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LONG RANGE RESEARCH ON PYROTECHNICS: BURNING CHARACTERISTICS OF BINARY MIXTURES.

Project No. TM2-9201A

Report No. 1

Picatinny Arsenal Serial No. 1669

16 October 1947

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PICATINNY ARSENAL

Authorization: Ordnance Research and Development Division, ORDTM

Project No.: TM2-9201A; Second Progress Report

Priority Designation: 3A

Project Title: Long Range Research on Pyrotechnics: Burning Characteristics of Binary Mixtures.

Object: To conduct a fundamental study of the physical and chemical characteristics of binary mixtures of oxidizing and reducing agents employed in pyrotechnic compositions to provide the basic data from which pyrotechnic compositions having specific characteristics can be formulated.

Summary: The physical, chemical and burning characteristics of binary mixtures containing atomized magnesium and the following oxidizing agents have been determined: potassium perchlorate and the nitrates of sodium, potassium, lithium, barium, strontium and calcium. A more detailed study was made of red light compositions containing strontium nitrate, magnesium (both ground and atomized), and organic binders and color intensifiers. The major results may be summarized as follows:

(a) The candlepower and burning rate values of the binary mixtures studied, increased with increasing amounts of magnesium to a maximum value which was obtained at 60 to 80 percent magnesium. This is far in excess of the stoichiometric quantity of magnesium.

(b) Of all the oxidizing agents used in these binary mixtures, sodium nitrate produced the highest candlepower values which were usually, though not always, accompanied by higher burning rates. The efficiencies (candle-seconds per gram) obtained with sodium nitrate compositions were greater than those obtained with all of the other binary mixtures except those containing calcium nitrate.

(c) With the addition of increasing amounts of binder or color intensifier, the candlepower and burning rate values of strontium nitrate mixtures decreased, while the red color values increased. However, red color values greater than 0.40 were obtained only when the binder or color intensifier was a chlorine compound. Spectrograms showed that in the absence of a chlorine compound, the red color was due to SrO bands, while the presence of a chlorine compound produced red SrCl bands in addition to the SrO bands already present.

Conclusions:

Basic data were obtained from which red light illuminant compositions can be formulated which will have a wide variety of candlepower, color and burning rate values. From these data, compositions can be formulated which will have greater candlepower and color values for the same burning rates than those now standard for use in Aircraft and Ground Signals.

For red color values greater than 0.40, the presence of a chlorine compound is necessary in strontium nitrate compositions. From the data obtained it is concluded that the use of sodium nitrate in standard white or yellow illuminant compositions will increase the efficiency of the compositions.

INTRODUCTION:

1. It was proposed (Ref. A) that a long range basic research program in pyrotechnic compositions be undertaken for the purpose of furnishing the fundamental data necessary for the development of optimum pyrotechnic compositions for photoflash bombs, reconnaissance flares, signals for ground and air forces, tracer ammunition, and other military pyrotechnics. The basic research program was approved (Ref. B) and this is a progress report covering the first phase of the fundamental study of the physical and chemical characteristics of binary mixtures of oxidizing and reducing agents employed in pyrotechnic compositions.

RESULTS:

2. The burning characteristics were determined for binary mixtures containing atomized magnesium, Grade A (Ref. C) and the following oxidizing agents: potassium perchlorate and the nitrates of sodium, lithium, potassium, barium, strontium and calcium. The data which are given in Table I and Figures 1 to 3 may be summarized as follows:

(a) Candlepower and burning rate values increased with increasing amounts of magnesium to a maximum value which was obtained at 60 to 80 percent magnesium (Figures 1 to 3).

(b) The maximum candlepower values were obtained with sodium nitrate compositions.

(c) For compositions containing up to 60 percent magnesium, the candlepower values decreased depending upon the oxidants employed. The order was as follows: sodium nitrate, barium nitrate, strontium nitrate, lithium nitrate, calcium nitrate, potassium nitrate and potassium perchlorate.

(d) All of the above binary mixtures were found to be comparatively insensitive to impact and friction.

3. The effect of particle size and shape of the magnesium upon the characteristics of strontium nitrate-magnesium mixtures was studied, (Table II). The results were as follows:

(a) Candlepower and burning rate values were found to increase with decreasing particle size (Figures 4 and 5).

(b) Compositions containing ground magnesium gave higher candlepower and burning rate values than those with atomized magnesium of the same granulation.

(c) Strontium nitrate mixtures containing ground magnesium, Grade A (Ref. C) were found to have lower ignition temperatures and to be more ignitable and more sensitive to friction than those mixtures containing the corresponding atomized magnesium.

(d) With increasing amounts of ground magnesium in the compositions, larger amounts of gas were evolved in the 120°C. Vacuum Stability Test. Compositions containing atomized magnesium gave only about 0.2 ml. of gas regardless of the amount of magnesium present.

4. A more detailed study was made of the physical and chemical characteristics of binary mixtures of strontium nitrate and magnesium, both ground and atomized. The effects of the addition of organic binders and color intensifiers upon the characteristics of these mixtures also were determined. The substances added were asphaltum, phenolformaldehyde resin, polyvinyl chloride, ethyl cellulose, calomel and hexachlorbenzene. The results are recorded in Tables III to X inclusive. Curves showing the effect of the addition of these substances on the candlepower, burning rate and color ratio values of the compositions are given in Figures 6 to 23 and 29 to 32. Spectrograms were prepared (Figures 24 - 28). The results may be summarized as follows:

(a) Lower candlepower and burning rate values were obtained with increasing amounts of binder or color intensifier except in the case of a few 80/20 mixtures of strontium nitrate and magnesium.

(b) Red color values increased with increasing amount of binder or color intensifier. Color values greater than 0.40 were obtained only where chlorine compounds were added.

(c) The addition of specific amounts of asphaltum, phenolformaldehyde resin or polyvinyl chloride decreased the candlepower and burning rate values to a greater extent than the corresponding addition of ethyl cellulose, calomel or hexachlorbenzene.

(d) The addition of polyvinyl chloride to strontium nitrate-magnesium mixtures lowered the ignition temperatures about 30°C. and increased the ignitibility of the compositions when atomized magnesium, Grade A, was employed. However, when ground magnesium, Grade A, was used, the ignition temperatures were increased about 40°C. with the addition of 10 or more parts of polyvinyl chloride. Here too, the ignitibility of the compositions was increased.

(e) The addition of polyvinyl chloride did not appreciably affect sensitivity to impact.

(f) In mixtures containing atomized magnesium, the sensitivity to friction was increased slightly with increasing amounts of polyvinyl chloride. When ground magnesium was employed, the sensitivity to friction decreased with increasing amounts of polyvinyl chloride. However, in no case was a reaction obtained when the fibre shoe was employed in the friction pendulum test. This may be due to the differences in specific surface of ground and atomized magnesium of the same sieve granulation.

DISCUSSION OF RESULTS:

5. Some of the most commonly used oxidizing agents in illuminant compositions are potassium perchlorate and the nitrates of barium, strontium, sodium and potassium (Ref. I). Therefore, a fundamental study was begun of the physical and chemical characteristics of binary mixtures containing these oxidizing agents and magnesium.

6. Although it was recognized that calcium and lithium nitrates are very hygroscopic, they were included among the oxidizing agents studied in order to determine the effect of calcium and lithium on the candlepower values of the compositions without introducing another factor such as a different anion. Should the presence of calcium and lithium be found desirable as spectral emitters, less hygroscopic salts than the nitrates would be employed. Because of their hygroscopicity, calcium and lithium nitrates are not likely to be used in pyrotechnic compositions. Therefore, characteristics such as ignition temperature, ignitibility, and sensitivity to impact and friction were not determined for compositions containing these salts.

7. The higher candlepower values obtained when the magnesium was present in excess of the stoichiometric quantity are believed to be due to the flames produced by the excess metal burning in air. It was observed that the size of the flame increased with increasing amount of magnesium in the compositions within the range studied.

8. The color of the flames produced by these binary mixtures was essentially white. However, the sodium nitrate mixtures gave a yellow tinted flame due to the spectral lines of sodium, the barium nitrate mixtures gave a green tinted flame due to spectral bands of barium oxide and the strontium nitrate mixtures gave a pink tinted flame due to spectral bands of strontium oxide. Compositions containing potassium nitrate and potassium perchlorate gave almost pure white lights, since potassium salts yield very few spectral lines in the visible region. Calcium nitrate mixtures gave light orange flames due chiefly to the CaO band. Lithium nitrate mixtures gave a very pale pink flame due to lithium lines.

9. After obtaining the characteristics of the binary mixtures, such as candlepower, burning rate, color value, ignition temperature,

ignitibility, sensitivity to impact and friction, and liberation of gas in vacuo at 120°C., it was decided to make a detailed study of the strontium nitrate-magnesium mixtures for the purpose of developing improved red light compositions. Here it was observed that ground magnesium mixtures gave considerably more gas in the 120°C. Vacuum Stability Test than atomized magnesium mixtures (Table II). Analysis of the gases evolved when ground magnesium was heated showed that they contained over 95 percent hydrogen. According to E. G. Bobalek and S. A. Shrader of the Dow Chemical Company (Ref. D), the gases ordinarily extracted from magnesium and its alloys consist of about 85 percent hydrogen, 10 percent oxides of carbon and less than 5 percent nitrogen. R. S. Busk and E. G. Bobalek (Ref. E) have shown that the hydrogen found in metallic magnesium and its alloys is due chiefly to the reaction of the magnesium with atmospheric moisture. They found that the storage of degassed metal in a hydrogen-filled desiccator for as much as six months did not affect its hydrogen content. However, when exposed for a few days to the normal humid atmosphere, the same metal absorbed hydrogen readily. They concluded that hydrogen forms an interstitial solid solution with magnesium to the extent of 15 to 20 cc. per 100 grams of metal.

10. Since magnesium normally reacts with water at room temperature with the formation of magnesium hydroxide, the presence of hydrogen on the surface is normal under atmospheric conditions. However, since the extent of this reaction or corrosion is dependent upon the area of the surface exposed, atomized magnesium particles, which have a much smaller surface than ground magnesium particles for the same granulation, will contain less hydrogen on the surface than ground magnesium.

11. Binary mixtures containing strontium nitrate and ground magnesium, Grade A, were found to be more ignitible and more sensitive to friction than similar mixtures containing atomized magnesium, Grade A (Table II). This is believed to be due to the greater surface area of the ground magnesium. However, upon the addition of polyvinyl chloride to mixtures containing either type of magnesium, the ignitibility and sensitivity to friction of the resulting corresponding mixtures were approximately the same (Tables IX and X). In no case was a reaction obtained with the fibre shoe, in the pendulum friction test, indicating that it was safe to load these compositions in paper or fiber cases.

12. From the results obtained in Tables III to VIII, the effect of the addition of a binder or color intensifier to a binary mixture of strontium nitrate and magnesium upon the candlepower and burning rate appears to be a function of its binding character. Thus, substances which have the stronger binding action such as asphaltum, phenolformaldehyde resin and polyvinyl chloride, produced lower candlepower and burning rates than those which have less binding action such as calomel, hexachlorbenzene and ethyl cellulose. The last would probably have a better binding

action if used in an alcoholic solution for wet mixing. However, only dry blending was employed in this study. The effect of wet blending will be studied and reported at a later date.

13. From the spectrograms prepared for each of the strontium nitrate compositions (Figures 24 to 28) it is evident that the red color of the flame for those compositions in which no chlorine compound was employed, was due to SrO bands at wavelengths of 5940 to 6500 Angstrom units. According to P. C. Mahanti (Ref. F) the bands marked SrO in Figures 24 to 28 are due to Sr_2. Some other observers, however, suggested that they were due to SrO (Ref. M). Therefore, spectrograms were taken at this Arsenal of strontium chloride excited in an atmosphere of nitrogen and in air. The SrO bands were very intense in the spectrograms taken in air. However, in nitrogen, these bands almost disappeared. This indicated that they were most likely SrO bands. The presence of very feeble bands of SrO when an atmosphere of nitrogen was used, is probably due to traces of oxygen in the nitrogen gas and in the electrodes (Fig. 33). Attempts are being made to further purify the nitrogen and to degass the electrodes. The strongest SrO band was found between 6,000 and 6,100 Angstrom units in the orange region, whereas the other less intense SrO bands occurred chiefly in the red region. Therefore, the light produced was essentially orange. Since the glass filter No. 2412 employed in measuring the red color value does not transmit very much light in the orange region (Ref. G), the red color values of these compositions were low.

14. A deep red light, rather than an orange light is desirable for pyrotechnic compositions. Therefore, it was necessary to add substances to the binary mixtures of strontium nitrate and magnesium which would produce intense bands in the red region of the spectrum. It was found (Ref. G) that chlorine compounds, when added to strontium nitrate mixtures, produced strontium chloride (diatomic SrCl) bands in the red region which are very much more intense than the SrO bands. Therefore, the addition of chlorine compounds produced much higher red color values under proper excitation conditions. The addition of asphaltum, ethyl cellulose and phenolformaldehyde resin, none of which contains chlorine, gave a maximum red color value of 0.41. The increase in color value with increasing amount of these three substances was due to the decrease in the flame temperature. However, with the addition of polyvinyl chloride a maximum red color value of 0.55 was obtained, while the addition of hexachlorbenzene gave 0.52.

15. The color values as expressed above and in accordance with the present standard procedure (Ref. G) represent only relative saturations. They do not describe the actual hue of the flame. Therefore, a new I.C.I. color meter is being developed at this Arsenal which will measure the I.C.I. trichromatic coefficients of the flame-colors. These values will describe both the hue and the saturation of the colors.

16. The spectra shown in Figures 24 to 28 are qualitative, indicating only the nature of the emitters. Work is in progress which will determine the quantitative distribution of spectral intensity for these and other compositions. From the quantitative data, it is believed that the flame temperatures and other data necessary to formulate a flame theory for pyrotechnic compositions, may be obtained.

17. Of the binders and color intensifiers tested, only polyvinyl chloride behaved as both a binder and color intensifier. Compositions containing polyvinyl chloride appeared to burn much more smoothly and evenly than those containing hexachlorbenzene. This is believed to be due to the binding action as well as the presence of hydrogen in the polyvinyl chloride, whereas hexachlorbenzene is completely saturated with chlorine and contains no hydrogen. The data in Tables V and VIII show that for similar compositions, larger red color values were obtained with the addition of polyvinyl chloride than with the addition of hexachlorbenzene to strontium nitrate-magnesium mixtures.

18. Because of the use of calomel in the standard Army M3 tracer composition (Ref. H), the effect of calomel on strontium nitrate-magnesium mixtures was included in this study (Table VII). Despite the fact that calomel contains chlorine, the highest red color value obtained with it was 0.36. The low color values are believed to be due to the fact that proper excitation conditions were not obtained. As indicated by the high candlepower values, the addition of calomel did not lower the flame temperatures as much as polyvinyl chloride or hexachlorbenzene. A higher red color value is obtained with the standard M3 tracer composition because in addition to the 23 percent calomel, there is present 9 percent asphaltum which lowers the flame temperature sufficiently to excite the SrCl molecules.

19. In October 1945 (Ref. I) a compilation was made of data on the characteristics of illuminant and signal compositions. Tables V, VI and VII of this compilation contain the essential data on all pyrotechnic items employing illuminant compositions and used in World War II. A comparison of the burning characteristics of a number of the red light compositions used in aircraft and ground signals with the burning characteristics of strontium nitrate, magnesium, polyvinyl chloride mixtures as given in Table X of this report shows that red light illuminant compositions can be selected from Table X which will have increased candlepower values for the same burning rate and color value (Table XI). In some cases improved color values together with increased candlepower values can be obtained.

CONCLUSIONS:

20. Basic data were obtained for binary mixtures from which it

may be concluded that:

a. Candlepower and burning rate values increase with increasing amounts of magnesium beyond the stoichiometric quantity up to about 60 to 80 percent magnesium.

b. Compositions containing spectral emitters in the visible region yield higher candlepower values than compositions which do not contain these emitters.

c. In the absence of organic substances, the binary mixtures containing atomized magnesium are comparatively insensitive to impact and friction.

21. From a more detailed study of binary mixtures of strontium nitrate and magnesium it may be concluded that:

a. Candlepower and burning rate values increase with decreasing particle size or with increasing surface area of magnesium.

b. Compositions containing ground magnesium give higher candlepower values accompanied by faster burning rates than those with atomized magnesium of the same granulation.

c. In the absence of organic material, mixtures containing ground magnesium are more ignitable and somewhat more sensitive to friction than those containing atomized magnesium. However, with the presence of increasing amounts of polyvinyl chloride in mixtures containing both types of magnesium, the ignitability and sensitivity to friction of the resulting mixtures are approximately the same.

d. Ground magnesium contains much more occluded gas than atomized magnesium.

e. A chlorine containing compound is required in strontium nitrate-magnesium mixtures to produce red color values greater than 0.40. Polyvinyl chloride is satisfactory material for this purpose and produced red color values as high as 0.55.

f. Basic data was obtained from which red light illuminant compositions can be formulated which will have greater candlepower and color values for the same burning rates than those now standard in Aircraft and Ground Signals.

EXPERIMENTAL PROCEDURE:

Materials

22. The following substances employed in this study were of

specification grade:

Magnesium, Type II, Grade A Consolidated Mining and Smelting Co., Canada.
Magnesium, Type II, Grade C Golwynne Chemical Co.
Magnesium, Type I, Grade A National Magnesium Co.
Magnesium, Type II, Grade C Magna Mfg. Co.
Sodium nitrate.
Strontium nitrate.
Barium nitrate.
Potassium nitrate.
Potassium perchlorate.
Calomel.
Hexachlorbenzene.
Polyvinyl chloride.
Asphaltum.
Ethyl cellulose.

In addition to the above, the following materials were also employed:

Lithium nitrate, C.P.
Calcium, nitrate, C.P.
Phenolformaldehyde resin B.R. 4036 Bakelite Co.

Procedures

23. The compositions were blended by passing the ingredients five times through a No. 30 U.S.Standard sieve. The compositions were pressed into thin walled paper cases, 1.4 square inches in crossectional area, in 5 increments of 50 grams each at loading pressures of 6,000 psi. and 10,000 psi. The candles were tested burning end upward at a distance of 32 feet in accordance with Specification No. 50-56-1 (Ref. G).

24. The 120°C. Vacuum Stability Tests were conducted and the sensitivity to impact and friction determined by standard Arsenal procedures (Ref. J).

25. The ignitability tests were conducted in the Tracer Starter Sensitivity Tester (Ref. K) modified so as to accomodate a standard 40 mm. Navy Mk. II tracer body which was used as the test piece (Ref. L). The compositions were loaded into these test pieces at 10,000 psi.

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Table I

Characteristics of Binary Mixtures Containing Oxidizing Agents and Atomized Magnesium, Grade A (Ref. C).

Composition (a) Parts by Weight: Oxidizer	Composition (a) Parts by Weight: Atom. Gr. A Magnesium	Horizontal Luminous Intensity Candles Per Square Inch	Burning Rate in./min.	Color Value	Ignition Temperature, °C.	Ignitability A4 Black Powder grams	Impact Test B.M.App., cm.	Pendulum Friction Test Reaction with Steel Shoe	Pendulum Friction Test Reaction with Fibre Shoe	120°C. Vacuum Stability Test, cc.gas/40 hrs.	Density gms./cc.	Efficiency Candle Seconds per gram
Sodium Nitrate	**Atom. Gr. A Magnesium**			**Yellow Color Value**								
80	20	4,500	2.4	-	635	> 5	85	None	-	0.30	1.91	3,600
70	30	38,500	7.7	-	630	> 5	95	None	-	0.35	1.87	9,700
58	42	102,000	13.1	0.025	630	0.5	100+	None	-	0.32	1.82	15,500
54	46	155,000	15.6	0.024	635	0.5	100+	None	-	0.31	1.79	20,000
50	50	180,000	18.8	0.026	635	1.25	100	None	-	0.36	1.74	20,000
40	60	386,000	26.7	0.029	620	1.25	100	None	-	0.32	1.71	31,000
30	70	685,000	39	0.036	620	1.75	100	None	-	0.32	1.65	36,000
25	75	785,000	43	0.033	-	> 5	100+	None	-	-	1.62	41,000
20	80	570,000	43	0.038	570	2.75	100+	None	-	0.33	1.59	30,000
15	85	445,000	32	0.041	570	5	100+	None	-	0.23	1.51	33,000
Barium Nitrate	**Atom. Gr. A Magnesium**											
80	20	6,500	2.9	pale green	680	> 5	100+	None	-	0.25	2.48	3,300
68	32	45,000	5.1	pale green	670	> 5	100+	None	-	0.25	2.24	14,000
64	36	53,000	6.7	pale green	640	> 5	100+	None	-	0.15	2.21	13,000
60	40	59,500	10.7	pale green	635	> 5	100+	None	-	0.18	2.08	9,800
50	50	186,000	26.8	pale green	615	1.25	100+	None	-	0.21	1.96	13,000
40	60	348,000	38.1	pale green	625	1.25	100+	None	-	0.16	1.88	17,500
30	70	360,000	40.3	pale green	615	> 5	100+	None	-	0.20	1.84	17,500
20	80	Erratic Burning		-	625	> 5	100+	None	-	0.22	1.83	-
Strontium Nitrate	**Atom. Gr. A Magnesium**			**Red Color Value**								
80	20	10,500	2.7	0.20	615	> 5	100+	None	-	0.13	2.32	6,500
70	30	34,000	6.0	0.19	600	> 5	100+	None	-	0.16	2.05	10,000
63.5	36.5	50,500	7.7	0.18	600	> 5	100+	None	-	0.15	1.95	12,500
60	40	68,500	8.9	0.16	600	> 5	100+	None	-	0.14	1.92	12,000
50	50	152,000	21.1	0.22	610	> 5	90	None	-	0.14	1.79	14,500
40	60	260,500	24.8	0.24	610	> 5	100	None	-	0.19	1.72	22,000
30	70	307,000	28.0	0.26	615	> 5	100+	None	-	0.27	1.63	24,000
25	75	286,000	24.0	0.31	620	> 5	100+	None	-	0.18	1.57	27,500
20	80	250,000	20.4	0.27	610	> 5	100+	None	-	-	1.52	33,000
Lithium Nitrate	**Atom. Gr. A Magnesium**			**Red Color Value**								
80	20	Erratic Burning									1.98	-
70	30	21,000	6.01	0.17							1.77	7,200
60	40	78,500	13.3	0.16							1.68	12,500
53	47	109,000	13.9	0.18							1.62	17,500
40	60	236,000	27.9	0.20							1.54	20,000
30	70	350,000	41.6	0.21							1.49	20,000
20	80	390,000	45.1	0.20							1.43	22,000
Calcium Nitrate	**Atom. Gr. A Magnesium**			**Red Color Value**								
80	20	3,500	1.8	0.22							1.99	3,500
70	30	25,000	4.0	0.16							1.96	11,500
57	43	64,000	6.8	0.16							1.86	18,500
52	48	86,000	8.4	0.18							1.81	20,000
40	60	188,000	12.5	0.25							1.73	32,000
30	70	382,000	22.0	0.28							1.56	40,000
25	75	400,000	23.3	0.29							1.51	41,000
20	80	362,000	21.5	0.30							1.50	41,000
Potassium Nitrate	**Atom. Gr. A Magnesium**											
80	20	900	2.3	White	660	> 5	80	None	-	0.16	1.81	800
70	30	1,100	4.7	White	650	2.75	80	None	-	0.13	1.75	500
62	38	27,500	6.9	White	660	1.5	90	None	-	0.15	1.73	8,400
58	42	36,000	8.5	White	655	2	75	None	-	0.11	1.72	9,000
50	50	55,000	13.3	White	650	1.75	90	None	-	0.15	1.68	9,000
40	60	86,000	21.8	White	645	1.75	90	None	-	0.13	1.62	9,000
30	70	119,000	29.3	White	635	1.5	100	None	-	0.13	1.56	9,500
25	75	116,000	31.1	White	-	4	100+	None	-	0.19	1.53	9,000
20	80	70,000	26.4	White	630	> 5	100+	None	-	0.13	1.53	6,300
Potassium Perchlorate	**Atom. Gr. A Magnesium**											
90	20	2,500	2.2	White	700	> 5	100+	None	-	0.30	1.91	2,100
70	30	17,500	3.8	White	710	> 5	100+	None	-	0.24	1.78	9,500
59	41	37,000	5.2	White	705	> 5	100+	None	-	0.28	1.72	15,000
50	50	45,000	7.0	White	715	> 5	100+	None	-	0.25	1.66	14,000
40	60	54,000	10.3	White	700	> 5	100+	None	-	0.26	1.60	12,000
30	70	171,000	28.5	White	700		100+	None	-	0.35	1.54	14,500
20	80	240,000	46	White	-		100+	None	-	0.22	1.51	12,500
15	85	167,000	47	White	-		100+	None	-	-	1.50	8,500

(a) Loading Pressure 10,000 psi. in 1.4 Square Inch Candle Cases.

