

SEMIQUANTITATIVE METHODS FOR DETERMINING
CERIUM, LANTHANUM, AND THORIUM
IN MONAZITE SANDS

BY

O. P. ARORA

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INTRODUCTION

Very little information has been published on the methods of analysis for cerium, lanthamum, and thorium. Chemical methods for their analyses involve complicated procedures and the time taken in their determinations is generally quite long. Monazite sands were selected for analysis since they contain all the three elements in sufficient quantity for semiquantitative work. Typical analyses of some of the monazite sands with their localities is as follows: (Hopkins, 1938, p. 15) and (Lawrence, 1943, p. 6)

Compounds (percent)	South Africa	Idaho	Other states in U.S.A.	General avg. as suggested by Miner
ThO ₂	3.20- 8.00	1.8- 3.2	1-4	5
CeO ₂	30.50-36.50	20.0-25.0	20-30	30
La ₂ O ₃ and oxides of Yttrium group	28.0-29.0	18.0-28.0	25-32	30
P ₂ O ₅	28.0-29.0	18.0-20.0	18-30	25
Al ₂ O ₃ , SiO ₂ CaO, MgO, Fe ₂ O ₃	3.0- 6.0	1.0- 4.0	1-10	5

The x-ray spectrograph and grating spectrograph were used for the semiquantitative analysis of cerium, lanthamum, and thorium. Six samples of monazite sand were examined, the sources of which are given in Table 1 (page 13).

DISCUSSION OF THE PROBLEM

The chemical properties of the rare earths are so strikingly similar that mixtures of these elements defy analysis by the usual methods of analytical chemistry. Although a majority of the rare earths can be determined spectrophotometrically, yet the absorbancy of their bands is not sufficient for measuring their concentrations below several per cent. (Fassel, 1952, p. 2012). An investigation was made to determine the content of cerium, lanthanum, and thorium in monazite sands. Qualitative work was done to determine the matrix and the trace elements present in monazite sands. This information was used in preparing standard samples for semiquantitative work.

The methods using the x-ray spectrograph and grating spectrograph are similar, except that the x-ray spectrograph uses x-radiations to excite the elements and an analysing crystal in place of a grating. The emitted radiation is passed through a collimator to a crystal which separates the radiation into its various wavelengths. The intensities of individual wavelength lines are measured as pulsations by a Geiger-counter. The intensity of radiation and the concentration of the element follow a linear relationship, which can be used for semiquantitative work.

Semiquantitative spectrographic analysis as suggested by Harvey (1947, pp. 1-25) was not used because of the nonavailability of the

sensitivity factors for cerium, lanthanum, and thorium in the matrix of monazite sands. Harvey's method is based on vaporizing a fixed, weighed amount of sample with 10 milligrams of pure graphite in a direct-current arc. In this method the line intensities are measured with respect to the background, rather than the absolute intensities. The concentration of the element is obtained by multiplying the ratio of the line intensity to the background intensity by a sensitivity factor of that line in that matrix.

Due to nonavailability of the sensitivity factors for cerium, lanthanum, and thorium in the matrix of monazite, Harvey's method had to be modified. In this modified method, a weighed amount of sample was vaporized with 10 milligrams of pure graphite. This fixed amount of graphite gives the same amount of carbon vapors in all the exposures. Considering the above fact, the intensities of the lines were evaluated and the percent transmissions for these lines were plotted against the concentrations of the elements on a logarithmic paper to obtain a working curve.

EXPERIMENTAL PROCEDURES

A. Qualitative analysis of monazite sands by grating spectrograph

The qualitative work by grating spectrograph was done on a three meter Baird spectrograph, (Baird, 6th conf.) using a grating having 15,000 lines per linear inch. Since the emission spectra of cerium, lanthanum, and thorium are very complex, a narrow slit width (25 microns) was used for maximum resolution.

A number of graphite electrodes were cut and arced for a set period of time with approximately 10 milligram sample. After the rack positions had been completed, the plate was processed.

The following operating conditions were maintained throughout the qualitative work:

Current	Direct-current 5 amperes
Voltage	50 volts
Slit width	25 microns
Spectral range	2250-3600 A 3450-4800 A
Plate	Eastman Kodak Spectrum Analysis Number 2
Gap	5 millimeters

Electrodes	Upper electrode: 3/16 inch diameter Lower electrode: 1/4 inch diameter
Developer	Eastman Kodak D-19
Time of hardening	2 minutes
Time of developing	5 minutes
Hardener	Chrome alum
Fixer-	Acid sodium thiosulfate
Time of fixing	10 minutes

The elements detected and their estimated concentration ranges are listed in the Table II (page 14).

B. Qualitative work by X-ray diffraction

1. Debye-Scherrer powder method: The qualitative work by the Debye-Scherrer method was done on a General Electric x-ray diffraction unit. The sample after being ground and screened through -200 mesh screen, was rolled to a wire shape with the help of Duco cement and amyl acetate. A No Screen strip film was exposed for three hours under a monochromatic radiation and a powder pattern was obtained. The diameter of the camera was found to be 145.2 millimeters. The observed d values were computed from the National Advisory Committee for Aeronautics tables, and the compounds determined by the Hanawalt card system (ASTM cards).

The following operating conditions were maintained throughout the qualitative work by the Debye-Scherrer method:

Camera	Debye-Scherrer
Target	Copper
Filter	Nickel

Primary voltage	192 volts
Secondary voltage	40 volts
Current	20 milliamperes
Time of exposure	5 hours
Film	No Screen (Eastman Kodak)
Slit system	Collimating pin hole
Specimen to film distance	71.6 millimeters

2. Method using North American Phillips diffraction unit: The qualitative work was also done by a North American Phillips X-ray Diffraction Unit (Buhler, 1953, pp. 3-5) using a goniometer and strip chart recorder. The lines were recorded on the strip chart with their intensities and the d values computed as in the previous qualitative method by x-ray diffraction.

The following operating conditions were maintained for the rate meter throughout the qualitative work:

Scale factor	16
Multiplier	0.8
Time constant	4 seconds
Target	Copper
Voltage	50 kilovolts
Current	20 milliamperes

The compounds detected, by the x-ray diffraction method are listed in the Table III (page 16) , and their d values and intensities are listed in the Tables XIV to XIX (pp. 34-40).

C. Preparation of standard samples for semiquantitative work

It was observed from the qualitative analysis by the x-ray

diffraction work that most of the monazite sands contain phosphates of cerium and lanthanum, with small and varying amounts of SiO_2 , Al_2O_3 , and CaO . Varied amounts of cerium oxide, lanthanum oxide, and thorium oxide were mixed in a matrix of SiO_2 , Al_2O_3 , and CaO by grinding with a mortar and pestle. The following analyses of the standard samples were computed from the weighed amounts used to prepare the samples.

Standard sample number	Cerium (per cent)	Lanthanum oxide (per cent)	Thorium oxide (per cent)
S-1	15.75	5.00	13.70
S-2	13.33	13.33	17.50
S-3	25.75	6.65	8.90
S-4	10.00	40.00	6.88
S-5	39.80	20.00	1.175
S-6	11.60	9.00	5.00

D. Semiquantitative analysis by grating spectrograph

The semiquantitative work was done by a three meter Baird spectrograph (Baird, 6th conf.). Other accessories used were the same as in the qualitative work by the grating spectrograph except that a series of filters was used to cut down the intensities of the lines and thus permit analysis of both high and low percentages of the elements present in the monazite sands.

Ten milligram samples mixed with 10 milligrams of SP-2 grade powdered graphite were vaporized in carefully machined undercut electrodes. The electrodes were burnt at a constant height of 9 millimeters down to the notch. The plate, after being exposed, was processed and the densities of the lines were evaluated by an Applied Research Laboratories comparator-densitometer (Sawyer, 2d. ed. pp. 263-265).

