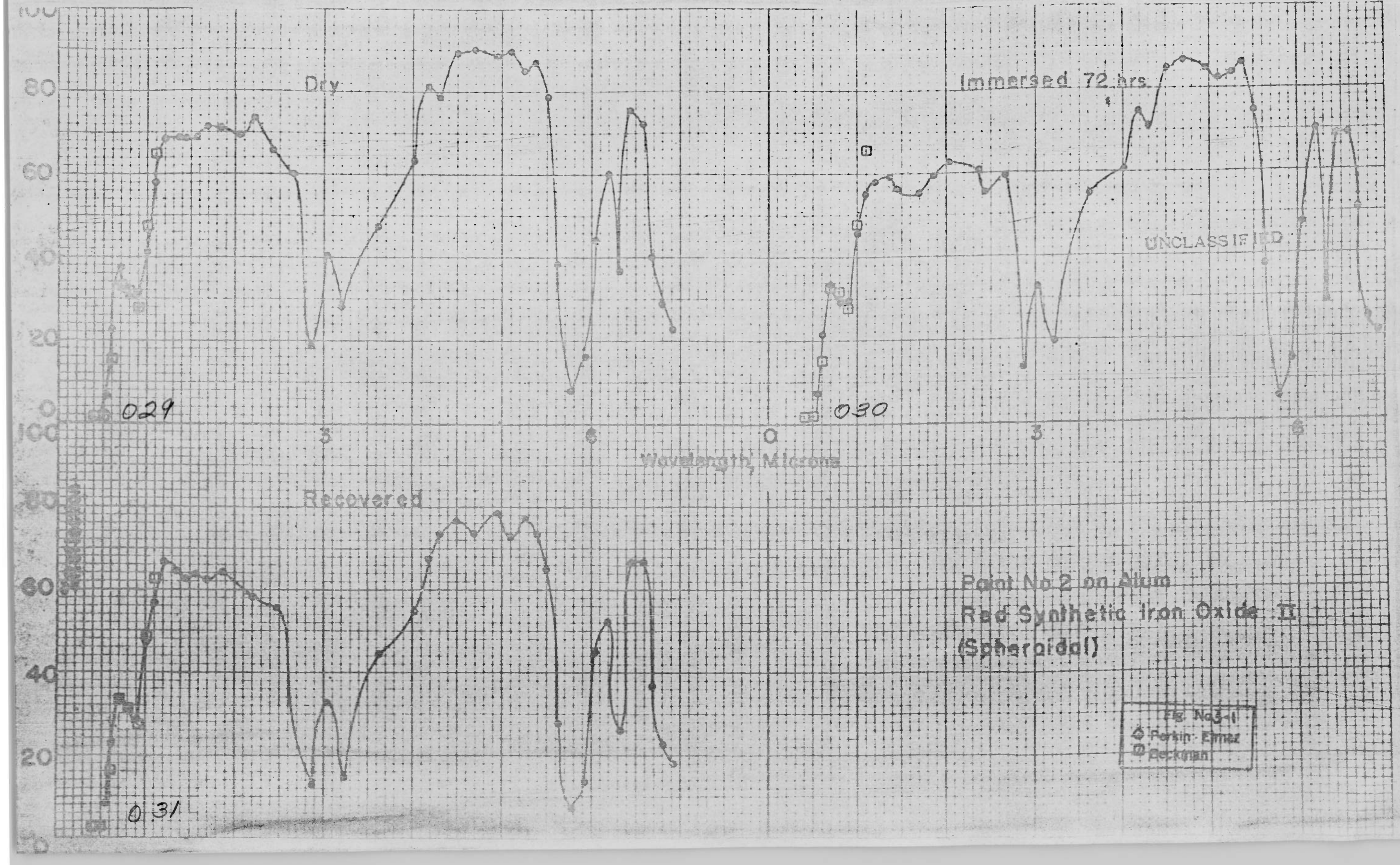
UNCLASSIFIED

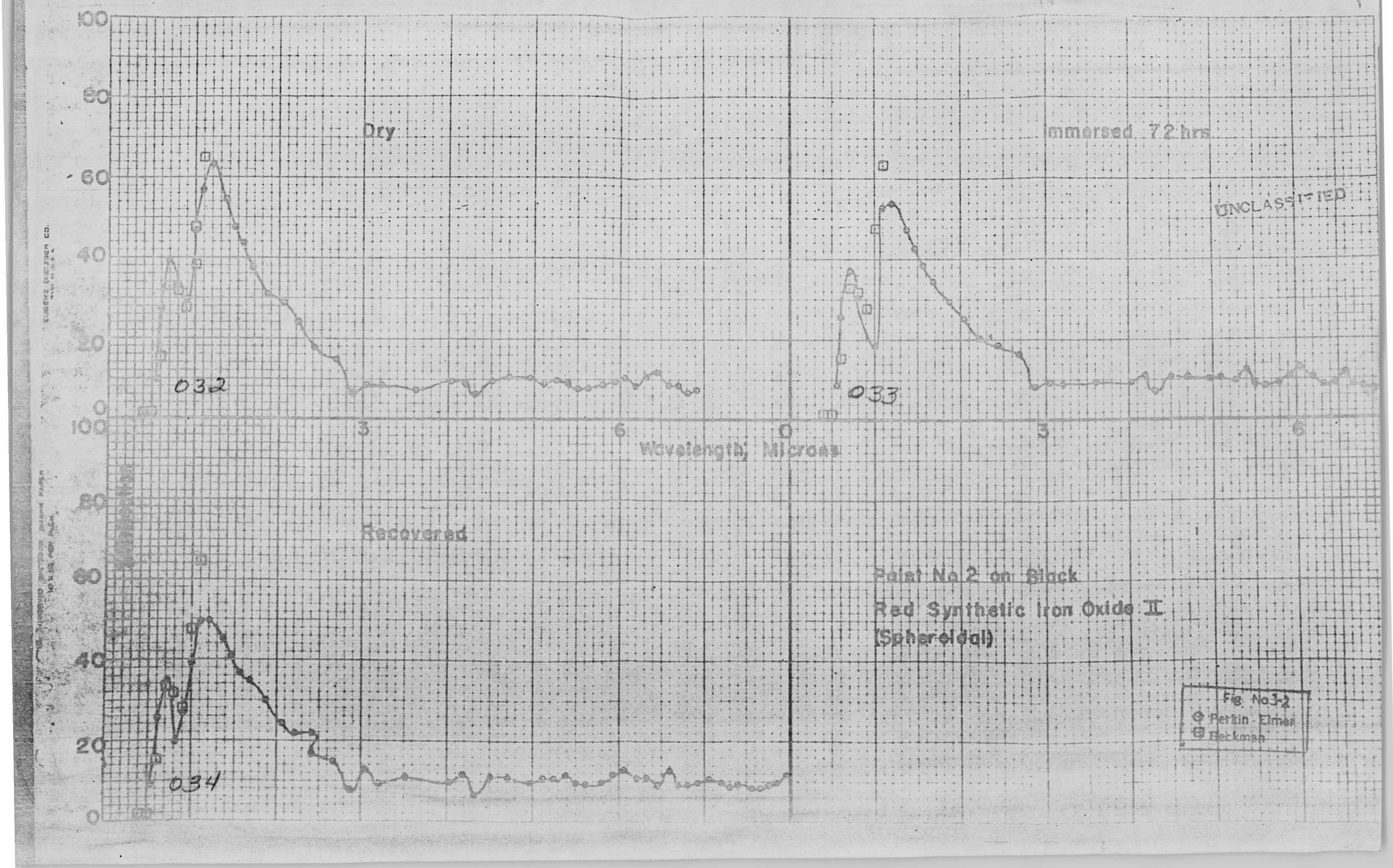
80
60
40
20
0
100

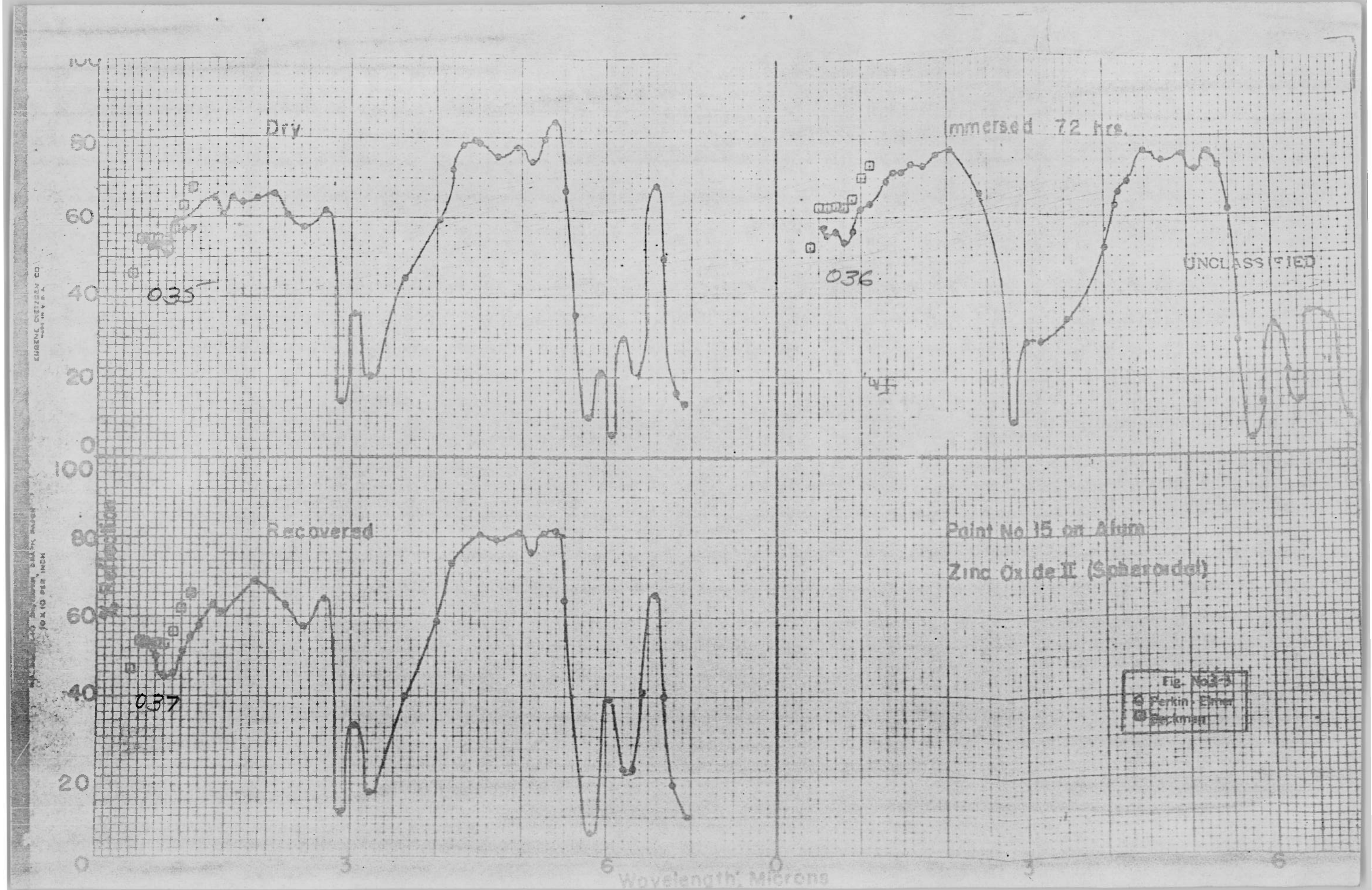
3
6
9
12

026

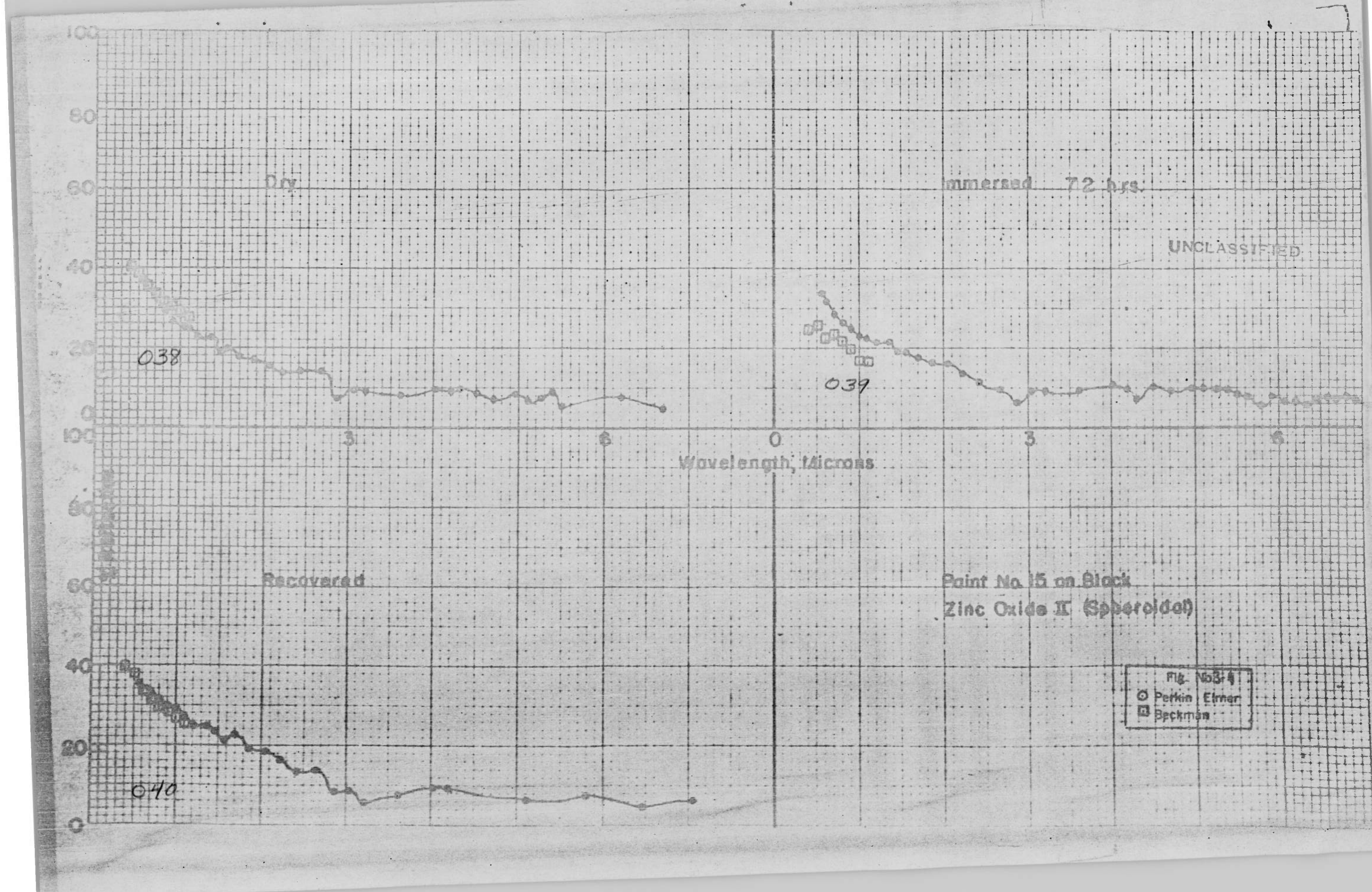

Fig. No. 2-29
Duplicate Perkin-Elmer runs
Beckman
Bark:
North American Jack Pine
(Pinus Banksiana)
UNCLASSIFIED
(%) Reflectance
Wavelength, Microns
027
Fig. No. 2-30
Duplicate Perkin-Elmer runs
Beckman
Bark:
Colorado Spruce
(Pinus Ponderosa)
028
0
20
40
60
80
100
3
6
9
12
15

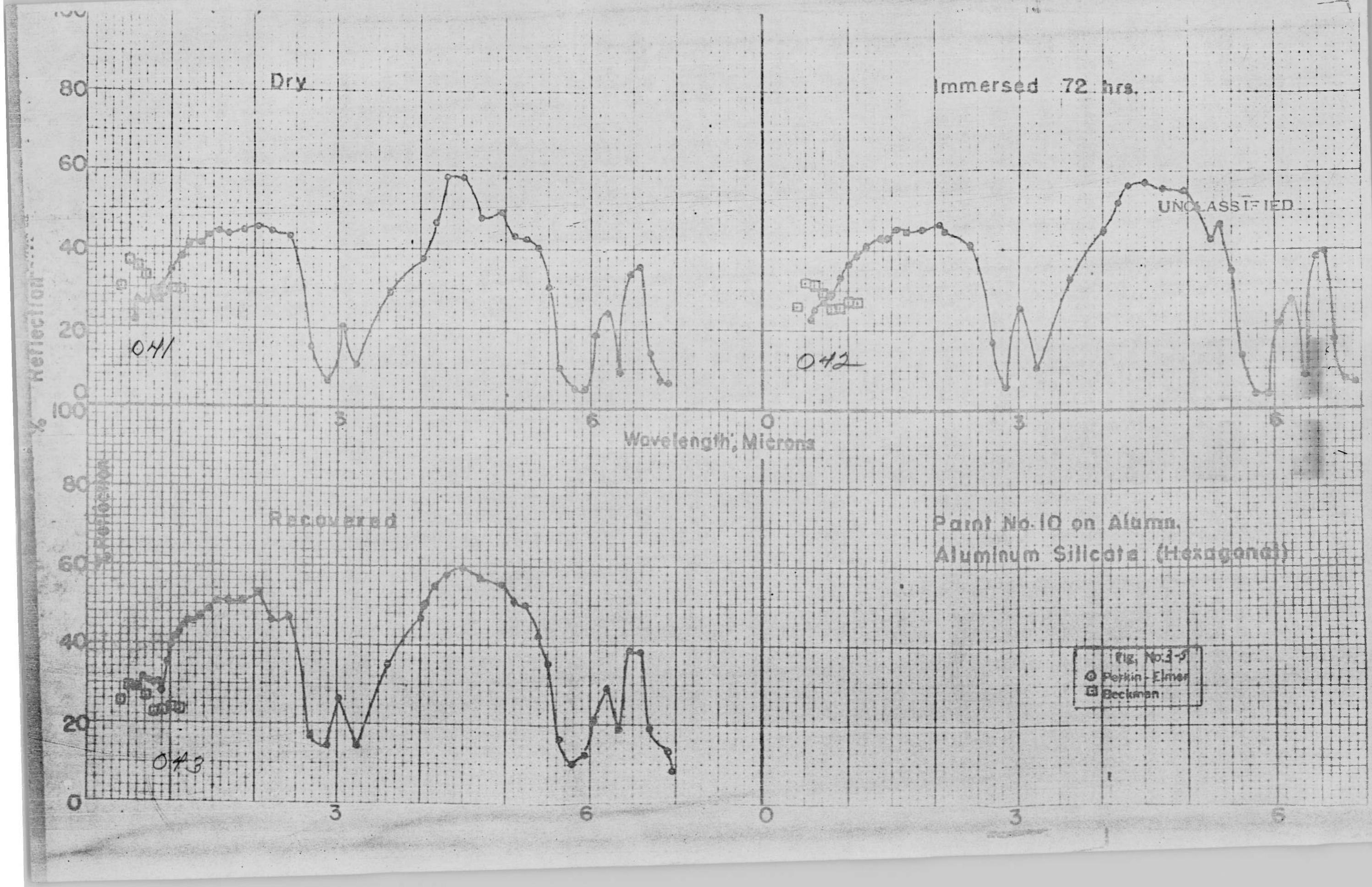

Dry
Immersed 72 hrs.
UNCLASSIFIED
029
030
Wavelength, Microns
Recovered
031
Point No 2 on Alum
Red Synthetic Iron Oxide II
(Spheroidal)
Fig. No 3-11
Perkin-Elmer
Beckman


Dry
Immersed 72 hrs
Recovered
032
033
034
Wavelength, Microns
Point No 2 on Black
Red Synthetic Iron Oxide II
(Spheroidal)
Fig. No 3-2
Perkin-Elmer
Beckman
UNCLASSIFIED

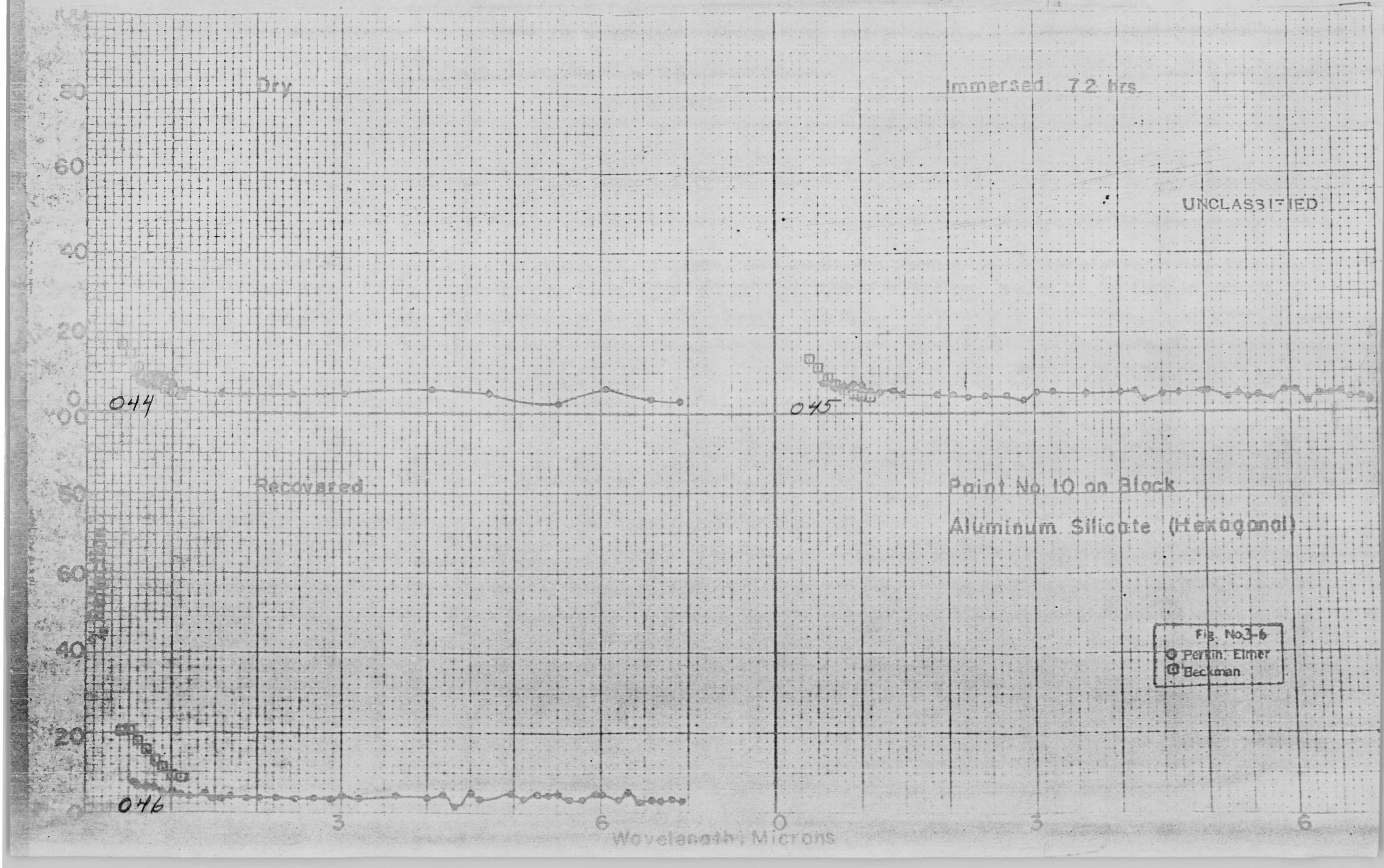

Dry
035
Immersed 72 hrs.
036
Recovered
037
Point No 15 on Afsim
Zinc Oxide II (Spheroidal)
Fig. No 3-3
Perkin-Elmer
Perkinelmer
Wavelength, Microns
UNCLASSIFIED