Table II

Characteristics of Binary Mixtures Containing Strontium Nitrate and Magnesium. Loading Pressure 10,000 psi.

Composition Parts by Weight: Strontium Nitrate	Composition Parts by Weight: Atom. Gr. A Magnesium	Horizontal Luminous Intensity Candles/sq.in.	Burning Rate in./min.	Red Color Value	Ignition Temperature, °C.	Ignitability A4 Black Powder, grams	Impact Test B.M.App., cm.	Pendulum Friction Test Reaction with Shoe[a]: Steel	Pendulum Friction Test Reaction with Shoe[a]: Fibre	120°C. Vacuum Stability Test, cc.gas/40 hrs.	Density, gms./cc.	Efficiency Candle Seconds per gram
80	20	10,500	2.7	0.20	615	>5	100/	None	-	0.13	2.32	6,500
70	30	34,000	6.0	0.19	600	>5	100/	None	-	0.16	2.05	10,000
63.5	36.5	50,500	7.7	0.18	600	>5	100/	None	-	0.15	1.95	12,500
60	40	68,500	8.9	0.16	600	>5	100/	None	-	0.14	1.92	12,000
50	50	152,000	21.1	0.22	610	>5	90	None	-	0.14	1.79	14,500
40	60	260,500	24.8	0.24	610	>5	100	None	-	0.19	1.72	22,000
30	70	307,000	28.0	0.26	615	>5	100/	None	-	0.27	1.63	24,000
25	75	286,000	24.0	0.31	620	>5	100/	None	-	0.18	1.57	27,500
20	80	250,000	20.4	0.27	610	>5	100/	None	-	-	1.52	33,000
	Magnesium, Ground, Grade A											
80	20	9,000	4.1	0.23	550	>5	100/	6PB	None	0.81	2.26	3,500
70	30	51,000	9.6	0.24	540	>5	100/	4E	None	1.38	2.11	9,000
63.5	36.5	108,000	16.0	0.25	535	1.0	95	7B	None	1.29	2.00	13,000
60	40	155,000	20.3	0.25	520	1.75	100/	6B	None	1.58	1.97	15,000
50	50	289,000	31.0	0.24	545	1.0	100/	21C,8PB,4E	None	1.76	1.88	18,500
40	60	359,000	38.0	0.24	550	1.0	100/	17B	None	2.41	1.72	20,000
30	70	545,000	38.0	0.23	555	1.0	100/	4B	None	2.83	1.62	32,500
25	75	640,000	34.0	0.21	545	1.25	100/	None	-	2.79	1.59	43,000
20	80	530,000	24.0	0.28	540	>5	100/	None	-	3.08	1.53	52,000
	Magnesium, Ground, Grade C											
80	20	5,000	4.5	0.22	580	>5	100/	None	-	1.09	2.30	1,700
70	30	46,000	7.7	0.18	565	1.25	100/	None	-	1.36	2.13	10,000
63.5	36.5	78,500	11.1	0.18	650	1.50	90	None	-	1.36	2.06	12,500
60	40	99,000	13.0	0.19	655	1.25	80	1B	None	1.30	2.01	14,000
50	50	168,000	22.0	0.20	655	1.75	100/	1C,2S,4B	None	1.36	1.84	15,000
40	60	264,000	27.0	0.24	640	2.50	100/	None	-	1.18	1.76	20,000
30	70	428,000	29.0	0.27	630	3.50	100/	4C,1S	None	1.49	1.68	32,000
25	75	420,000	27.0	0.31	640	>5	100/	None	-	1.54	1.65	34,000
20	80	360,000	22.0	0.32	655	>5	100/	None	-	1.45	1.58	37,000
	Magnesium, Atom., Grade C											
80	20	3,500	2.8	0.21	580	>5	90	None	-	0.13	2.40	2,000
70	30	19,000	4.4	0.17	575	>5	95	None	-	0.12	2.22	7,000
63.5	36.5	29,000	4.5	0.17	565	>5	95	None	-	0.17	2.15	11,000
60	40	34,000	4.8	0.19	570	1.0	75	None	-	0.19	2.09	12,500
50	50	54,000	7.4	0.21	570	1.25	100/	None	-	0.27	1.99	13,500
40	60	107,000	11.7	0.28	575	1.25	100/	None	-	0.30	1.89	17,500
30	70	erratic	-	-	-	-	-			-	1.74	-

[a] The letters used to describe the reaction have the following interpretation:

B - burning
PB - partial burning
C - crackles
E - explosions
S - sparks

Table III

Effect of Asphaltum on the Burning Characteristics of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A. Loading Pressure 6,000 psi.

Composition Parts by Weight							
Strontium Nitrate	Magnesium	Asphaltum	Candlepower[a]	Burning Rate in./min.	Red Color Value	Horizontal Luminous Intensity Candles/sq.in.	Remarks
80	20	0	16,000	5.7	0.26	11,500	Pink
		5	18,000	5.5	0.29	13,000	Slag
		10	22,000	5.1	0.31	15,500	Slag
		20	4,000	2.0	0.37	3,000	Orange
70	30	0	70,000	13	0.20	50,000	White
		5	35,500	5.4	0.25	25,000	
		10	22,000	3.4	0.39	15,500	
		20	3,500	2.3	0.40	2,500	
60	40	0	190,000	25	0.19	135,000	White
		5	53,000	8.6	0.30	38,000	
		10	36,500	4.8	0.37	26,000	
		20	5,500	2.3	0.39	4,000	
50	50	0	275,000	34	0.20	196,000	White
		5	93,500	9.1	0.30	67,000	
		10	46,500	4.4	0.36	33,000	
		20	2,000	2.3	0.33	1,400	
40	60	0	370,000	34	0.25	264,000	White
30	70	0	550,000	31	0.26	392,000	Pink
		5	100,000	7.9	0.35	71,000	
		10	16,500	3.7	0.37	12,000	
		20	-	Erratic	-	-	Sparks
15	85	0	150,000	12	0.27	107,000	Pink
		5	16,000	5.2	0.29	11,000	
		10	2,000	2.9	0.25	1,400	Yellow
		20	-	Erratic	-	-	Yellow

[a] Determine in 1.4 sq.in. candle cases.

Table IV

Effect of Phenolformaldehyde Resin on the Burning Characteristics of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A, Loading Pressure 6,000 psi.

Composition Parts by Weight							
Strontium Nitrate	Magnesium	Phenolformaldehyde Resin	Candlepower[a]	Burning Rate in./min.	Red Color Value	Horizontal Luminous Intensity Candles/sq.in.	Remarks
80	20	0	16,000	5.7	0.26	11,500	Pink
		5	14,500	7.1	0.30	10,500	Slag
		10	23,500	5.5	0.32	17,000	
		20	11,000	3.3	0.41	8,000	
70	30	0	70,000	13	0.20	50,000	White
		5	46,000	6.9	0.21	33,000	
		10	38,000	5.5	0.29	27,000	
		20	17,500	4.0	0.38	12,500	
60	40	0	190,000	25	0.19	135,000	White
		5	67,000	9.7	0.25	48,000	
		10	53,000	6.4	0.31	38,000	
		20	25,500	4.6	0.37	18,000	
50	50	0	275,000	34	0.20	196,000	White
		5	119,000	11.7	0.26	85,000	
		10	78,500	6.7	0.32	56,000	
		20	17,500	4.5	0.36	12,500	Sparks
30	70	0	550,000	31	0.26	391,000	Pink
		5	164,000	10.6	0.33	117,000	
		10	58,000	6.7	0.35	41,000	
		20	11,000	4.1	0.30	8,000	
15	85	0	150,000	12	0.27	107,000	Pink
		5	36,000	7.3	0.28	26,000	Sparks
		10	6,500	4.3	0.30	4,500	Sparks
		20	1,000	2.6	Yellow	700	Sparks

[a] Determined in 1.4 sq. in. candle cases.

Table V

Effect of Polyvinyl Chloride on the Burning Characteristics of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A. Loading Pressure 6,000 psi.

Composition Parts by Weight							
Strontium Nitrate	Magnesium	Polyvinyl Chloride	Candlepower[a]	Burning Rate in./min.	Red Color Value	Horizontal Luminous Intensity Candles/sq.in.	Remarks
80	20	0	16,000	5.7	0.26	11,500	Pink
		5	13,000	4.6	0.31	9,000	Slag
		10	17,000	4.6	0.35	12,000	Slag
		20	15,000	4.1	0.50	10,500	Slag
70	30	0	70,000	13	0.20	50,000	White
		5	56,000	7.7	0.23	40,000	
		10	44,000	6.3	0.33	31,000	
		20	30,000	6.5	0.47	21,000	
		30	25,500	5.5	0.55	18,000	
60	40	0	190,000	25	0.19	135,000	White
		5	86,000	10.5	0.26	61,000	
		10	80,000	11.0	0.35	57,000	
		20	69,000	7.9	0.47	49,000	
		30	37,000	6.8	0.55	26,000	
50	50	0	275,000	34	0.20	196,000	White
		5	151,000	13.1	0.32	107,000	
		10	108,000	8.2	0.34	77,000	
		20	46,000	5.6	0.51	33,000	
		30	12,500	5.3	0.48	9,000	Sparks
30	70	0	550,000	31	0.26	391,000	Pink
		5	253,000	12.5	0.39	180,000	
		10	100,000	8.2	0.50	71,000	
		20	17,500	5.9	0.47	12,500	
		30	6,000	5.1	0.37	4,500	Slag
15	85	0	150,000	12	0.27	107,000	Pink
		5	71,500	7.8	0.45	51,000	
		10	20,500	5.9	0.46	14,500	
		20	6,500	5.1	0.38	4,500	

a Determined in 1.4 sq.in. candle cases.

Table VI

Effect of Ethyl Cellulose on the Burning Characteristics of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A. Loading Pressure 6,000 psi.

Composition Parts by Weight							
Strontium Nitrate	Magnesium	Ethyl Cellulose	Candlepower[a]	Burning Rate in./min.	Red Color Value	Horizontal Luminous Intensity Candles/sq.in.	Remarks
70	30	0	70,000	1.3	0.20	50,000	White
		5	47,000	9.0	0.21	33,000	
		10	37,000	7.7	0.26	26,000	
60	40	0	190,000	25	0.19	135,000	White
		5	103,000	15.5	0.22	73,000	
		10	68,000	8.2	0.30	48,000	
50	50	0	275,000	34	0.20	196,000	White
		5	190,000	21.0	0.27	135,000	
		10	120,000	11.6	0.31	86,000	
30	70	0	550,000	31	0.26	391,000	Pink
		5	342,000	17.5	0.32	244,000	
		10	142,000	9.8	0.36	100,000	

[a] Determined in 1.4 sq.in. candle cases.

Table VII

Effect of Mercurous Chloride (Calomel) on the Burning Characteristics of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A. Loading Pressure 6,000 psi.

Composition Parts by Weight							
Strontium Nitrate	Magnesium	Mercurous Chloride	Candlepower[a]	Burning Rate in./min.	Red Color Value	Horizontal Luminous Intensity candles/sq.in.	Remarks
80	20	0	16,000	5.7	0.26	11,500	Pink
		5	7,000	4.8	0.24	5,000	Slag
		10	6,000	4.3	0.25	4,000	Slag
		20	6,000	3.7	0.28	4,000	Slag
		30	Did not ignite.				
70	30	0	70,000	13	0.20	50,000	White
		5	57,000	9.7	0.20	41,000	
		10	49,500	8.3	0.20	35,000	
		20	36,000	6.6	0.20	26,000	
		30	26,500	6.5	0.22	19,000	
60	40	0	190,000	25	0.19	135,000	White
		5	115,000	14.3	0.19	82,000	
		10	97,000	12.3	0.22	69,000	
		20	63,500	10.0	0.22	45,000	
		30	67,000	9.4	0.22	48,000	
50	50	0	275,000	34	0.20	196,000	White
		5	187,000	21.4	0.22	134,000	
		10	158,000	16.7	0.24	113,000	
		20	112,000	12.5	0.26	80,000	
		30	82,000	10.0	0.29	58,500	
40	60	0	370,000	34	0.25	391,000	White
		5	220,000	24.0	0.23	157,000	
		10	220,000	19.0	0.26	157,000	
		20	178,000	13.7	0.29	127,000	
		30	167,000	10.8	0.32	119,000	
30	70	0	550,000	31	0.26	107,000	Pink
		5	393,000	22.2	0.30	280,000	
		10	370,000	17.3	0.32	264,000	
		20	252,000	12.7	0.34	180,000	
		30	218,000	11.0	0.36	155,000	

a Determined in 1.4 sq.in. candle cases.

Table VIII

Effect of Hexachlorbenzene on the Burning Characteristics of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A. Loading Pressure 6,000 psi.

Composition Parts by Weight: Strontium Nitrate	Magnesium	Hexachlorbenzene	Candlepower[a]	Burning Rate in./min.	Red Color Value	Horizontal Luminous Intensity candles/sq.in.	Remarks
80	20	0	16,000	5.7	0.26	11,500	Pink Slag
		5	14,500	4.7	0.29	10,000	
		10	13,000	4.4	0.34	9,000	
		20	7,500	4.4	0.41	5,000	
70	30	0	70,000	13	0.20	50,000	White
		5	58,000	7.6	0.22	41,000	
		10	44,500	7.0	0.24	32,000	
		20	26,000	5.4	0.36	18,500	
		30	22,500	5.4	0.43	16,000	
60	40	0	190,000	25	0.19	135,000	White
		5	106,000	12.4	0.24	76,000	
		10	83,500	10.4	0.27	60,000	
		20	51,000	6.7	0.41	36,000	
		30	39,500	6.4	0.44	28,000	
50	50	0	275,000	34	0.20	196,000	White
		5	157,000	16.4	0.30	112,000	
		10	146,000	12.9	0.34	104,000	
		20	87,500	8.5	0.48	62,000	
		30	40,000	7.9	0.52	28,000	
30	70	0	550,000	31	0.26	391,000	Pink
		5	397,500	17.8	0.35	283,000	
		10	282,000	14.9	0.41	201,000	
		20	109,000	11.5	0.48	78,000	
		30	48,000	10.4	0.41	34,000	
15	85	0	150,000	12	0.27	107,000	Pink
		5	155,000	11.2	0.38	111,000	
		10	122,000	12.0	0.40	87,000	
		20	65,000	11.1	0.37	46,000	

a Determined in 1.4 sq.in. candle cases.

Table IX

Characteristics of Pyrotechnic Compositions Containing Strontium Nitrate, Ground Magnesium, Grade A (Ref. C) and Polyvinyl Chloride.

Composition Parts by Weight: Strontium Nitrate	Composition Parts by Weight: Ground, Grade A Magnesium	Composition Parts by Weight: Polyvinyl chloride	Horizontal Luminous Intensity Candles Per Square Inch	Burning Rate in./min.	Color Value: Red	Color Value: Green	Ignition Temperature, °C.	Ignitability at 10,000 psi. A4 Black Powder, grams	Impact Test B.M. App., cm.	Pendulum Friction Test Reaction with Shoe[a]: Steel	Pendulum Friction Test Reaction with Shoe[a]: Fibre	120°C. Vacuum Stability Test, cc.gas/40 hrs.	Density gms./cc.	Efficiency Candle Seconds Per Gram
80	20	0	9,000	4.1	0.23	0.19	550	>5	100+	6PB	None	0.81	2.26	3,500
		5	12,500	4.5	0.28	0.22	545	2.5	95	5B	None	0.85	2.16	5,000
		10	13,000	4.2	0.33	0.18	590	>5	100+	2C	None	0.79	2.04	5,500
		15	7,000	4.0	0.38	0.13	590	0.5	100+	23C	None		2.05	3,000
70	30	0	51,000	9.6	0.24	0.18	540	>5	100+	4E	None	1.38	2.11	9,000
		5	39,000	7.3	0.22	0.23	535	0.75	100+	14C,1B	None	1.46	2.06	9,500
		10	32,000	5.6	0.31	0.20	585	0.75	90	2C	None	1.45	1.97	12,500
		15	30,000	5.0	0.40	0.13	570	0.75	100+	13C	None		1.91	11,500
63.5	36.5	0	108,000	16.0	0.25	0.18	535	1.0	95	7B	None	1.29	2.00	13,000
		5	63,000	9.8	0.24	0.23	525	0.75	100+	8C,4B	None	1.55	1.99	12,000
		10	41,500	6.2	0.37	0.17	580	0.75	100	None	-	1.68	1.85	13,000
		15	36,000	5.4	0.42	0.14	570	0.50	80	6C	None		1.87	13,000
60	40	0	155,000	20.3	0.25	0.18	520	1.75	100+	6B	None	1.58	1.97	15,000
		5	65,000	10.6	0.26	0.22	590	—	100+	18C,1B	None	1.50	1.84	12,500
		10	50,000	7.2	0.36	0.18	585	0.5	80	2C	None	1.51	1.84	14,000
		15	42,000	5.8	0.42	0.13	560	0.5	100+	6C	None		1.84	14,000
50	50	0	289,000	31.0	0.24	0.23	545	1.0		21C,8PB,4E	None	1.76	1.88	18,500
		5	94,000	12.5	0.32	0.18	585	>5	100+	13C,5B	None	1.76	1.86	15,500
		10	93,000	8.0	0.37	0.15	590	0.75	85	None	-	1.83	1.74	24,000
		15	63,000	6.6	0.44	0.13	555	0.50	100+	5C	None		1.74	20,000
40	60	0	359,000	38.0	0.24	0.22	550	1.0	100+	17B,3E	None	2.41	1.72	20,000
		5	185,000	13.3	0.31	0.16	575	>5	100+	2PB	None	2.12	1.70	30,000
		10	120,000	8.0	0.42	0.12	570	1.0	100+	None	-	2.23	1.68	32,000
		15	65,000	7.1	0.51	0.10	>535	0.75	100	6C	None		1.69	20,000
30	70	0	545,000	38.0	0.23	0.24	555	1.0	100+	4B	None	2.83	1.62	32,500
		5	206,000	12.1	0.37	0.14	585	>5	100+	None	-	2.43	1.60	39,000
		10	80,000	7.5	0.50	0.10	580	>5	100+	None	-	2.45	1.61	24,000
		15	36,000	6.7	0.52	0.10	>560	>5	95	None	-		1.60	12,000
25	75	0	640,000	34.0	0.21	0.25	545	1.25	100+	None	-	2.79	1.59	43,000
		5	147,000	10.0	0.41	0.12	585	>5	100+	None	-	2.48	1.54	35,000
		10	54,000	7.1	0.49	0.11	575	>5	100+	None	-	2.47	1.54	18,000
		15	22,000	5.9	0.50	0.12	>560	>5	100	None	-		1.56	8,500
20	80	0	530,000	24.0	0.28	0.18	540	>5	100+	None	-	3.08	1.53	52,000
		5	83,000	7.9	0.46	0.12	590	>5	100+	None	-	2.53	1.51	24,500
		10	38,000	6.4	0.48	0.12	595	>5	100+	None	-	2.59	1.52	14,000
		15	18,000	5.4	0.48	0.13	>570	>5	100+	None	-	—	1.52	8,000

[a] The letters used to describe the reaction have the following interpretation:

B - burning
PB - partial burning
C - crackles
E - explosions

Table X

Characteristics of Pyrotechnic Compositions Containing Strontium Nitrate, Atomized Magnesium, Grade A and Polyvinyl Chloride.