The following conditions were maintained throughout the semi-quantitative work by the grating spectrograph:

Spectrograph	Heird three meter grating spectrograph
Current	Direct-current 11.5-12 amperes
Plate	Eastman Kodak Spectrum Analysis Number 2
Amount of sample	10 milligrams
Amount of graphite	10 milligrams
Filters	0.48 percent transmission
Time	90 seconds
Spectral range	2250-3450 A 3450-4800 A
Slit width	50 microns

The results of semiquantitative analysis are shown in Tables IV, V, and VI (pp.17-21).

E. Semiquantitative analysis by x-ray spectrograph

The semiquantitative work was done by a North American Phillips Company X-ray Spectrograph. Fig. 1 (Behr, 1953, pp. 3-7) shows the principles of operation and the basic geometry of the x-ray spectrograph.

A -200 mesh ground sample was subjected to an intense, short wavelength, primary x-radiation from a tungsten target, causing the elements to fluoresce. By manually scanning with the goniometer the maximum-intensity lines for the desired elements were located and the time for a fixed number of counts was recorded.

The following operating conditions were maintained throughout the semiquantitative work by the x-ray spectrograph:

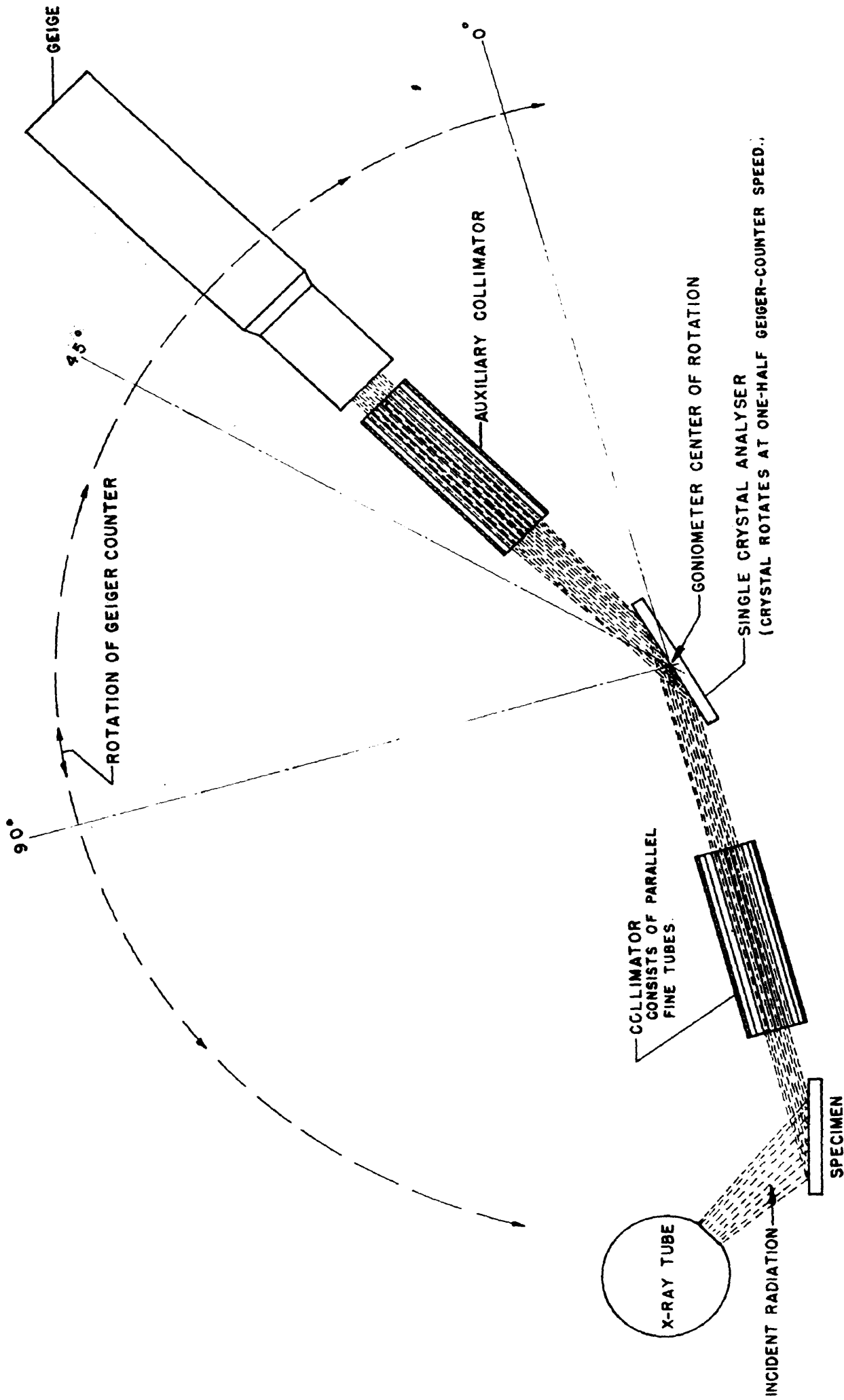


Fig. I BASIC GEOMETRY OF FLUORESCENT ANALYSIS UNIT

Scaler meter

Input	Negative
Operation	Fixed count
Scale factor	16 for lanthanum 16 for cerium 4 for thorium

Rate meter

Scale factor	16
Time constant	4 seconds
Multiplier	0.8
Target	Tungsten
Voltage	50 kilovolts
Current	40 milliamperes
Voltage to the Geiger tube	1500 volts
Angle 2θ	49.19° for cerium 51.56° for lanthanum 15.56° for thorium
Total counts	6400 (four consecutive readings of 1600 counts)

The results of semiquantitative analysis for cerium, lanthanum, and thorium are listed in the Tables VIII, X, and XII (pages 25, 28, and 31).

CONCLUSIONS

The results of qualitative analysis by the grating spectrograph are shown in Table II (Page 14). The qualitative analysis by the grating spectrograph shows the presence of cerium, lanthanum, thorium, phosphorus, calcium, aluminum, silicon, as the chief major elements, magnesium, manganese, yttrium, titanium as minor elements, and dysprosium, molybdenum, selenium, tungsten, uranium, and vanadium as trace elements. The compounds detected by the x-ray diffraction analysis are shown in Table III (page 16) and their d values are tabulated in Tables XIV to XIX (pages 34-40). The x-ray diffraction analysis shows the presence of cerium and lanthanum as their phosphates, thorium and titanium as dioxides, and calcium and aluminum as their silicates. Some of the d values of the lines were not verified as there were no d values listed in the ASTM cards for cerium and lanthanum as their phosphates. However, cerium and lanthanum phosphates were chemically prepared in the laboratory and their d values were obtained by the powder method as listed in Tables XX and XXI (pages 41-42). The powder method of x-ray diffraction is not very sensitive at low concentrations.

The results obtained by semiquantitative analysis by the grating spectrograph are shown in Tables IV, V, and VI (pages 17-22). These results, if compared with the general average as given

by H. S. Miner (Hopkins, 1938, p. 15) and Lawrence (1943, pp. 1-5) do not show an error of more than 30 to 50 percent, which is the amount of accuracy generally expected in semiquantitative work (Harvey, 1947, p. 15). The reproducibility in the x-ray spectrograph seems to be fairly good as shown in Tables VIII, X, and XII (pages 25-31).

The results as shown in the Table XIII (page 32) show some discrepancy between the two methods followed for semiquantitative analysis. This may be due to the various errors involved in the methods. The possible sources of errors in the grating spectrographic work were inaccuracy in weighing the sample, amount of sample vaporized, fluctuations in the current and voltage, inconsistency of the gap between the electrodes, spattering of the sample, wandering of the arc, effect of the major constituent on the line intensity, and the photographic variability. The possible sources of error in the x-ray spectrographic work were absorption effect, intensity losses due to scattering of x-rays, fluctuations in the current and voltage, mesh grind, and statistics of counting.