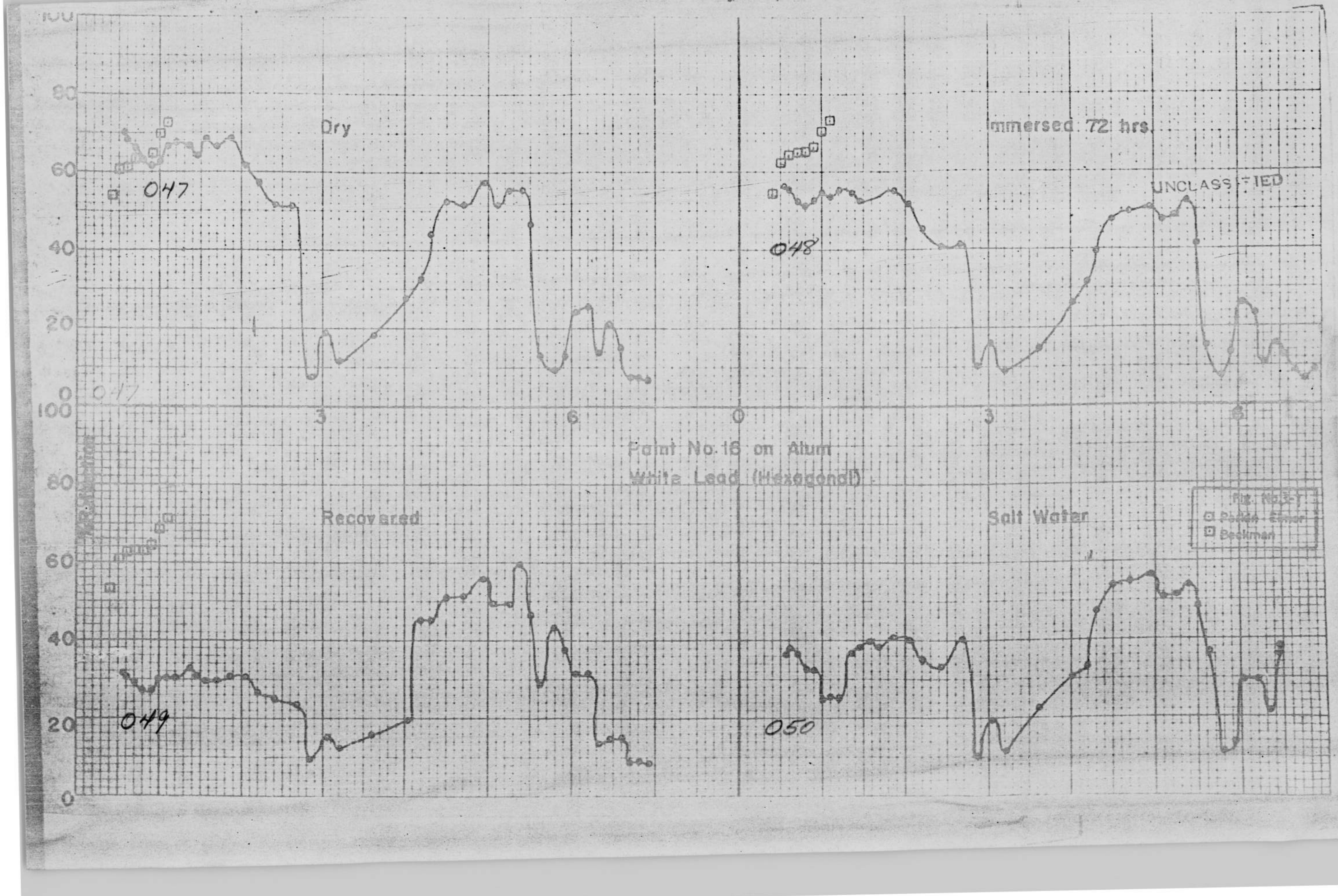
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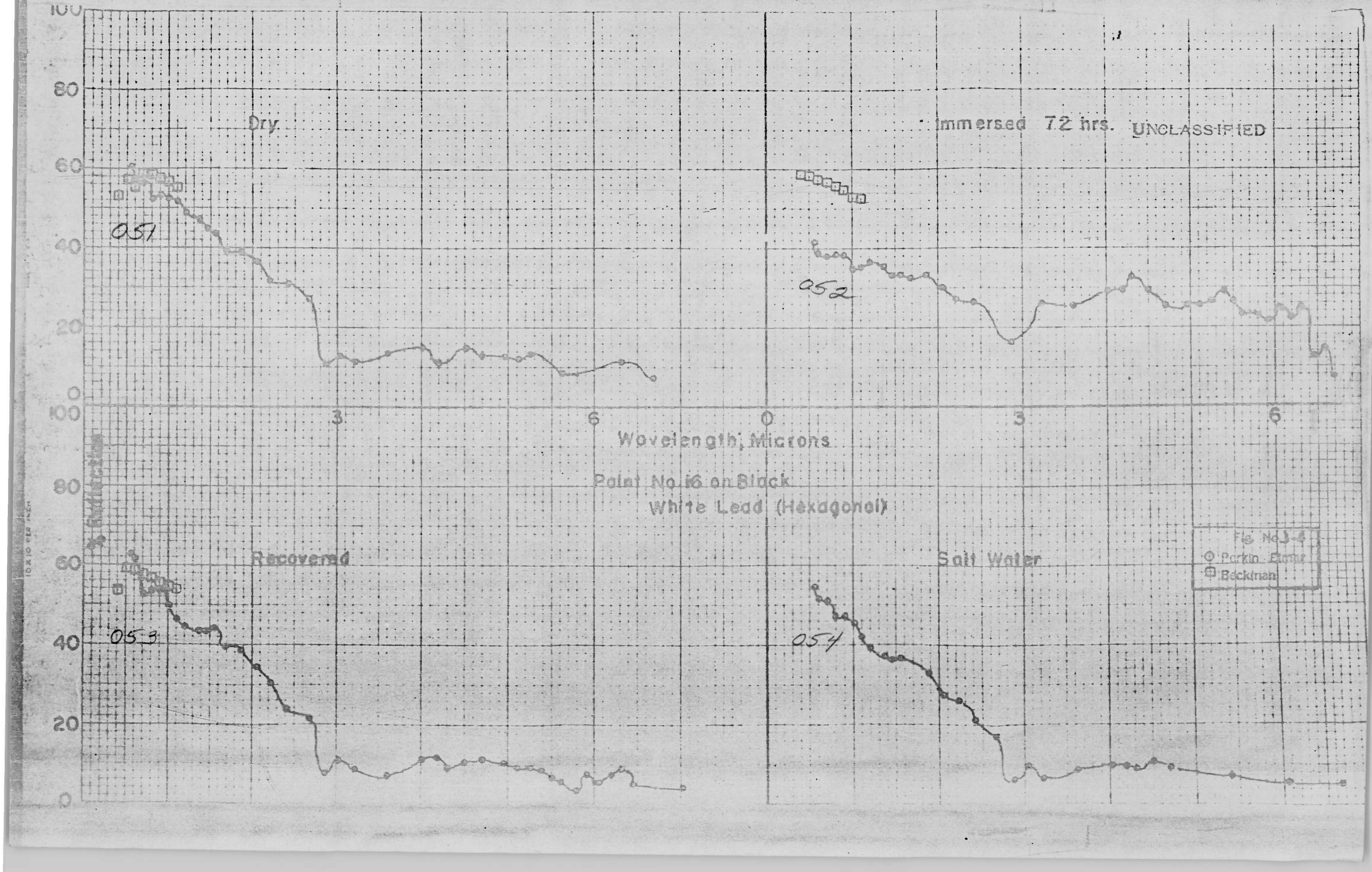



Dry
Immersed 72 hrs.
041
042
043
Recovered
% Reflection
Wavelength, Microns
UNCLASSIFIED
Paint No. 10 on Alumn.
Aluminum Silicate (Hexagonal)
Fig. No. 3-5
Perkin-Elmer
Beckman

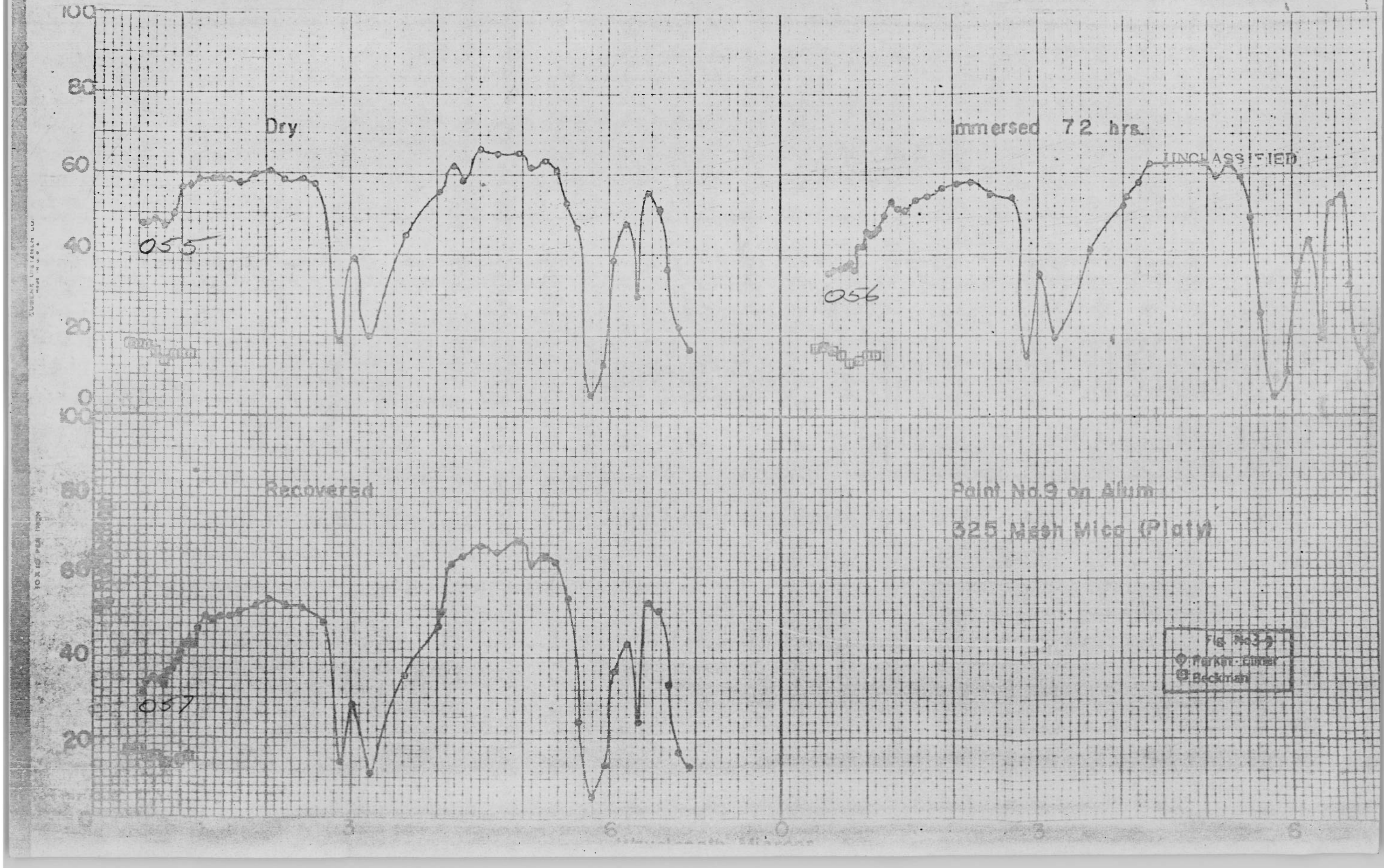
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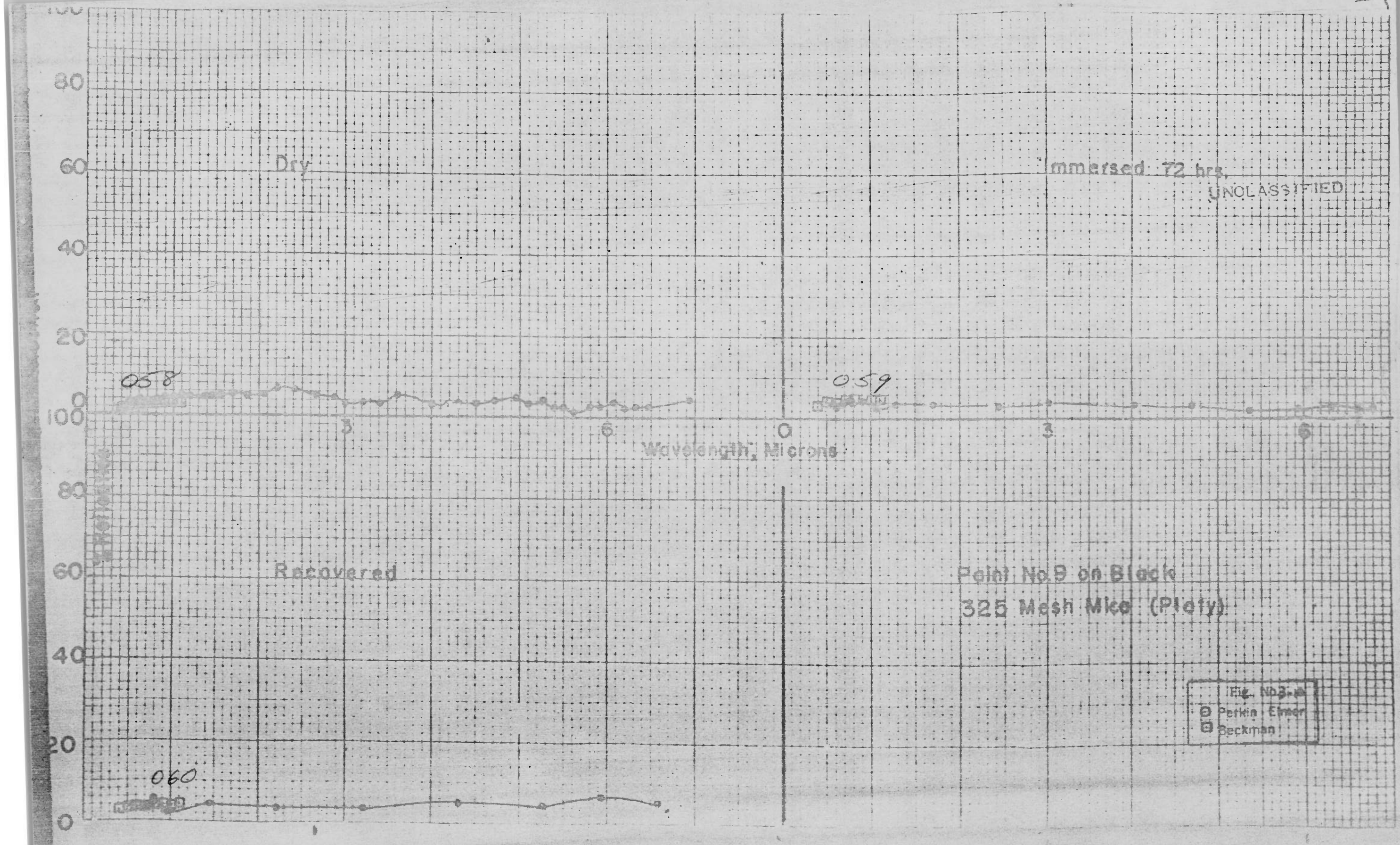

Dry
047
Immersed 72 hrs.
048
UNCLASSIFIED
Point No. 16 on Alum
White Lead (Hexagonal)
Recovered
049
Salt Water
050
Ref. No. 3-T
Beckman
100
80
60
40
20
0
3
6
0
3
6


Dry
Immersed 72 hrs.
UNCLASSIFIED
051
052
100
80
60
40
20
0
3
6
0
3
6
Wavelength, Microns
Point No. 16 on Black
White Lead (Hexagonal)
Recovered
Salt Water
053
054
Fig. No. 3-4
Perkin Elmer
Beckman

UNCLASSIFIED

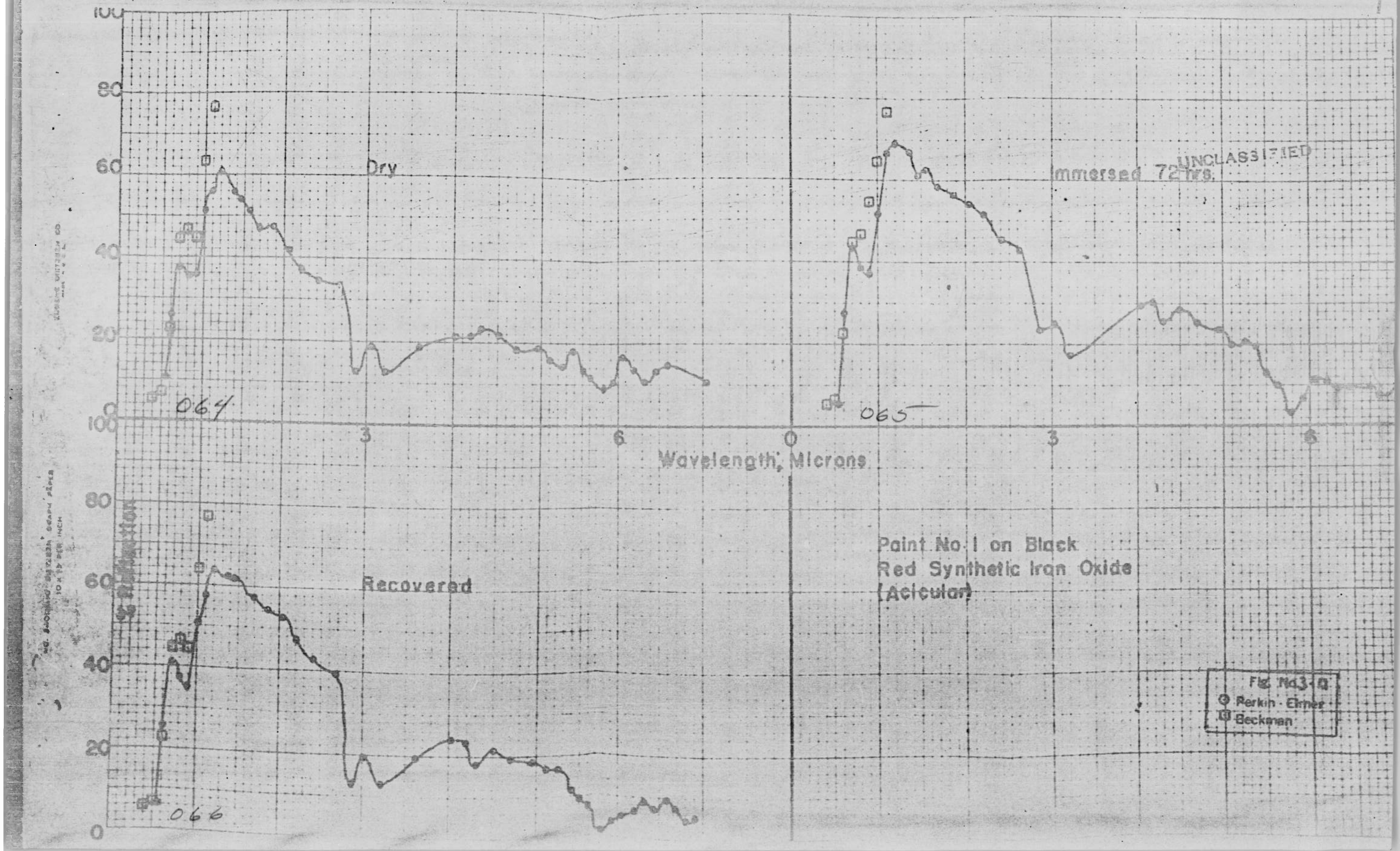


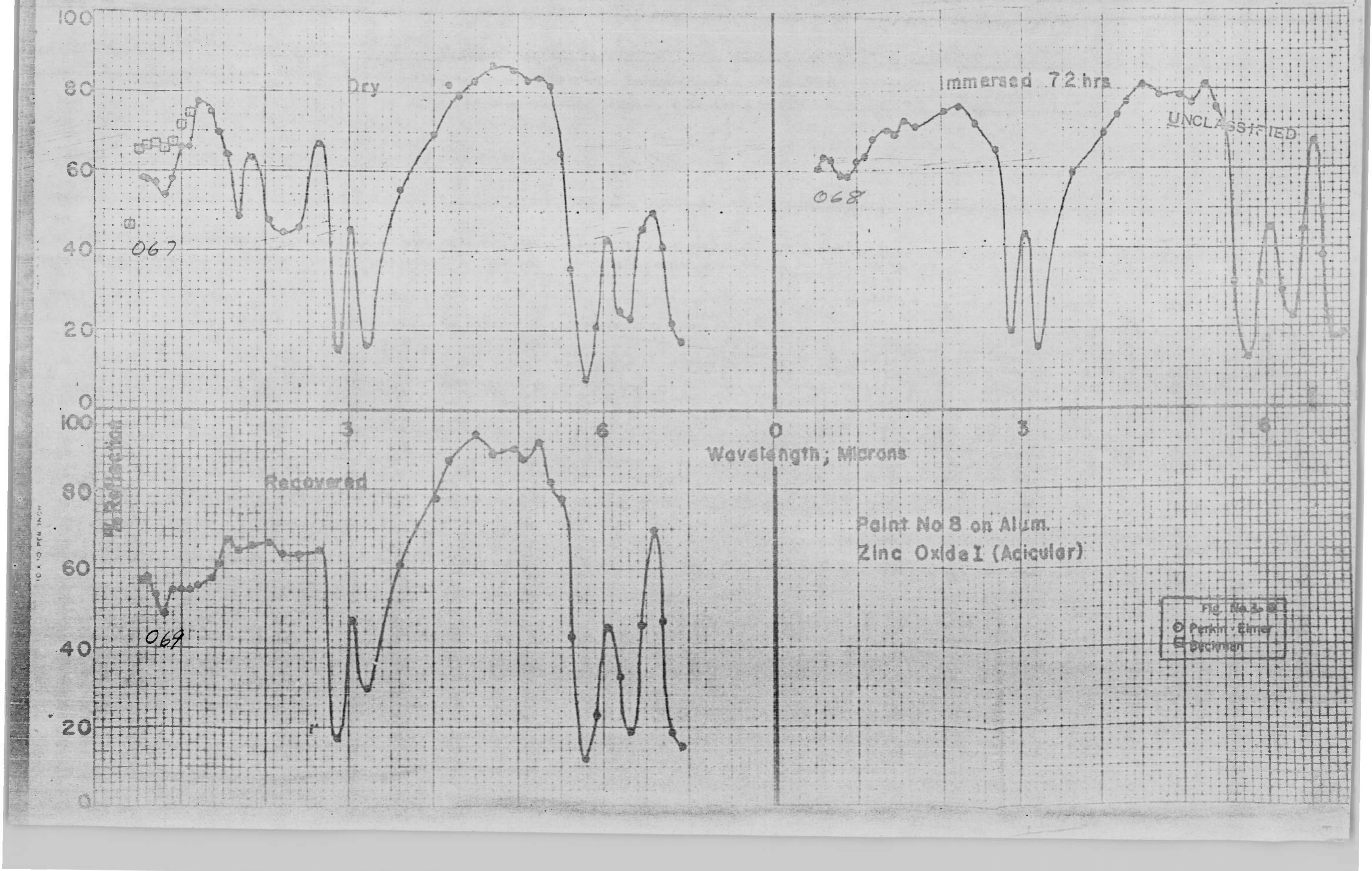
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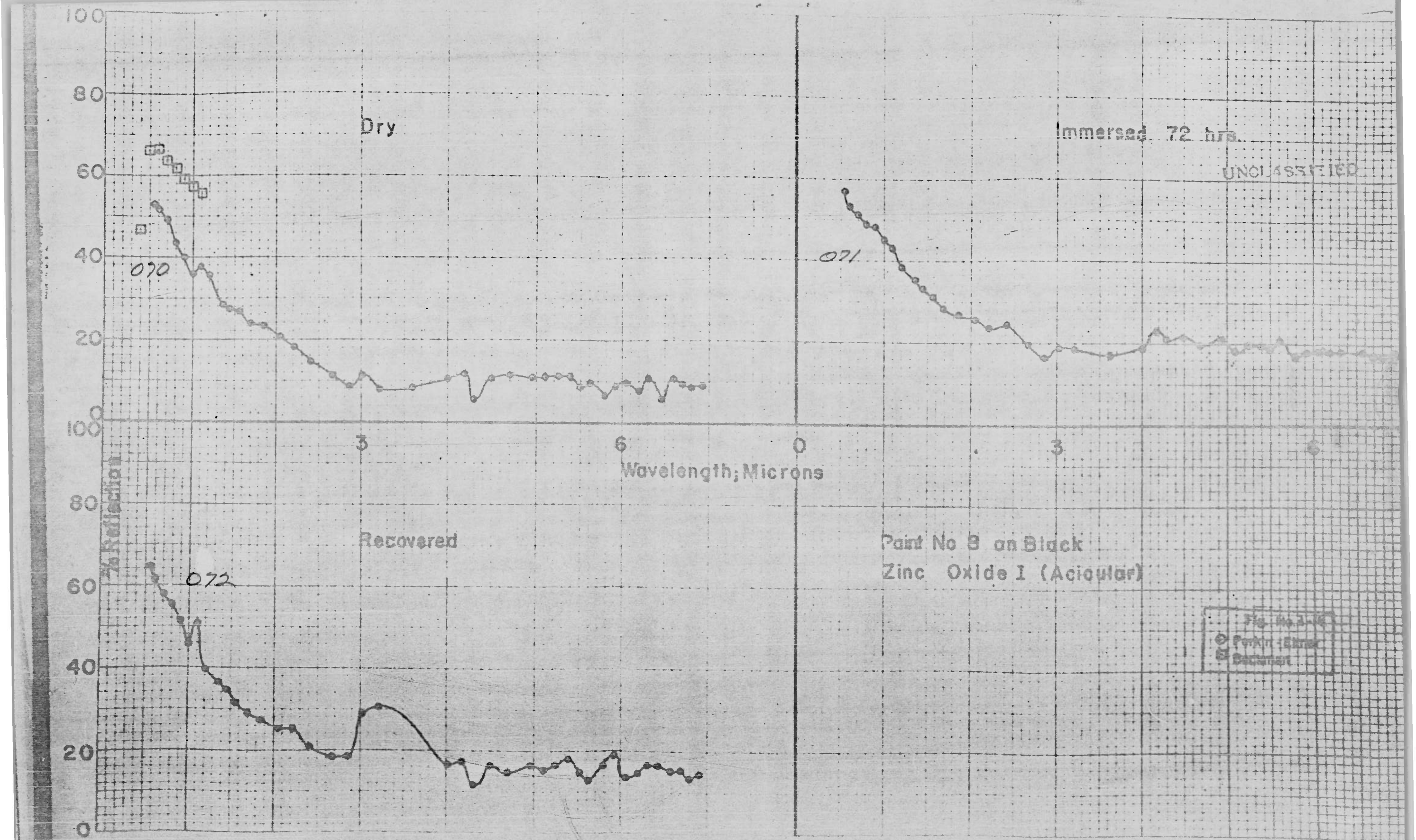