Composition [a] Parts by Weight: Strontium Nitrate	Atom. Gr. A Magnesium	Polyvinyl Chloride	Horizontal Luminous Intensity Candles Per Square Inch	Burning Rate, in./min.	Color Value Red	Ignition Temperature, °C.	Ignitability at 10,000 psi. A4 Black Powder, grams	Impact Test B.M.App., cm.	Pendulum Friction Test Reaction with Steel Shoe	Pendulum Friction Test Reaction with Fibre Shoe	120°C. Vacuum Stability Test, cc.gas/40 hrs.	Density gms./cc.	Efficiency Candle Seconds Per Gram
80	20	0	10,500	2.7	0.20	615	>5	100+	None	-	0.13	2.32	6,500
		1	10,000	3.5	0.22	575	>5	100+	None	-	0.19	2.20	4,850
		5	13,000	3.9	0.25	570	>5	100	None	-	0.14	2.16	5,500
		10	11,000	4.1	0.27	510	>5	100+	None	-	0.36	2.12	4,560
		15	13,000	4.1	0.37	560	1.00	100+	16 crackles	None	0.10	2.06	5,600
		20	10,000	3.4	0.44	555	0.75	100+	None	-		2.07	5,300
70	30	0	34,000	6.0	0.19	600	>5	100+	None	-	0.16	2.05	10,000
		1	33,500	5.4	0.19	570	>5	100+	12 crackles	None	0.29	2.06	11,000
		5	33,000	5.3	0.20	565	0.75	100	None	-	0.18	2.07	9,000
		10	27,000	4.8	0.28	515	0.75	100	13 crackles	None	0.32	1.95	10,500
		15	25,000	4.8	0.40	550	1.00	100+	21 crackles	None	0.11	1.95	10,000
		20	25,000	3.8	0.46	555	0.75	100+	None	-	-	1.95	12,500
		25	22,000	4.5	0.49	550	1.00	100+	None	-	0.22	1.85	9,500
63.5	36.5	0	50,500	7.7	0.18	600	>5	100+	None	-	0.15	1.95	12,500
		1	50,000	7.5	0.17	575	>5	100+	6 crackles	None	0.18	1.98	12,000
		5	43,000	6.1	0.21	570	0.75	100+	None	-	0.17	1.96	13,000
		10	29,000	5.4	0.32	545	1.20	100+	8 crackles	None	0.30	1.93	10,000
		15	32,000	4.9	0.42	575	0.75	100+	19 crackles	None	0.09	1.88	12,500
		20	33,000	4.3	0.46	560	0.75	100+	None	-	-	1.89	15,000
		25	31,000	4.6	0.51	570	0.75	100+	None	-	0.19	1.82	13,500
60	40	0	68,500	8.9	0.16	600	>5	100+	None	-	0.14	1.92	12,000
		1	65,000	10.1	0.20	570	>5	100+	None	-	0.21	1.87	12,500
		5	45,500	7.4	0.25	570	1.00	100+	11 crackles	None	0.23	1.90	12,000
		10	36,000	5.7	0.35	540	1.00	100+	6 crackles	None	0.21	1.90	12,000
		15	38,000	5.1	0.43	570	0.75	100+	24 crackles	None	0.16	1.84	14,500
		20	41,500	4.4	0.49	570	1.00	100+	None	-	-	1.86	18,500
		25	33,500	4.7	0.51	560	0.75	100+	None	-	0.20	1.74	15,000
50	50	0	152,000	21.1	0.22	610	>5	90	None	-	0.14	1.79	14,500
		1	114,000	13.8	0.25	560	>5	100+	None	-	0.21	1.81	15,500
		5	67,000	7.8	0.28	555	1.25	100+	10 crackles	None	0.21	1.80	16,000
		10	75,000	6.1	0.35	550	1.25	100+	7 crackles	None	0.12	1.78	25,000
		15	55,000	5.8	0.45	575	1.00	100+	9 crackles	None	0.13	1.76	19,500
		20	45,500	4.9	0.53	570	0.75	100+	None	-	-	1.78	19,000
		25	37,000	5.2	0.52	560	1.00	100+	None	-	0.23	1.68	15,500
40	60	0	260,500	24.8	0.24	610	>5	100	None	-	0.19	1.72	22,000
		1	170,000	17.3	0.26	570	>5	100+	None	-	0.19	1.72	20,500
		5	88,000	9.3	0.30	575	1.25	100+	None	-	0.40	1.70	20,000
		10	88,000	6.4	0.42	585	1.00	100+	9 crackles	None	0.14	1.69	25,000
		15	74,500	5.7	0.47	570	1.00	95	9 crackles	None	0.18	1.69	28,000
		20	35,000	4.7	0.54	560	1.00	100+	None	-	-	1.69	16,000
		25	16,000	5.2	0.50	555	1.00	100+	None	-	0.24	1.64	7,000
30	70	0	307,000	28.0	0.26	615	>5	100+	None	-	0.27	1.63	24,000
		1	292,000	18.3	0.26	585	>5	100+	None	-	0.21	1.62	36,000
		5	125,000	8.4	0.39	575	>5	100+	None	-	0.37	1.62	33,500
		10	58,000	5.8	0.48	535	0.75	100+	None	-	0.13	1.61	23,000
		15	22,000	5.0	0.55	575	1.00	100+	None	-	0.18	1.61	10,000
		20	13,500	4.7	0.51	555	1.00	100+	None	-	-	1.62	6,500
20	80	0	250,000	20.4	0.27	610	>5	100+	None	-	-	1.52	33,000
		1	214,000	13.4	0.32	595	>5	100+	None	-	0.23	1.54	38,000
		5	77,000	6.8	0.43	605	>5	100+	None	-	0.32	1.54	26,500
		10	26,000	4.8	0.48	600	>5	100+	None	-	0.16	1.54	10,500
		15	11,500	4.2	0.48	590	0.75	100+	None	-	0.20	1.53	6,500
		20	9,500	3.9	0.49	580	-	100+	None	-	-	1.49	6,000
15	85	0	Erratic										
		1	71,500	8.0	0.35	600	>5	100+	None	-	0.22	1.50	21,500
		5	34,000	5.9	0.43	605	>5	100+	None	-	0.36	1.51	14,000
		10	12,000	5.6	0.43	600	>5	100+	None	-	0.16	1.52	5,000
		15	6,500	4.3	0.43	605	>5	100+	None	-	0.18	1.50	3,500

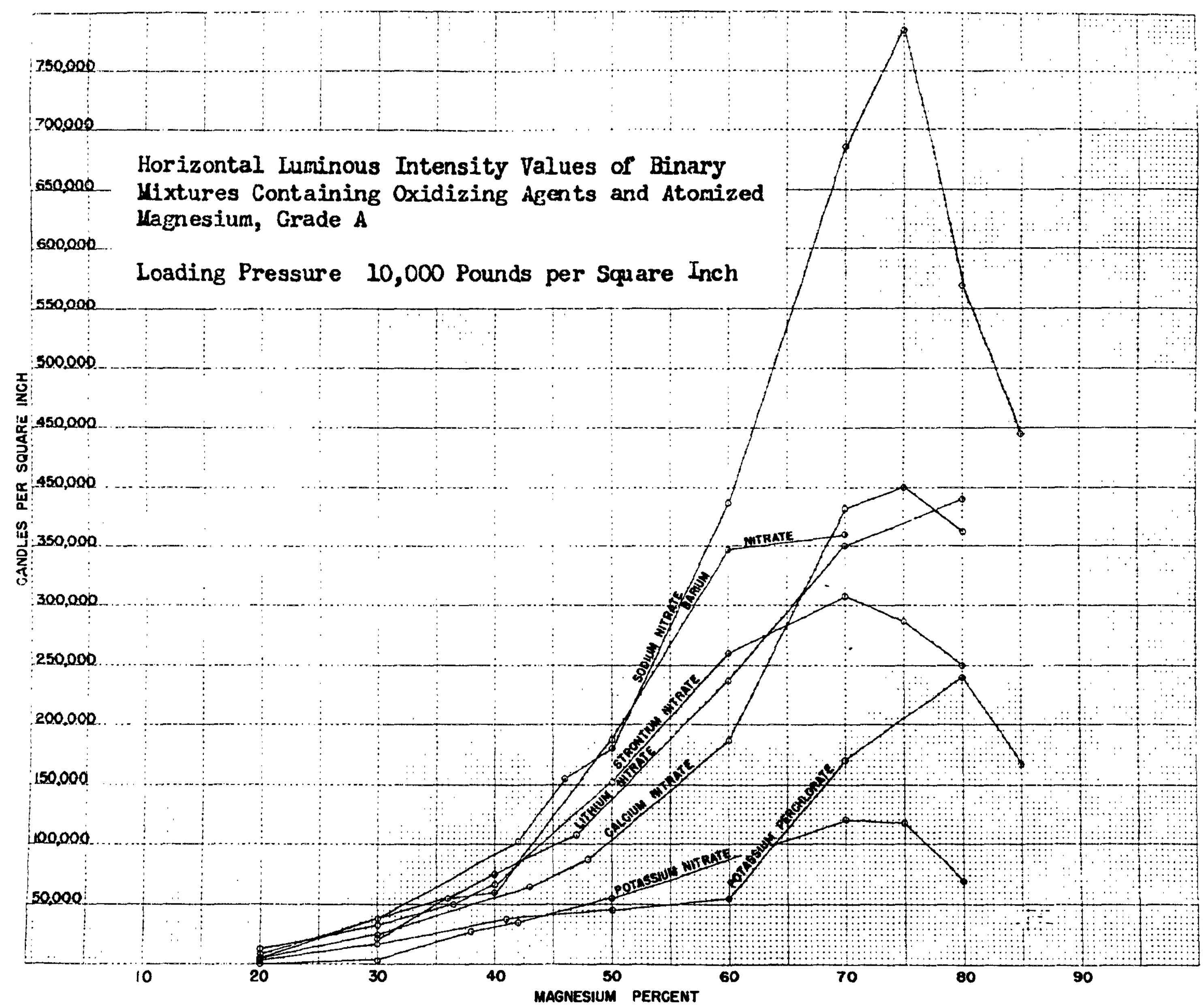
[a] Loading Pressure 10,000 psi. in 1.4 Square Inch Candle Cases.

Table XI

A Comparison of Standard Red Illuminant Compositions with Compositions Containing Strontium Nitrate, Magnesium and Polyvinyl Chloride.

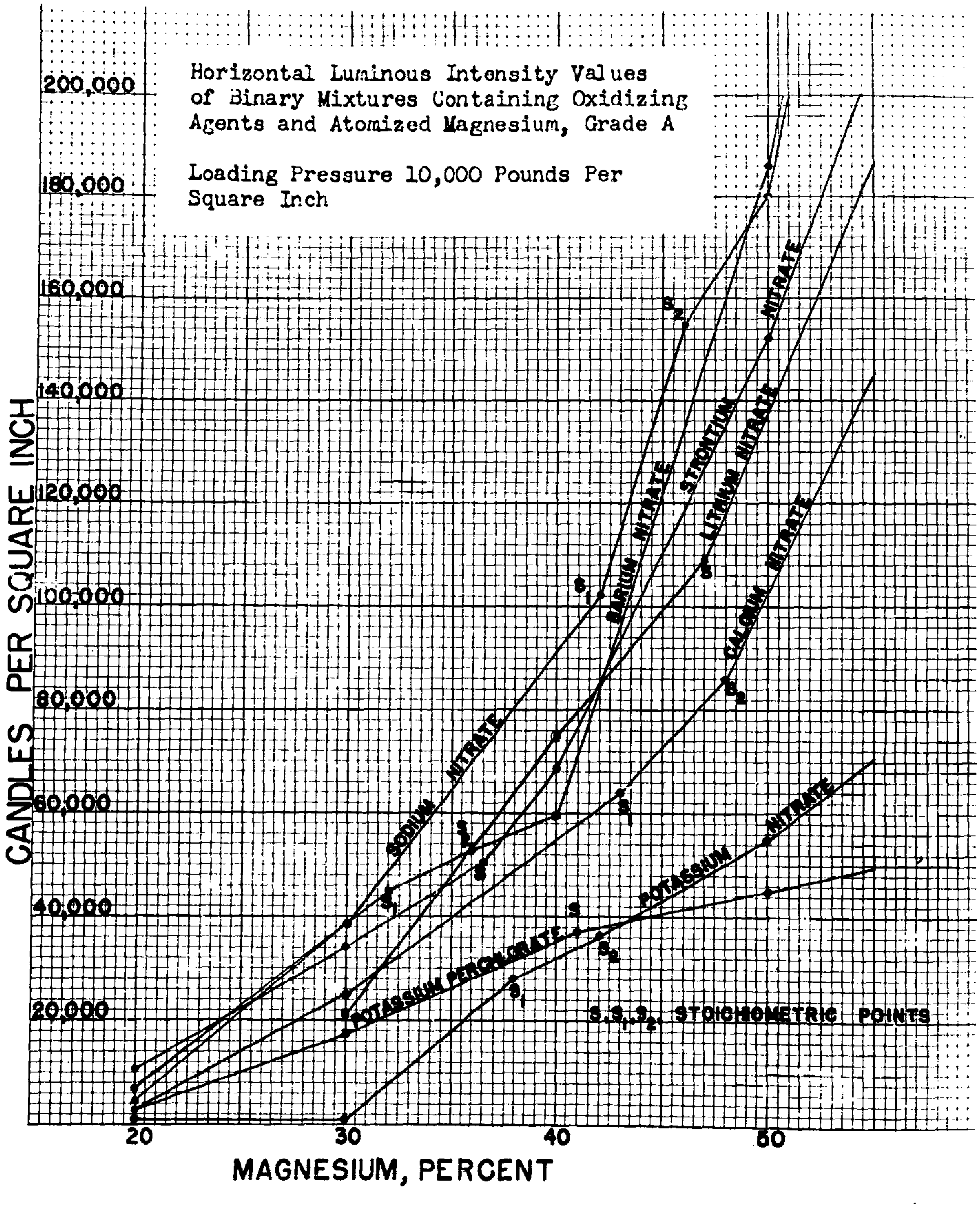
Item	Present Requirements of Illuminant Composition (Ref. I)			Compositions in Table X having Approximately the same Burning Rate	
	Maximum Burning Rate in./min.	Minimum Candle-power per sq.in.	Red Color Value	Red Color Value	Candlepower per sq.in.
Signal, Aircraft Red Star, Parachute, M11	5	18,000	0.44	0.53	45,000
Red Star, Parachute, M14	3.6	1,500	-	0.44	10,000
Double Star: Red-Red, AN-M37A1	4.9	9,600	0.42	0.53	45,000
Single Star: Red, AN-M43A1	6.5	9,600	0.42	0.42	88,000
Tracer, Double Star: Red Tracer, AN-M56-58A1	12	25,000	0.38	0.37	206,000[a]
Red Star, AN-M53-58A1	5	22,000	0.38	0.53	45,000
Signal, Ground Red Star, Parachute, M51A1 or M51A1B2	5.1	20,000	0.44	0.53	45,000
Red Star, Cluster, M52A1 or M52A1B2	3.8	11,500	0.41	0.46	25,000

[a] From Table IX.



M-33356 PICATINNY ARSENAL ORDNANCE DEPARTMENT

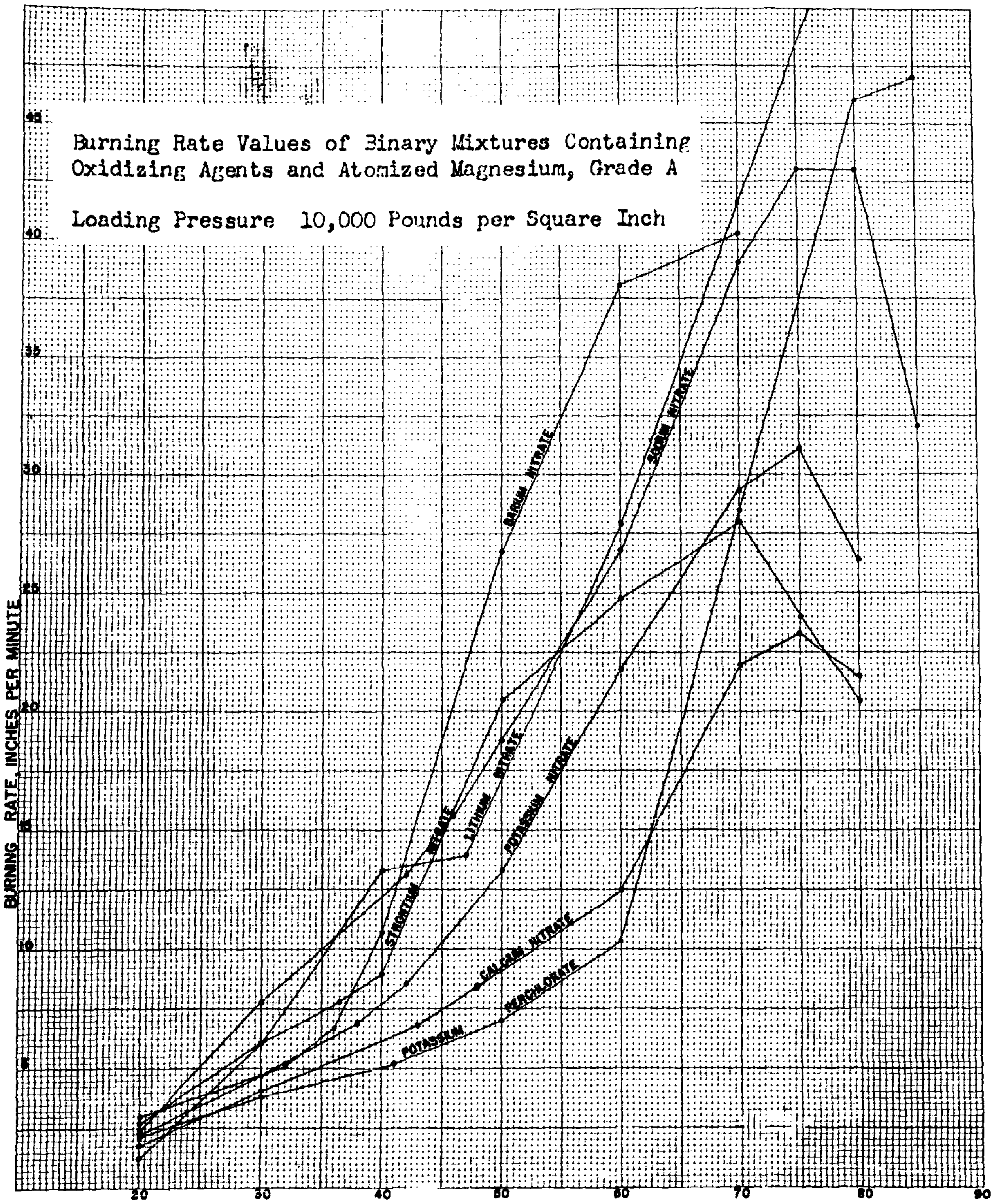
Figure 1



M-33357

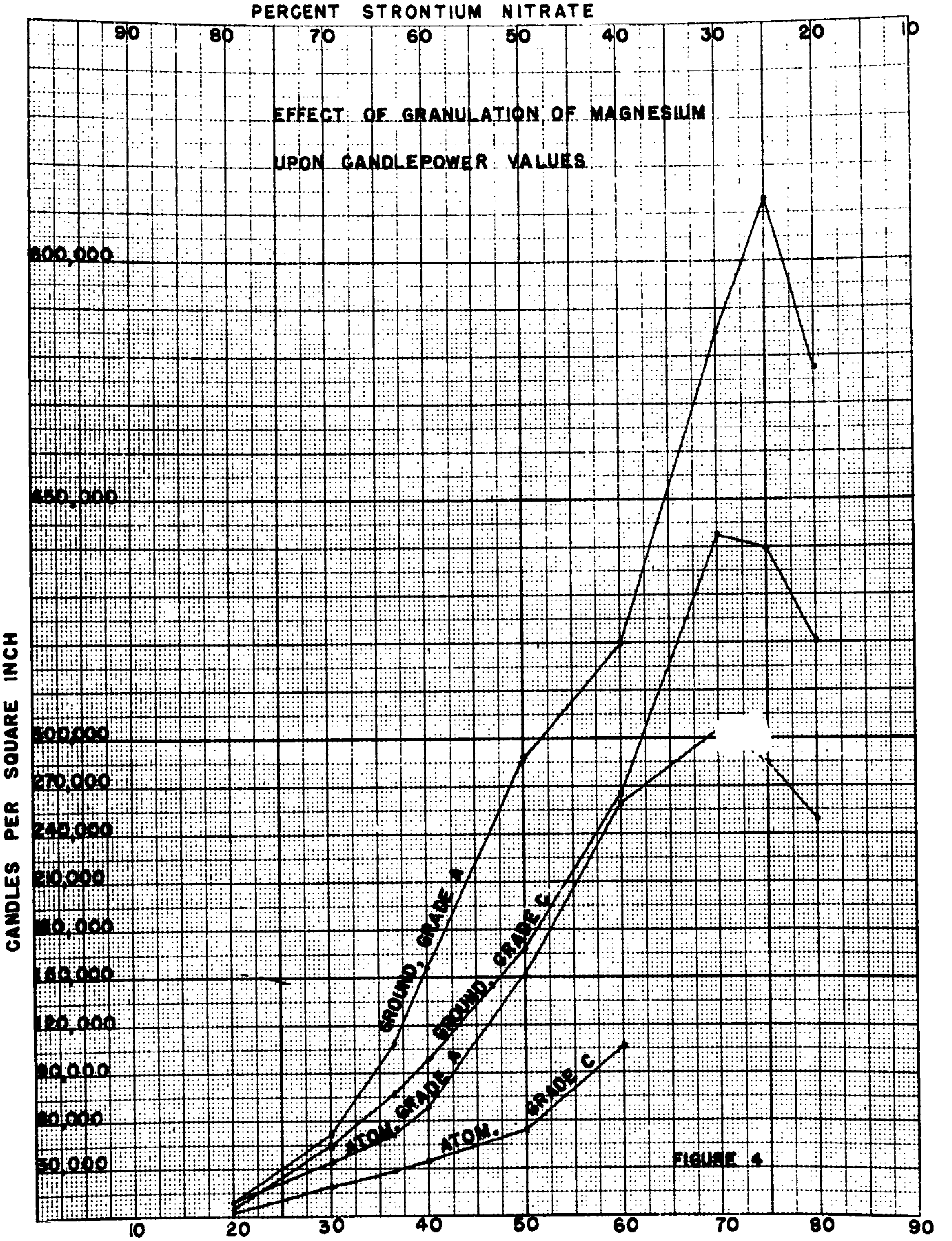
PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 2