Table I

The following is the description of the samples and source of supply:

Description of sample	Source of supply
Monazite sand number 1	Experimental Plant
Monazite sand number 2	Copper Fassett
Monazite sand number 3	South Africa
Monazite sand number 4	Korea
Monazite sand number 5	Idaho
Monazite sand number 6	Climax Molybdenum Company

Table II

Estimated concentration ranges for elements detected in monazite sands

Elements	Monazite Sample Number					
	1	2	3	4	5	6
Si	S	P	S	S	P	S
P	P	S	P	P	P	S
Mn	M	S	S	W	S	S
Fe	M	P	M	W	M	M
Al	S	S	S	M	S	S
Mg	M	M	W	-	S	S
Ca	S	S	S	M	S	S
Co	P	P	P	P	P	P
Th	S	S	S	S	S	M
Y	M	S	M	M	M	M
Dy	M	M	W	W	-	W
Pb	W	M	-	M	W	M
Nb	W	W	W	-	S	M
Se	W	-	W	-	-	-
W	W	W	W	T	M	W
Yb	W	M	T	-	-	-
U	T	W	T	T	W	W
V	T	W	T	T	W	W
Ti	S	S	M	W	S	P
Rh	T	-	-	T	T	M
Cu	-	S	M	S	M	-

Table II (Continued)

Elements	Monasite Sample Number						
	1	2	3	4	5	6	
Ba	-	-	M	-	M	T	
Li	T	M	T	W	W	M	
Ag	-	T	-	-	-	-	
Na	-	M	-	-	W	W	
La	P	P	P	P	P	P	

Procedure and symbols used for reporting line intensities and approximate concentrations

Persistent	P	100-10 percent
Strong	S	10-1 percent
Moderate	M	1-0.1 percent
Weak	W	0.1-0.01 percent
Trace	T	0.01-0.001 percent

Table III

Results of qualitative analysis by x-ray diffraction¹

Monazite Sample Number	Compounds Detected
1	CePO ₄ , LaPO ₄ , ThO ₂ , TiO ₂ , CaO·SiO ₂
2	CePO ₄ , LaPO ₄ , ThO ₂ , TiO ₂
3	CePO ₄ , LaPO ₄ , ThO ₂ , TiO ₂ , CaO·SiO ₂ , Al ₂ O ₃ ·SiO ₂
4	CePO ₄ , LaPO ₄ , ThO ₂ , CaO·SiO ₂
5	CePO ₄ , LaPO ₄ , ThO ₂ , CaO·SiO ₂
6	CePO ₄ , LaPO ₄ , ThO ₂ , CaO·SiO ₂

1. For tabulated d values see Tables XIV to XIX.

Table IV

Results of semiquantitative analysis of cerium content of monazite sands
by grating spectrograph

Line used 4737 A

Cerium (percent)		Transmission (percent)
15.75	Standard Samples	16.5
39.80	" "	1.5
10.0	" "	55.0
11.60	" "	45.0
Sample number 1		13.5
Sample number 2		11.0
Sample number 3		12.9
Sample number 4		9.5
Sample number 5		12.0
Sample number 6		13.2

Results

Sample number	Cerium (percent)
1	17.25
2	18.5
3	17.5
4	19.6
5	18.0
6	17.3

Graph 1. Working curve for cerium

Line 4737 A

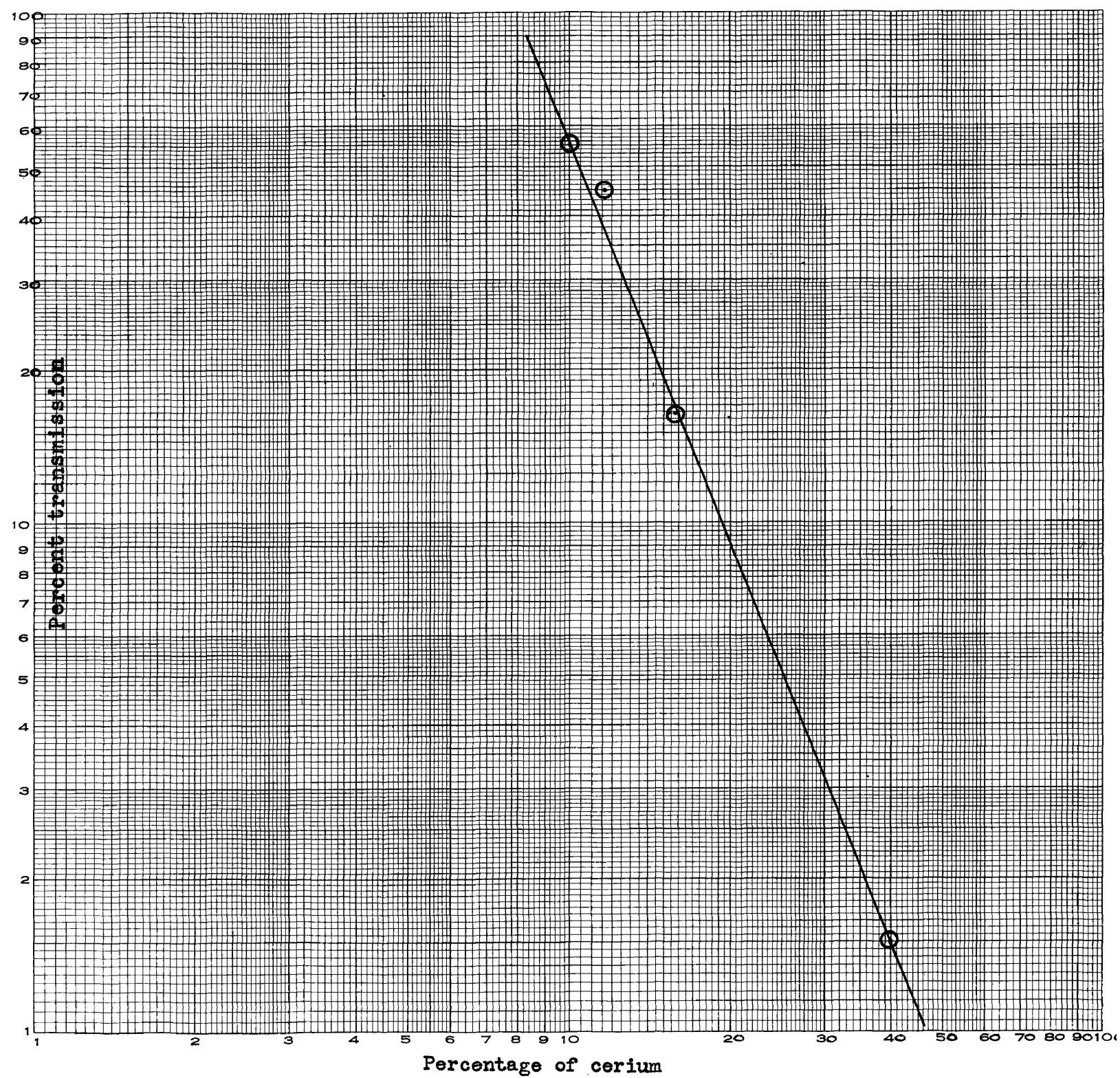


Table V

Results of semiquantitative analysis of the lanthanum content of monazite sands by the grating spectrograph

Line used 4748.3 A

Lanthanum oxide (percent)		Transmission (percent)
9.0	Standard Samples	36.0
13.33	" "	21.8
6.65	" "	50.0
20.0	" "	13.5
Sample number 1		27.5
Sample number 2		38.0
Sample number 3		26.0
Sample number 4		35.5
Sample number 5		34.9
Sample number 6		31.0