Dry
Immersed 72 hrs
UNCLASSIFIED
061
062
063
Wavelength, Microns
Recovered
Paint No. 1 on Alum
Red Synthetic Iron Oxide
(Acicular)
Perkin Elmer
Beckman

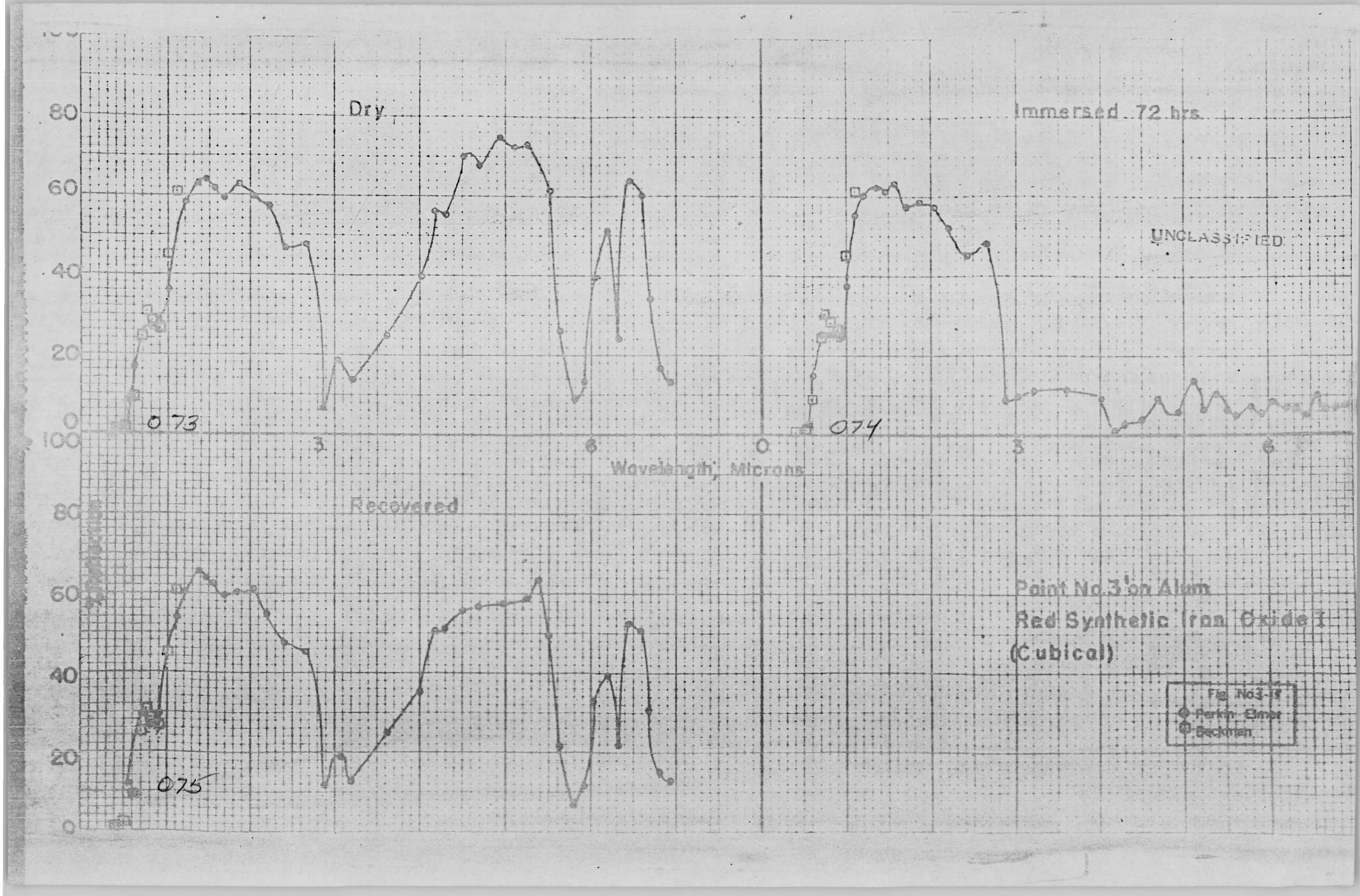
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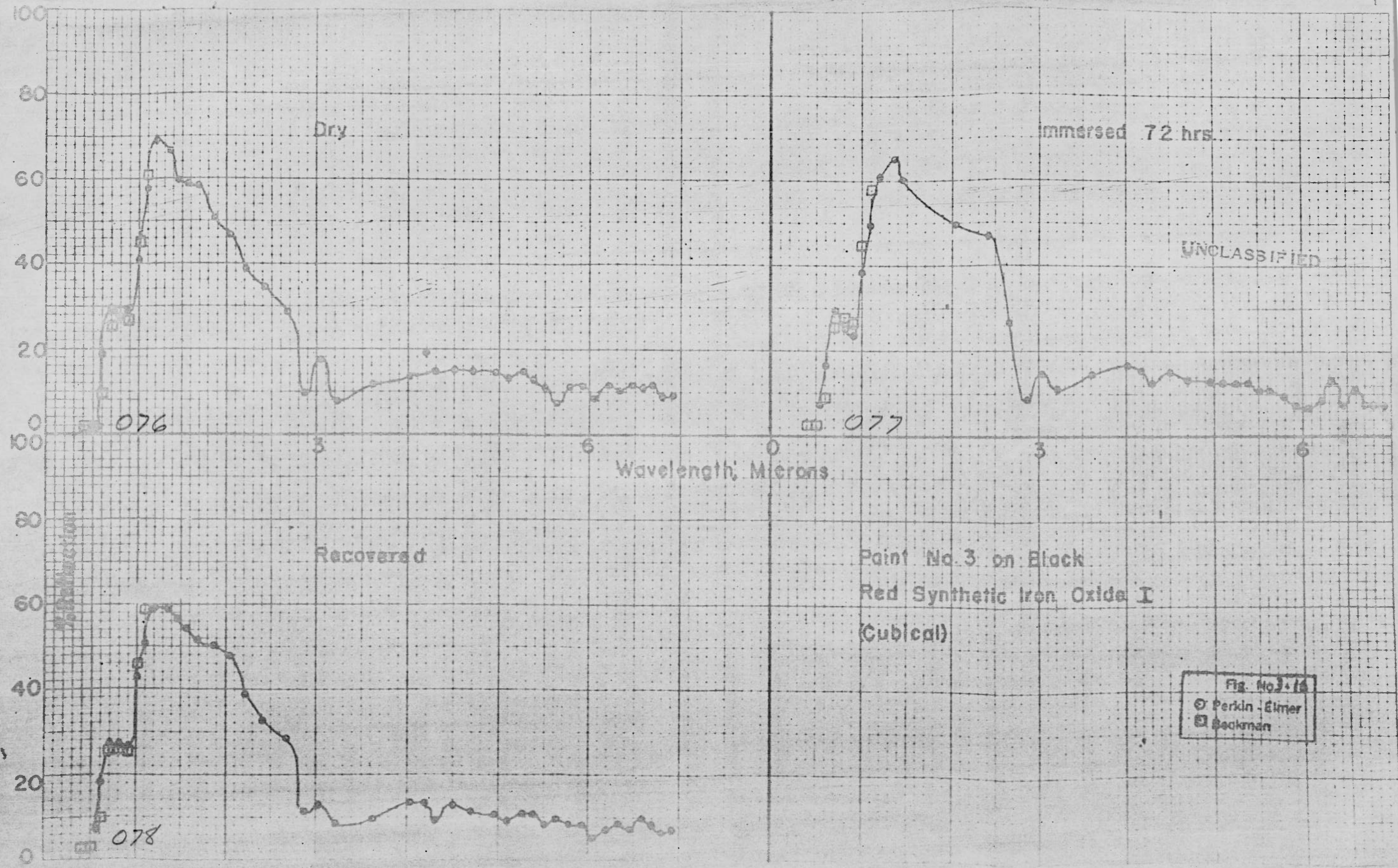

100
80
60
40
20
0
Dry
067
Immersed 72 hrs.
068
UNCLASSIFIED
100
80
60
40
20
0
% Reflectance
Recovered
069
3
6
0
3
6
Wavelength; Microns
Paint No 8 on Alum.
Zinc Oxide I (Acicular)
Fig. No. 3-87
© Perkin - Elmer
Beckman

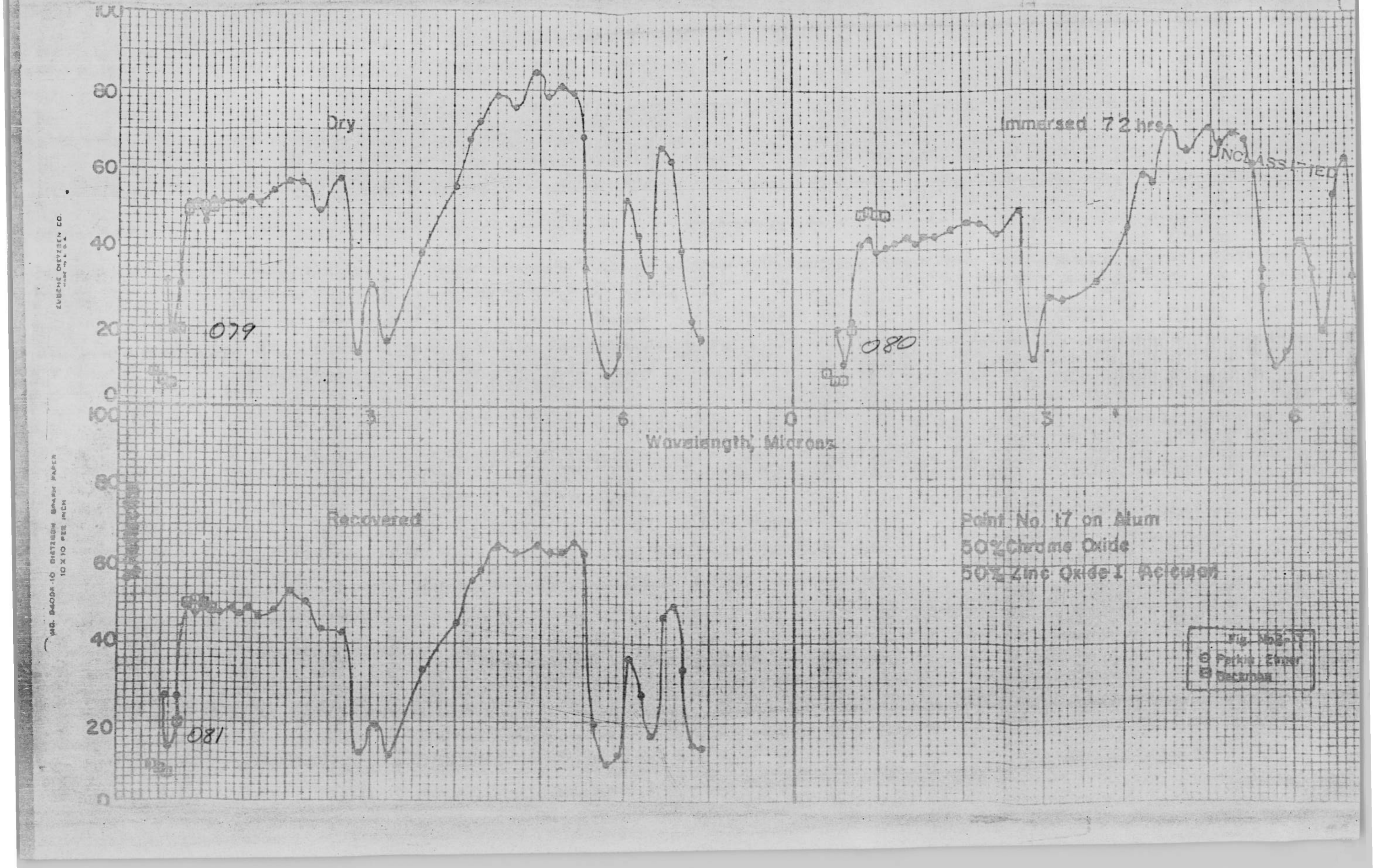
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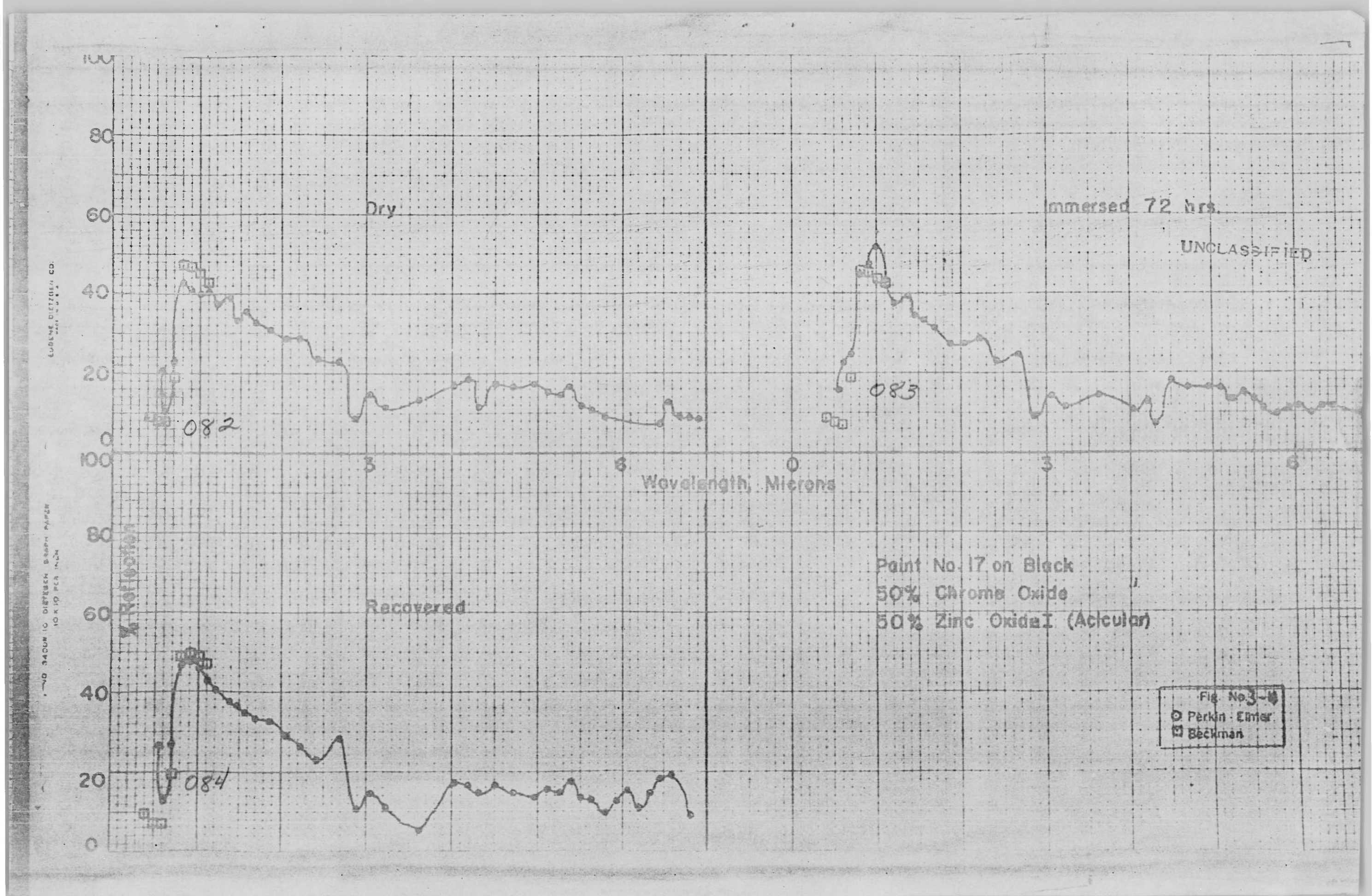


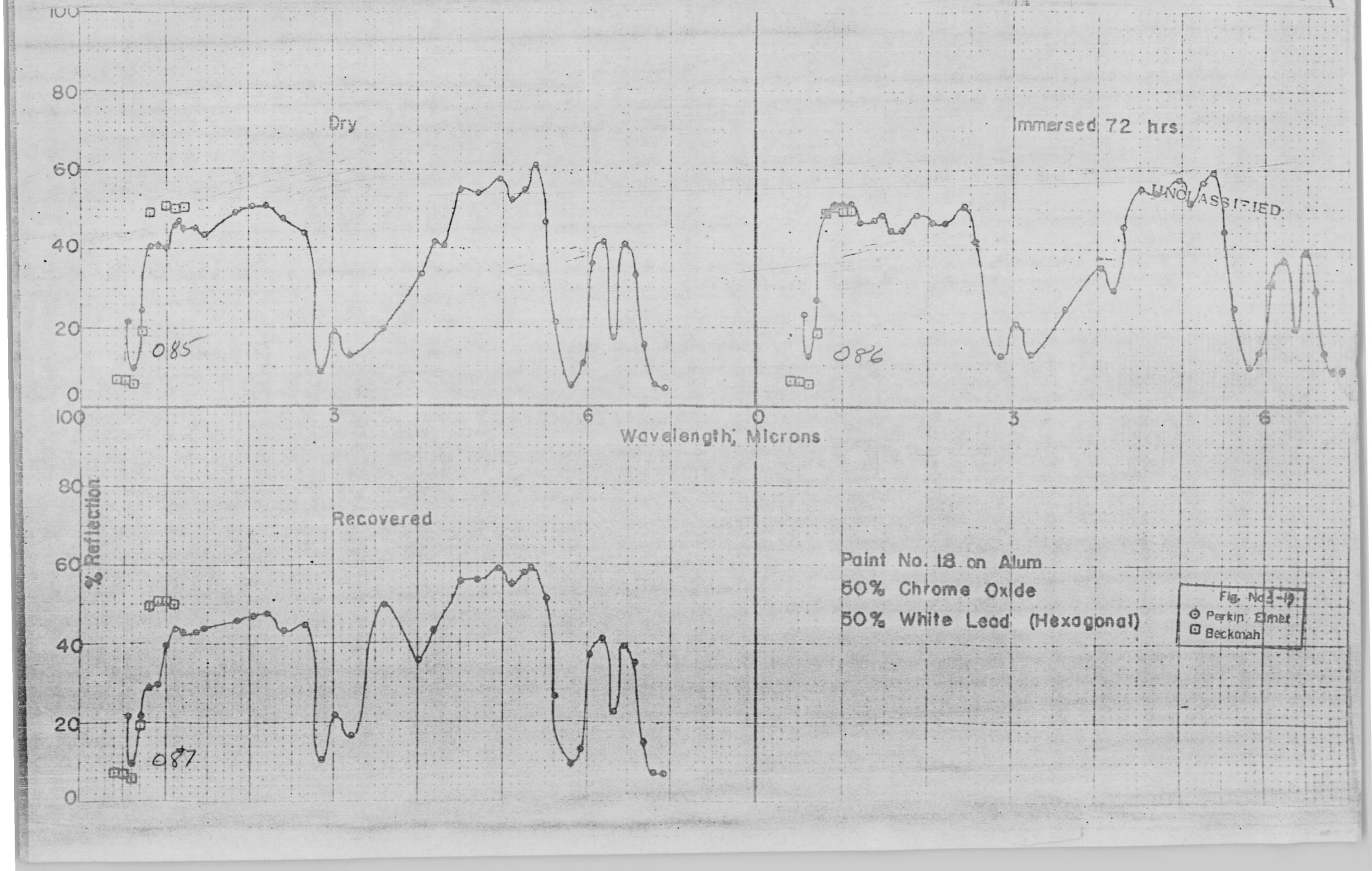

Dry
Immersed 72 hrs.
UNCLASSIFIED
80
60
40
20
0
100
0 73
074
3
6
0
3
6
Wavelength, Microns
Recovered
80
60
40
20
0
075
Point No.3 on Alum
Red Synthetic Iron Oxide I
(Cubical)
Fig. No3-18
Perkin Elmer
Beckman

UNCLASSIFIED

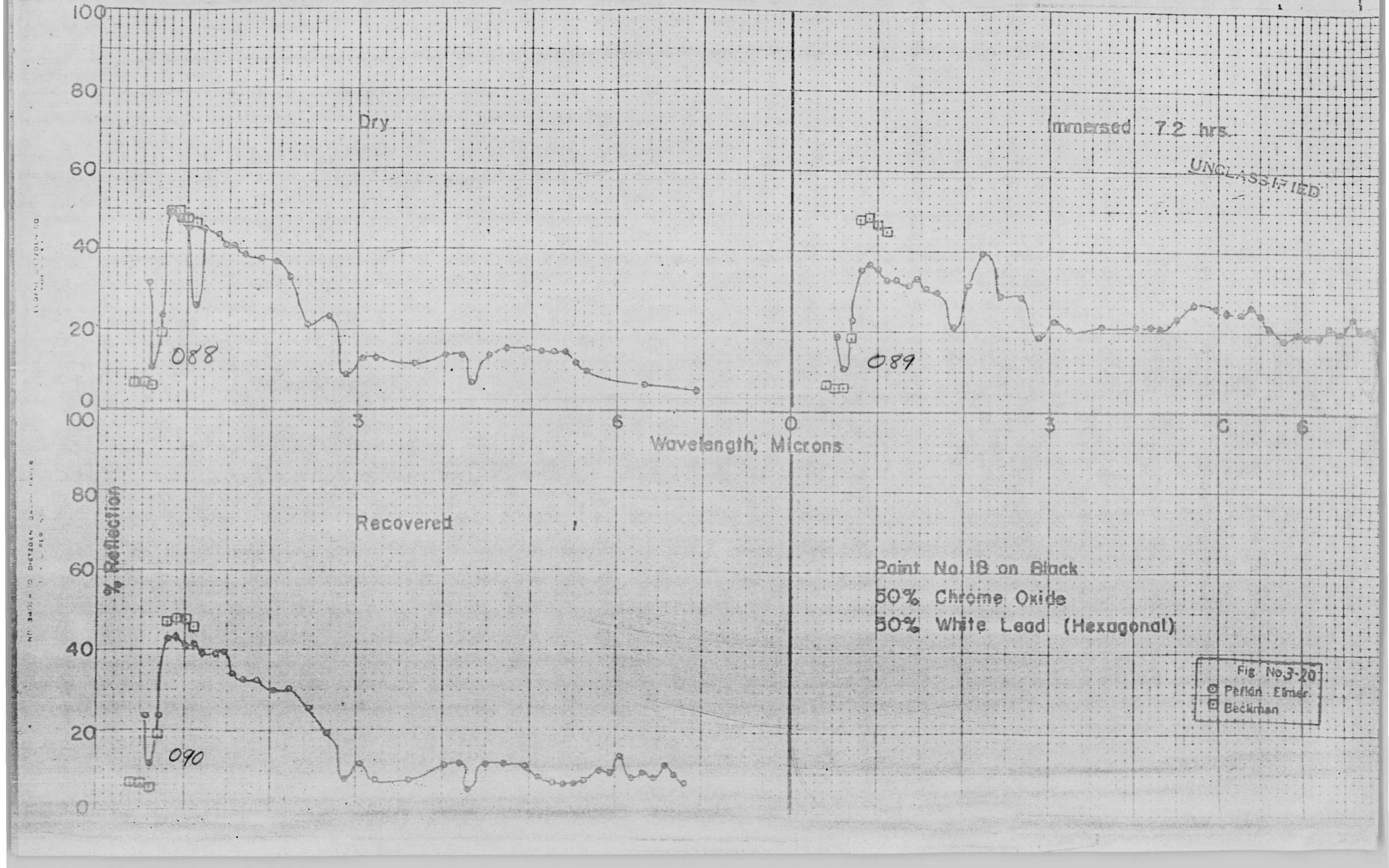



Dry
079
Immersed 72 hrs
080
UNCLASSIFIED
Recovered
081
Wavelength, Microns
Point No. 17 on Alum
50% Chrome Oxide
50% Zinc Oxide Reflection
Fig. No. 17
Perkin Elmer
Reflectance
100
80
60
40
20
0
3
6
9