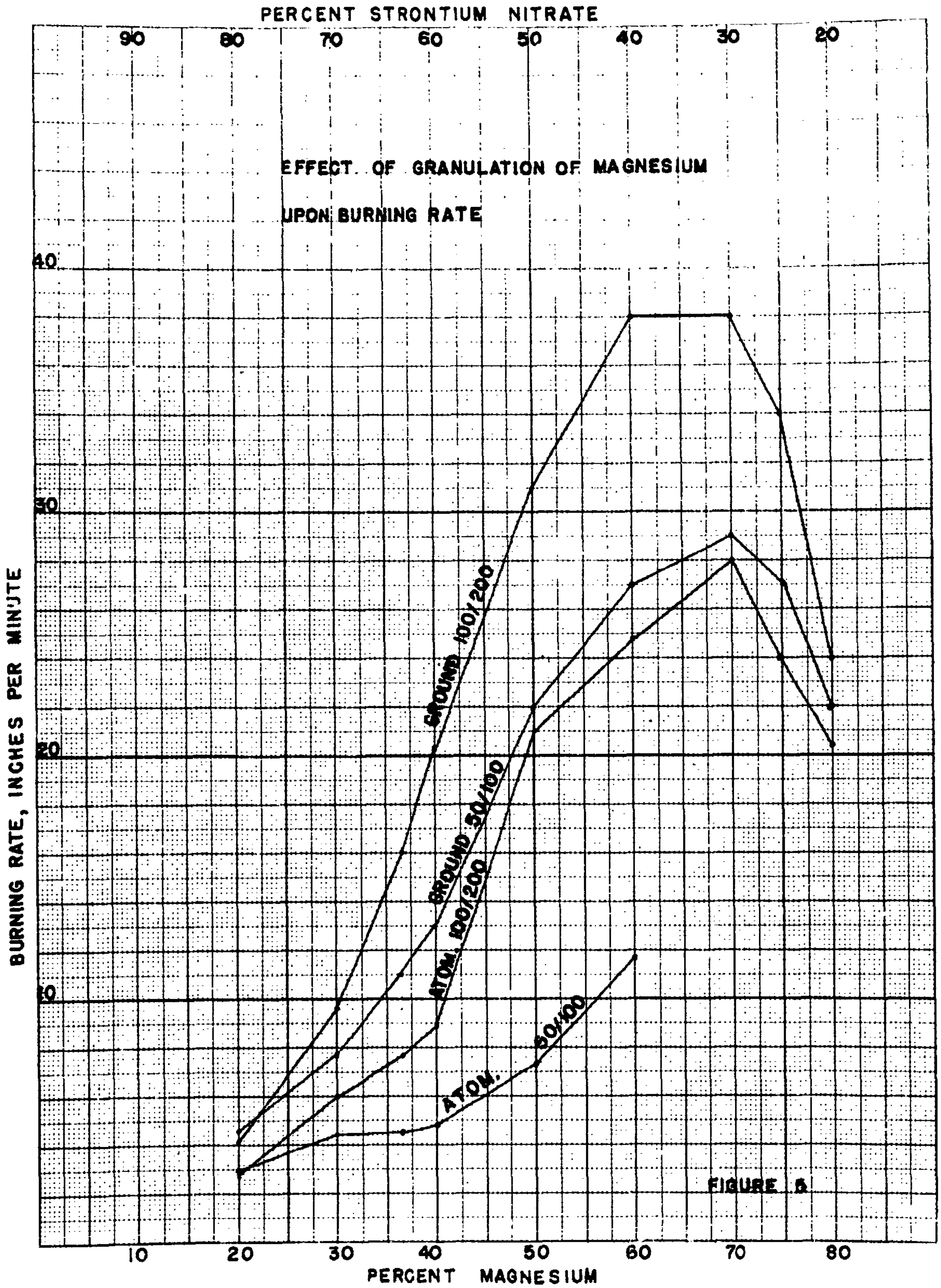
M-33358 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 3



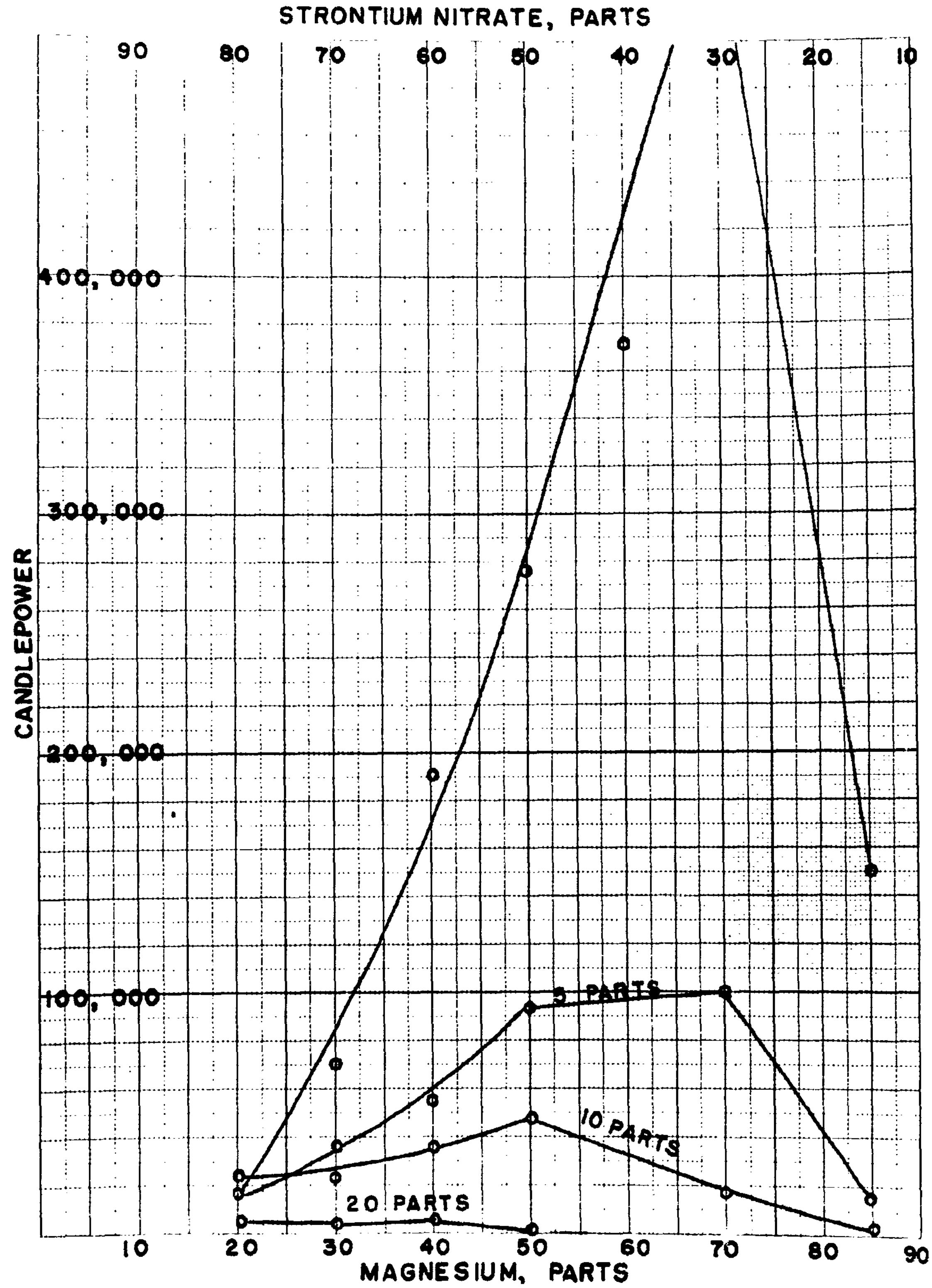
A-2335-3?? PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 4



M-33358/2 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 5

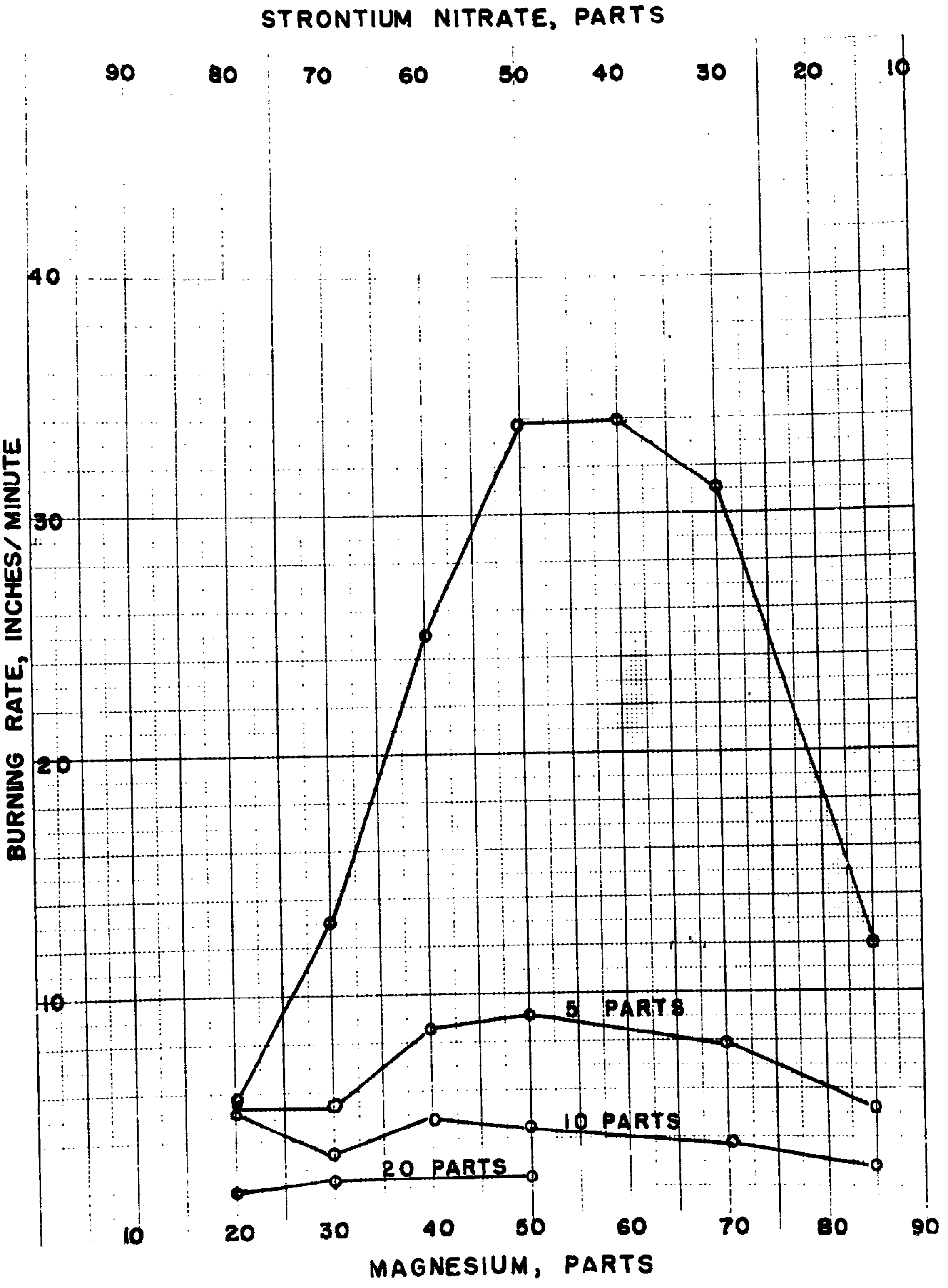


M-28050 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 6

Effect of Asphaltum Upon the Candlepower of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

(T)

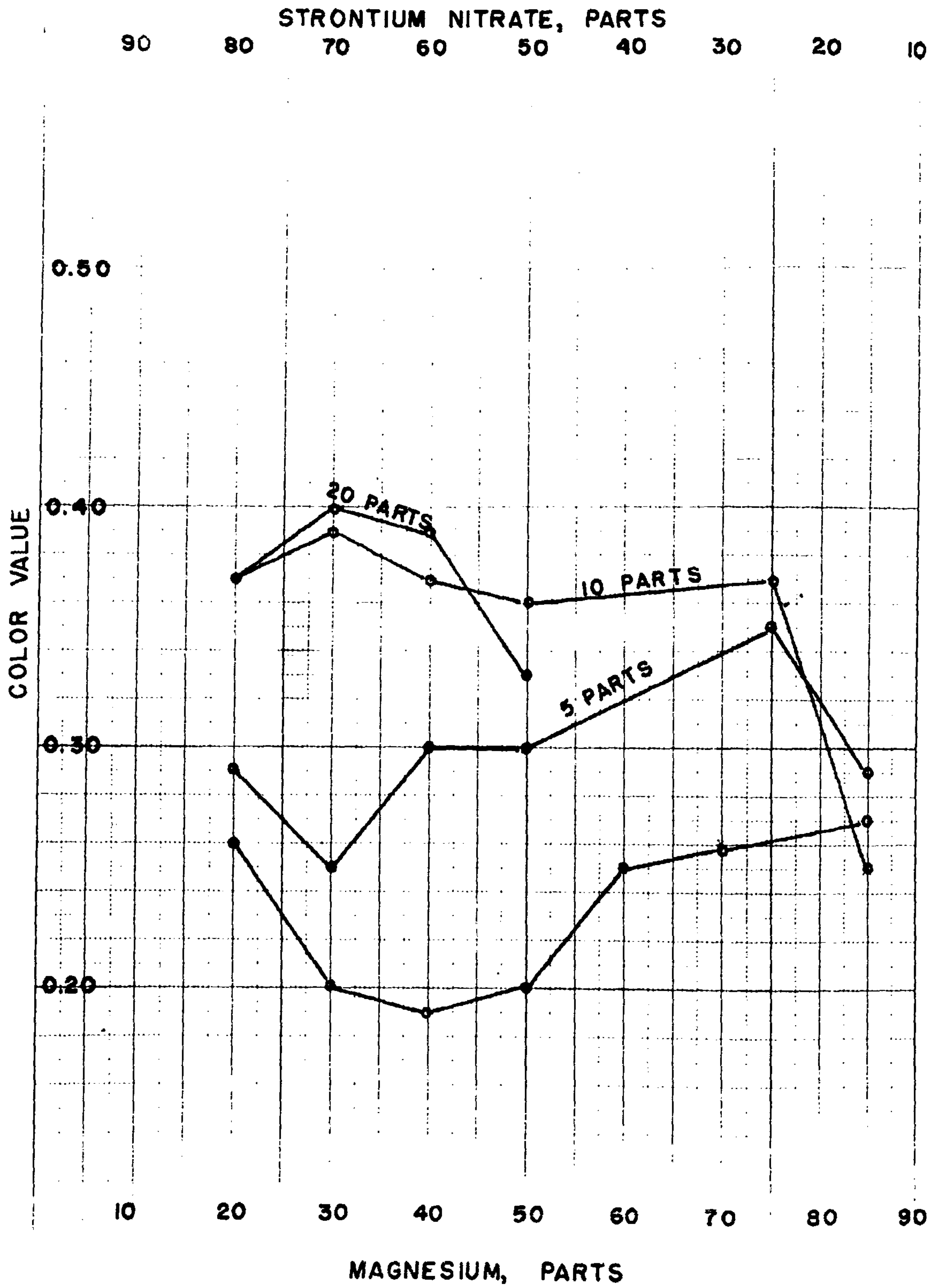


M-28051 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 7

Effect of Asphaltum Upon the Burning Rate of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

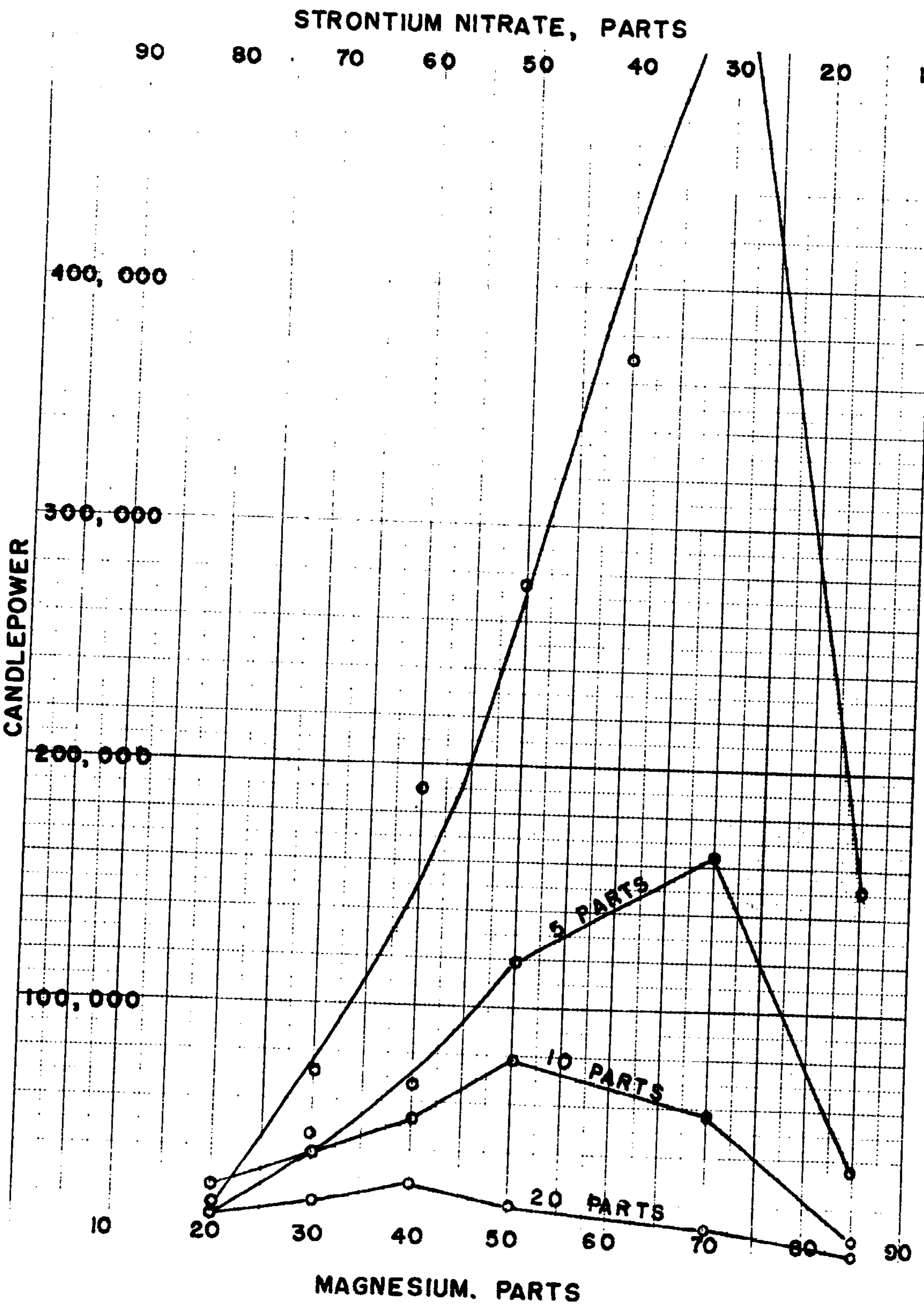
(T)



M-28052 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 8
Effect of Asphaltum Upon the Color Value of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

(T)

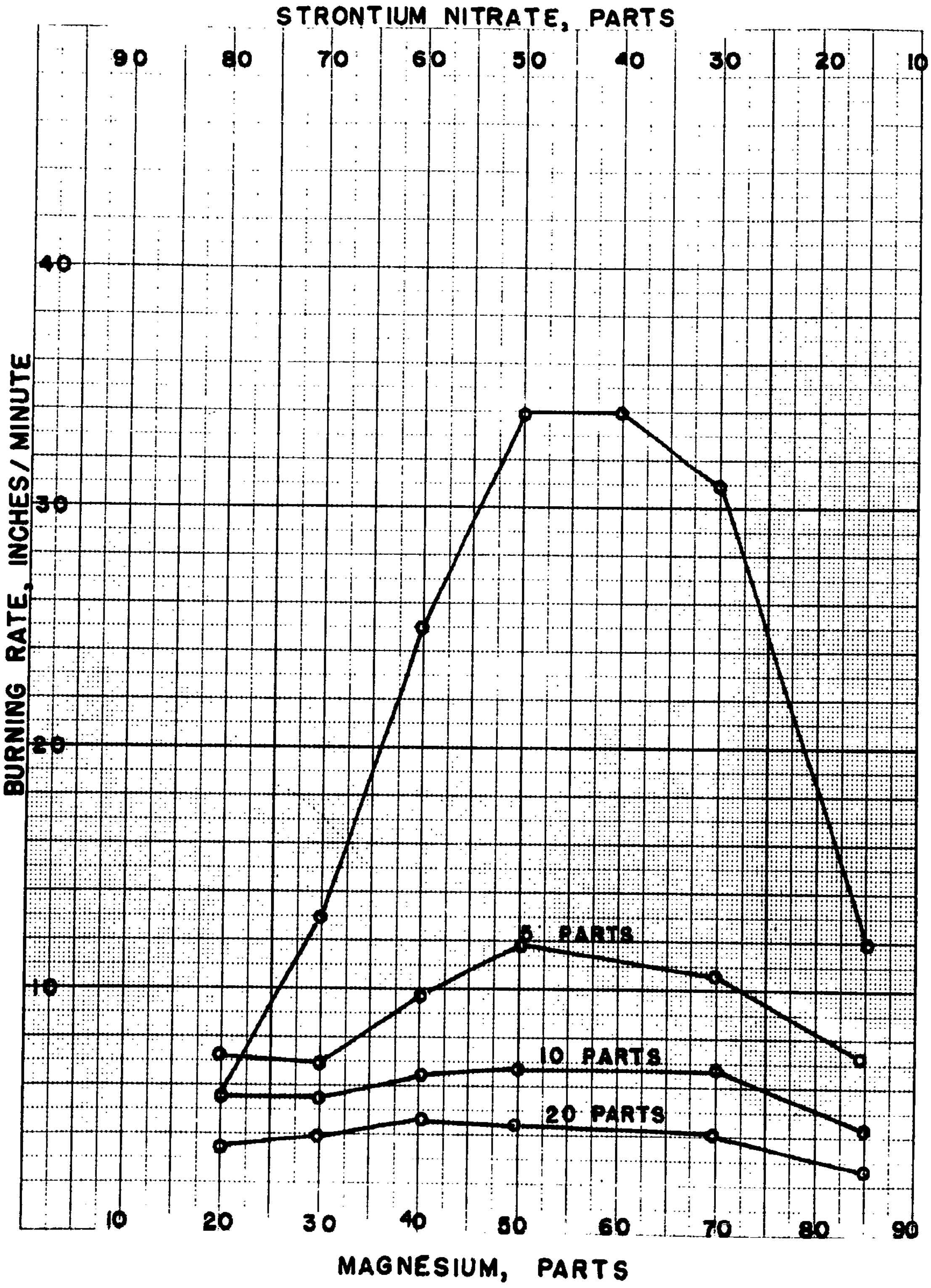


M-28053

PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 9
Effect of Phenolformaldehyde Resin Upon the Candlepower of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