Results

Sample number	Lanthanum oxide (percent)
1	11.0
2	8.4
3	11.5
4	9.0
5	9.2
6	10.0

Graph 2. Working curve for lanthanum
Line 4748.3 A

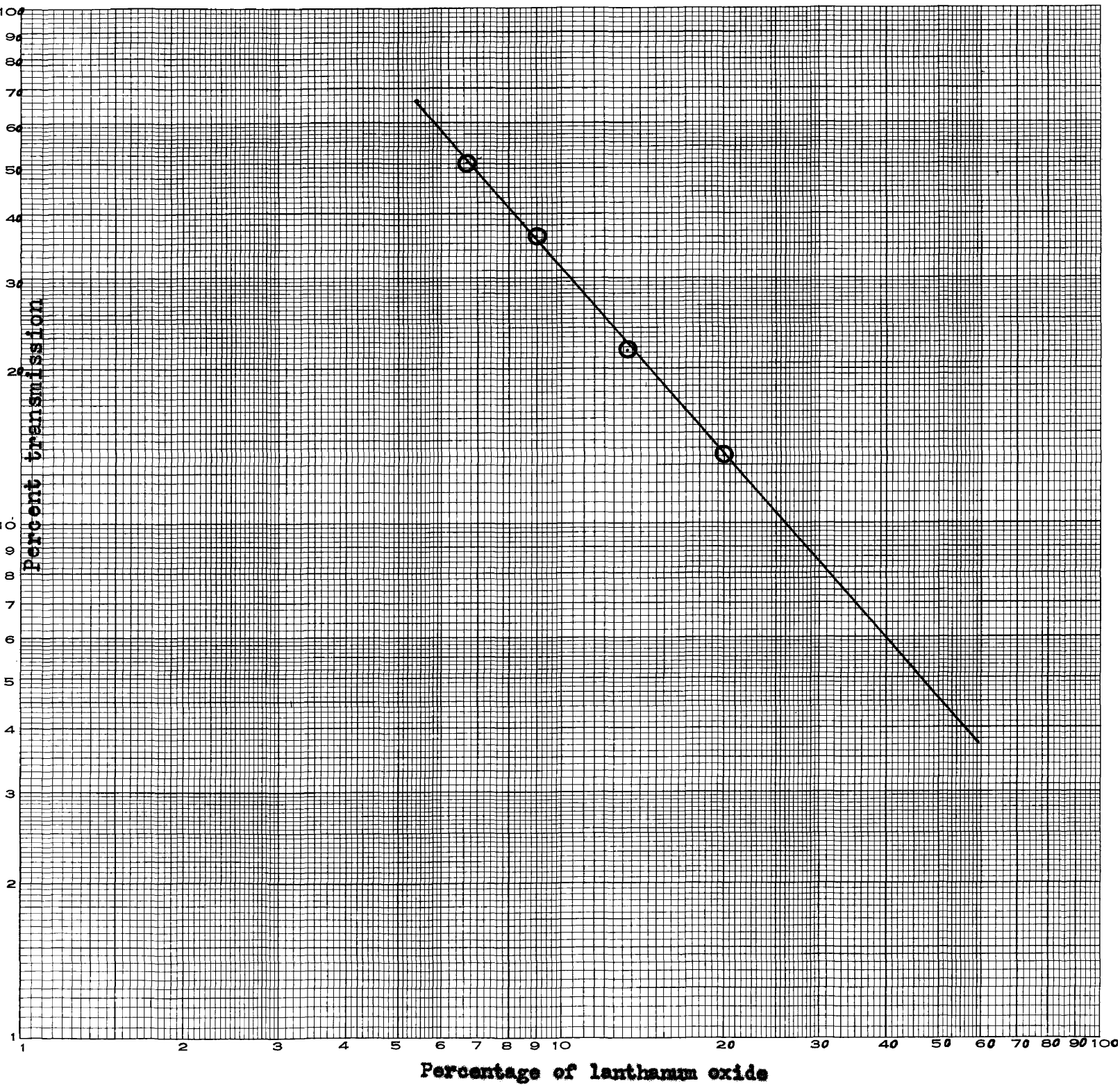


Table VI

Results of semiquantitative analysis of thorium content of monazite sands
by grating spectrograph

Line used h619.5 A

Thorium oxide (percent)		Transmission (percent)
1.175	Standard Samples	62.00
6.88	" "	28.00
13.7	" "	20.00
8.9	" "	24.00
Sample number 1		51.00
Sample number 2		51.00
Sample number 3		50.00
Sample number 4		41.00
Sample number 5		49.00
Sample number 6		51.00

Results

Monazite sand sample number	Thorium oxide (percent)
1	1.95
2	1.95
3	2.0
4	3.05
5	2.1
6	1.95

Graph 3. Working curve for thorium

Line 4619.5 A

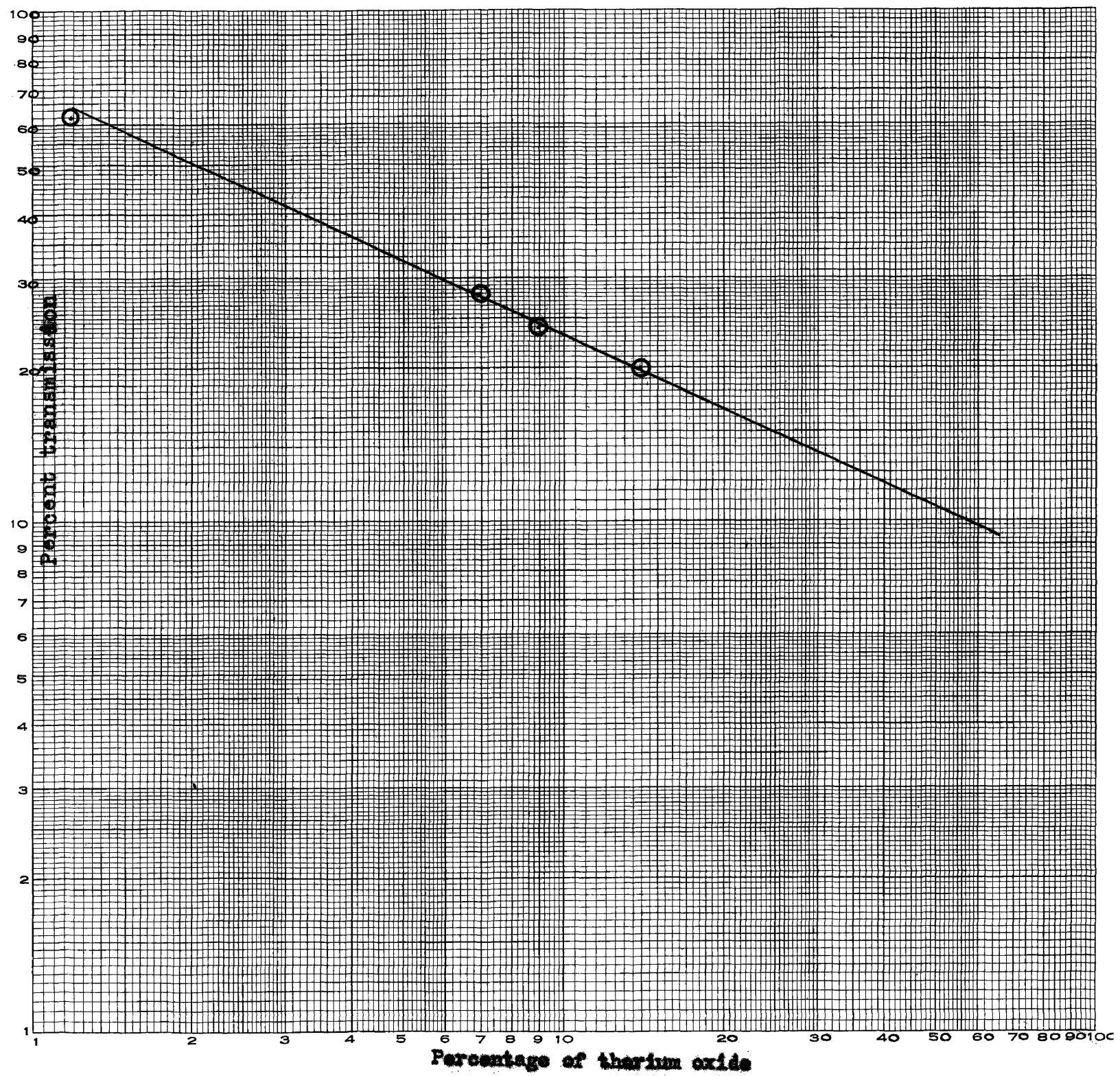


Table VII

Results of counts per second vs. cerium content in standard samples by the x-ray spectrograph