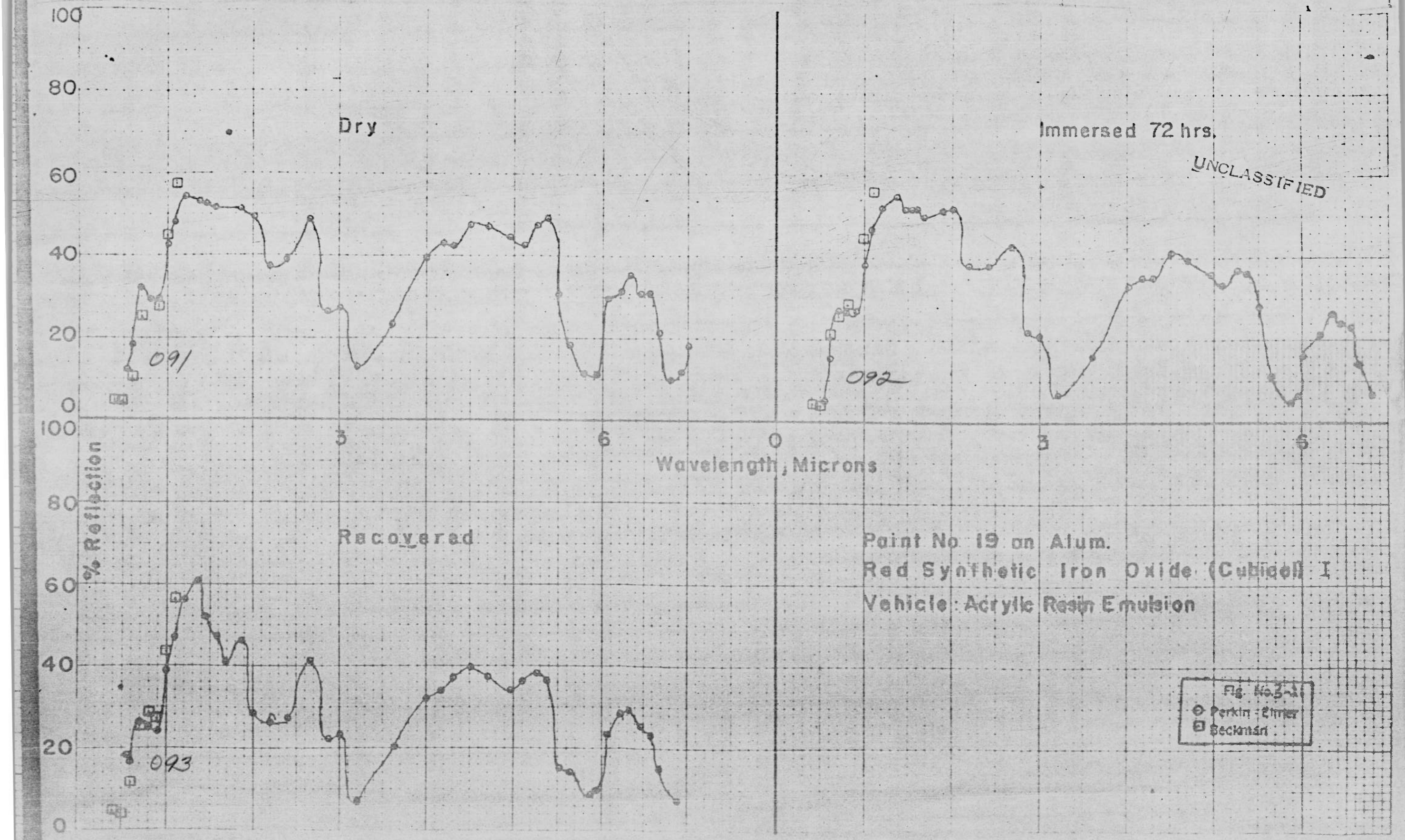

Dry
Immersed 72 hrs.
UNCLASSIFIED
082
083
Wavelength, Microns
% Reflection
Recovered
084
Paint No. 17 on Black
50% Chrome Oxide
50% Zinc Oxide I (Acicular)
Fig. No. 3-B
Perkin - Elmer
Beckman
EUGENE DIETZGEN CO.
TWO 340 UNIT 10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH


Dry
Immersed 72 hrs.
UNCLASSIFIED
085
086
087
Recovered
% Reflection
Wavelength, Microns
100
80
60
40
20
0
3
6
Paint No. 18 on Alum
50% Chrome Oxide
50% White Lead (Hexagonal)
Fig. No. 3-19
Perkin Elmer
Beckman

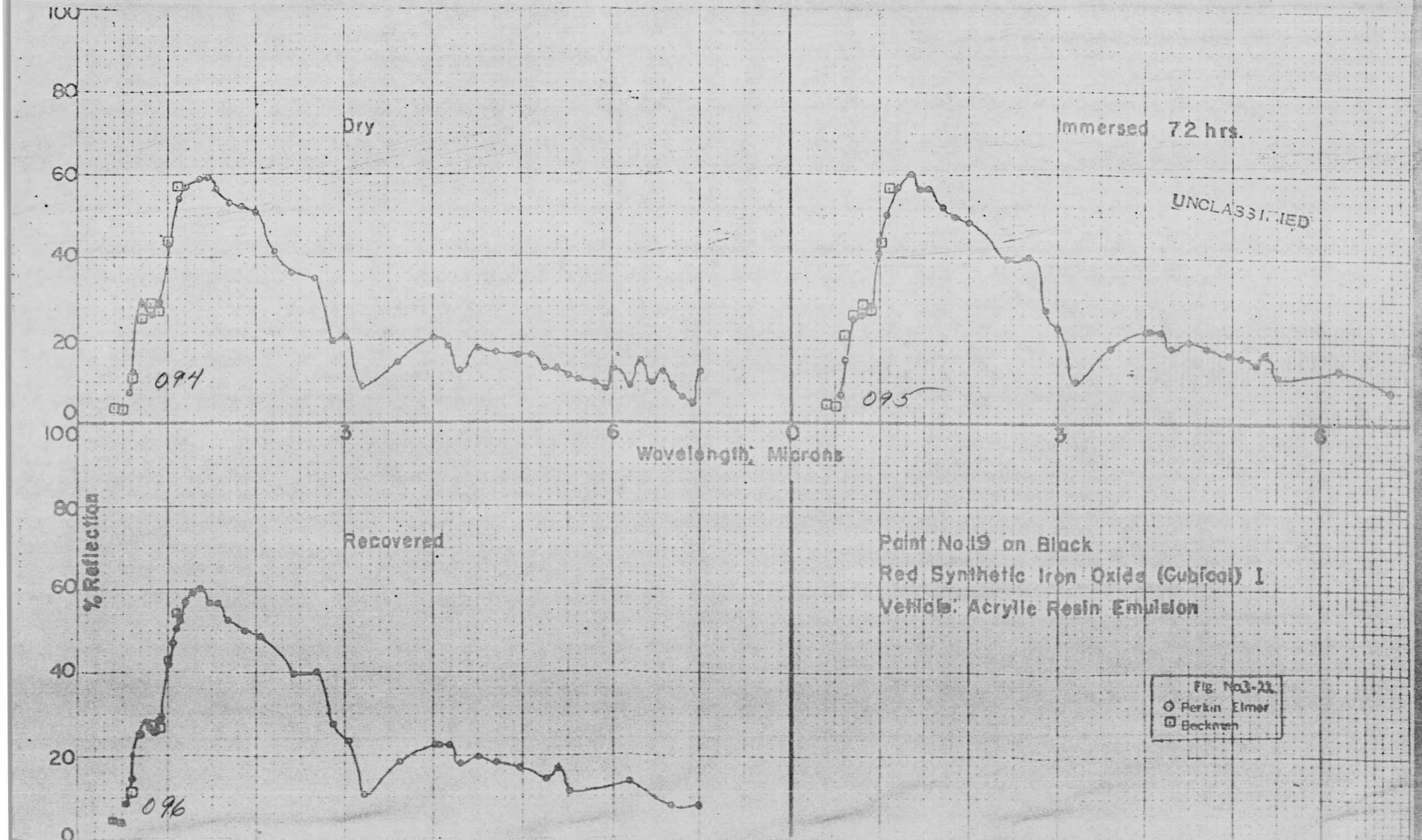
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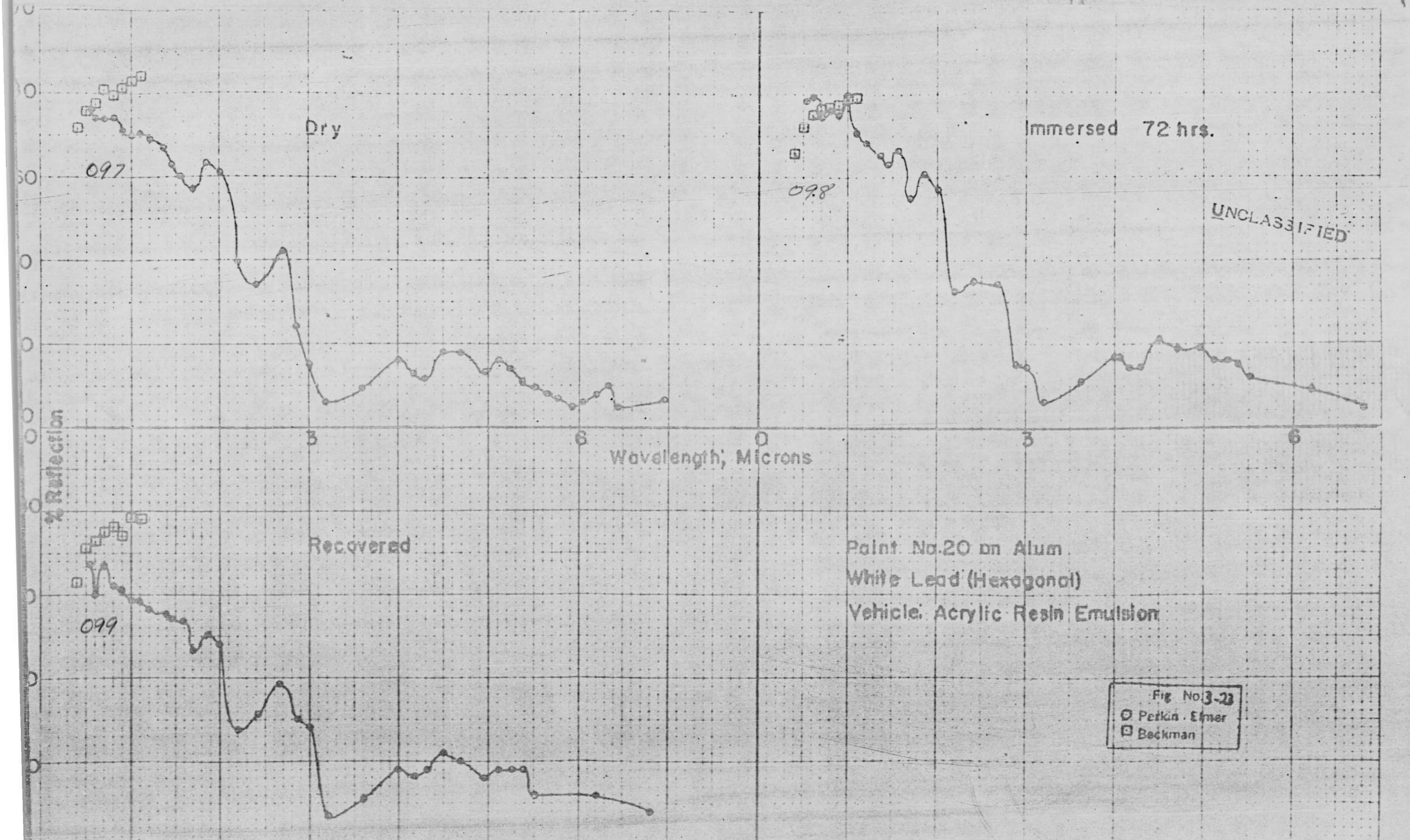
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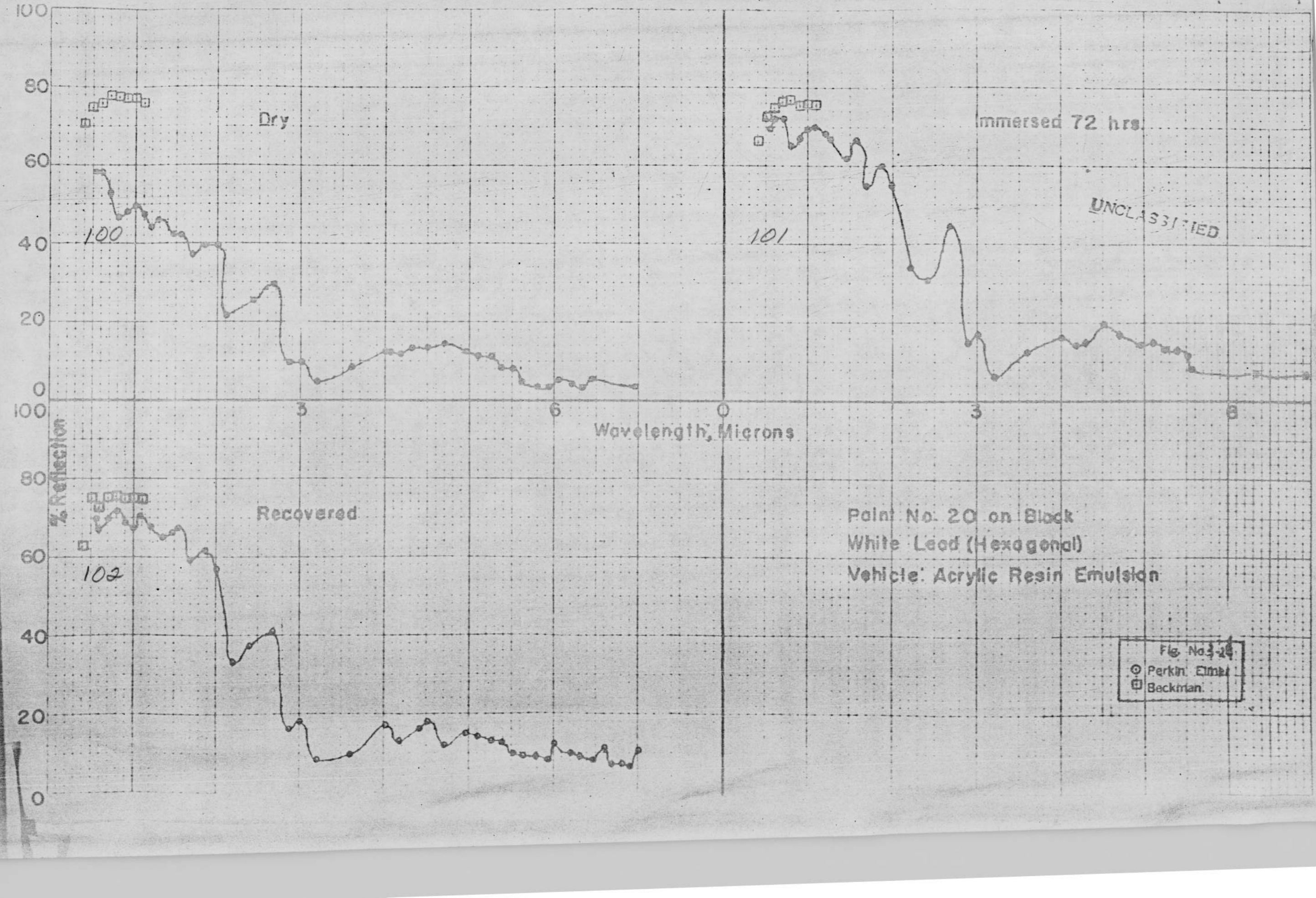


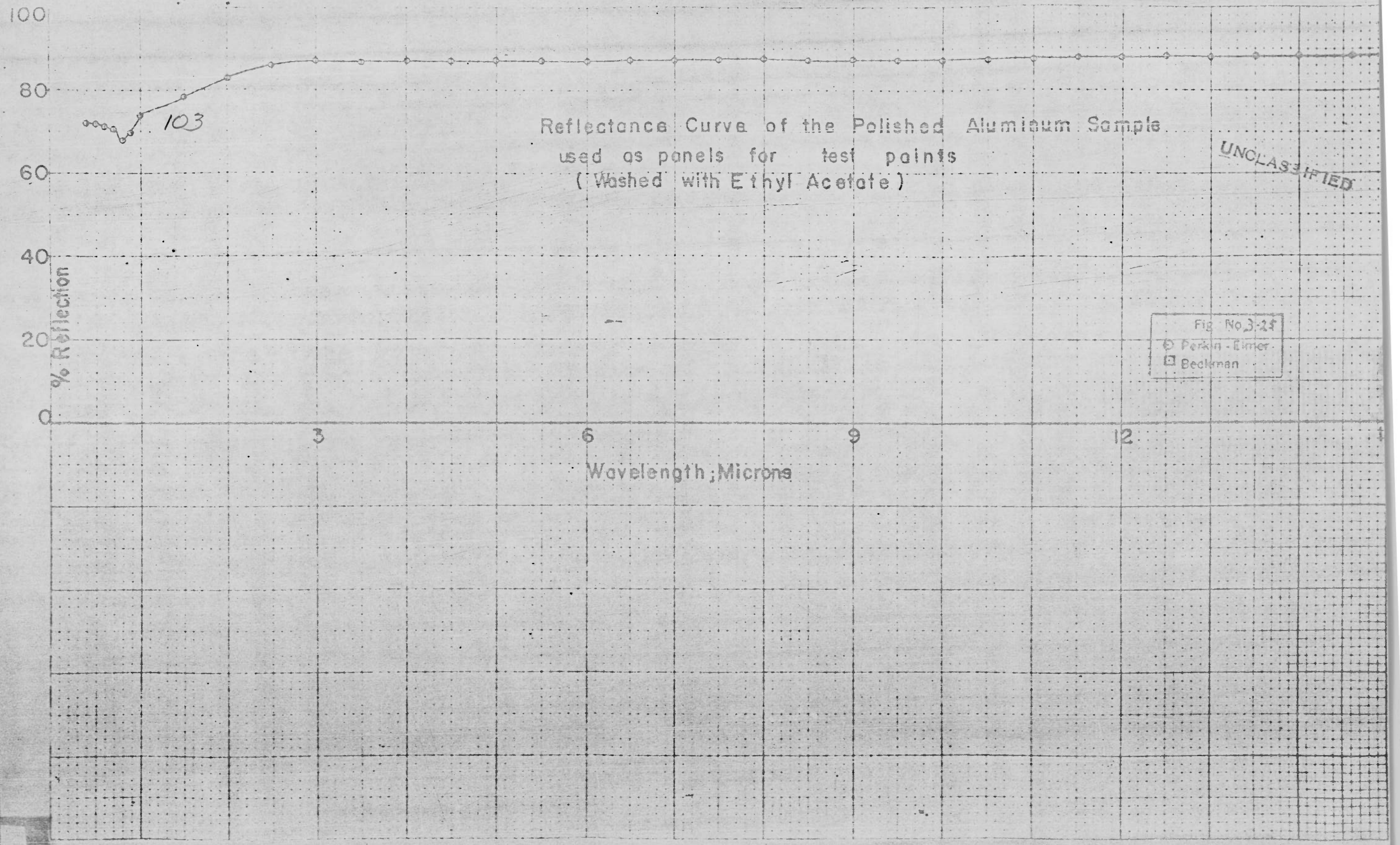
UNCLASSIFIED



UNCLASSIFIED




100
80
60
40
20
0
Dry
100
Immersed 72 hrs.
101
UNCLASSIFIED
3
6
9
Wavelength, Microns
% Reflection
Recovered
102
Paint No. 20 on Black
White Lead (Hexagonal)
Vehicle: Acrylic Resin Emulsion
Fig. No. 3-24
Perkin Elmer
Beckman


100
80
60
40
20
0
% Reflection
3
6
9
12
Wavelength ; Microns
103
Reflectance Curve of the Polished Aluminum Sample
used as panels for test points
(Washed with Ethyl Acetate)
UNCLASSIFIED
Fig No 3-25
Perkin - Elmer
Beckman

UNCLASSIFIED

On Black

Vehicle
Alkyd Resin No 3875
(Air dried)