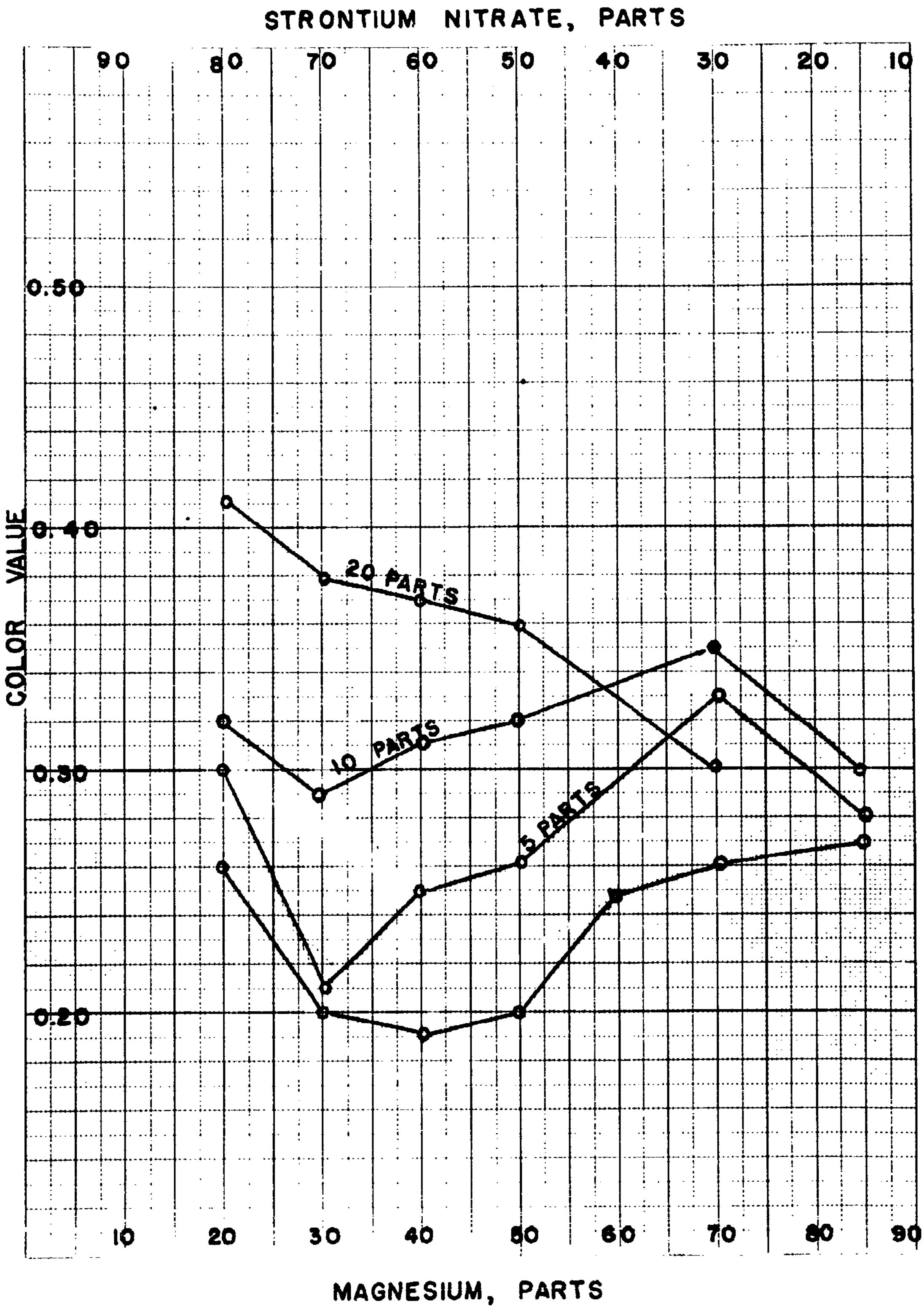
(T)



M-28054 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 10
Effect of Phenolformaldehyde Resin Upon the Burning Rate of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

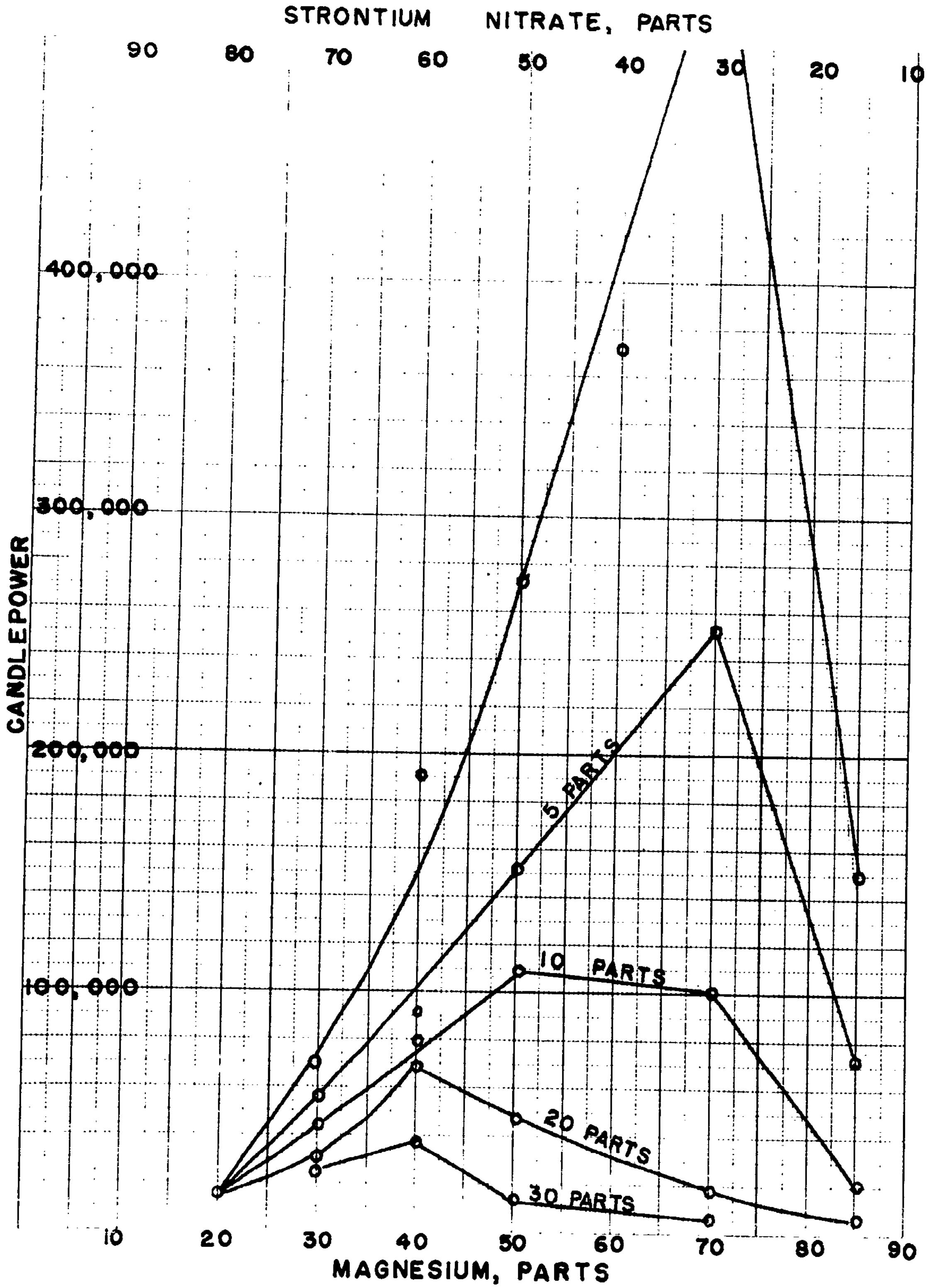
(T)



M-28055 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 11
Effect of Phenolformaldehyde Resin Upon the Color Value of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

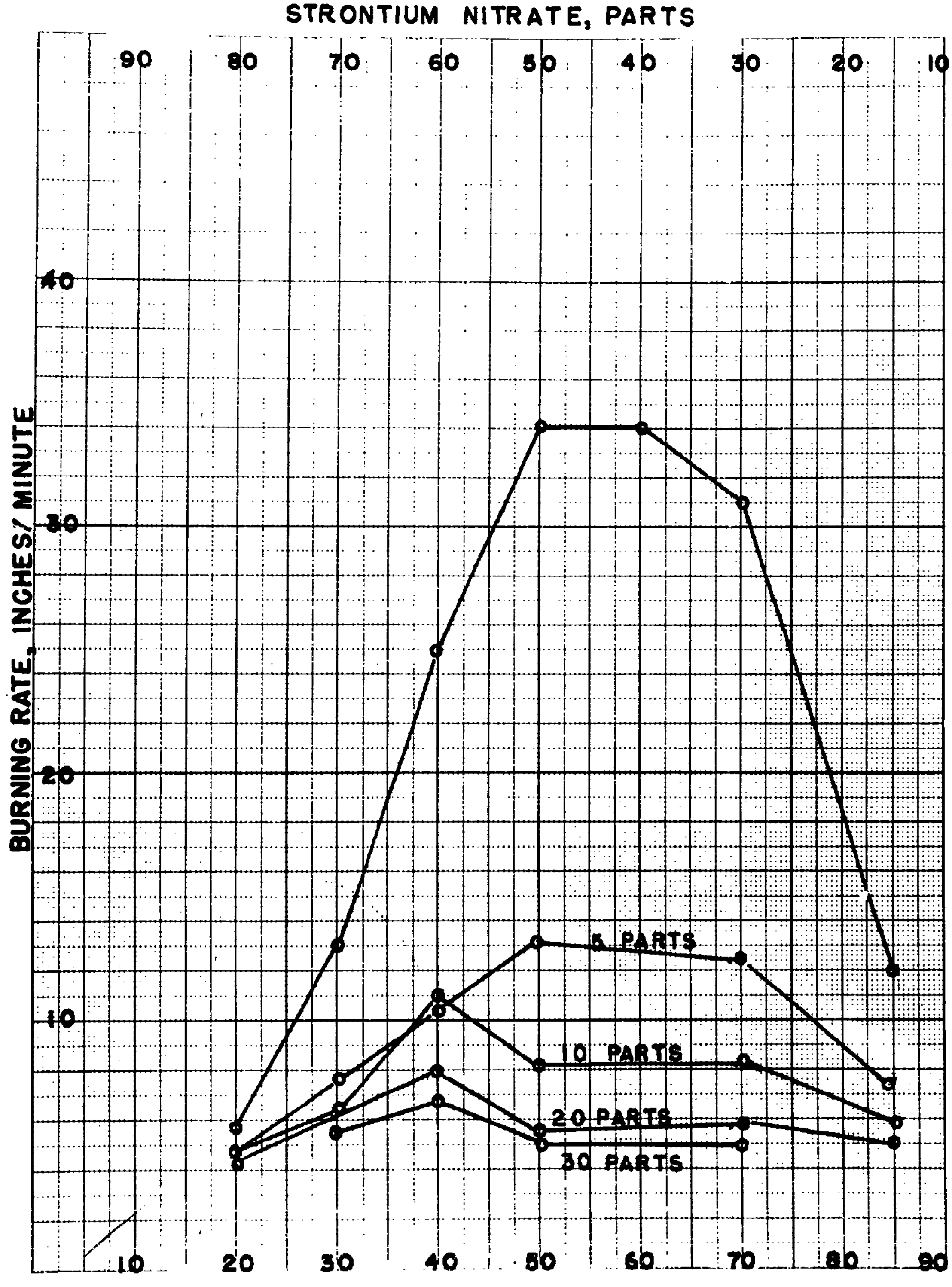
(T)



M-28056 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 12
Effect of Polyvinyl Chloride Upon the Candlepower of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

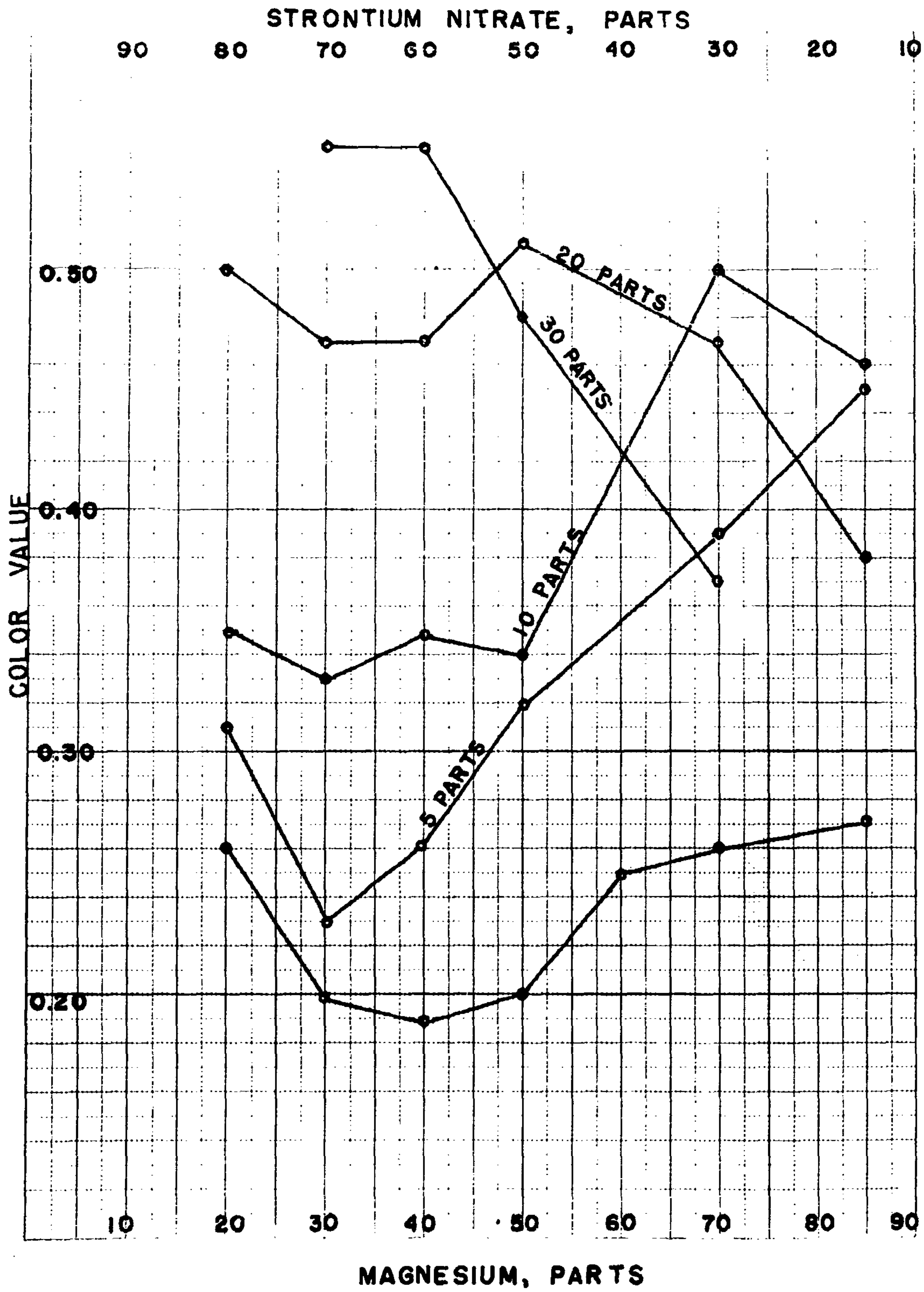
(T)



M-28057 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 13
Effect of Polyvinyl Chloride Upon the Burning Rate of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

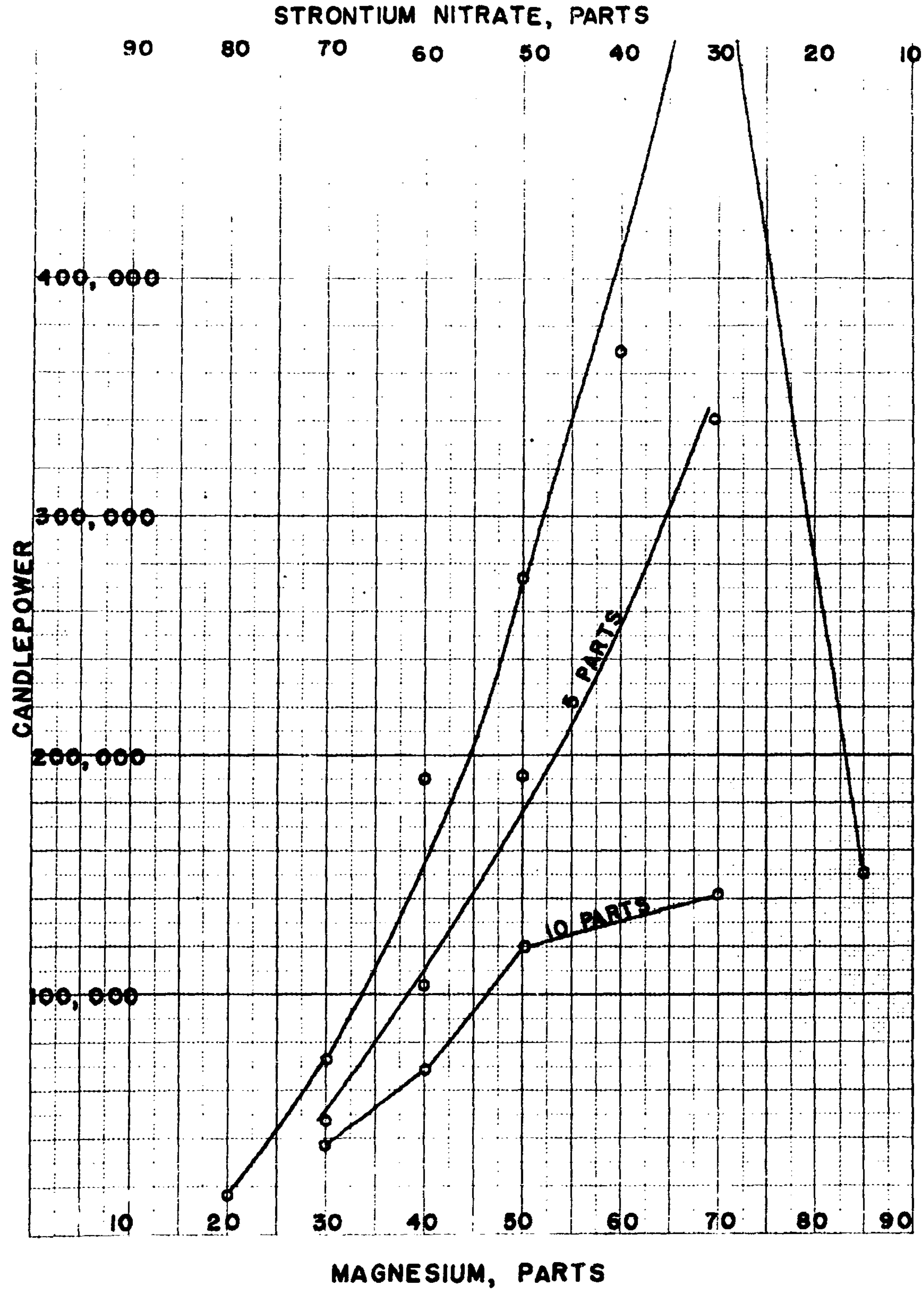
(T)



M-28058 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 14
Effect of Polyvinyl Chloride Upon the Color Value of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

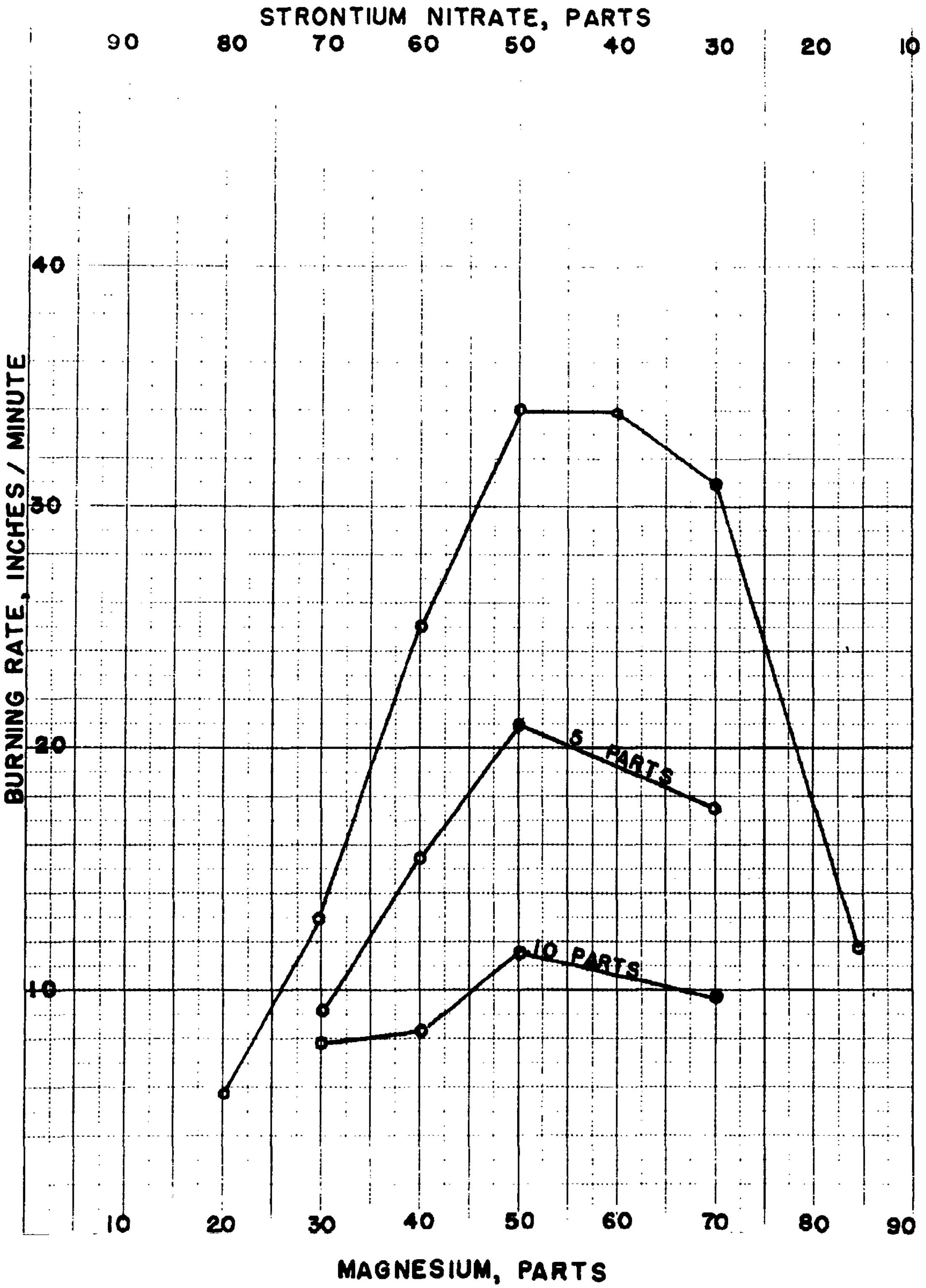
(T)