Standard sample number	Total counts	Time (sec)	Counts per Second	Cerium (percent)
S-1	6400	52.0	123	15.75
S-2	6400	57.8	111	13.33
S-3	6400	20.2	317	39.8
S-4	6400	76.2	84	9.9
S-5	6400	31.4	204	25.75

A working curve (Graph 4) was plotted with counts per second vs. percent composition of cerium by weight.

Graph 4 Working curve for cesium
Angle $2\theta = 49.19^\circ$

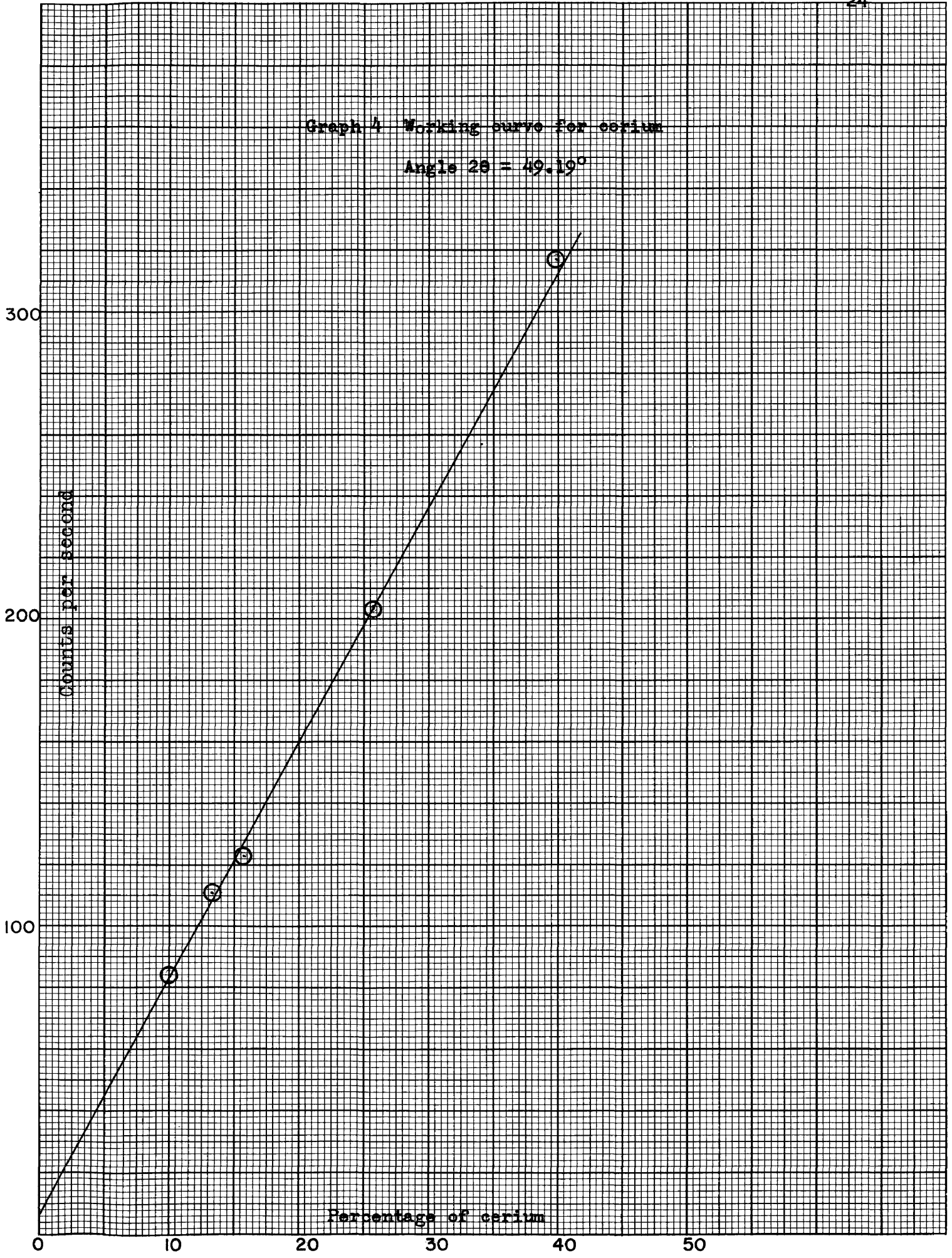


Table VIII

Results of semiquantitative analysis of cerium content in monazite sands
by X-ray spectrograph

Angle $2\theta = 49.19^\circ$

Sample number	Total counts (4 in a row)	Time (seconds)	Counts per second	Cerium (percent)	Av. Cerium (percent)	Standard Deviation
1	6400	39.0	164.4	20.60	20.32	.194
	6400	39.2	163.5	20.25		
	6400	39.1	164.0	20.50		
	6400	39.6	162.0	20.15		
	6400	38.0	161.0	20.10		
2	6400	50.4	127.0	15.75	16.05	.43
	6400	50.4	127.0	15.75		
	6400	50.2	127.8	16.00		
	6400	48.1	133.0	16.75		
	6400	50.0	130.0	16.75		
3	6400	45.4	141.0	17.60	17.53	.075
	6400	46.5	138.0	17.40		
	6400	45.8	140.0	17.50		
	6400	45.8	140.5	17.55		
	6400	45.6	141.0	17.60		
4	6400	42.5	151.0	19.00	18.90	.095
	6400	42.4	151.0	19.00		
	6400	42.6	150.5	18.75		
	6400	42.6	150.5	18.75		
	6400	42.6	151.0	19.00		
5	6400	41.8	153.0	19.25	19.17	.087
	6400	42.0	152.5	19.20		
	6400	42.2	152.0	19.00		
	6400	42.0	152.5	19.20		
	6400	42.1	152.5	19.21		
6	6400	46.0	139.1	17.50	17.27	.179
	6400	47.0	136.2	16.66		
	6400	45.2	141.0	17.50		
	6400	46.0	139.1	17.30		
	6400	45.8	139.9	17.40		

Table IX

Results of counts per second vs. lanthanum content in standard samples
by X-ray spectrograph

Standard sample number	Total Counts	Average time (seconds)	Counts per second	La ₂ O ₃ (percent)
S-1	6400	240	26.7	5.0
S-2	6400	109	58.7	13.33
S-3	6400	214	30.0	6.65
S-5	6400	89.8	72.0	20.0

A working curve (Graph 5) was plotted with counts per second against percent composition of lanthanum oxide by weight.