Fig. No. 3-6
○ Perkin-Elmer
□ Beckman

104

100
80
60
40
20
0

3
6
9
12

Wavelength, Microns

% Reflection

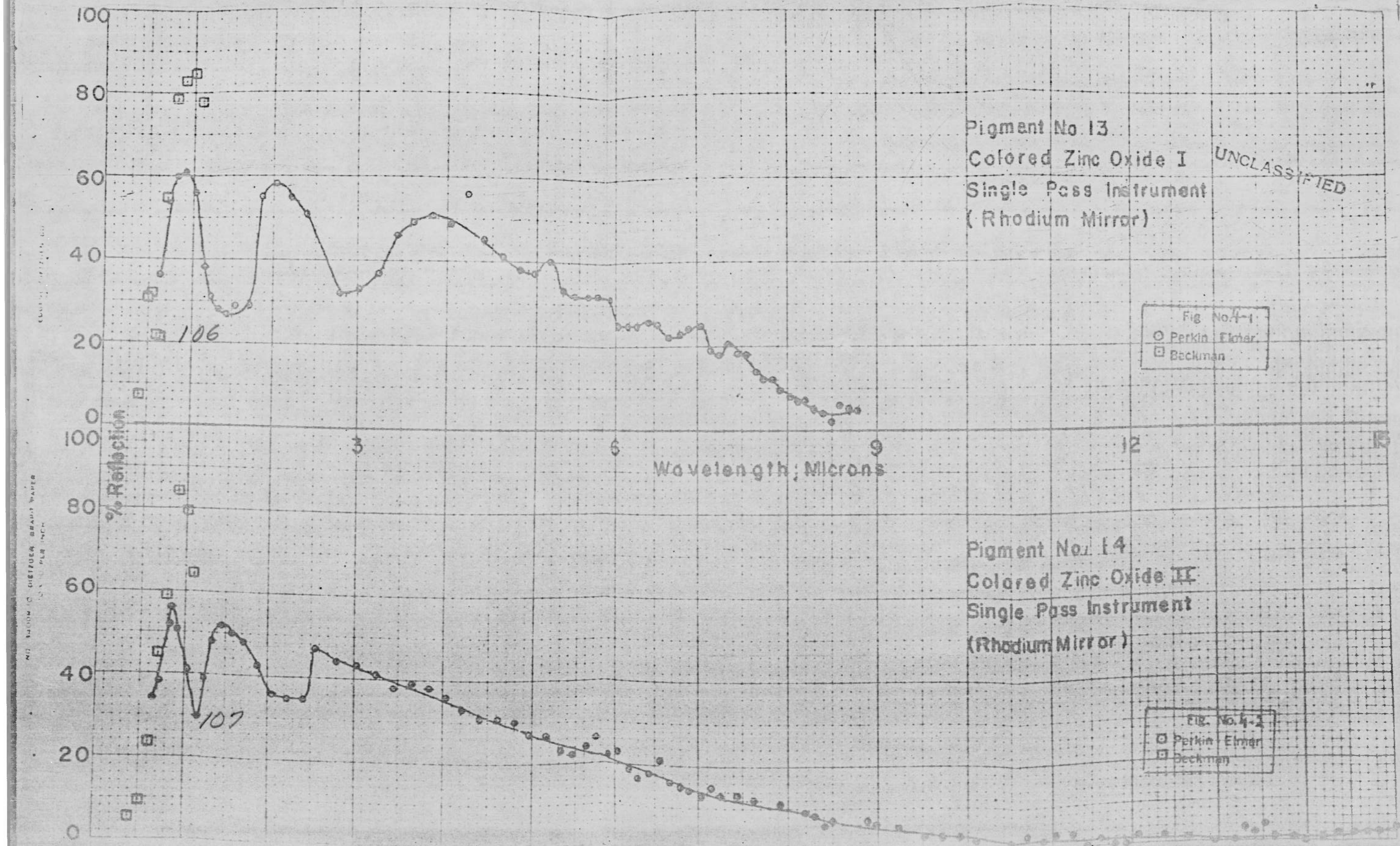
On Aluminum

105

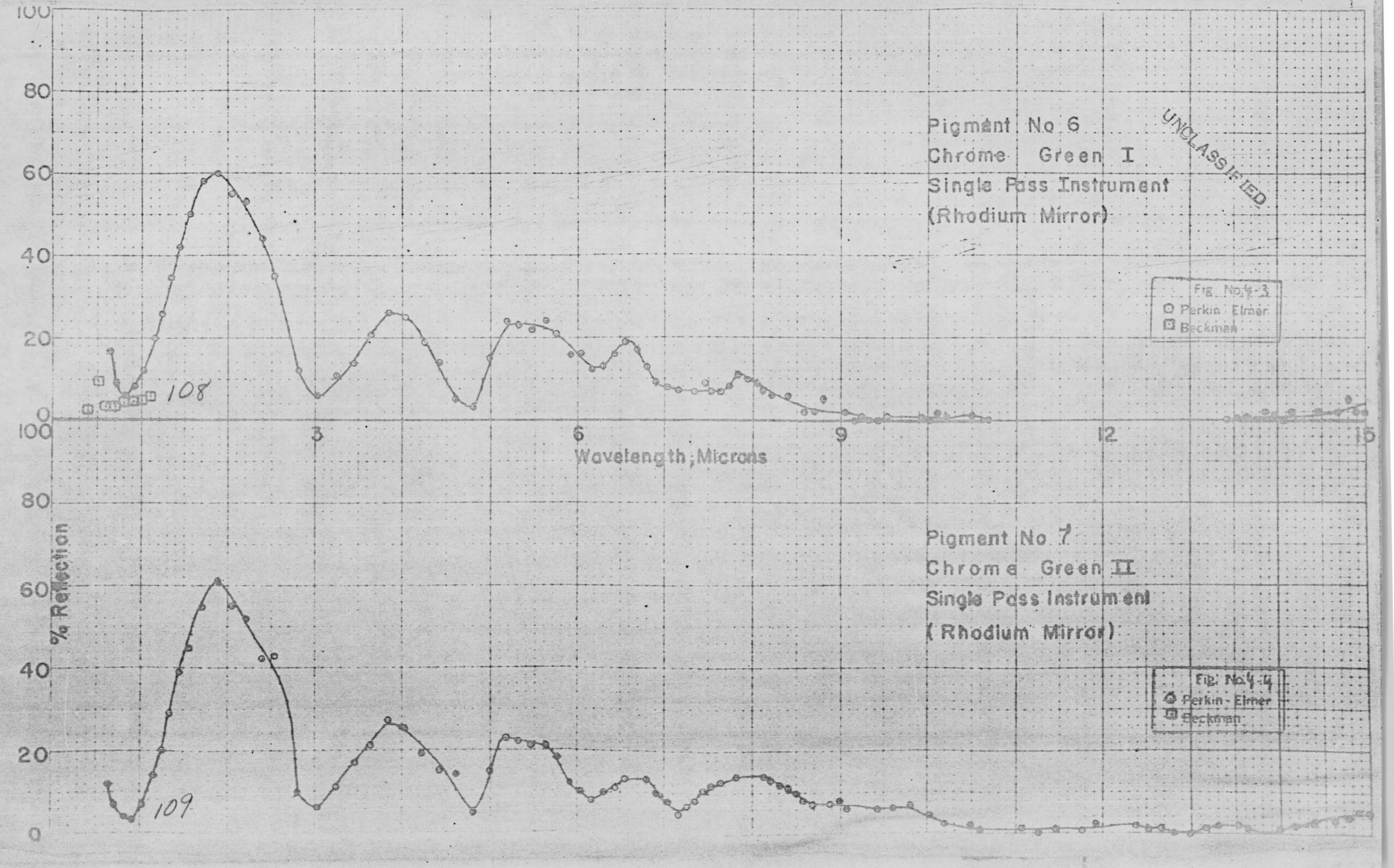
Fig. No. 3-7
○ Perkin-Elmer
□ Beckman

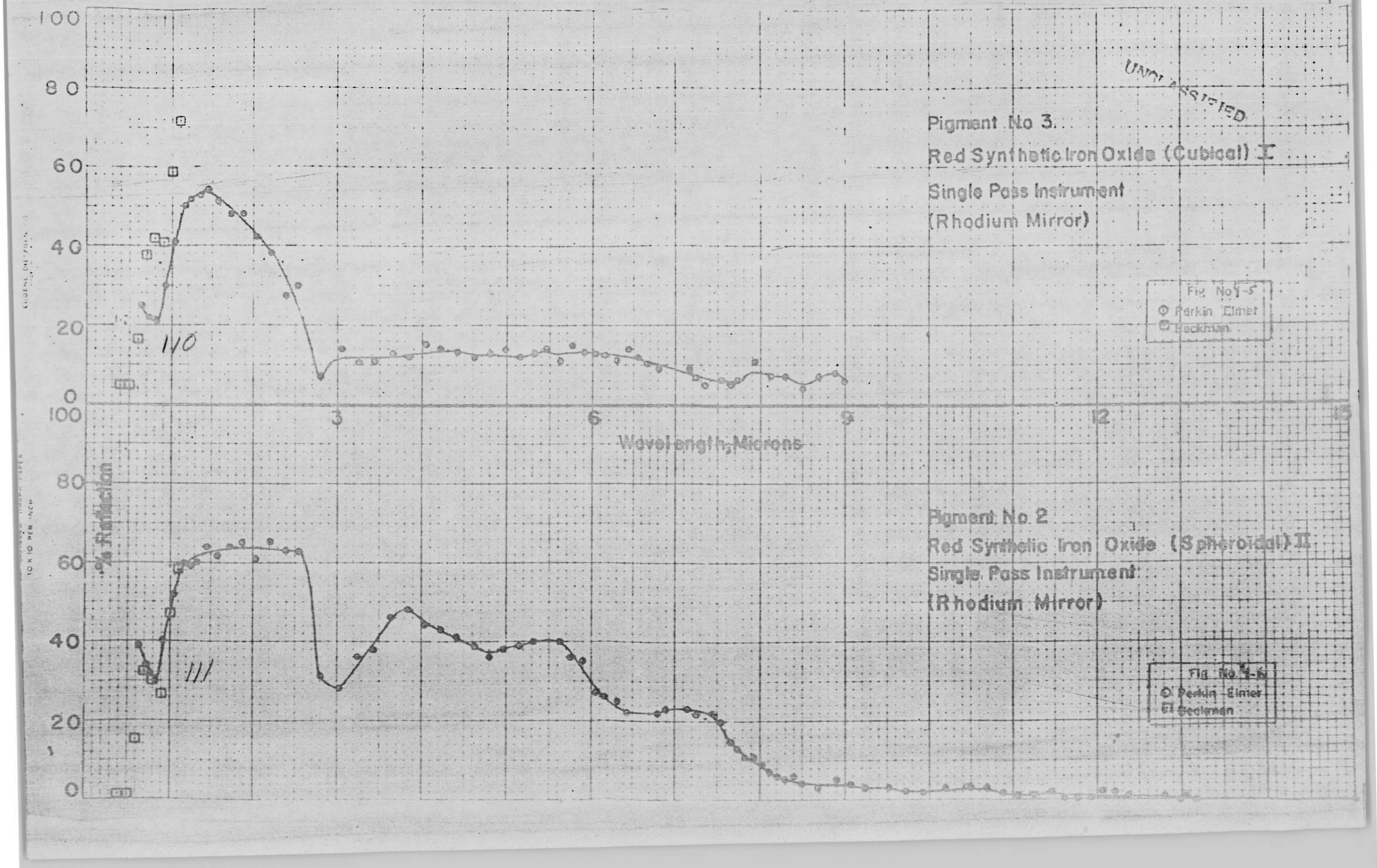
100
80
60
40
20
0

UNCLASSIFIED

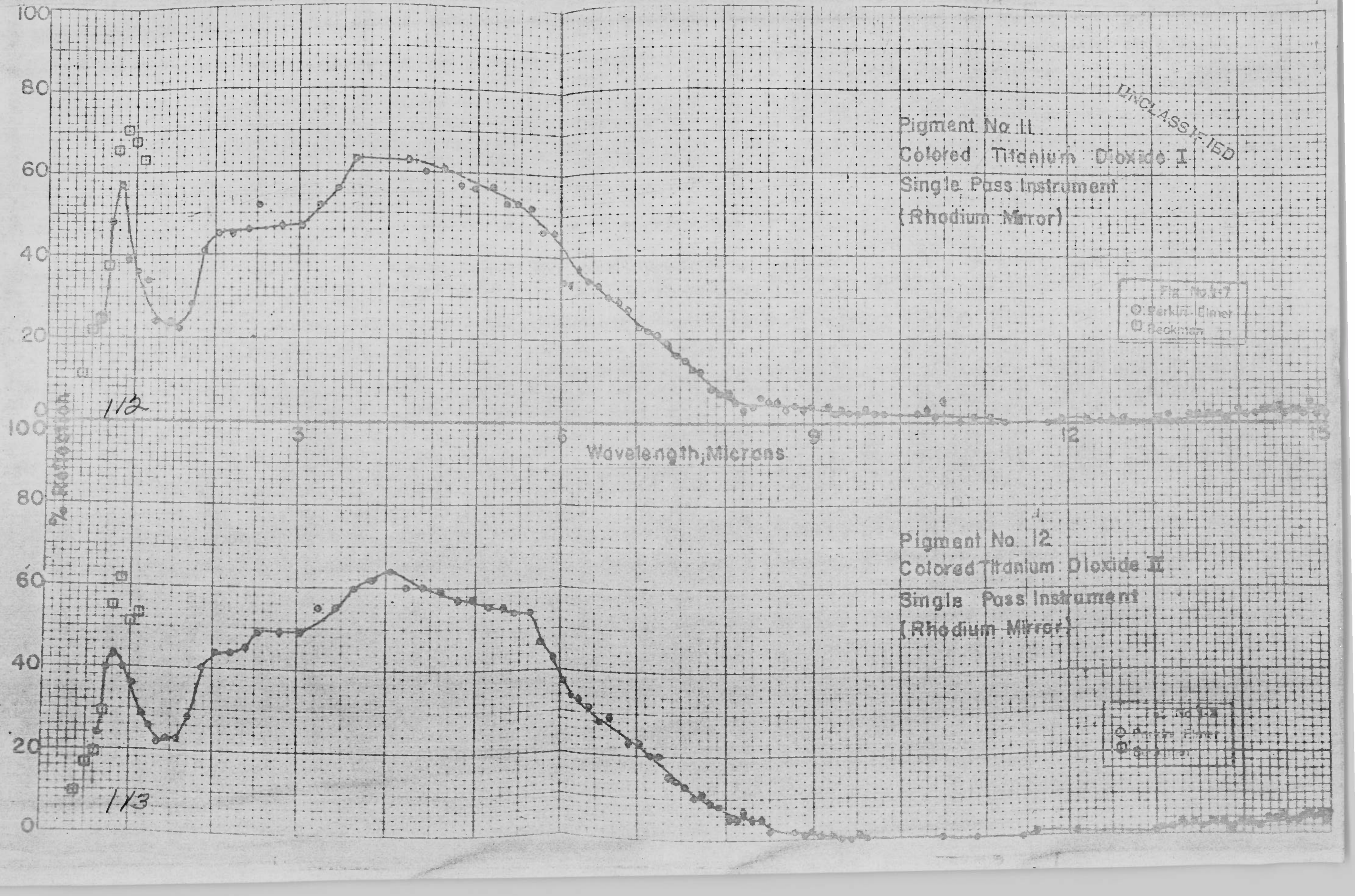


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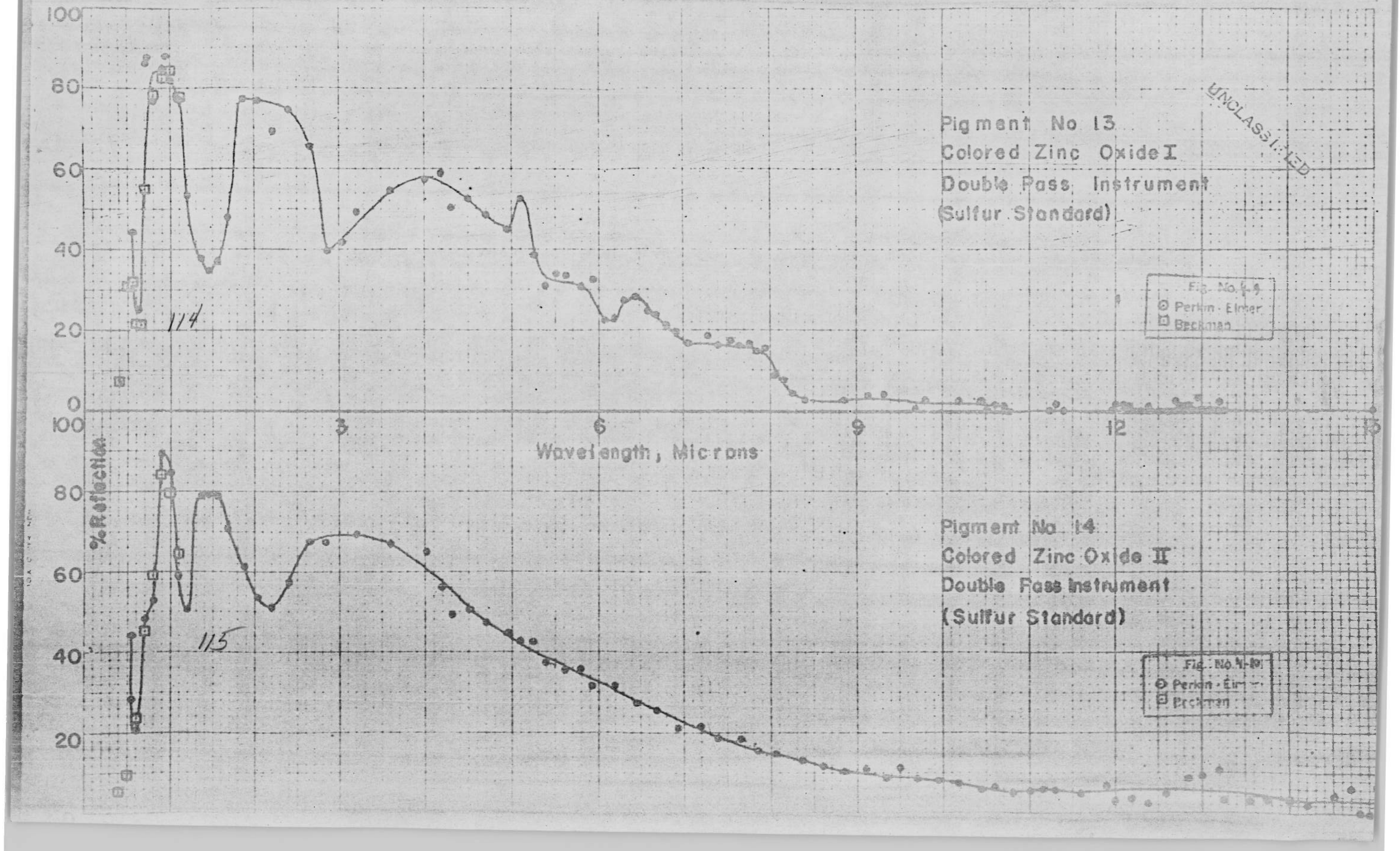



100
80
60
40
20
0
100
80
60
40
20
0
% Reflection
3
6
9
12
Wavelength, Microns
UNCLASSIFIED
Pigment No 3.
Red Synthetic Iron Oxide (Cubical) I
Single Pass Instrument
(Rhodium Mirror)
Fig No 1-5
Perkin Elmer
Beckman
110
Pigment No 2
Red Synthetic Iron Oxide (Spheroidal) II
Single Pass Instrument
(Rhodium Mirror)
Fig No 1-6
Perkin Elmer
Beckman
111

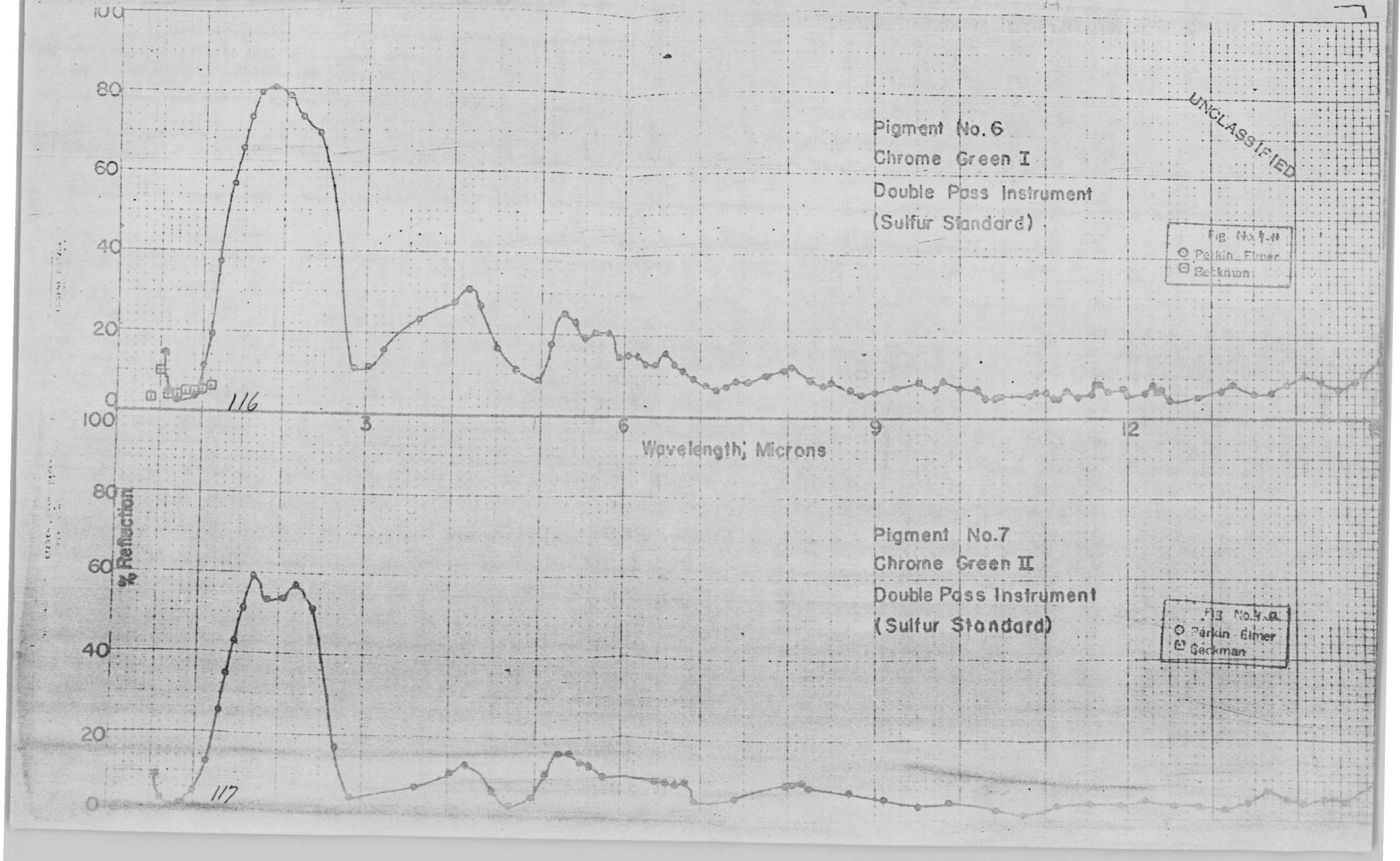
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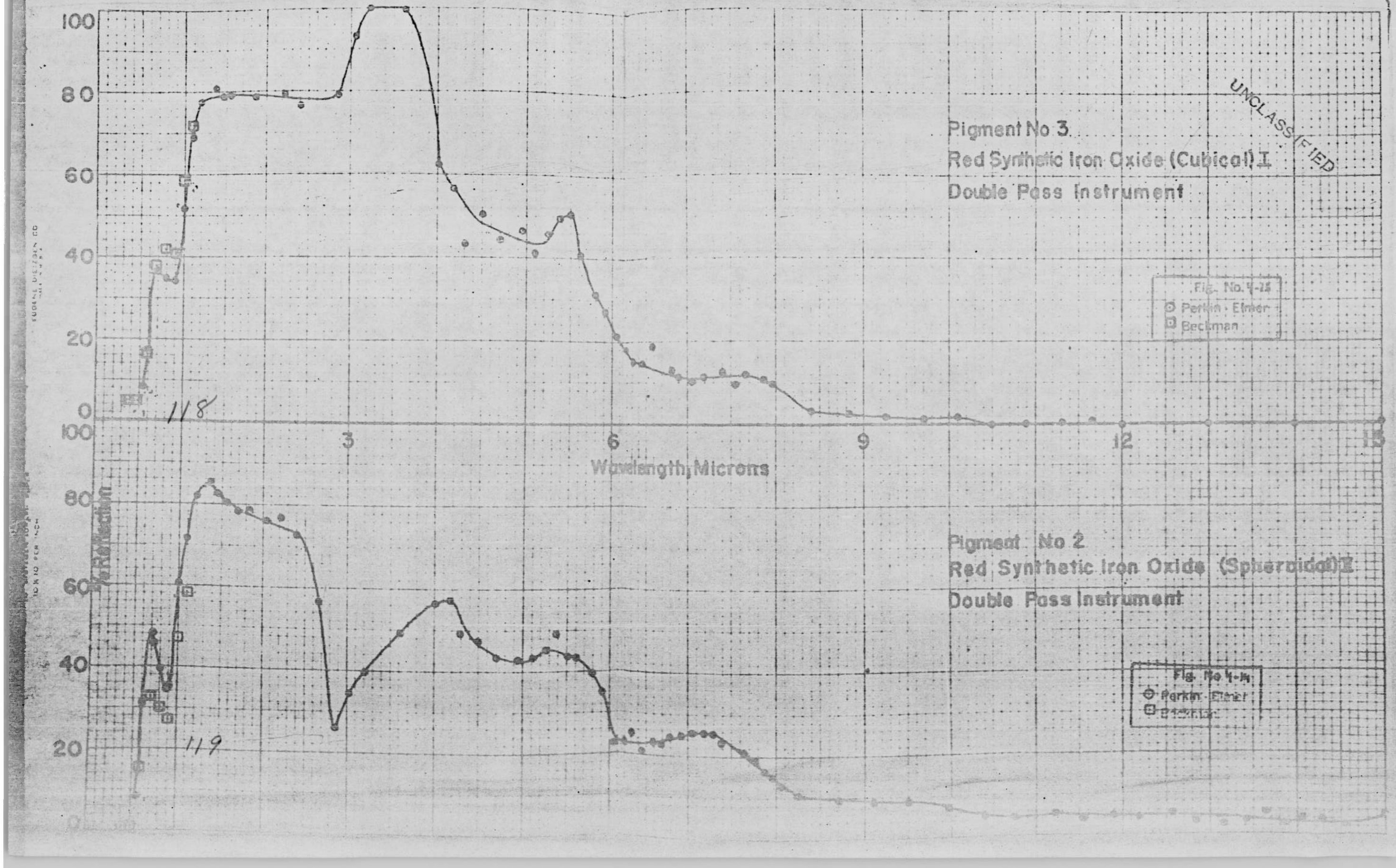
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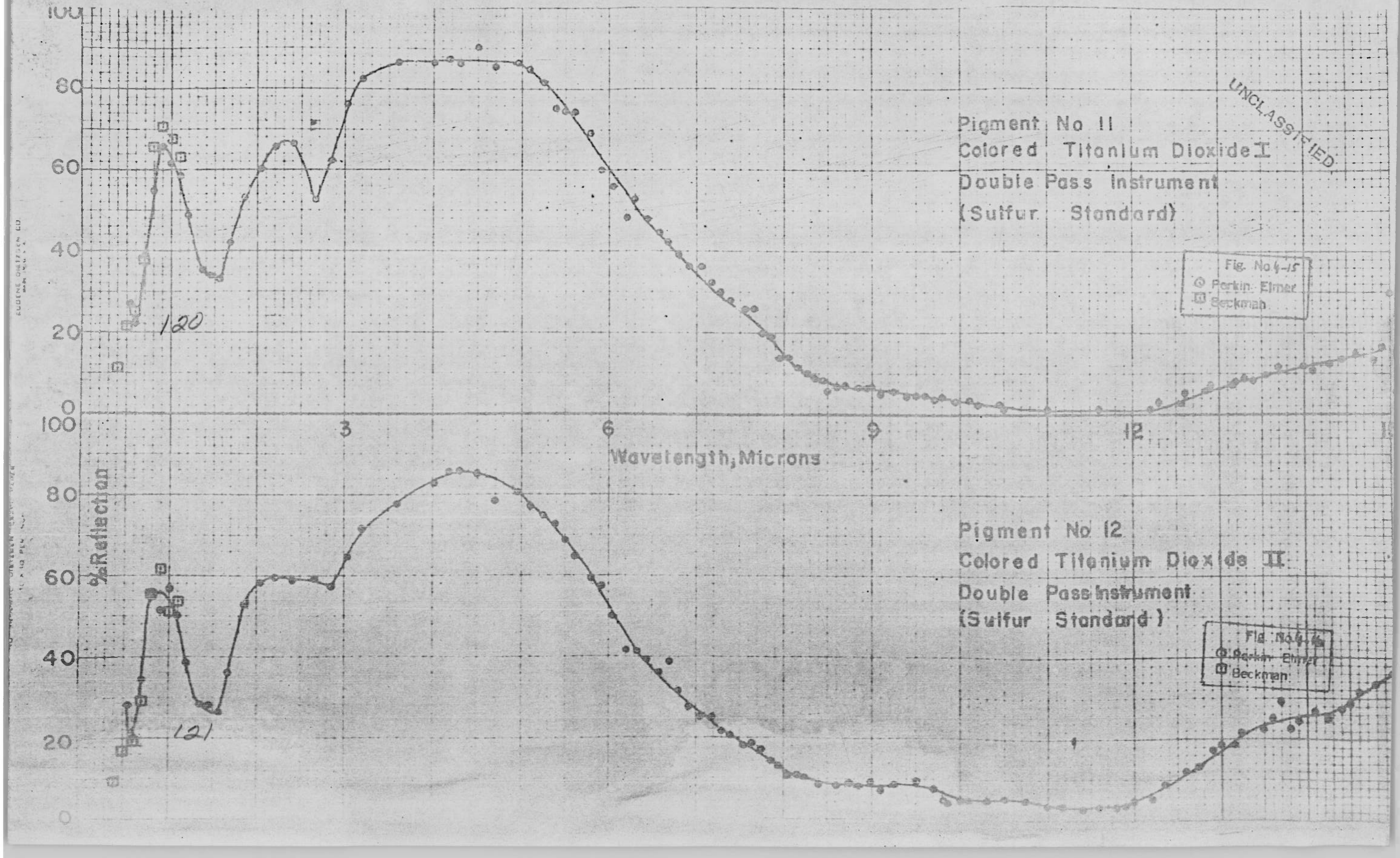
UNCLASSIFIED