M-28059 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 15
Effect of Ethyl Cellulose Upon the Candlepower of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

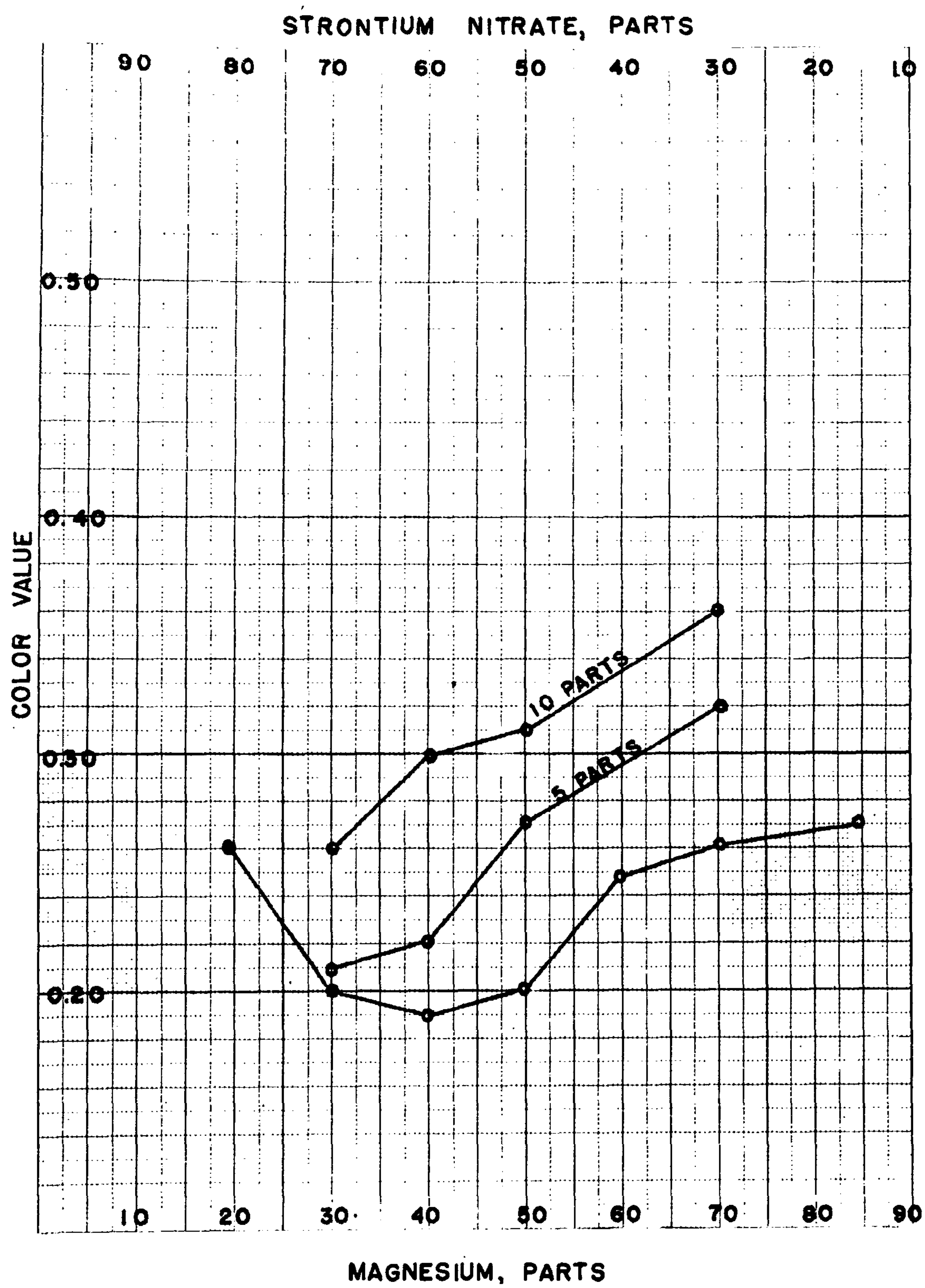
(T)



M-28060 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 16
Effect of Ethyl Cellulose Upon the Burning Rate of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

(T)

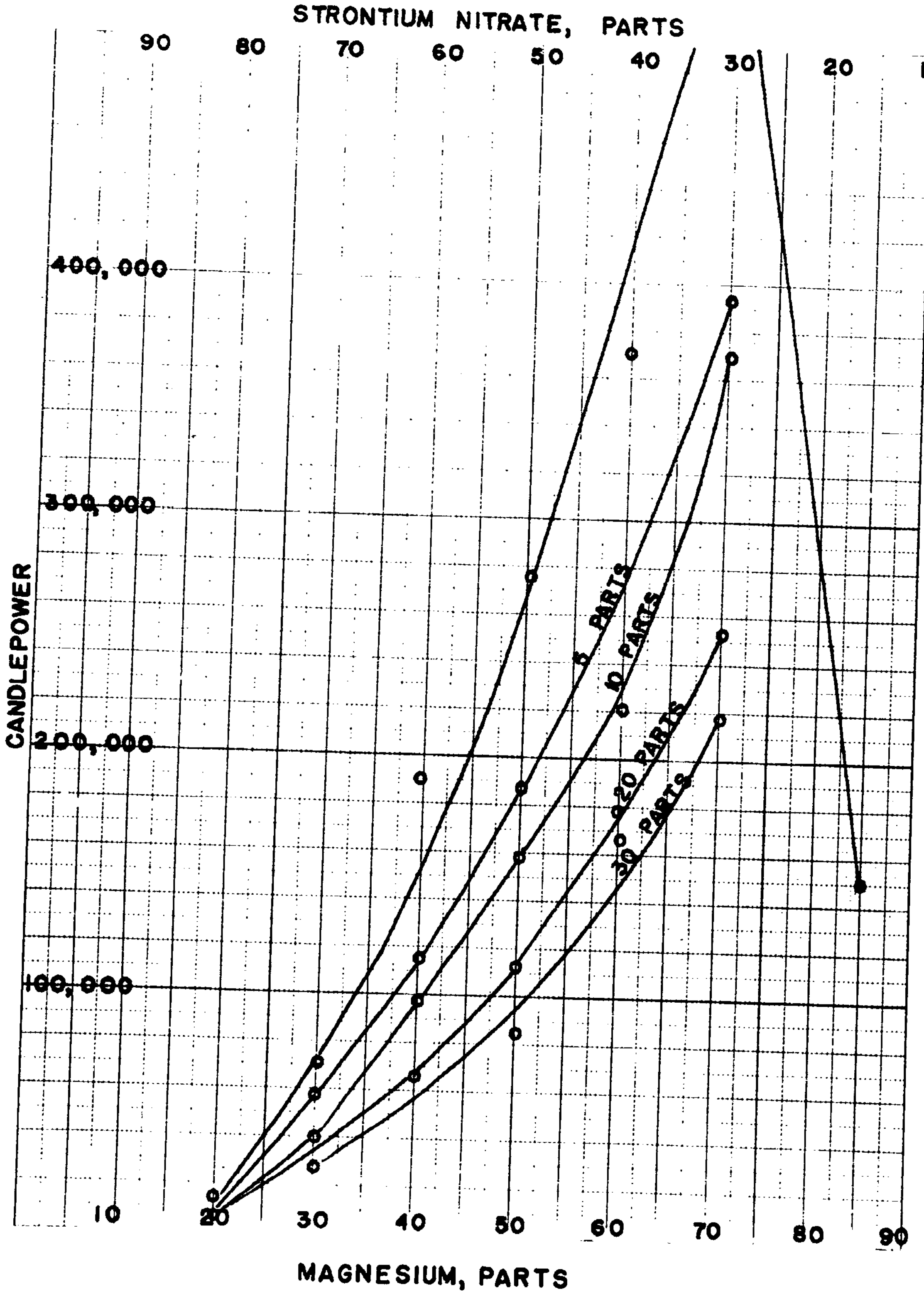


M-28061 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 17

Effect of Ethyl Cellulose Upon the Color Value of Mixtures Containing Stontium Nitrate and Ground Magnesium, Grade A

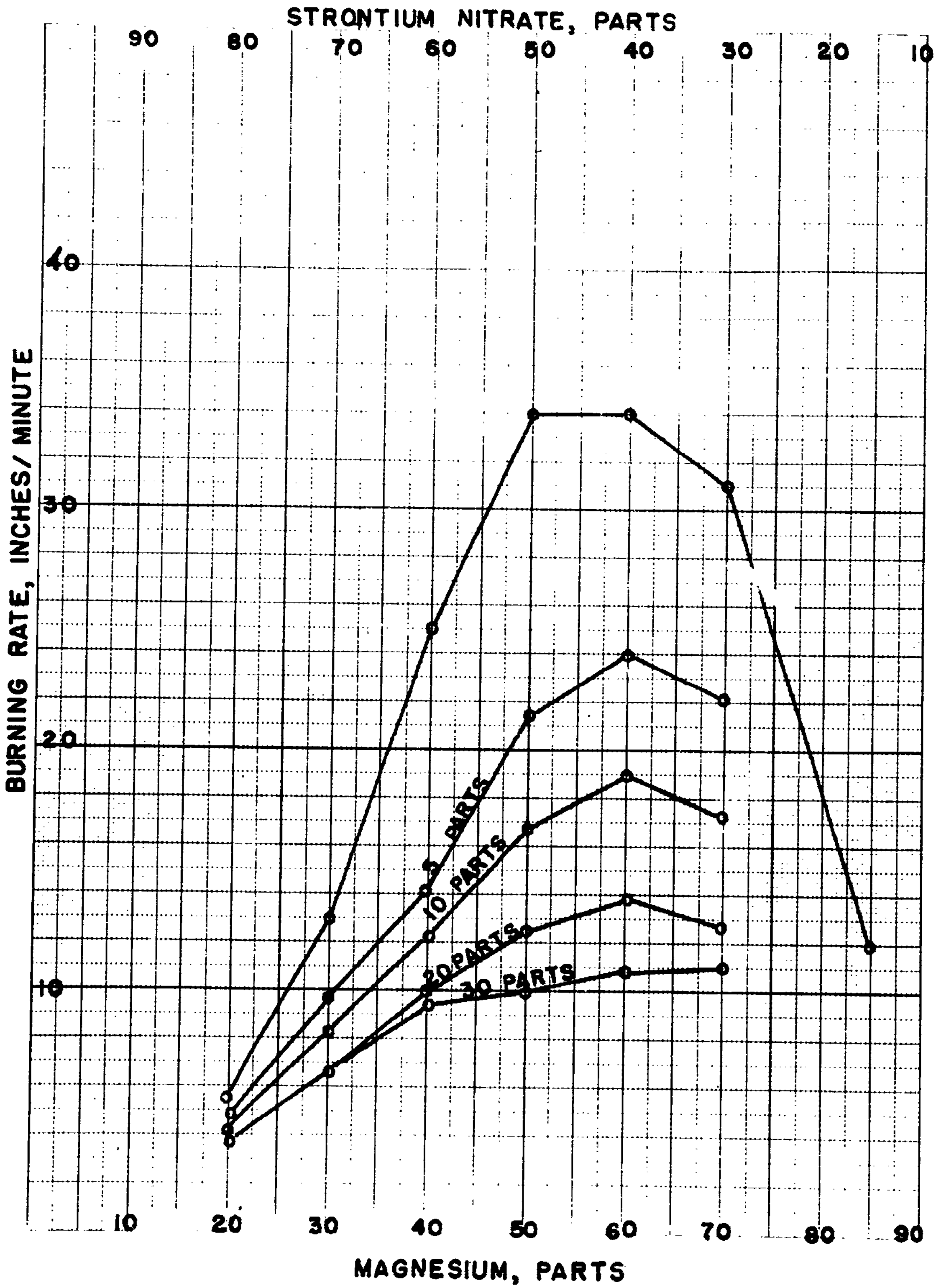
(T)



M-28062 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 18
Effect of Calomel Upon the Candlepower of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

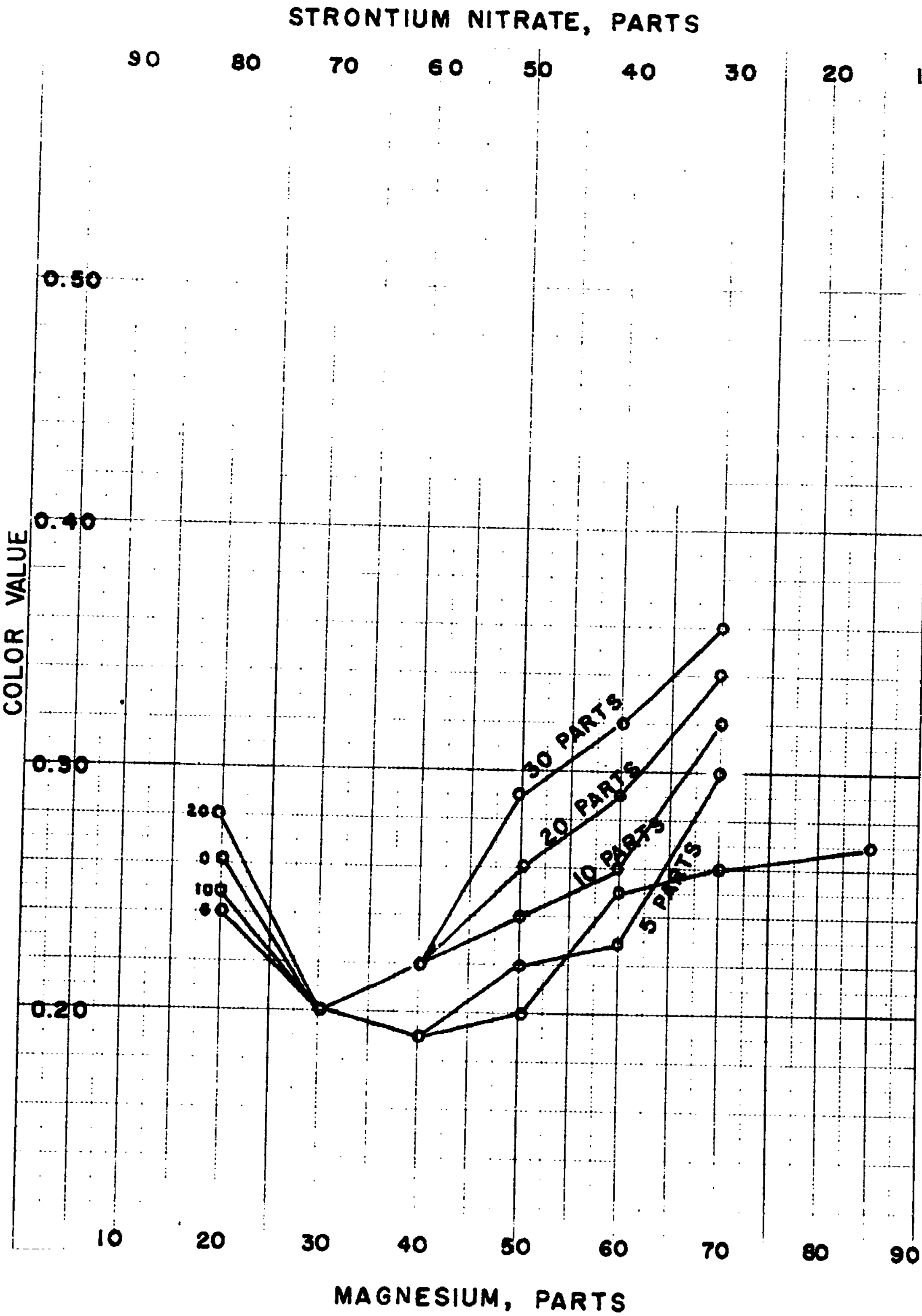
(T)



M-28063 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 19
Effect of Calomel Upon the Burning Rate of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

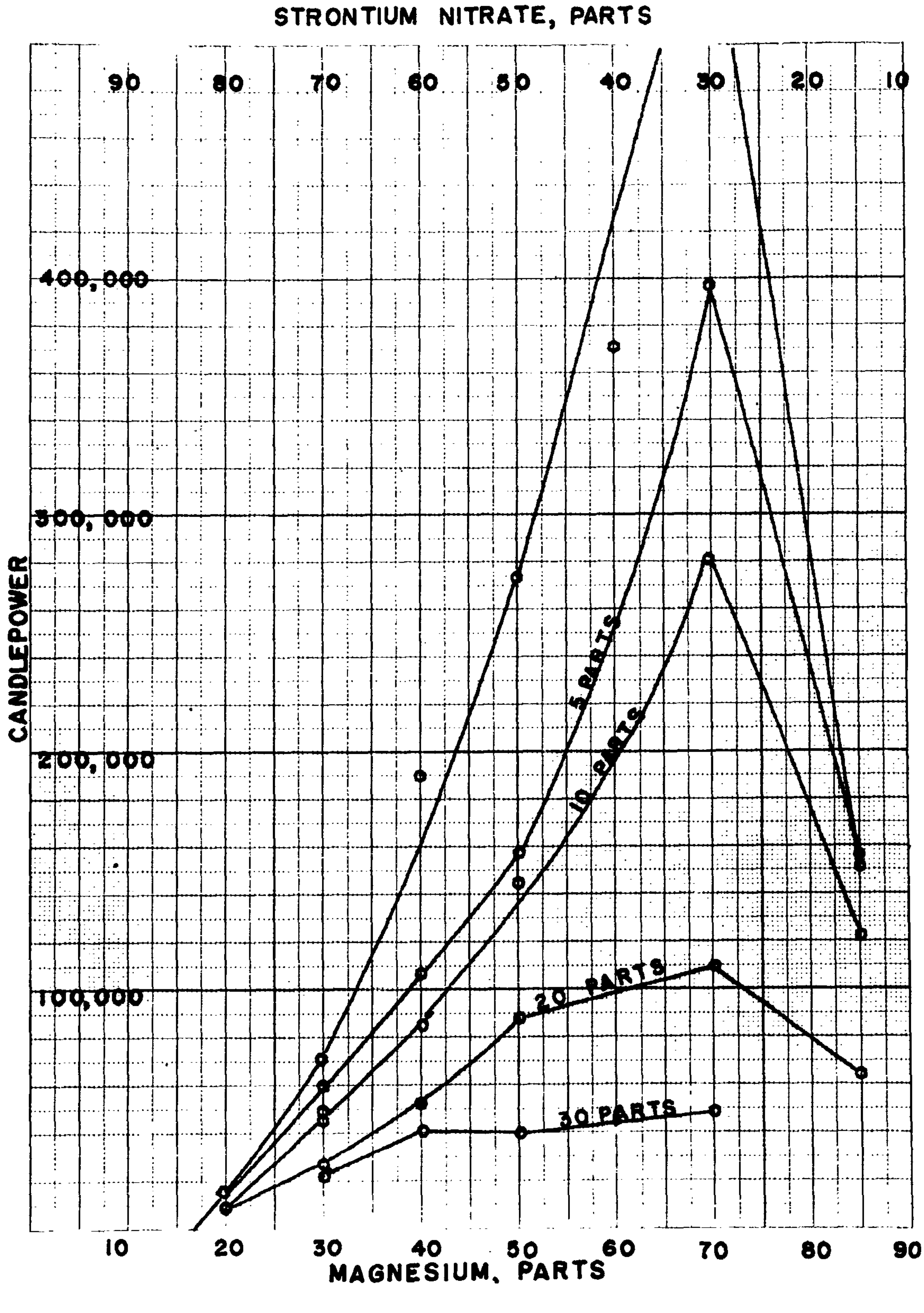
(T)



M-28064 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 20
Effect of Calomel Upon the Color Value of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

(T)

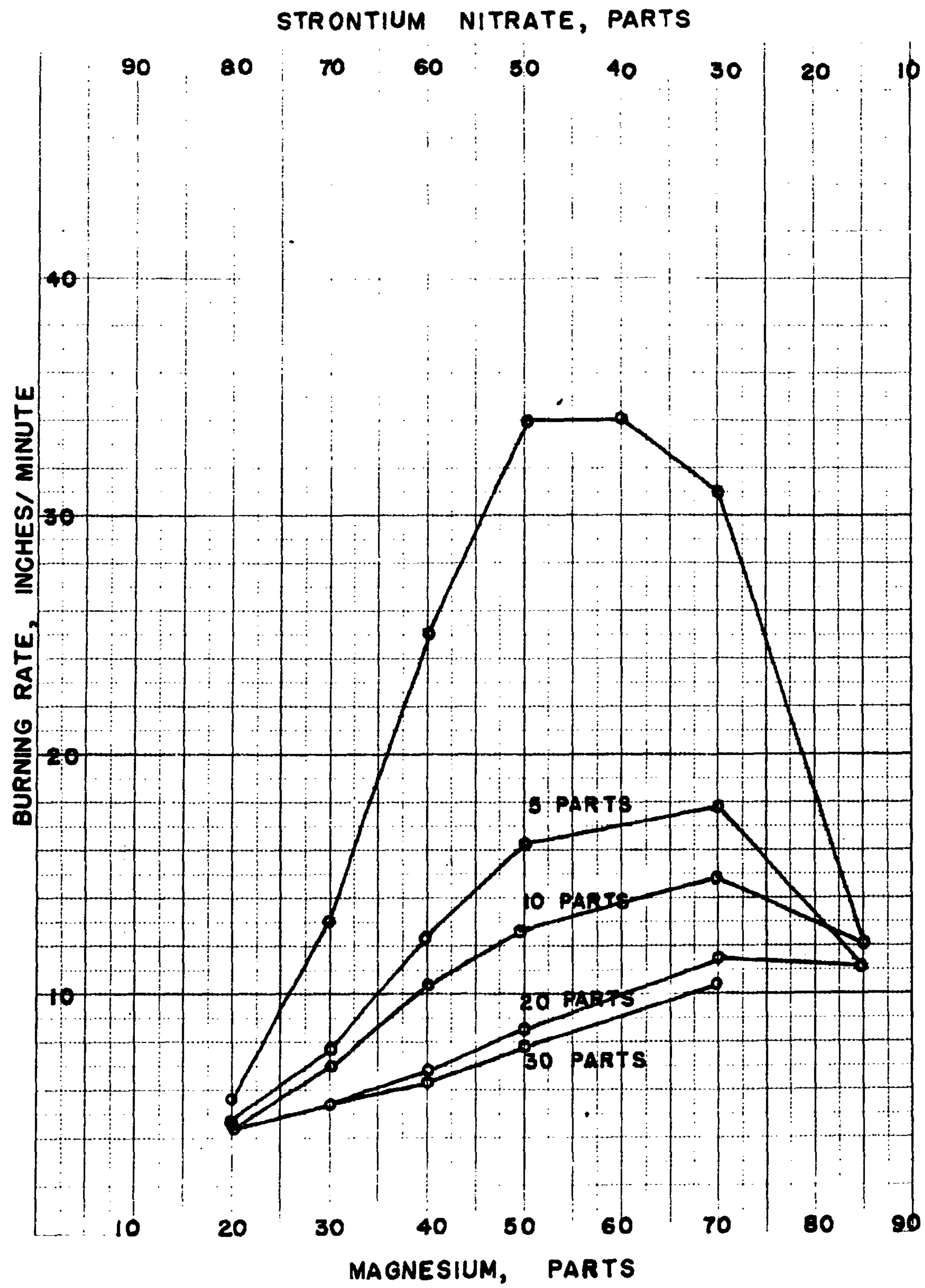


M-28065 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 21

Effect of Hexachlorbenzene Upon the Candlepower of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