Graph 5 Working curve for Lanthanum

Angle $2\theta = 51.56^\circ$

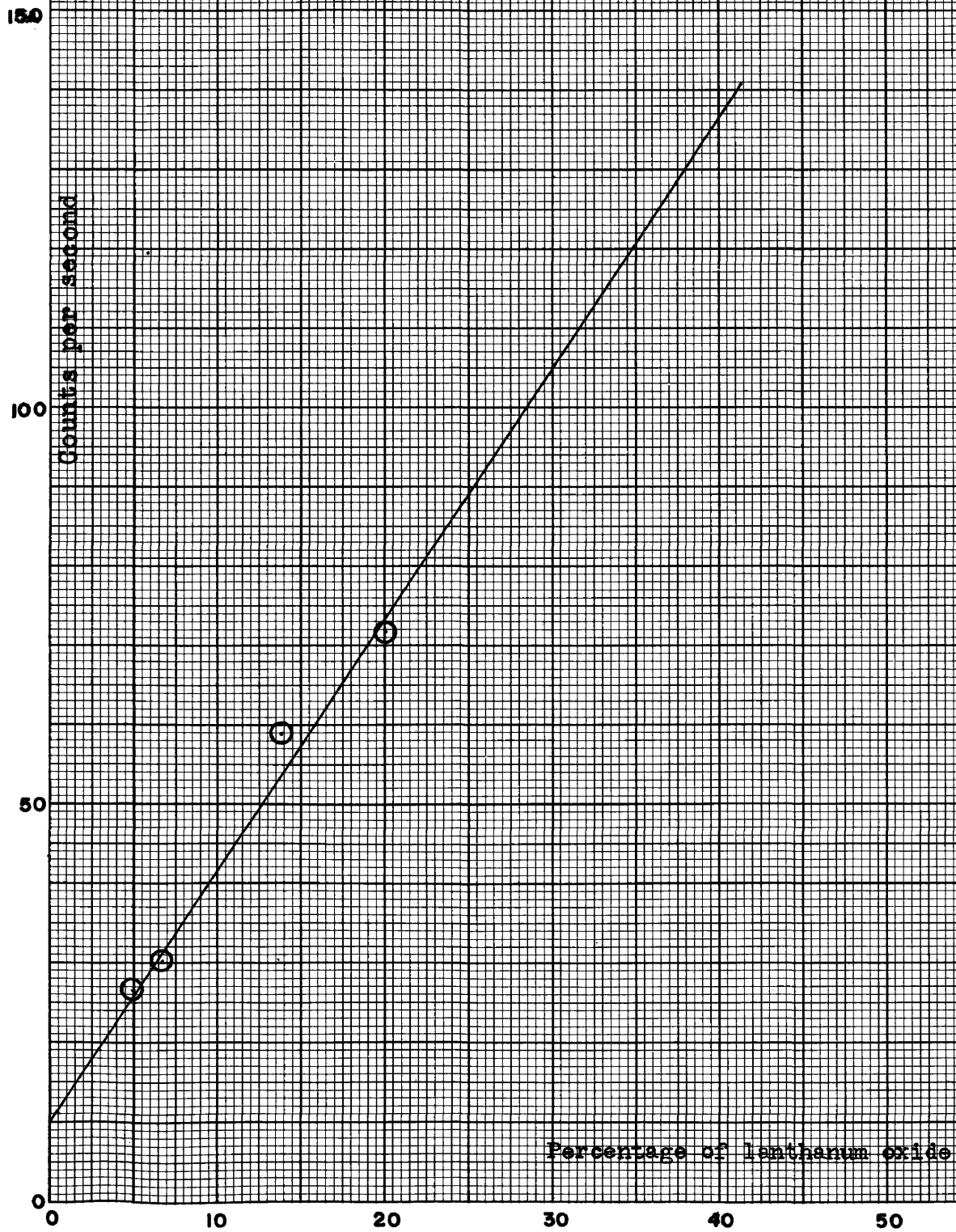


Table X

Results of semiquantitative analysis of lanthanum content in monazite sands
by X-ray spectrograph

Angle 2θ = 51.56°

Sample number	Total counts	Time (seconds)	Counts per second	Lanthanum oxide (percent)	Avg. Lanthanum oxide (percent)	Standard deviation
1	6400	129.1	49.6	12.66	12.57	0.1225
	6400	131.6	48.7	12.33		
	6400	128.9	49.6	12.66		
	6400	129.2	49.5	12.60		
	6400	156.0	49.5	12.60		
2	6400	156.0	40.15	9.90	9.91	0.259
	6400	152.4	42.6	10.25		
	6400	156.0	41.7	9.98		
	6400	155.0	41.4	9.95		
	6400	156.0	41.0	9.70		
3	6400	152.6	42.6	10.25	10.29	0.0316
	6400	149.3	43.5	10.34		
	6400	151.0	43.0	10.30		
	6400	150.6	43.2	10.33		
	6400	150.0	43.4	10.34		
4	6400	134.2	47.6	11.80	11.98	0.313
	6400	133.9	48.5	12.33		
	6400	133.9	48.5	12.33		
	6400	136.0	47.0	11.65		
	6400	134.0	47.7	11.90		
5	6400	126.2	50.7	13.10	12.99	0.121
	6400	130.2	49.0	12.75		
	6400	127.2	50.4	13.00		
	6400	126.0	50.0	13.00		
	6400	126.9	50.6	13.10		
6	6400	141.2	45.5	11.10	11.19	0.0276
	6400	139.2	46.2	11.25		
	6400	139.8	46.8	11.10		
	6400	139.3	46.0	11.25		
	6400	139.0	46.1	11.21		

Table XI

Results of counts per second vs. thorium content of standard samples by X-ray spectrograph

Sample Number	Total Counts	Average time (seconds)	Counts per second	ThO ₂ (percent)
S-1	6400	85.9	74.5	13.7
S-3	6400	125.	51.3	8.9
S-4	6400	153.	41.8	6.88
S-5	6400	400.	16.0	1.175

A working curve was plotted (Graph 6) with counts per second vs. percent composition of thorium oxide by weight.