UNCLASSIFIED



UNCLASSIFIED



UNCLASSIFIED

On Block

Point No 13
Colored Zinc Oxide 1
Single Pass Instrument
(Rhodium Mirror)

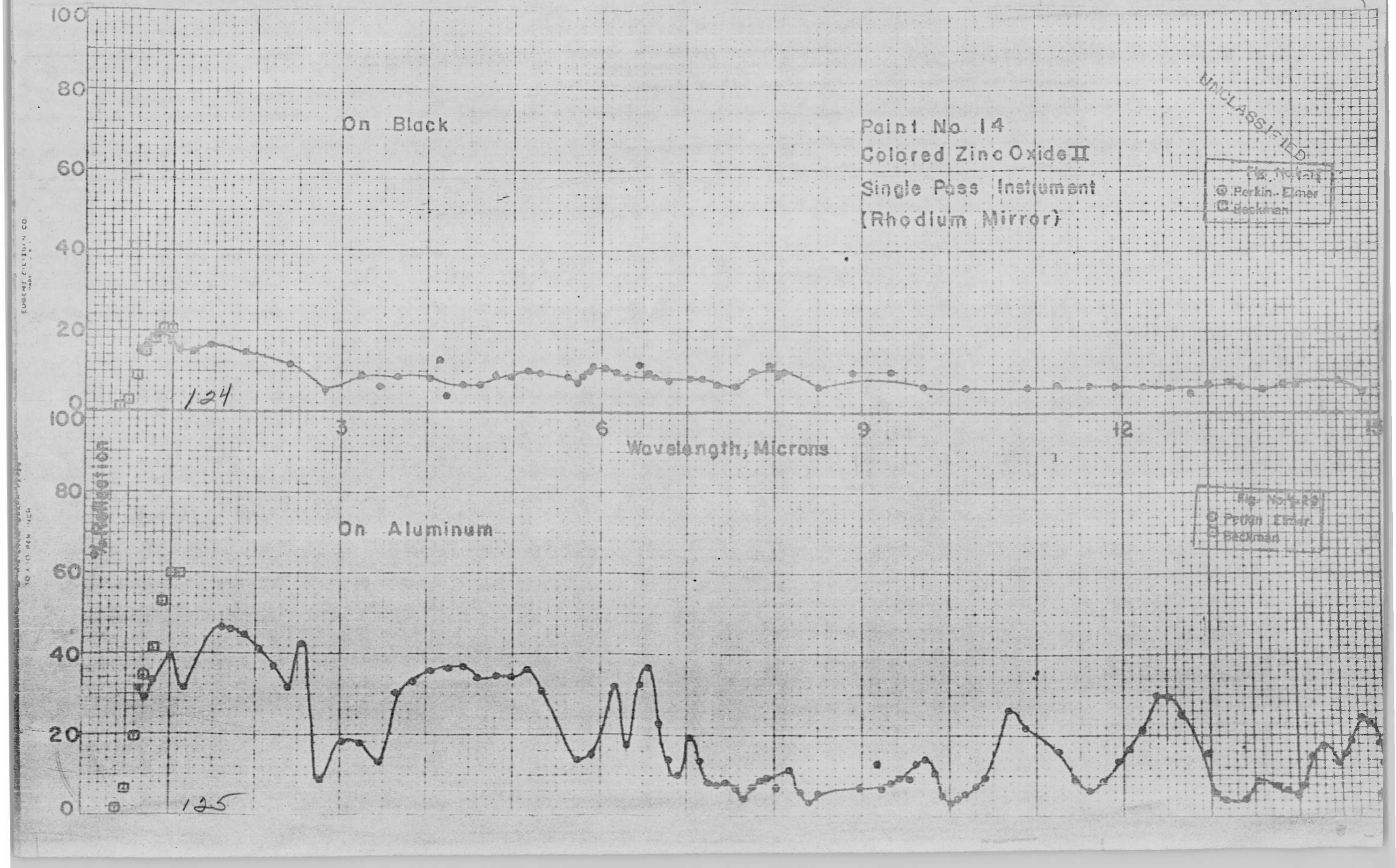
122

On Aluminum

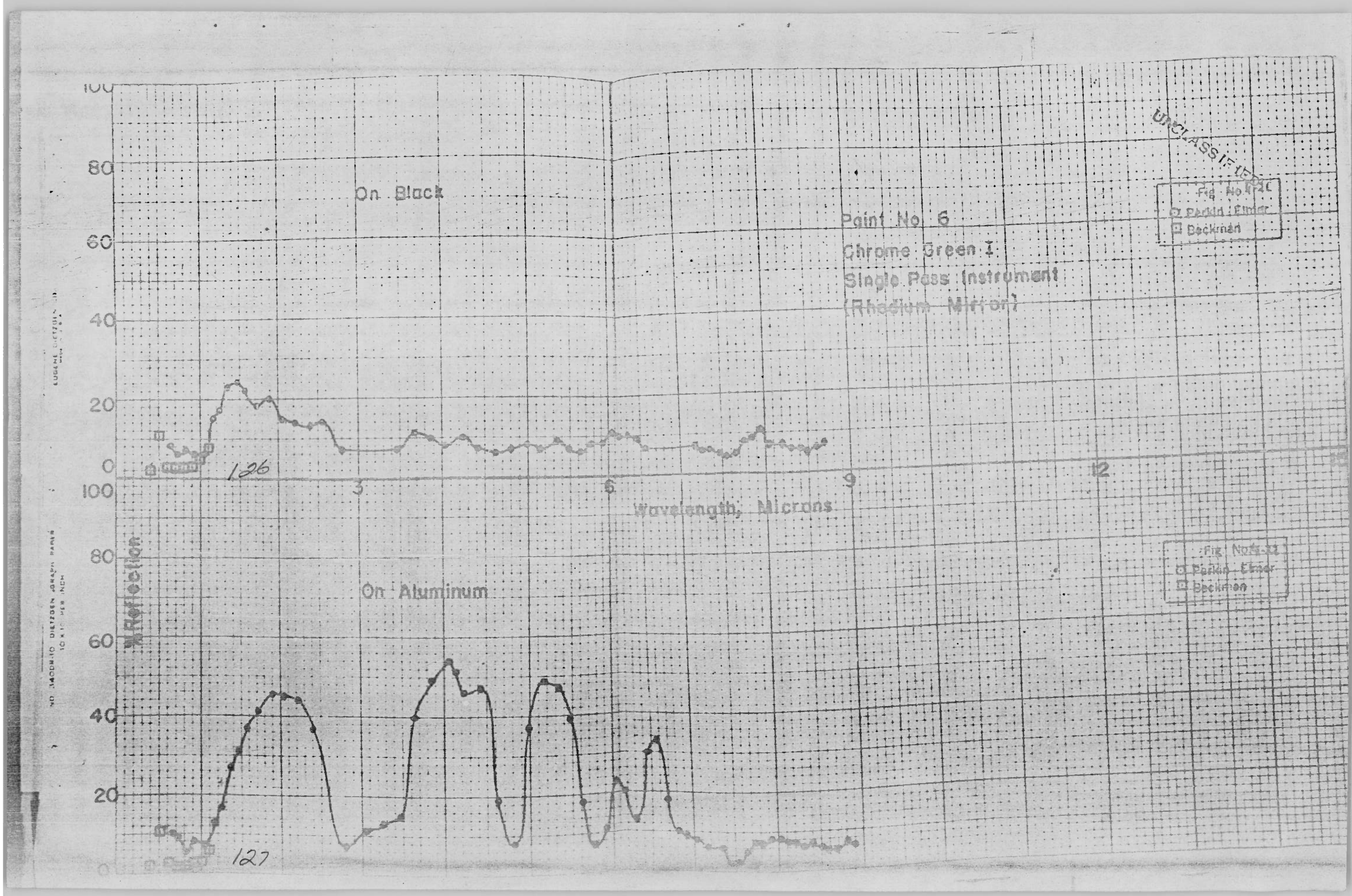
123

Wavelength, Microns

100
80
60
40
20
0


On Black
Paint No. 14
Colored Zinc Oxide II
Single Pass Instrument
(Rhodium Mirror)
UNCLASSIFIED
Fig. No. 14
Perkin-Elmer
Beckman
100
80
60
40
20
0
124
3
6
9
12
Wavelength, Microns
% Reflection
On Aluminum
Fig. No. 15
Perkin Elmer
Beckman
125

UNCLASSIFIED



UNCLASSIFIED

On Black

Paint No. 7
Chrome Green II
Single Pass Instrument
(Rhodium Mirror)

File No. 128
Perkin Elmer

100
80
60
40
20
0

128

On Aluminum

% Reflection

100
80
60
40
20
0

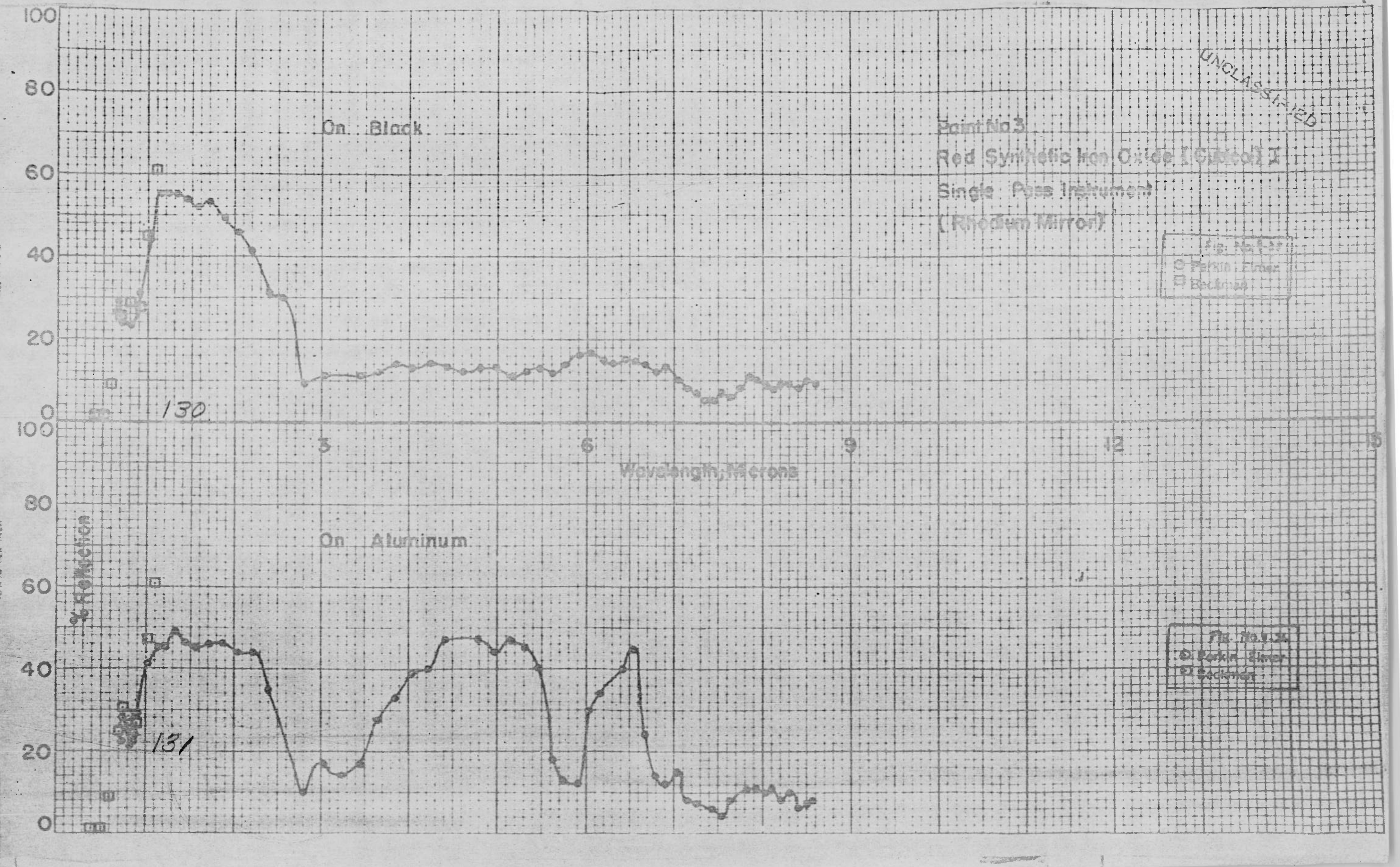
3
6
9
12

Wavelength, Microns

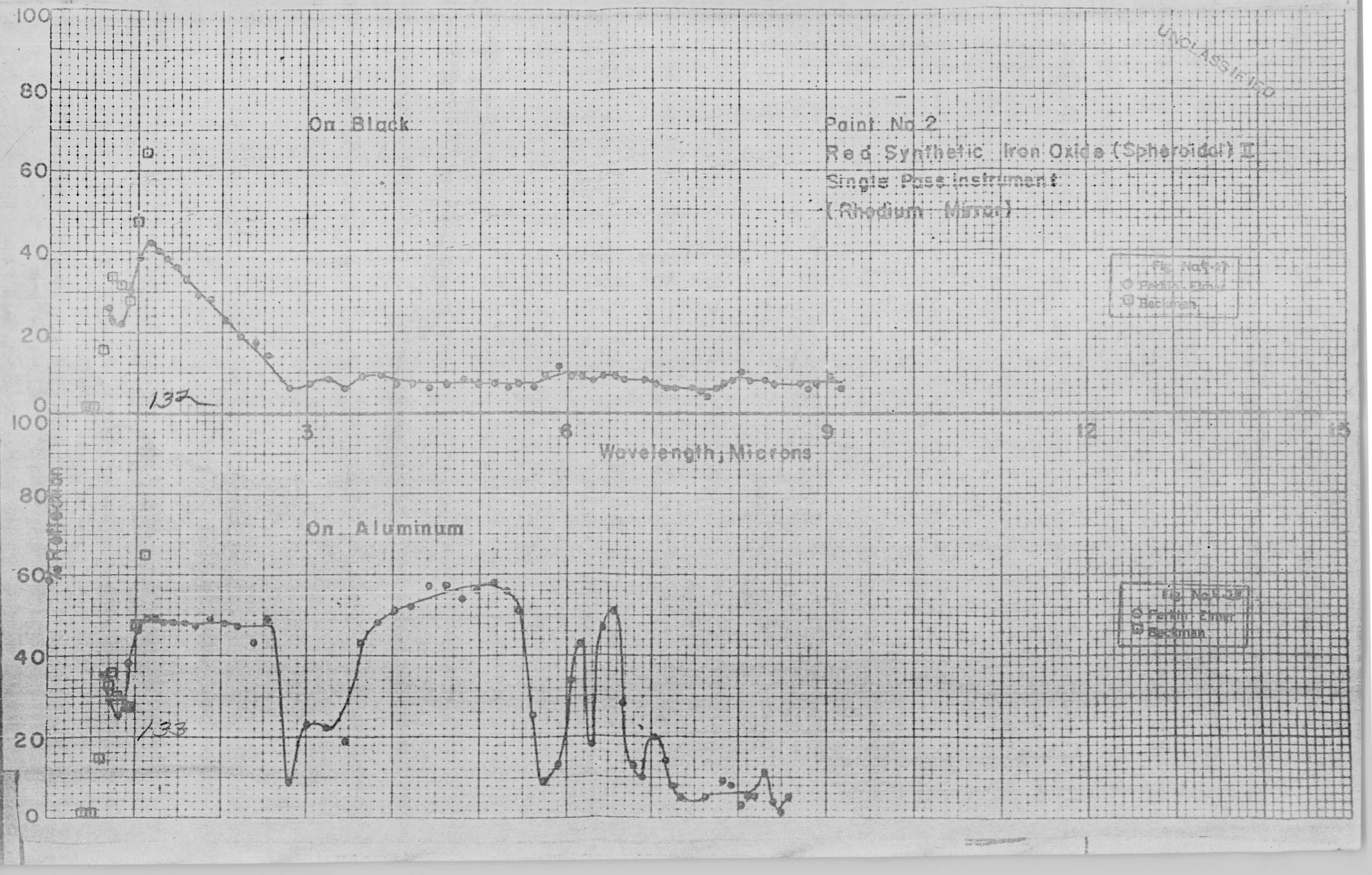
File No. 129
Perkin Elmer
Beckman

129

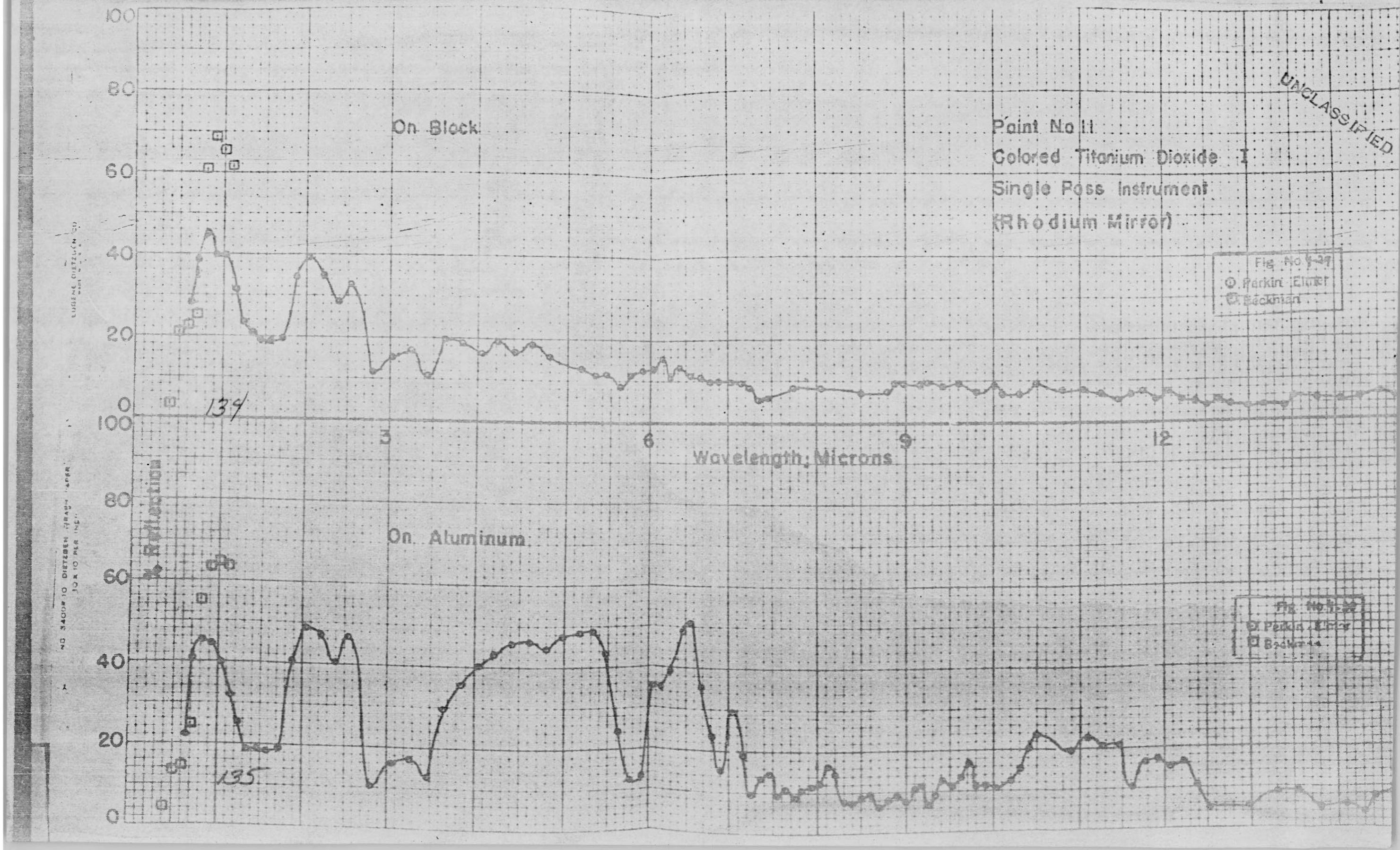
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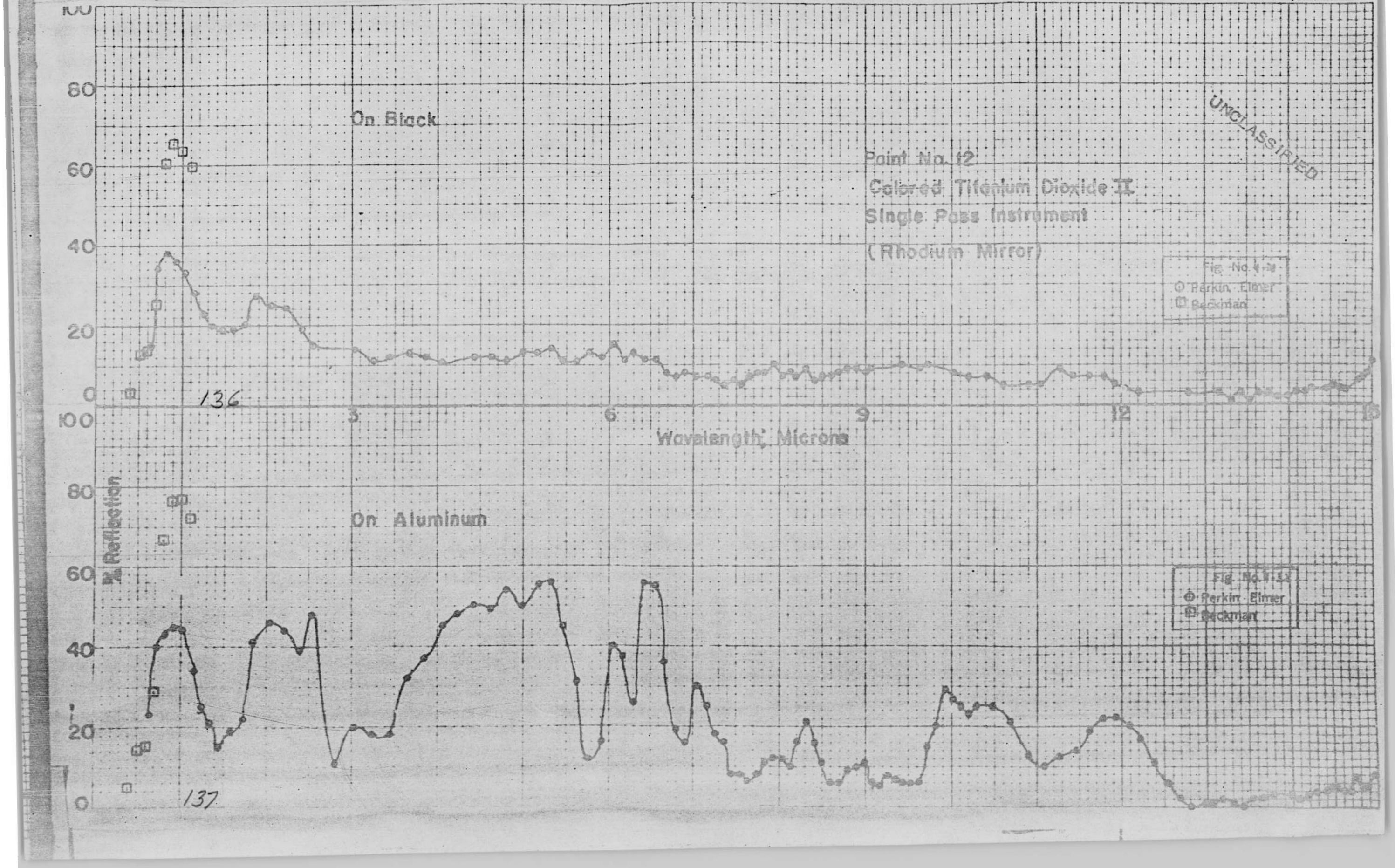
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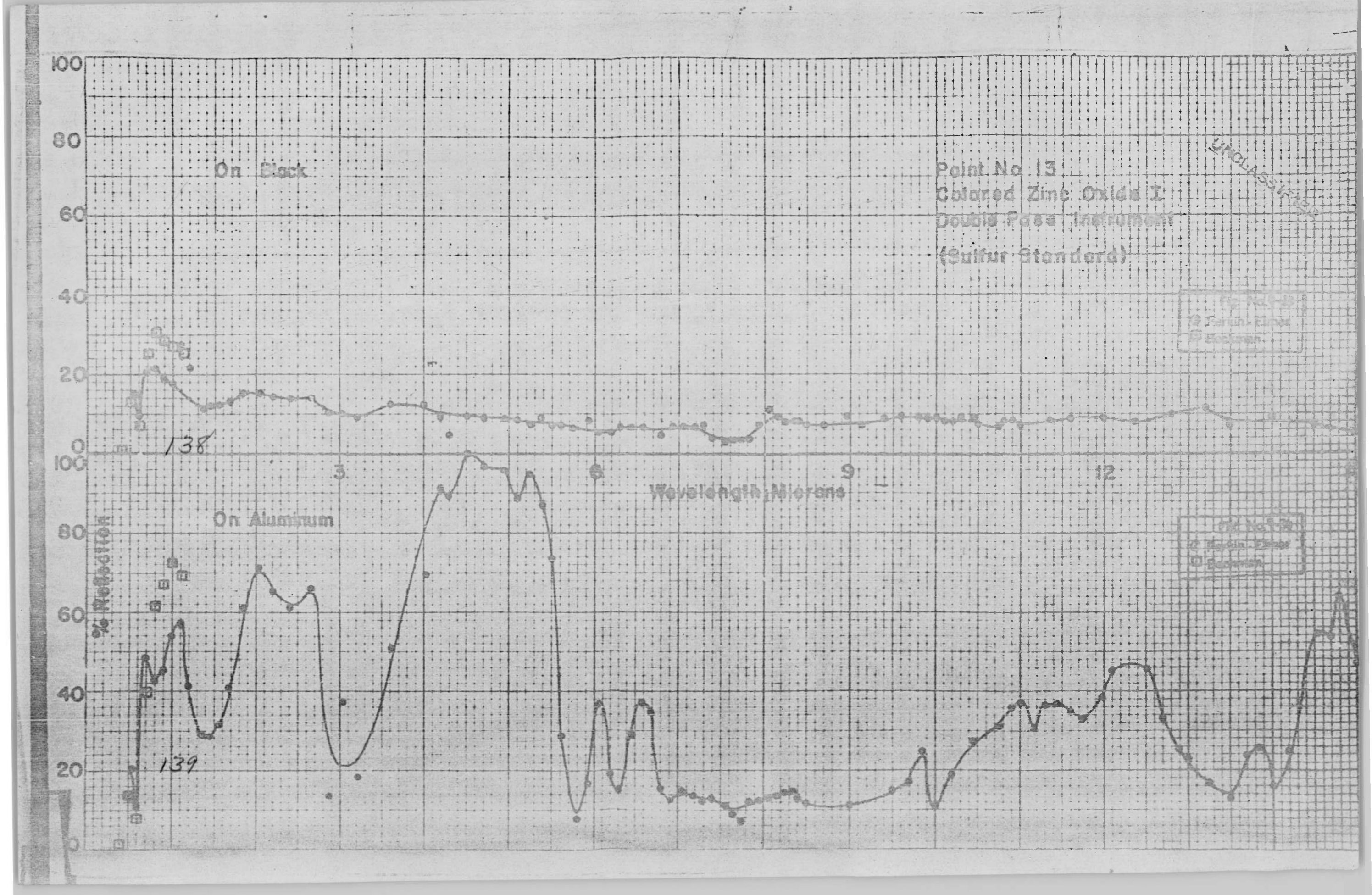