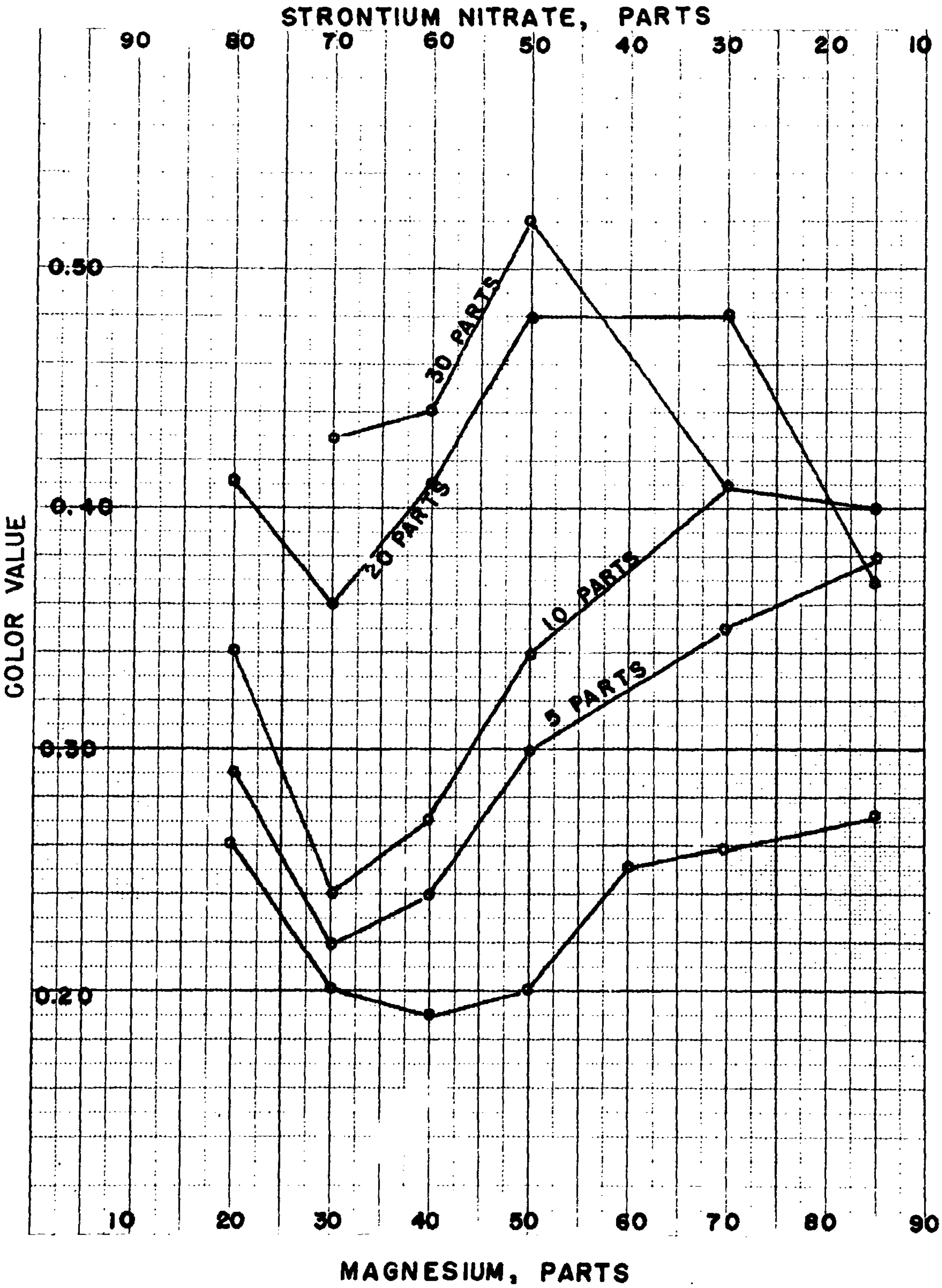
(T)



M-28066 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 22
Effect of Hexachlorbenzene Upon the Burning Rate of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

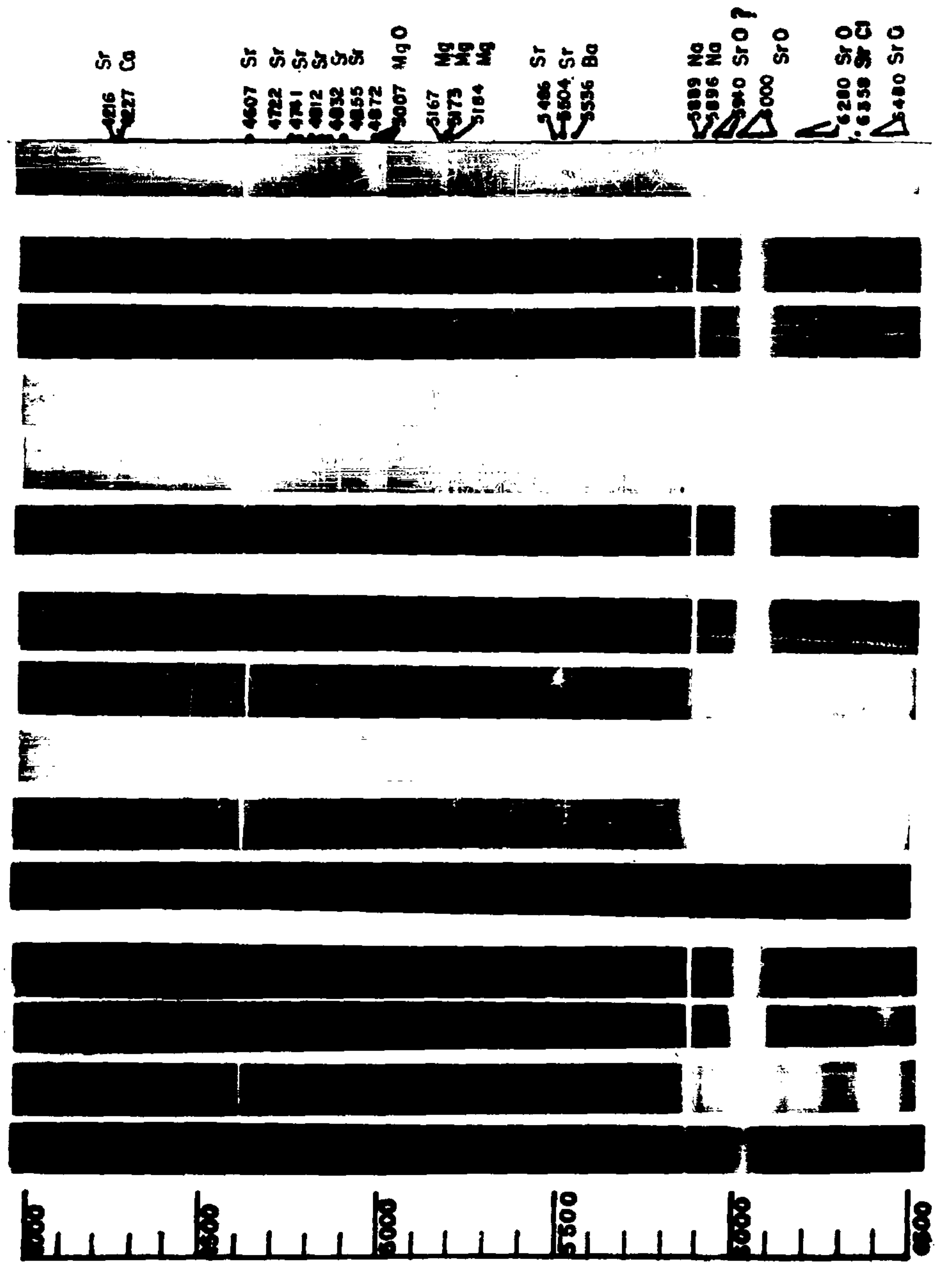
(T)



M-28067 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 23
Effect of Hexachlorbenzene Upon the Color Value of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

(m)

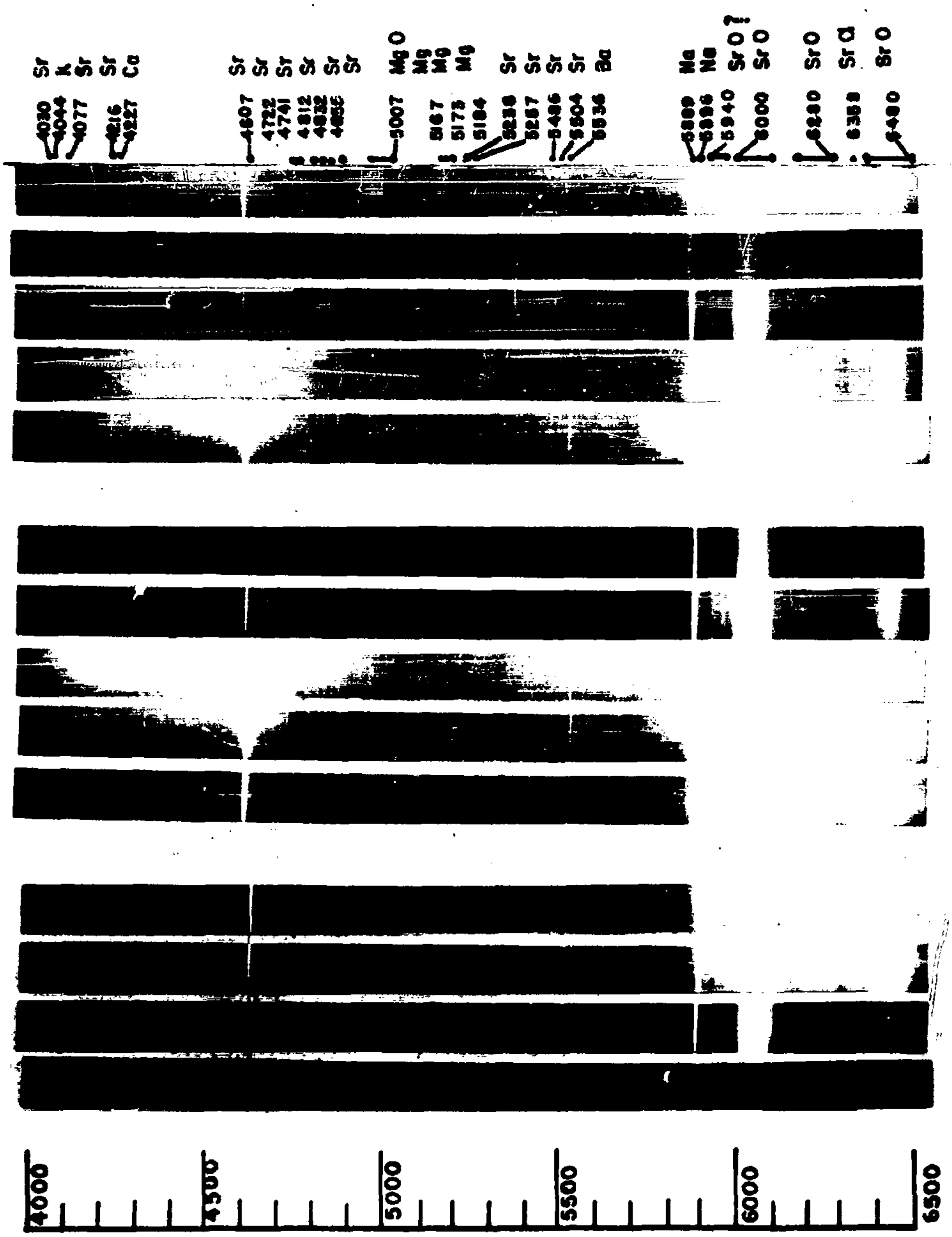


$Sr(NO_3)_2$	Mg	ASPHALTUM
15	85	0
80	20	5
70	30	5
50	50	5
30	70	5
15	85	5
80	20	10
70	30	10
50	50	10
30	70	10
15	85	10
80	20	20
70	30	20
50	50	20
30	70	20

M-28070 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 24
Spectrograms of Strontium Nitrate / Magnesium / Asphaltum Mixtures

(T)

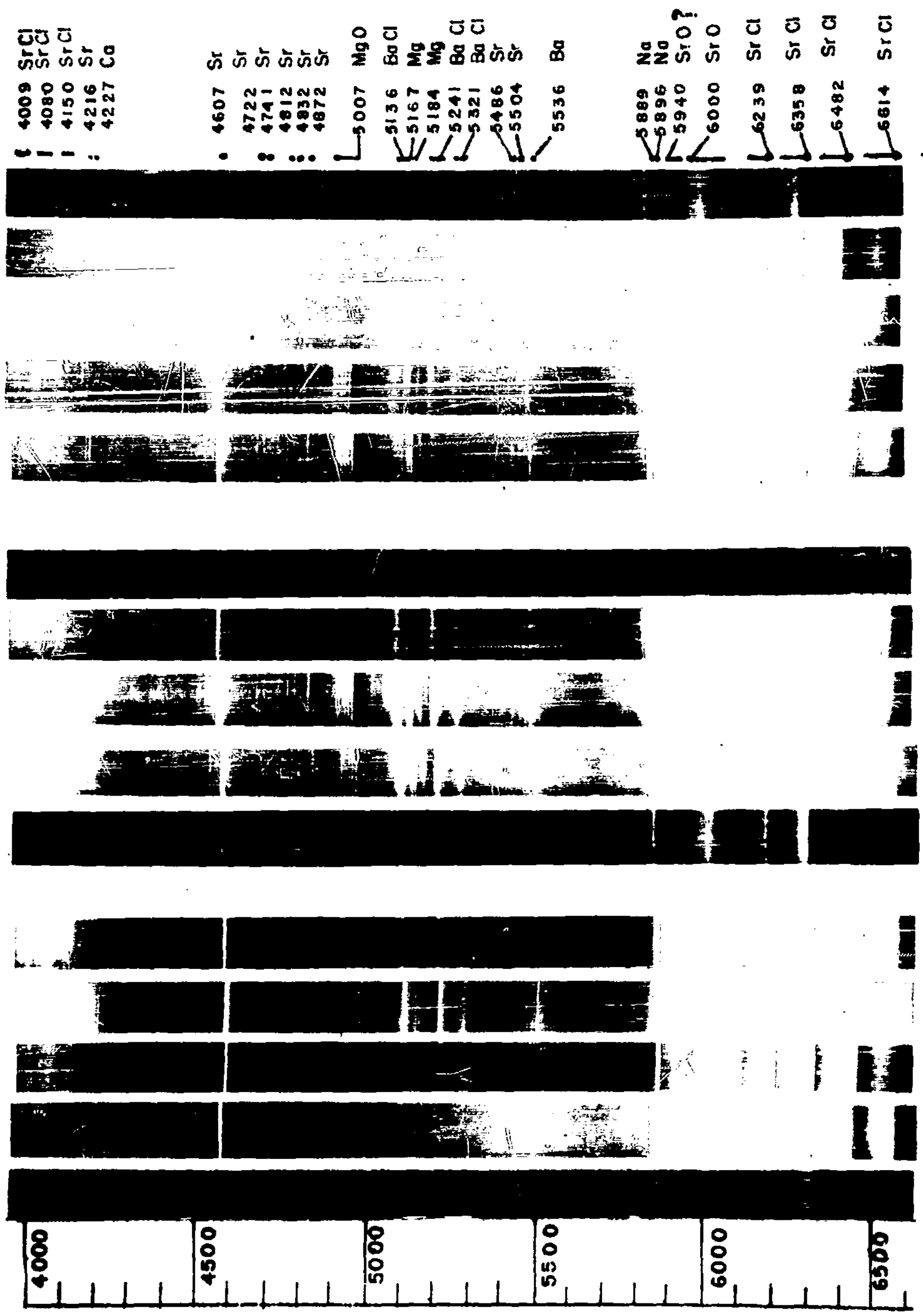


$Sr(NO_3)_2$	Mg	Phenol Formaldehyde Resin
15	85	0
80	20	5
70	30	5
60	40	5
30	70	5
80	20	10
70	30	10
60	40	10
50	50	10
30	70	10
80	20	20
50	50	20
30	70	20
15	85	20

M-28071 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 25
Spectrograms of Strontium Nitrate / Magnesium / Asphaltum Mixtures

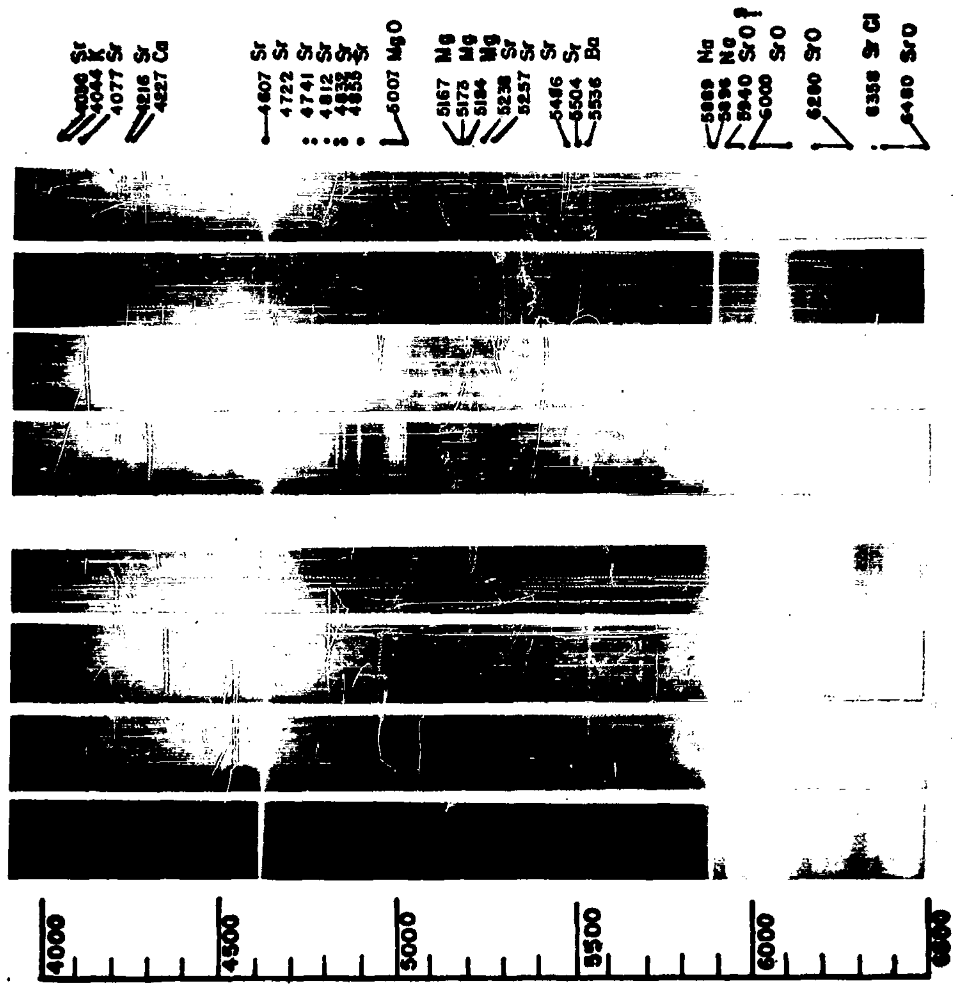
$Sr(NO_3)_2$	Mg	Polyvinyl Chloride
80	20	5
70	30	5
50	50	5
30	70	5
85	15	5
80	20	20
70	30	20
60	40	20
50	50	20
30	70	20
70	30	30
60	40	30
50	50	30
40	60	30
30	70	30



M-28072 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 26
Spectrograms of Strontium Nitrate / Magnesium / Polyvinyl Chloride Mixtures

(T)