Graph 6 Working curve for thorium
Angle $2\theta = 15.56^\circ$

Counts per second

Percentage of thorium oxide

150
100
50
0

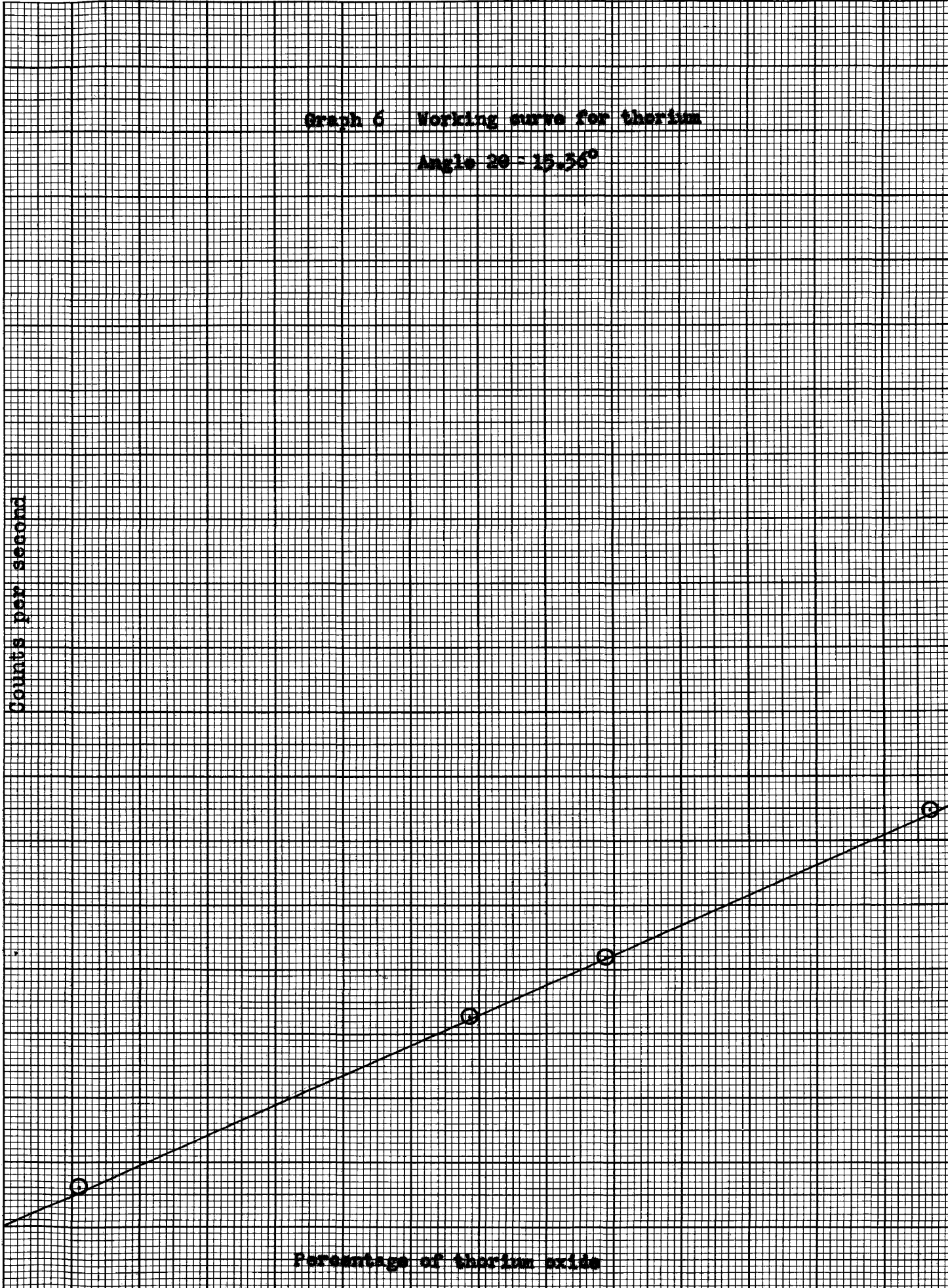


Table XII

Results of semiquantitative analysis of thorium content in monazite sands by x-ray spectrograph

Angle 2θ = 15.56°

Sample number	Total counts	Time (seconds)	Counts per second	Thorium oxide (percent)	Avg. Thorium oxide (percent)	Standard deviation
1	1600	70.4	22.8	2.55	2.50	0.0516
	1600	71.6	22.4	2.50		
	1600	71.6	22.4	2.50		
	1600	71.6	22.4	2.50		
	1600	71.0	22.6	2.55		
2	1600	69.6	23.0	2.75	2.78	0.0224
	1600	69.25	23.1	2.80		
	1600	69.6	23.0	2.77		
	1600	69.1	23.1	2.80		
	1600	69.2	23.0	2.79		
3	1600	76.0	21.1	2.55	2.28	0.0276
	1600	76.1	21.0	2.55		
	1600	80.0	20.0	2.15		
	1600	76.0	21.1	2.50		
	1600	76.5	20.9	2.25		
4	1600	57.0	28.2	3.80	3.76	0.04
	1600	58.6	27.3	3.75		
	1600	57.8	28.2	3.80		
	1600	58.1	27.6	3.75		
	1600	58.8	27.2	3.70		
5	1600	75.6	21.2	2.50	2.52	0.056
	1600	75.1	21.3	2.52		
	1600	74.9	21.3	2.55		
	1600	75.0	21.3	2.55		
	1600	75.5	21.2	2.50		
6	1600	69.8	23.2	2.75	2.62	0.161
	1600	70.4	22.8	2.65		
	1600	71.4	22.4	2.50		
	1600	69.0	23.2	2.75		
	1600	69.2	23.4	2.80		

TABLE XIII

Comparison of results

Sample number	Cerium analysis		Thorium analysis		Lanthanum analysis	
	X-ray spectrograph (Ce percent)	Grating spectrograph (Ce percent)	X-ray spectrograph (ThO ₂ percent)	Grating spectrograph (ThO ₂ percent)	X-ray spectrograph (La ₂ O ₃ percent)	Grating spectrograph (La ₂ O ₃ percent)
1	20.32	17.25	2.50	1.95	12.57	11.00
2	16.05	18.50	2.78	1.95	9.91	8.40
3	17.53	17.50	2.28	2.00	12.99	11.50
4	18.90	19.60	3.80	3.08	11.98	9.00
5	19.17	18.00	2.32	2.10	10.29	9.20
6	17.27	17.30	2.62	1.95	11.19	10.00

APPENDIX

The following procedure was adopted for reporting the estimated intensities for the powder method:

VS	Very strong
S	Strong
M	Moderate
W	Weak
VW	Very weak

The following symbols were used for denoting the presence of a compound in the sample :

a	Cerium phosphate
b	Lanthanum phosphate
c	Thorium oxide
d	Rutile, TiO_2
	$CaO.SiO_2$
	$Al_2O_3.SiO_2$

Appendix I

Table XIV

Results of the d values of monazite sand sample number 1

Debye-Scherrer method

Method using North American Phillips x-ray diffraction unit

	Estimated d exp'tl intensity	d card	Compound	Intensity	d exp'tl	d card	Compound
W	5.04			0.30	4.71		
W	4.628			0.30	4.66		
M	4.24	4.10	b	0.20	4.28	4.40	a
M	3.42	3.49	a	0.40	4.15	4.10	b
S	3.23	3.25	b	0.27	4.09		
VS	3.03	3.06	b	0.38	3.49	3.49	a
VW	2.93	2.96	c	0.35	3.465	3.45	a
M	2.82	2.83	a	0.65	3.2766		
M	2.5448	2.59	b	0.52	3.25	3.25	b
W	2.46	2.40	a	0.30	3.12		
M	2.16	2.18	a	1.00	3.07	3.066	b
				0.90	2.98		
S	2.10	2.09	c	0.32	2.97	2.96	c
H	1.94	1.97	c	0.20	2.93		
W	1.869	1.869	c	0.65	2.85	2.85	a
MS	1.84	1.845	a	0.30	2.49	2.49	d
M	1.74	1.7386	b	0.15	2.46	2.46	f
M	1.7168			0.40	2.43	2.40	a
MS	1.6749	1.68	d	0.20	2.37	2.37	c
VW	1.63	1.62	d	0.35	2.268	2.26	c
VW	1.5856			0.38	2.12	2.118	b
VW	1.52			0.21	2.044	2.01	b
W	1.3154	1.345	b	0.30	1.96	1.97	c
M	1.2679	1.28	b	0.30	1.89		

Table XIV Contd.

Debye-scherrer method		Method using North American Phillips x-ray diffractio. unit					
Estimated intensity	d exp'tl	d card	Compound	Intensity	d exp'tl	d card	Compound
W	1.18	1.16	d	0.30	1.855	1.74	b
W	1.11	1.14	c	0.30	1.74	1.73	f
				0.35	1.73	1.68	d
				0.40	1.68	1.61	c
				0.20	1.618	1.35	d
				0.20	1.35	1.345	b
				0.20	1.346	1.338	d
				0.21	1.338	1.24	c
				0.20	1.24	1.2267	b
				0.20	1.22	1.20	d
				0.20	1.21		

Results

The monazite sand sample number 1 contains CePO_4 , LaPO_4 , ThO_2 , TlO_2 , CaO and SiO_2 .