UNCLASSIFIED



UNCLASSIFIED




On Black
On Aluminum
% Reflection
Wavelength, Microns
Point No. 13
Colored Zinc Oxide I
Double-Pass Instrument
(Sulfur Standard)
138
139
100
80
60
40
20
0
3
6
9
12

UNCLASSIFIED

On Black

Paint No 14
Colored Zinc Oxide II
Double Pass Instrument
(Sulfur Standard)

Fig. No 13C
○ Perkin-Elmer
□ Beckman

100
80
60
40
20
0

140

3 6 9 12

Wavelength, Microns

% Reflection

On Aluminum

Fig. No 13D
○ Perkin-Elmer
□ Beckman

100
80
60
40
20
0

141

10 X 10 PER INCH

On Black

Paint No. 6
Chrome Green I
Double Pass Instrument
(Sulfur Standard)

Unpolarized

Perkin-Elmer
Beckman

142

100
80
60
40
20
0

3
6
9
12

Wavelength, Microns

% Reflectance

On Aluminum

143

100
80
60
40
20
0

10 X 10 PER INCH

On Black

Point No 7
Chrome Green III
Double Pass Instrument
(Sulfur Standard)

UNCLASSIFIED

Fig. No. 5-96
Perkin-Elmer
Beckman

144

100
80
60
40
20
0

3
6
9
12

Wavelength; Microns

% Reflection

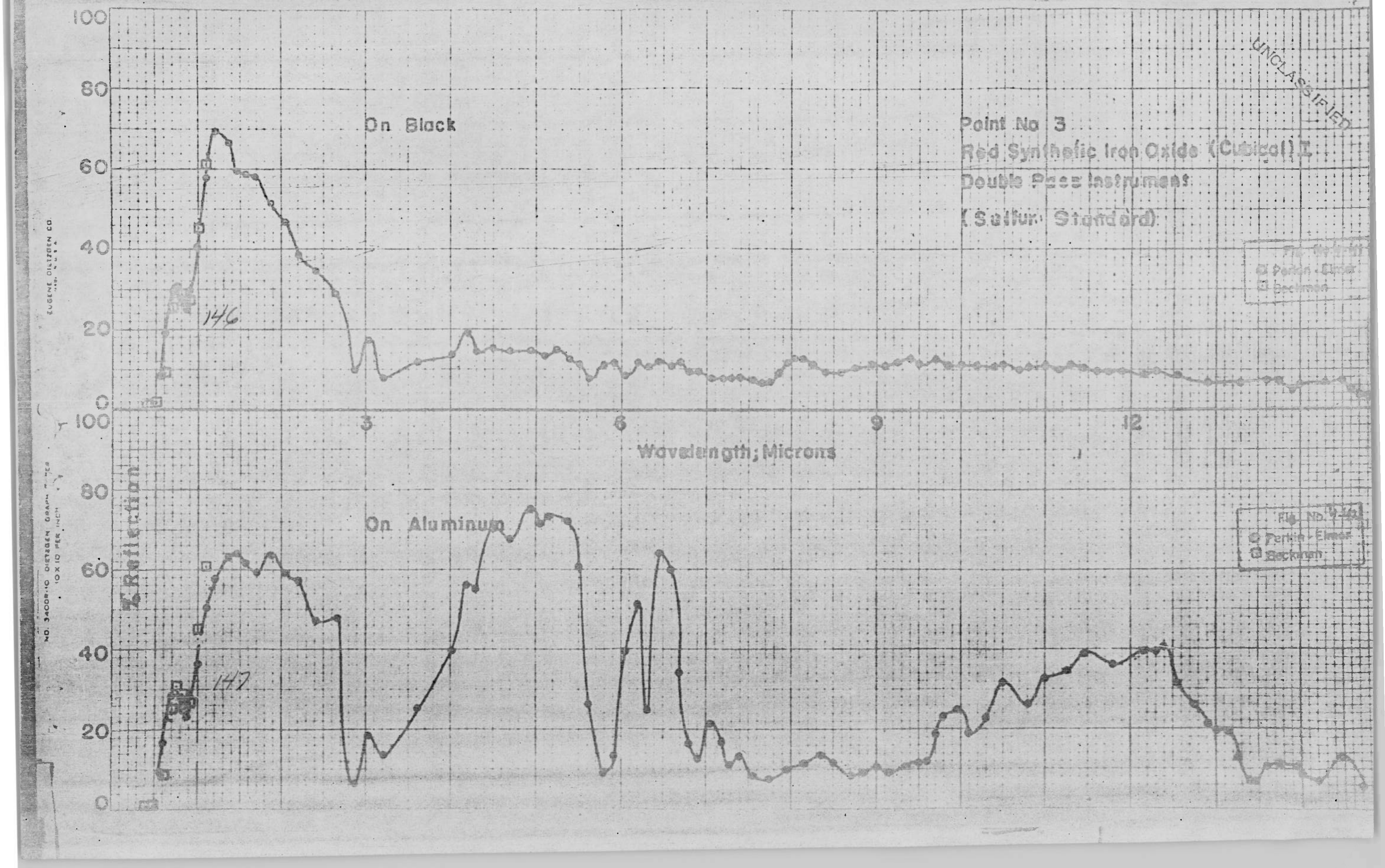
On Aluminum

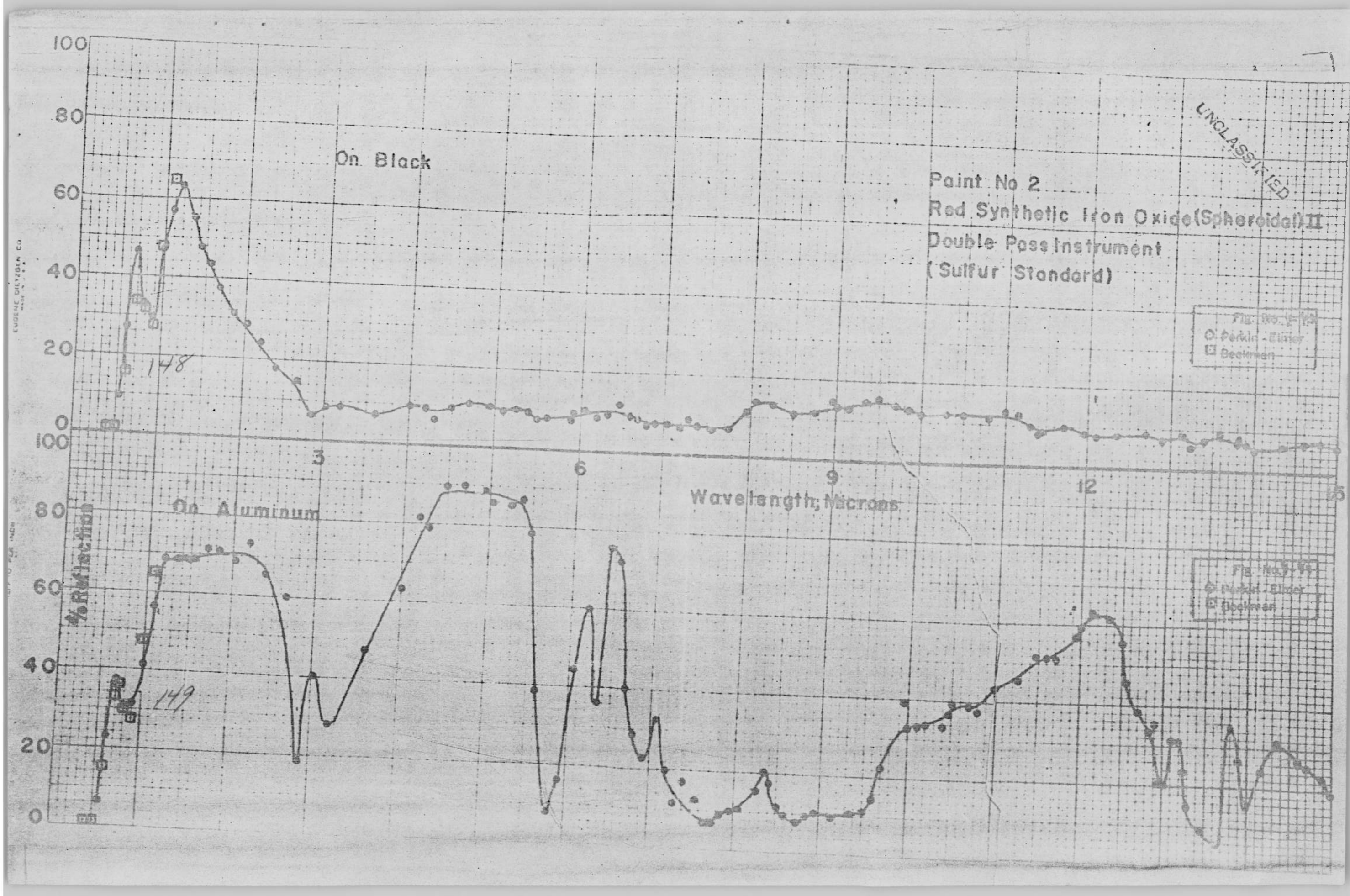
Fig. No. 5-96
Perkin-Elmer
Beckman

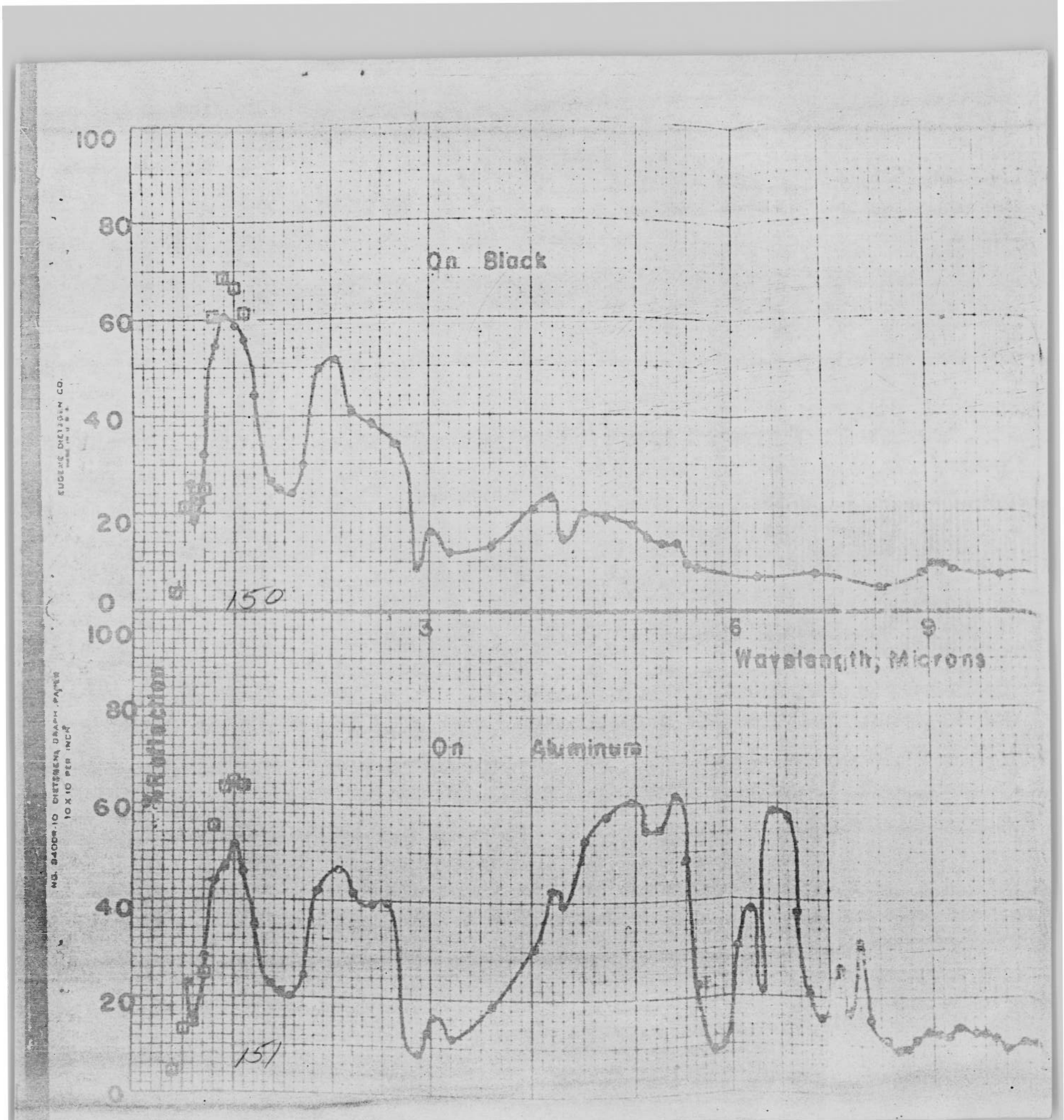
145

100
80
60
40
20
0

UNCLASSIFIED




UNCLASSIFIED
On Black
Paint No 2
Red Synthetic Iron Oxide(Spheroidal)II
Double Pass Instrument
(Sulfur Standard)
148
On Aluminum
149
% Reflection
Wavelength, Microns
100
80
60
40
20
0
3
6
9
12
15


100
80
60
40
20
0
On Black
150
3
6
9
Wavelength, Microns
Reflection
On Aluminum
151

Paint No. 12
Colored Titanium Dioxide II
Joule Pass Instrument
(Sulfur Standard)