Table IV

Results of the d values of monasite sand sample number 2

Debye-Scherrer method

Method using North American Phillips x-ray diffraction unit

Estimated intensity	d exp'tl	d card	Compound	Intensity	d exp'tl	d card	Compound
VW	5.1168			0.40	5.19		
VW	4.516			0.40	4.66		
W	4.148	4.10	b	0.50	4.13	4.11	b
W	3.50	3.49	a	0.50	4.13		
S	3.2786	3.25	b	0.60	3.49	3.49	a
VS	3.066	3.06	b	0.80	3.288	3.25	b
W	2.977	2.97	c	1.00	3.07	3.066	a
M	2.481	2.40	a	0.30	2.95	2.97	c
M	2.217	2.18	a	0.70	2.84	2.84	a
S	2.3295	2.188	b	0.20	2.59		
M	1.987	1.97	c	0.20	2.44	2.40	a
W	1.92			0.40	2.17		
S	1.855	1.86	c	0.70	2.125	2.118	b
M	1.7561	1.738	b	0.35	1.955	1.97	c
M	1.7264	1.73	f	0.55	1.8579	1.8636	b
M	1.6439			0.25	1.78		
VW	1.633	1.62	d	0.20	1.73	1.73	f
W	1.5956			0.35	1.68	1.68	d
W	1.528			0.20	1.70	1.68	d
VW	1.376	1.38	f			1.68	d
M	1.2738	1.29	d			1.70	c
M	1.2268	1.2268	b				

Results

The monasite sand sample number 2 contains CaPO_4 , LaPO_4 , Tm_2O_3 , TlO_2 .

The following are the d values for the monazite sand sample number 2

Debye-Scherrer Method

Method using North American Phillips Company x-ray diffraction unit

Estimated d intensity	d exp'tl	d card	Compound	Intensity	d exp'tl	d card	Compound
M	3.98	4.11	b	0.19	4.43	4.42	a
M	3.469	3.49	a	0.19	4.11	4.11	b
S	3.288	3.25	b	0.41	3.49	3.49	a
VS	3.066	3.066	b	0.39	3.46	3.45	a
W	2.96	2.96	c	1.00	3.2786		
M	2.844	2.84	a	0.81	3.24	3.25	b
W	2.58	2.59	b	1.00	3.07	3.066	b
W	2.43	2.42	g	0.34	2.97	2.96	c
M	2.1727	2.17	a	0.25	2.93	2.93	g
S	2.1218	2.118	b	0.49	2.84	2.84	a
M	1.95	1.97	c	0.31	2.589	2.59	b
W	1.887	1.887	a	0.32	2.45	2.46	f
S	1.8579			0.34	2.17	2.18	a
M	1.751	1.74	b	0.43	2.13	2.16	a
M	1.7269	1.73	g	0.34	2.11	2.118	b
M	1.6794			0.32	1.97	1.97	c
M	1.6374	1.64	g	0.33	1.9609	1.960	g
VW	1.4587	1.46	g	0.18	1.93	1.93	g
M	1.27	1.226	b	0.25	1.88	1.89	a
H.	1.2257	1.226	b	0.41	1.87	1.87	a
H	1.0948			0.42	1.864	1.84	b
				0.65	1.855		
				0.46	1.852		
				0.28	1.757		
				0.27	1.75	1.74	f
				0.22	1.746	1.74	b
				0.27	1.73	1.73	g

Results

The monazite sand sample number 3 contains CePO_4 , LaPO_4 , ThO_2 , CaO , SiO_2 , Al_2O_3 , SiO_2 , TiO_2 .

Table XVII

Results of the d values of monasite sand sample number 4

Debye-Scherrer method

Method using North American Phillips x-ray diffraction unit

Estimated intensity	d exp'tl	d card	Compound	Intensity unit	d exp'tl	d card	Compound
W	5.04			0.35	4.12	4.10	a
W	4.628			0.40	3.49	3.49	a
M	4.24	4.10	a	0.30	3.47	3.45	a
M	3.42	3.49	a	1.00	3.2786	3.25	b
S	3.28	3.25	b	1.00	3.066	3.06	b
VS	3.04	3.06	b	0.50	2.97	2.97	c
VW	2.98	2.97	c	0.60	2.837	2.84	a
M	2.82	2.84	a	0.25	2.59	2.59	b
M	2.56	2.59	b	0.30	2.42	2.46	f
W	2.46	2.46	f	0.20	2.38	2.38	f
S	2.16	2.118	b	0.30	2.235	2.235	
M	2.10			0.40	2.12	2.118	b
W	1.94	1.97	c	0.25	1.95	1.97	c
MS	1.869	1.864	b	0.30	1.88	1.89	a
M	1.84	1.84	b	0.32	1.85	1.89	b
K	1.74	1.73	f	0.40	1.73	1.73	f
MS	1.7168			0.26	1.686	1.63	c
VW	1.63	1.63	c	0.30	1.27	1.27	f
W	1.52						

ResultsThe monasite sand, sample number 4 contains CaPO_4 , LaPO_4 , ThO_2 , CaO-SiO_2 .

Table XVIII

Results of the d values of monazite sand sample number 5

Debye-Scherrer method

Method using North American Phillips x-ray diffraction unit

	Estimated d intensity	d exp't'l	d card	Compound	Intensity	d exp't'l	d card	Compound
W	3.46		3.49	a	0.50	4.117	4.11	a
S	3.25		3.25	b	0.30	3.49	3.49	a
S	3.03		3.06	b	0.88	3.2786	3.25	b
S	2.82		2.81	a	1.00	3.066	3.06	b
M	2.565				0.60	2.96	2.96	c
M	2.16		2.18	a	0.75	2.84	2.84	a
M	2.118		2.118	b	0.20	2.42	2.46	f
M	1.936		1.97	c	0.46	2.176	2.18	a
M	1.85		1.87	a	0.65	2.12	2.16	a
W	1.74		1.74	f	0.50	1.96	1.97	c
W	1.719		1.73	f	0.40	1.869	1.864	b
W	1.675		1.68	c	0.20	1.75	1.74	f
M	1.269		1.27	f	0.20	1.73	1.73	f
M	1.2246		1.226	b	0.20	1.68	1.68	c
					0.40	1.226	1.226	b

ResultsThe monazite sand sample number 5 contains $CePO_4$, $LaPO_4$, ThO_2 , CeO , SiO_2 .

Table XIX

The following are the d values for the monazite sand sample number 6

Debye-Scherrer method

Method using North American Phillips Company X-ray diffraction unit

Estimated intensity	d exp'tl	d card	Compound	Intensity	d exp'tl	d card	Compound
M	4.13	4.10	a	0.40	3.49	3.49	a
M	3.48	3.49	a	1.00	3.24	3.25	b
S	3.269	3.25	b	0.80	3.27		
VS	3.07	3.06	b	0.41	2.95	2.96	c
W	2.955	2.96	c	1.00	3.05	3.06	b
M	2.837	2.84	a	0.25	2.92	2.93	e
M	2.576	2.59	b	0.50	2.83	2.84	e
W	2.425	2.40	a	0.30	2.42	2.40	a
MS	2.168	2.18	a	0.20	2.36		
S	2.12	2.118	b	0.30	2.23		
N	1.95	1.97	c	0.30	2.10		
VW	1.88	1.89	c	0.20	2.07	2.04	f
M	1.8494	1.86	a	0.35	1.96	1.97	c
M	1.7436	1.74	b	0.25	1.86	1.87	a
M	1.724	1.73	f	0.28	1.75	1.74	b
M	1.67	1.68	c	0.30	1.68	1.68	d
W	1.6288			0.25	1.57	1.53	f
W	1.616	1.61	c	0.20	1.32	1.33	d
M	1.226	1.226	b	0.20	1.27	1.28	b
VW	1.22	1.20	d	0.20	1.227	1.227	b

Results

The monazite sand sample number 6 contains $CePO_4$, $LaPO_4$, TbO_2 , $CaO \cdot SiO_2$.

Table XX

Results of the d values obtained from artificially prepared lanthanum phosphate

<u>Estimated intensity</u>	<u>d values</u>
	4.1
S	3.25
V3	3.066
	2.82
N	2.59
M	2.116
K	2.01
W	1.86
	1.74
W	1.54
W	1.2268

Table XII

Results of the d values obtained from artificially prepared corium phosphate

<u>Estimated intensity</u>	<u>d values</u>
N	4.42
N	3.49
N	3.45
S	2.84
N	2.35
N	2.18
N	2.16
S	1.87

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