On Black

152

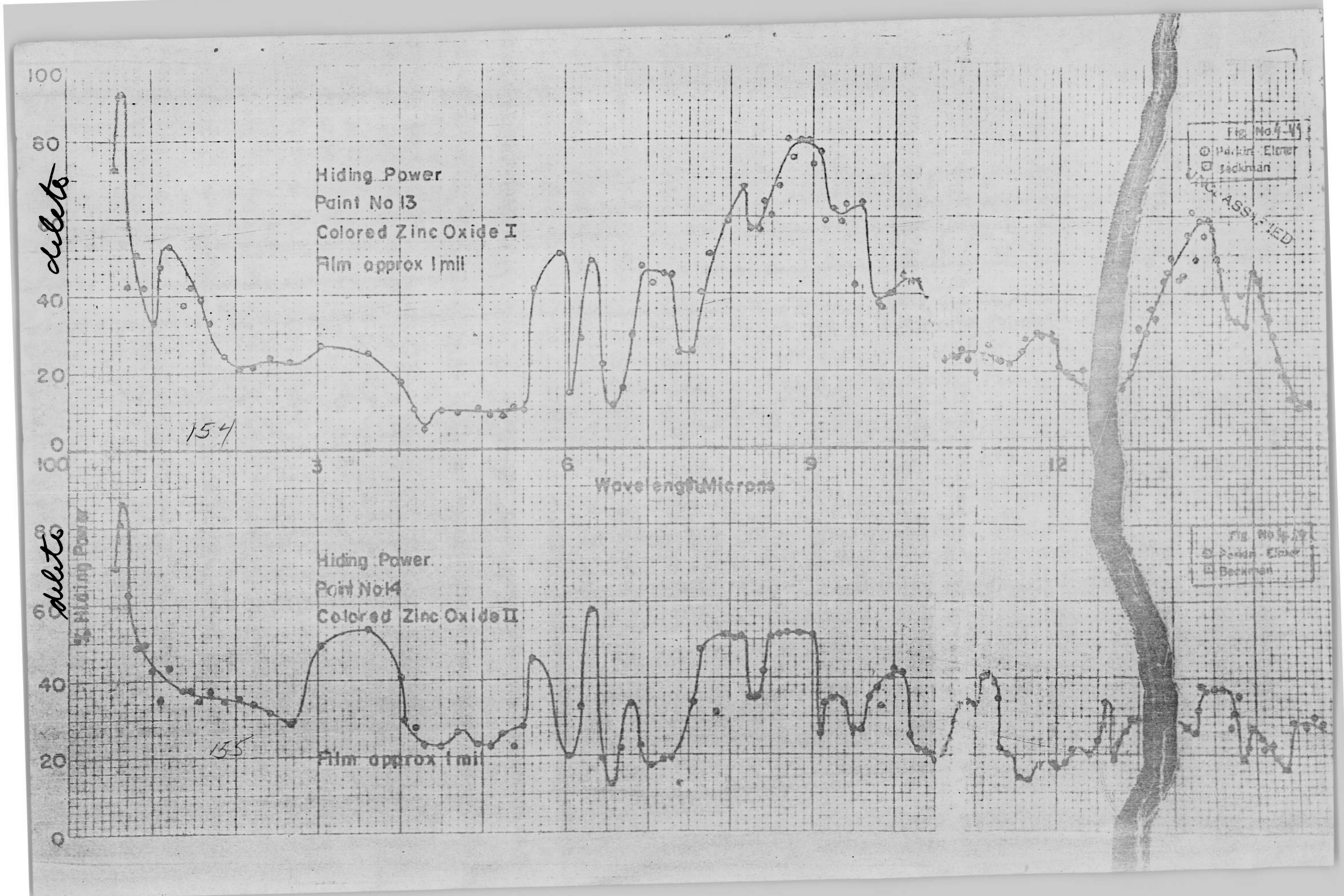
On Aluminum

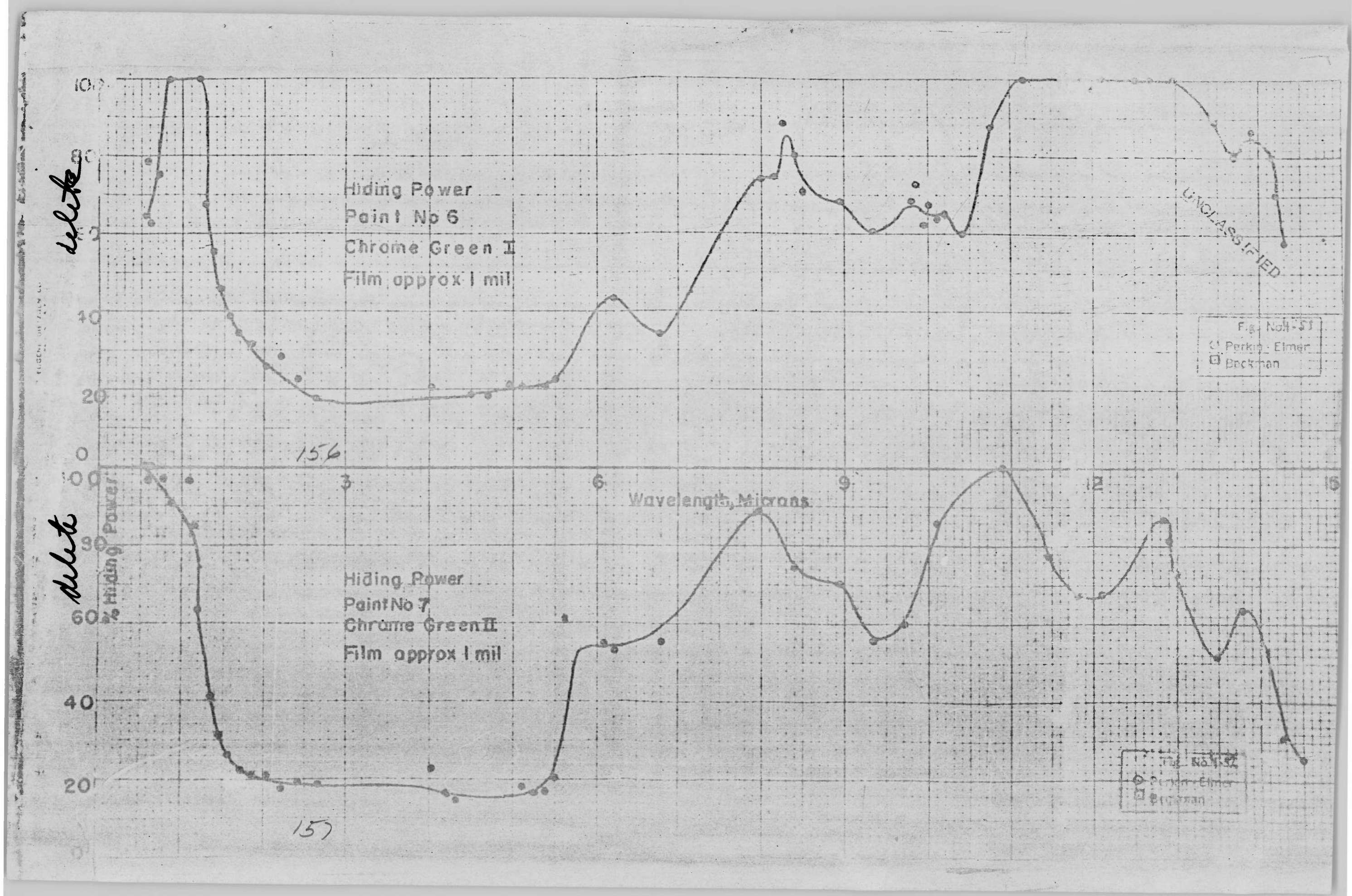
153

% Reflection

Wavelength, Microns

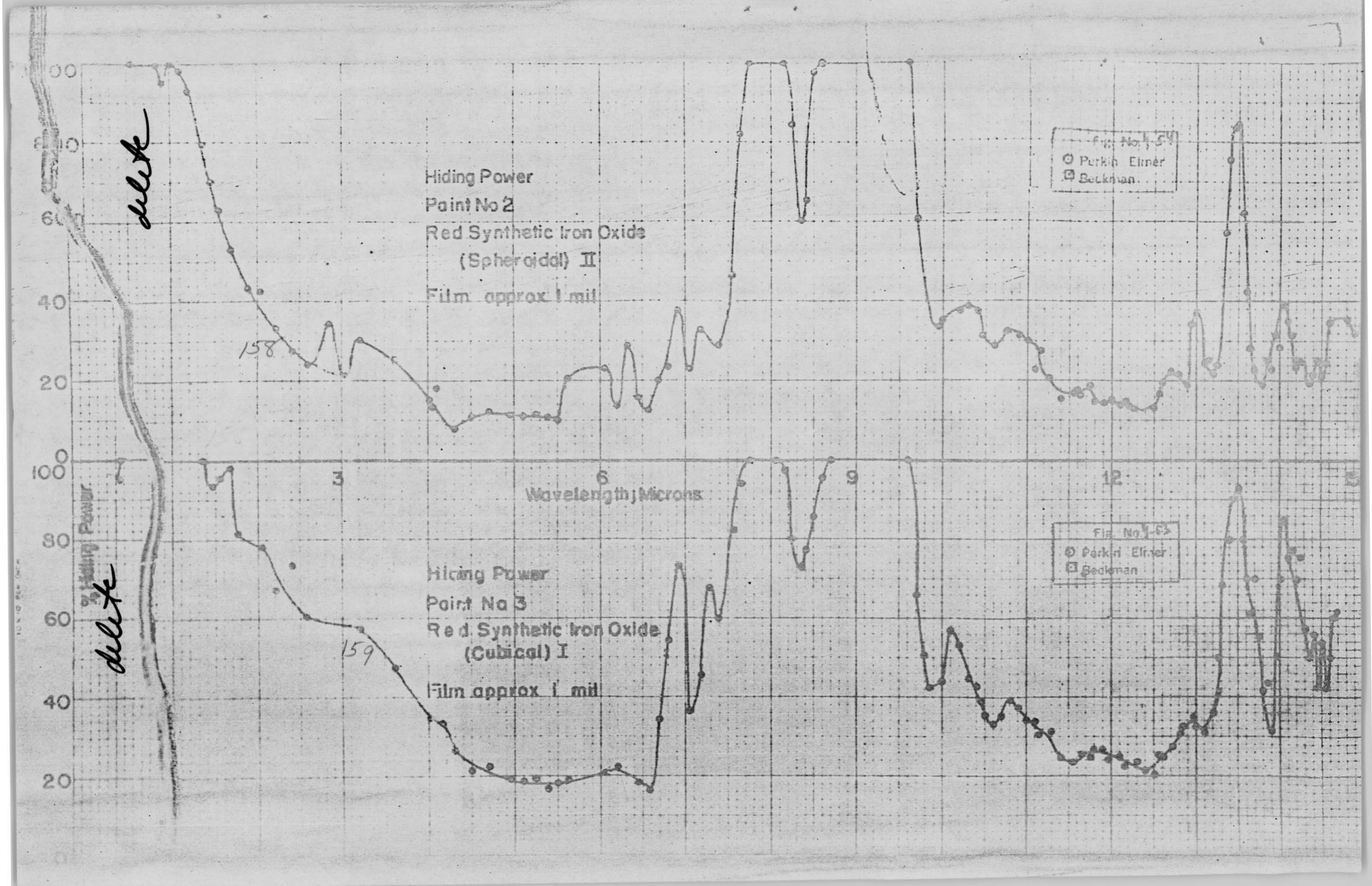
UNCLASSIFIED

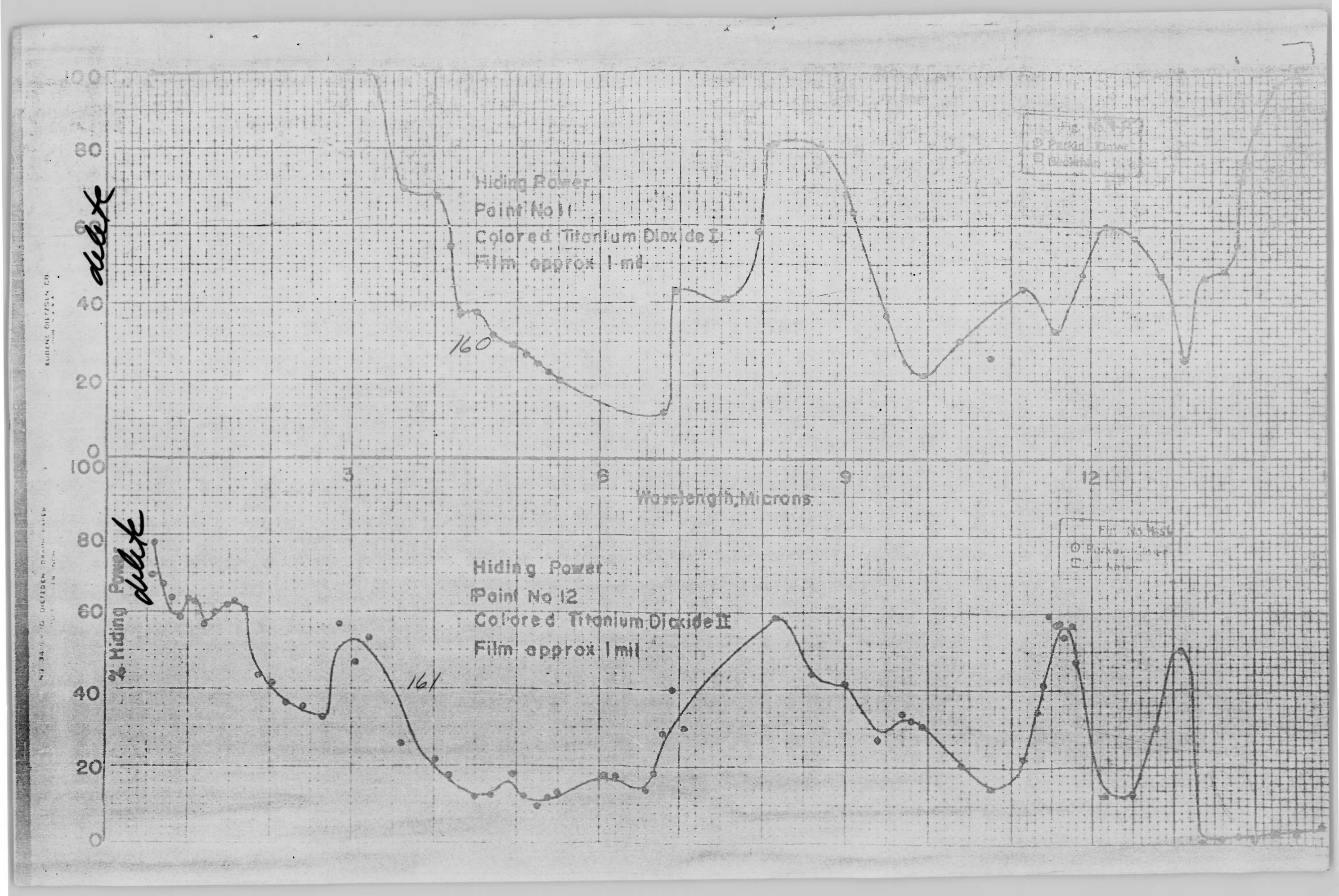

Hiding Power
Paint No 13
Colored Zinc Oxide I
Film approx 1 mil
154
Wavelength Microns
Hiding Power
Paint No 14
Colored Zinc Oxide II
Film approx 1 mil
155
ASSIFIED

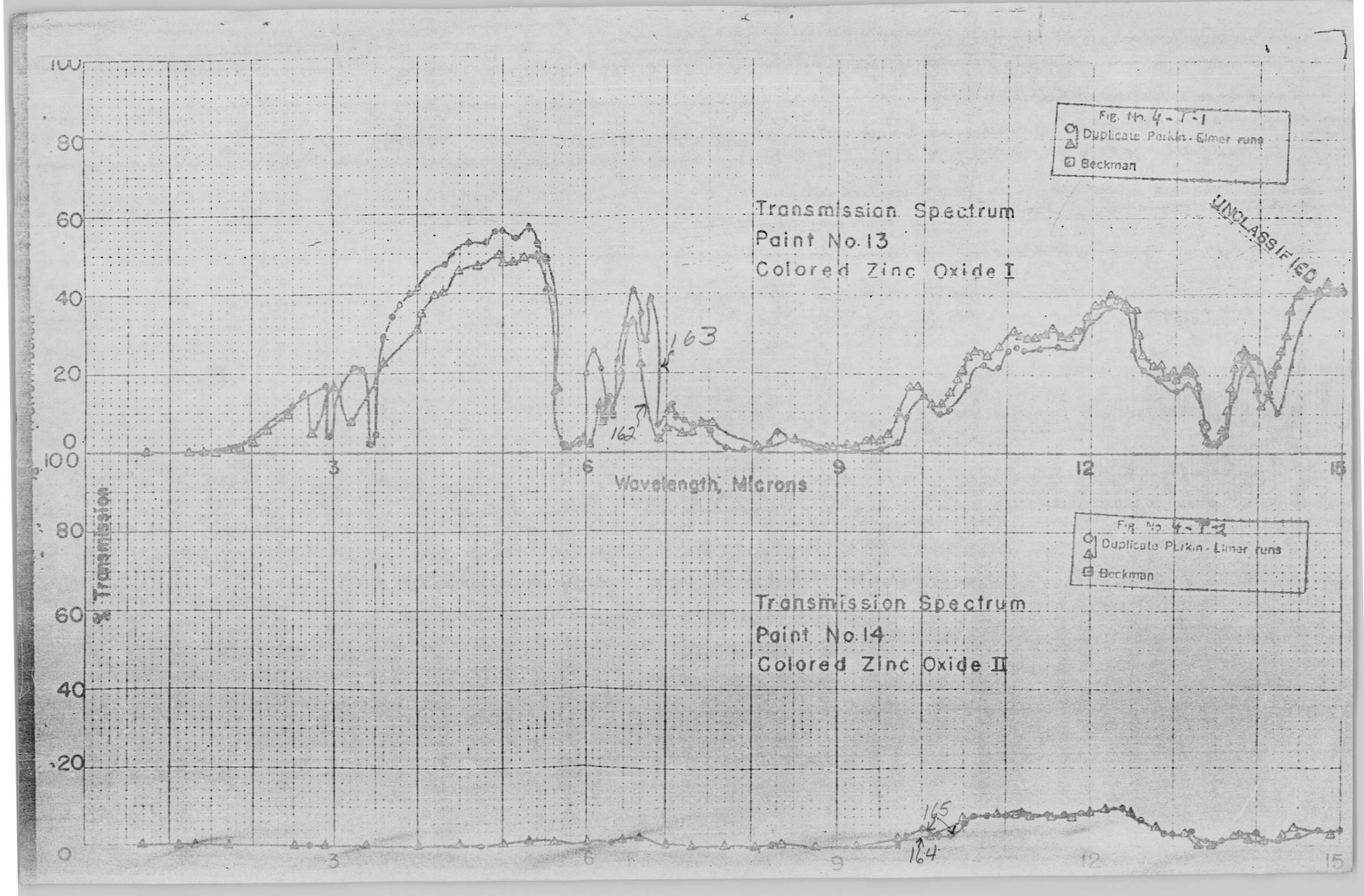

Hiding Power
Point No 6
Chrome Green II
Film approx 1 mil
UNCLASSIFIED
Wavelength, Microns
Hiding Power
Point No 7
Chrome Green II
Film approx 1 mil

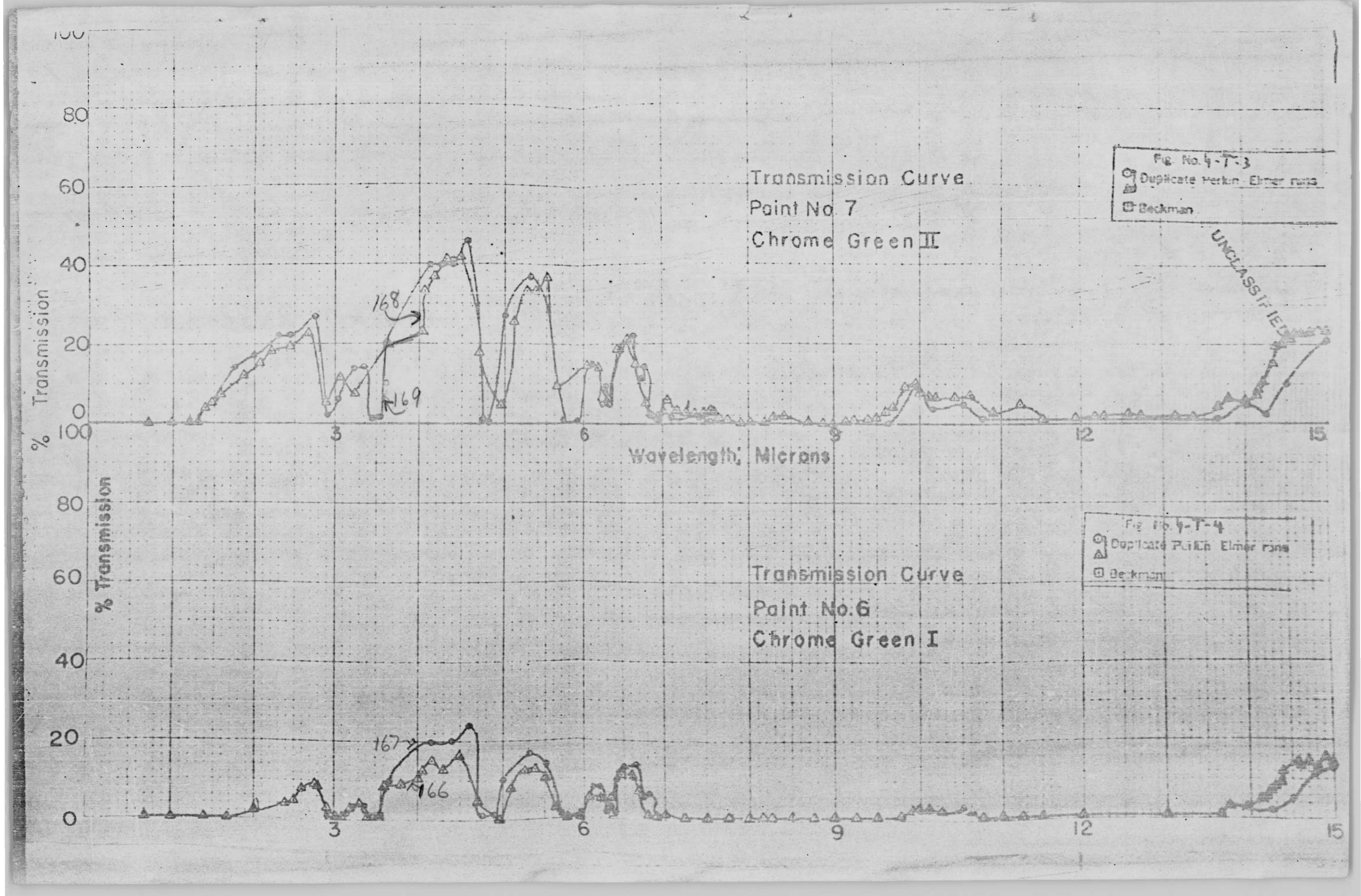
156

157

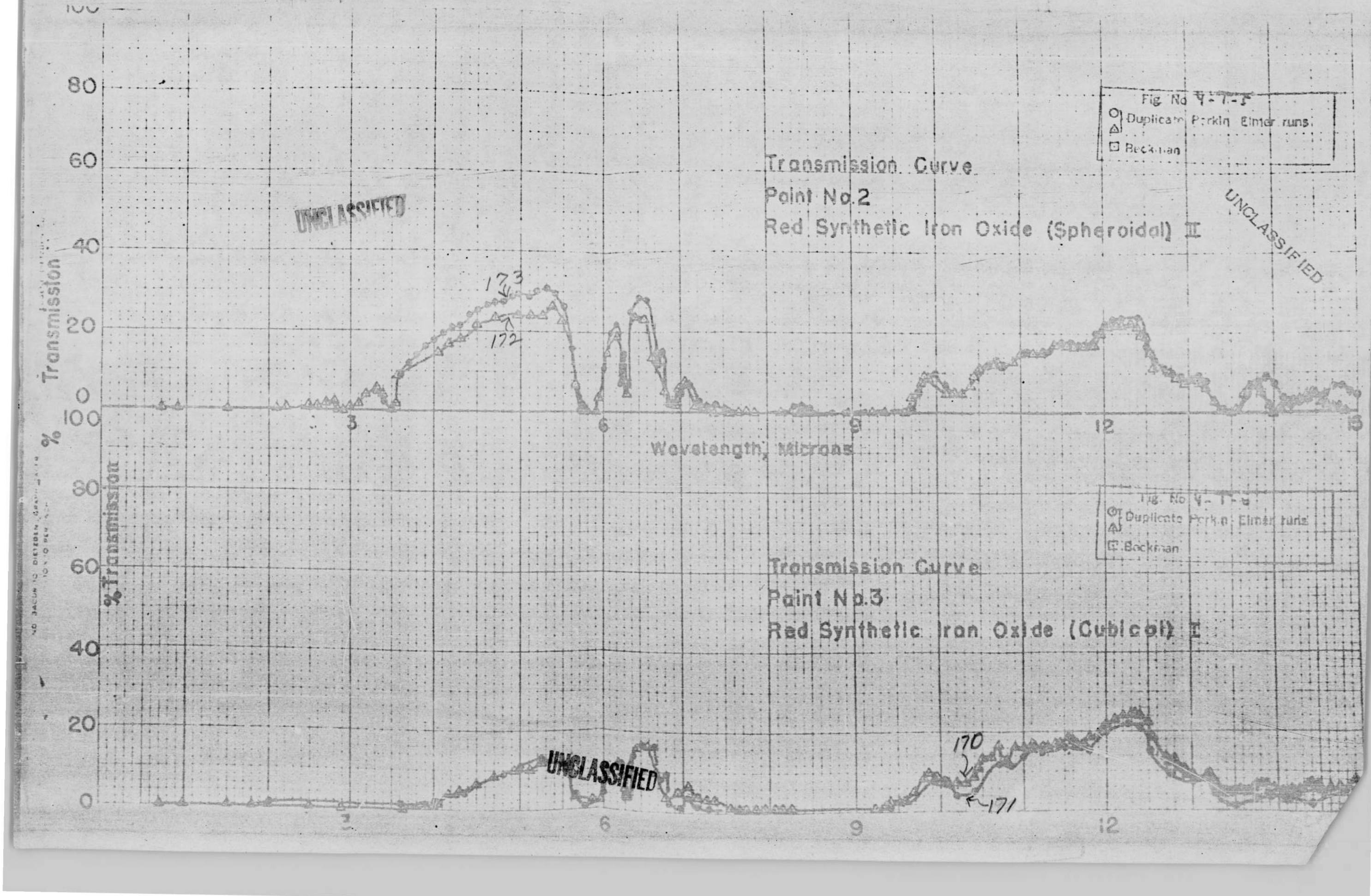

Hiding Power
Paint No 2
Red Synthetic Iron Oxide
(Spheroidal) II
Film approx 1 mil
158
Fig. No. 1-54
Perkin Elmer
Beckman
% Hiding Power
Wavelength, Microns
Hiding Power
Paint No 3
Red Synthetic Iron Oxide
(Cubical) I
Film approx 1 mil
159
Fig. No. 1-55
Perkin Elmer
Beckman


100
80
60
40
20
0
% Hiding Power
dilute
Hiding Power
Paint No 11
Colored Titanium Dioxide I
Film approx 1 mil
160
3
6
9
12
Wavelength, Microns
Hiding Power
Paint No 12
Colored Titanium Dioxide II
Film approx 1 mil
161

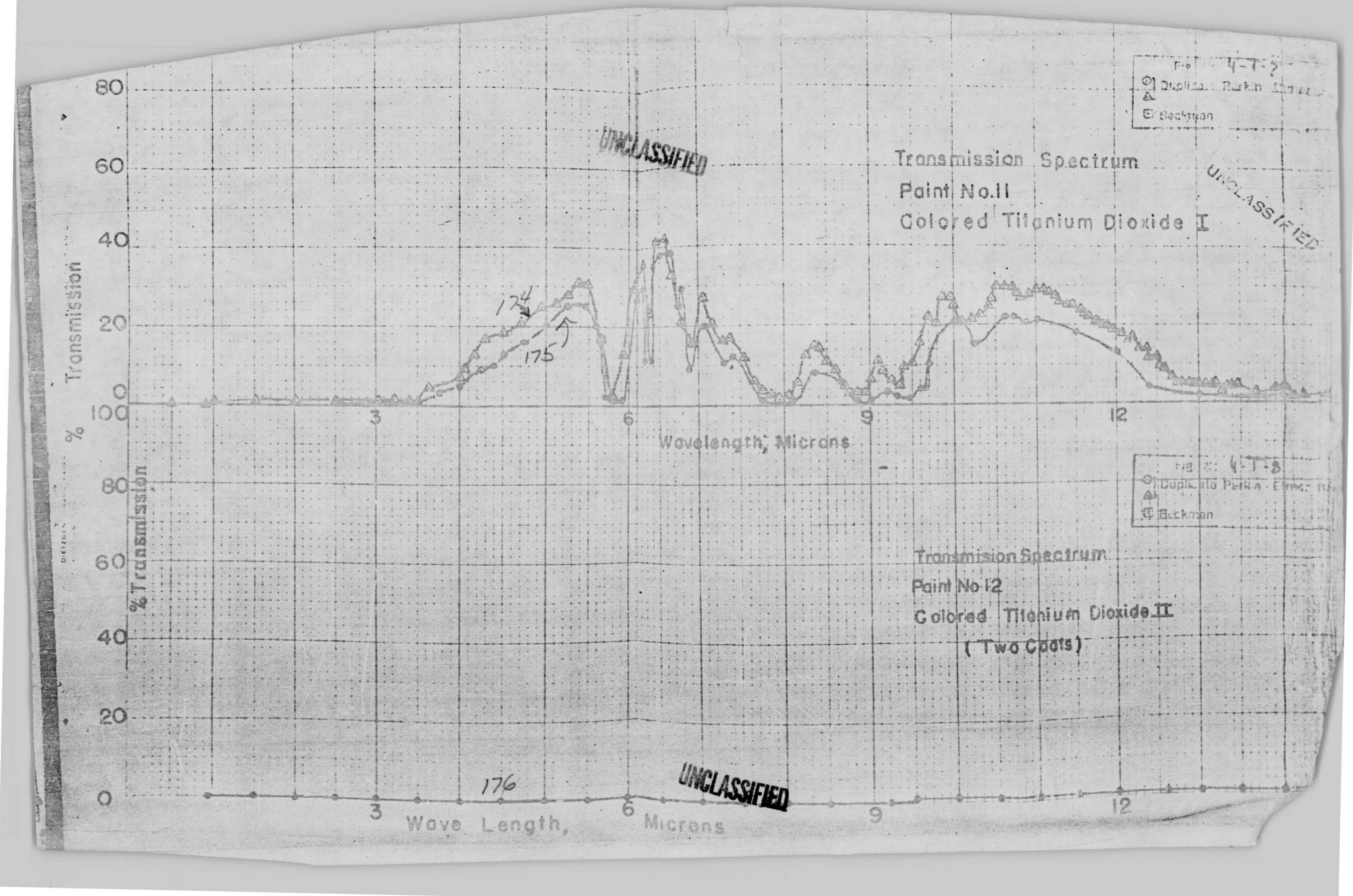

Fig. No. 4-T-1
Duplicate Perkin-Elmer runs
Beckman
Transmission Spectrum
Paint No. 13
Colored Zinc Oxide I
UNCLASSIFIED
163
162
100
80
60
40
20
0
3
6
9
12
15
Wavelength, Microns
% Transmission
Fig. No. 4-T-2
Duplicate Perkin-Elmer runs
Beckman
Transmission Spectrum
Paint No. 14
Colored Zinc Oxide II
165
164


% Transmission
100
80
60
40
20
0
3
6
9
12
15
Wavelength, Microns
Transmission Curve
Point No. 7
Chrome Green II
Fig. No. 4-T-3
Duplicate Perkin Elmer runs
Beckman
168
169
UNCLASSIFIED
Transmission Curve
Point No. 6
Chrome Green I
Fig. No. 4-T-4
Duplicate Perkin Elmer runs
Beckman
167
166

UNCLASSIFIED



UNCLASSIFIED



UNCLASSIFIED

UNCLASSIFIED