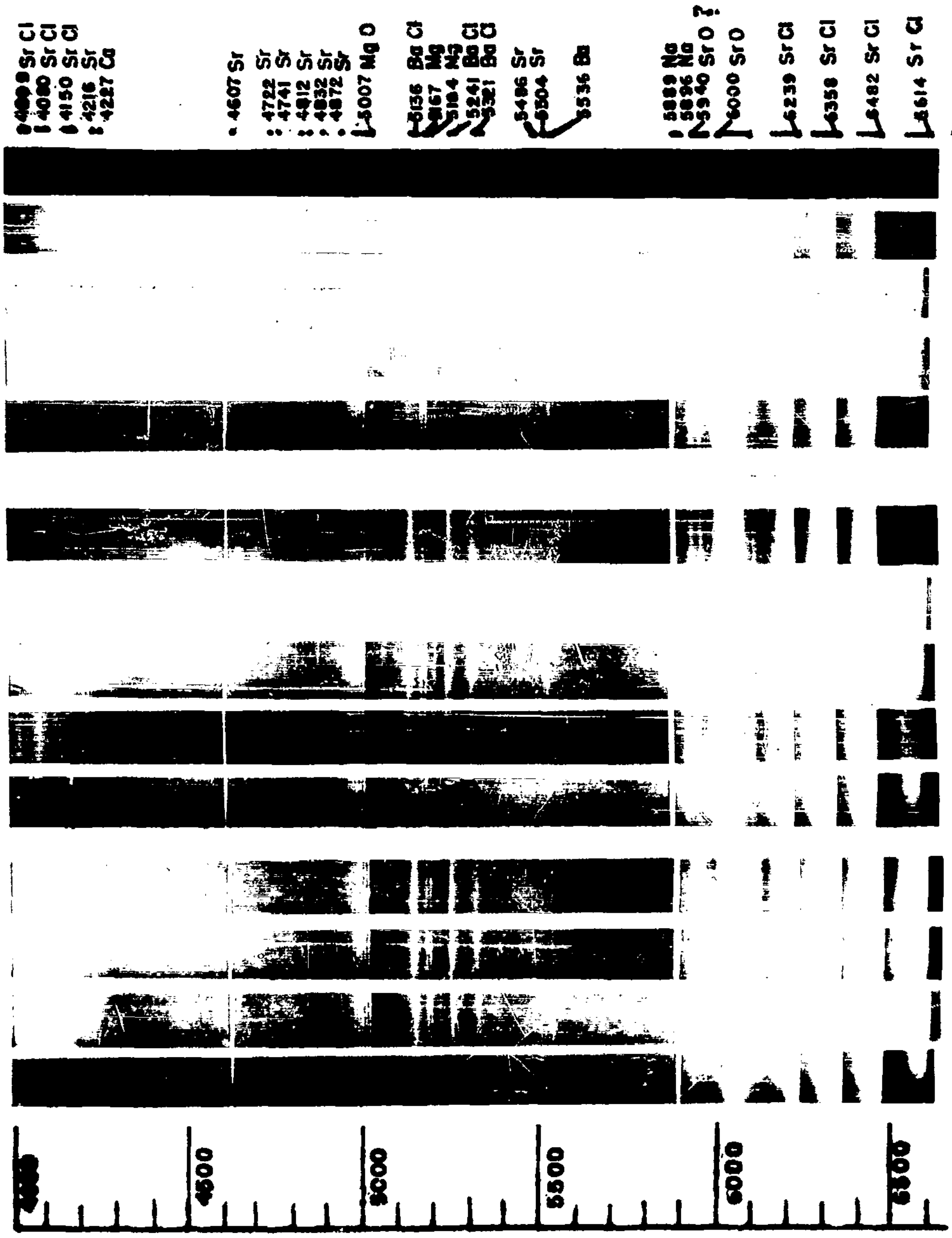


Sr(NO3)2	Mg	Ethyl Cellulose
15	85	0
70	30	5
60	40	5
30	70	5
70	30	10
60	40	10
50	50	10
30	70	10

M-28073 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 27
Spectrograms of Strontium Nitrate / Magnesium / Ethyl Cellulose Mixtures

(T)



$Sr(NO_3)_2$	Mg	C_6Cl_6
80	20	5
70	30	5
60	40	5
30	70	5
15	85	5
80	20	20
60	40	20
50	50	20
30	70	20
15	85	20
70	30	30
60	40	30
50	50	30
30	70	30

M-28074 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 28
Spectrograms of Strontium Nitrate / Magnesium / Hexachlorbenzene Mixtures

(T)

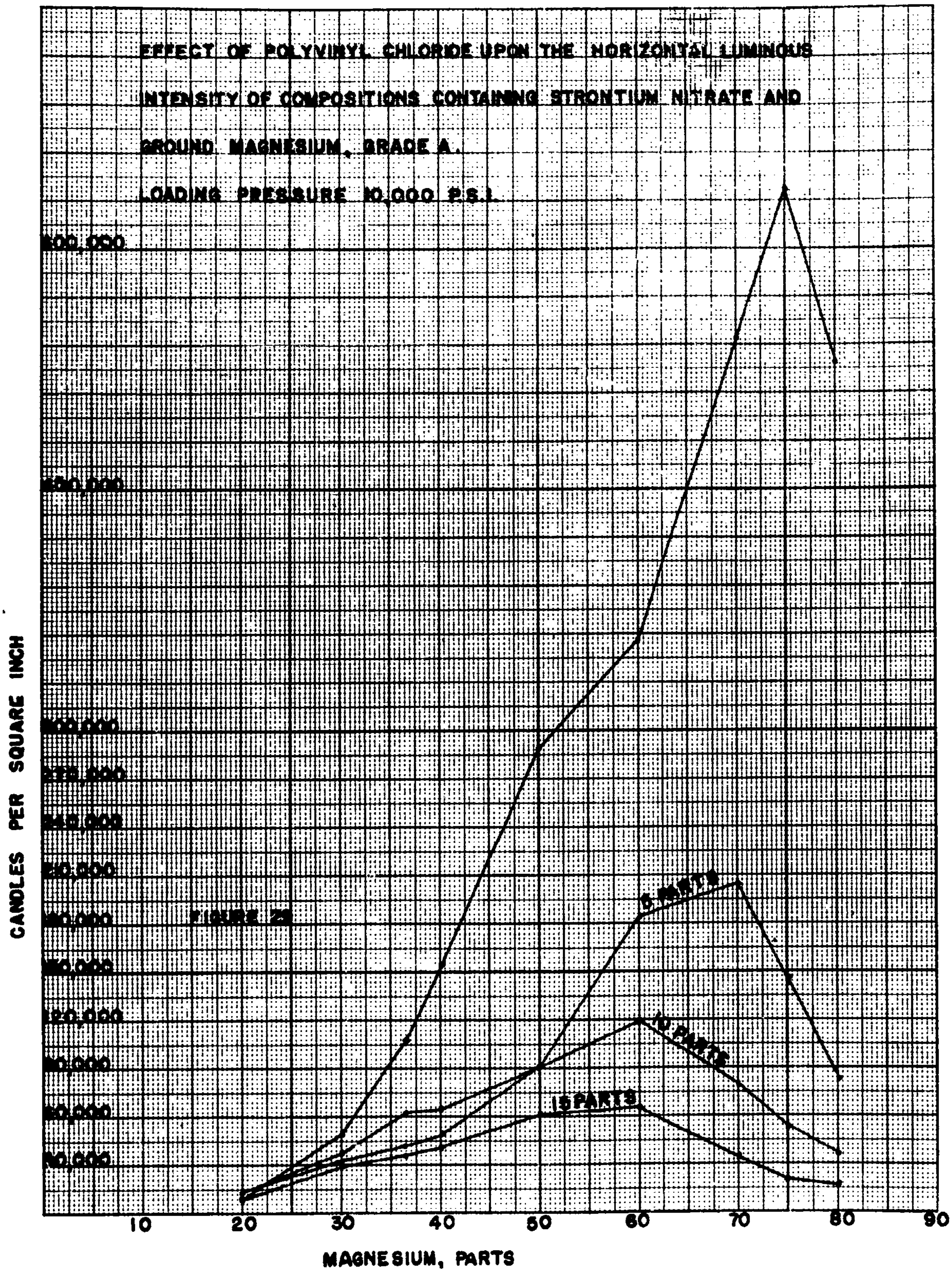

EFFECT OF POLYVINYL CHLORIDE UPON THE HORIZONTAL LUMINOUS
INTENSITY OF COMPOSITIONS CONTAINING STRONTIUM NITRATE AND
GROUND MAGNESIUM, GRADE A.
LOADING PRESSURE 10,000 P.S.I.
CANDLES PER SQUARE INCH
120,000
5 PARTS
10 PARTS
15 PARTS
10
20
30
40
50
60
70
80
90
MAGNESIUM, PARTS

Figure 29

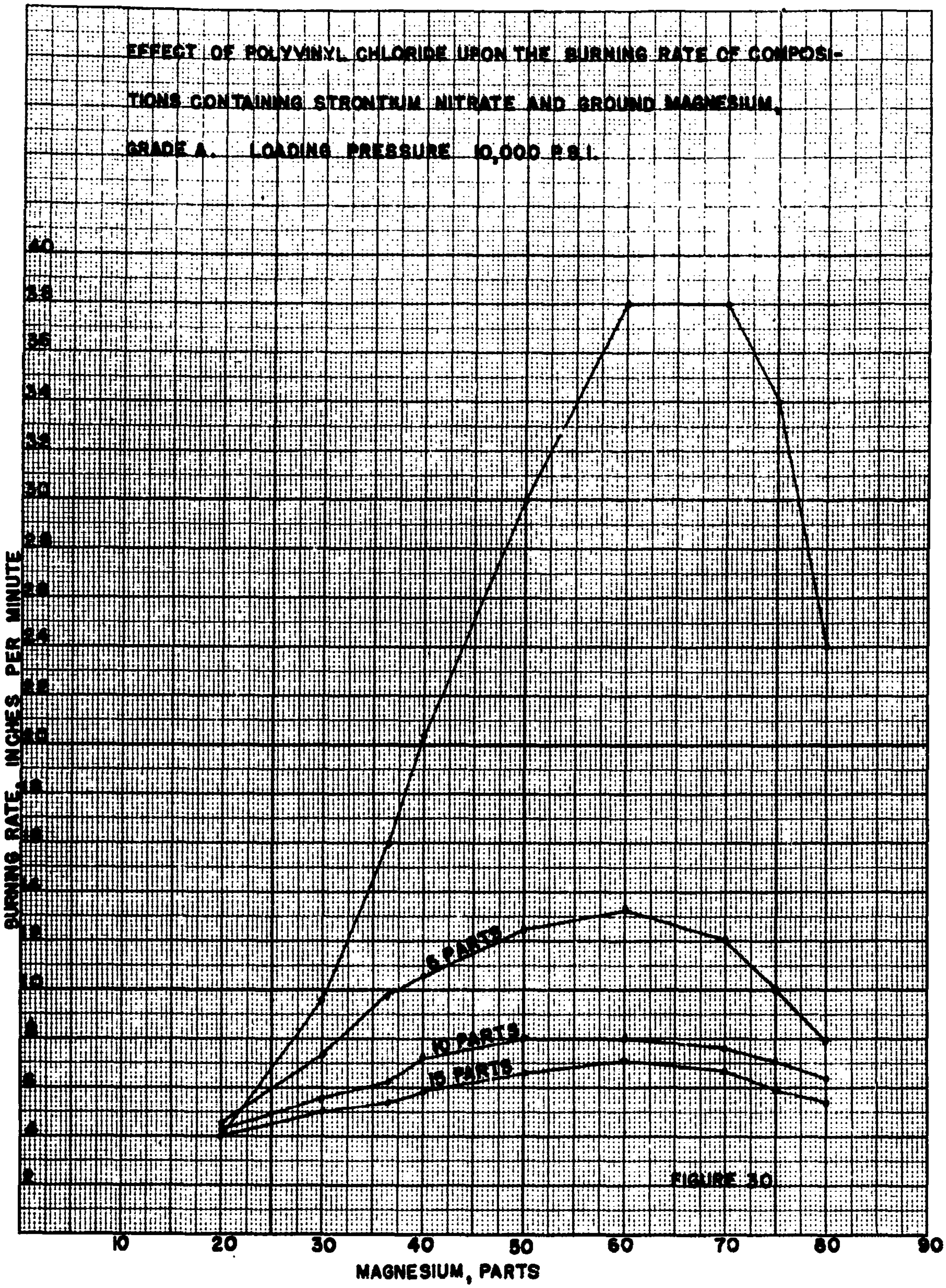
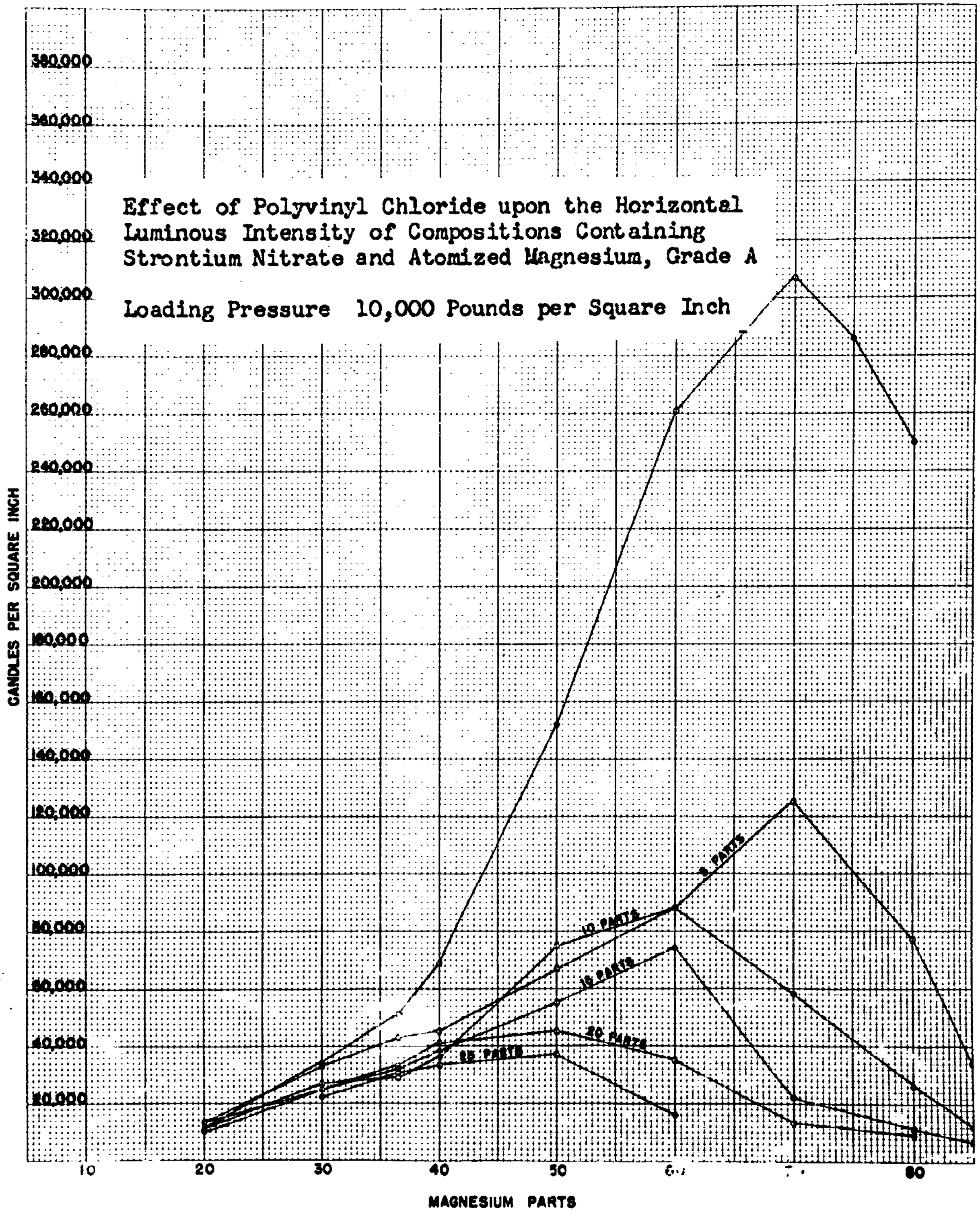
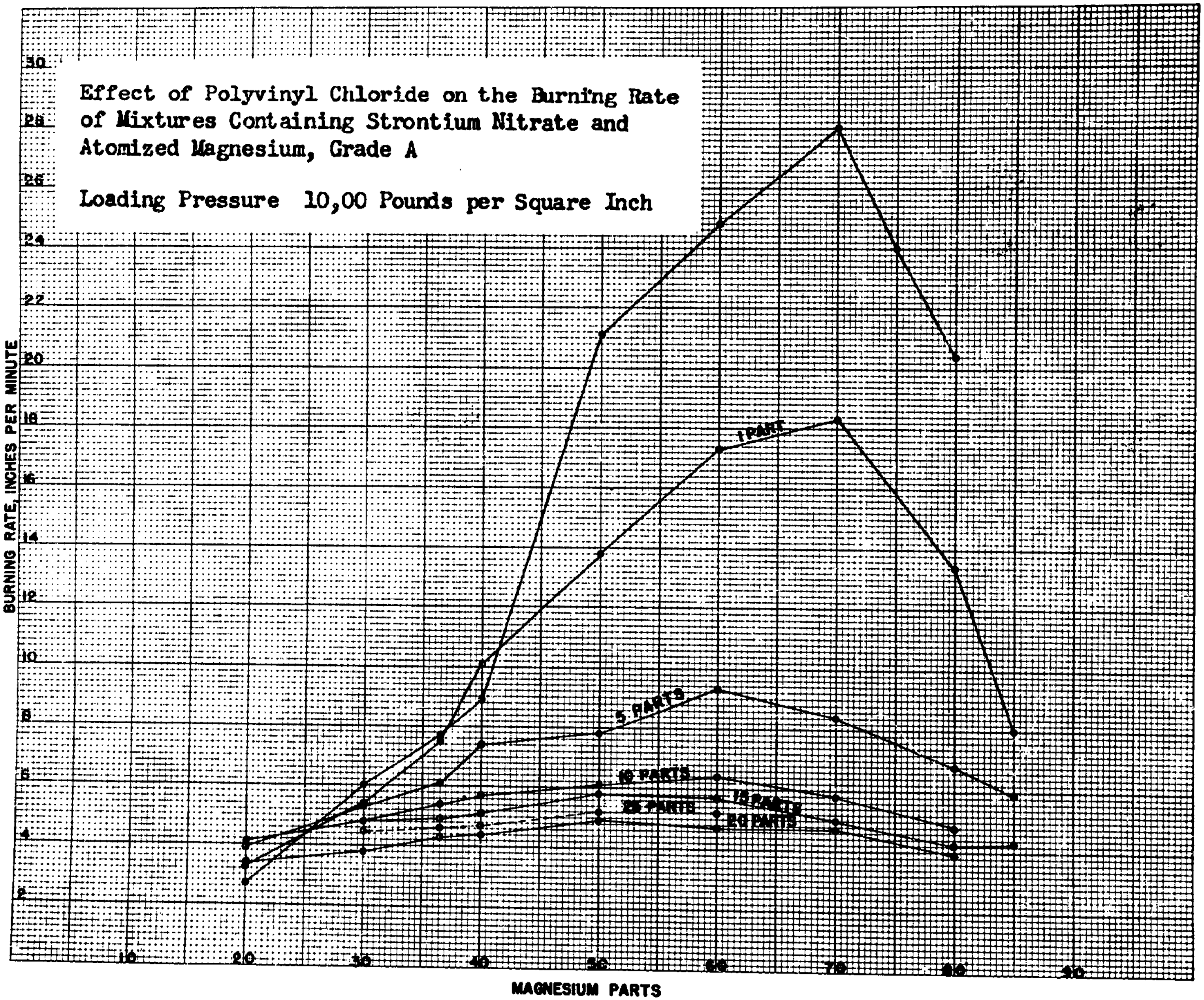

EFFECT OF POLYVINYL CHLORIDE UPON THE BURNING RATE OF COMPOSITIONS CONTAINING STRONTIUM NITRATE AND GROUND MAGNESIUM, GRADE A. LOADING PRESSURE 10,000 P.S.I.
BURNING RATE, INCHES PER MINUTE
5 PARTS
10 PARTS
15 PARTS
FIGURE 30
10
20
30
40
50
60
70
80
90
MAGNESIUM, PARTS

Figure 30



M-33359 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Figure 31



M-33360

PICATINNY ARSENAL

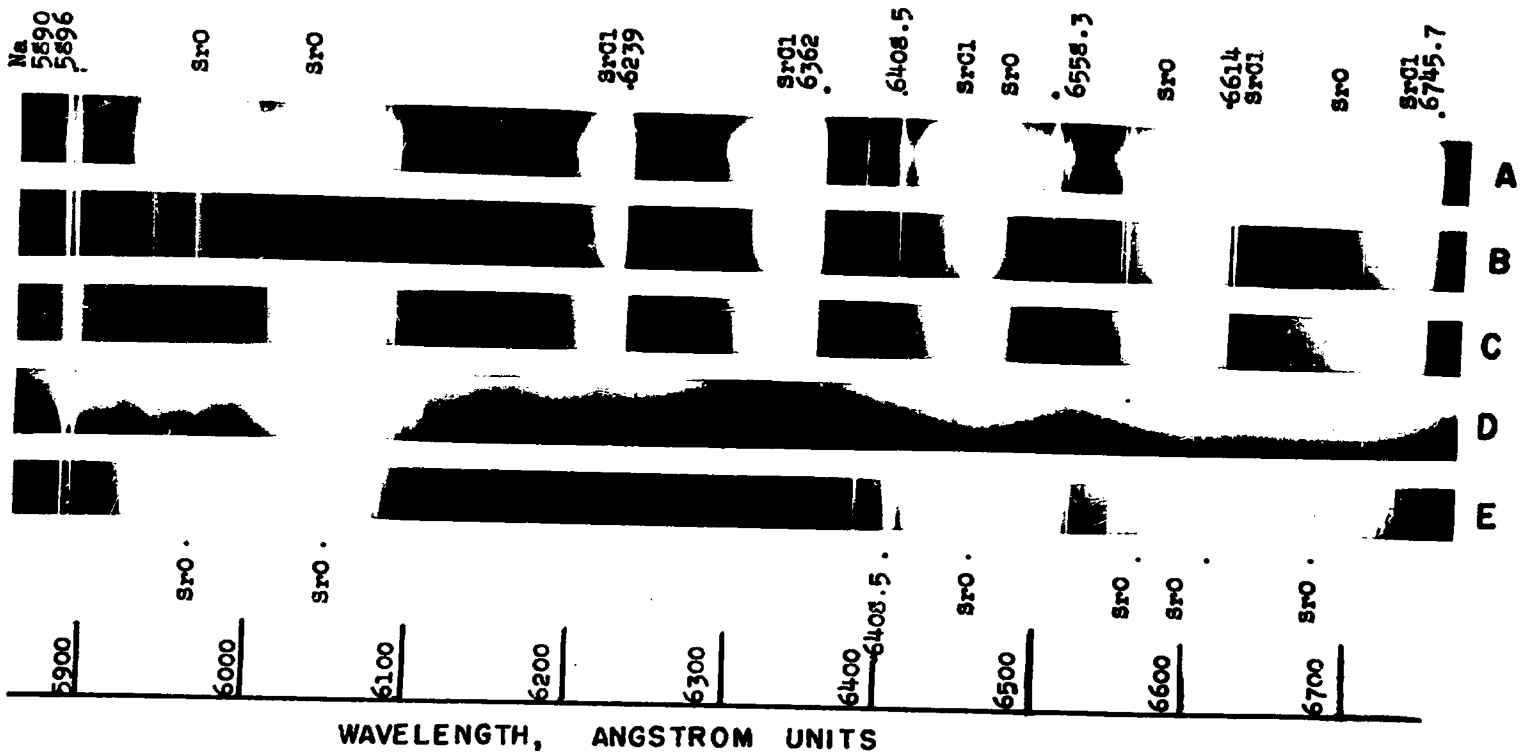
ORDNANCE DEPARTMENT

Figure 32

HIGH RESOLUTION SPECTROGRAMS

SHOWING ORANGE AND RED PORTIONS OF SPECTRUM

OF STRONTIUM SALTS AND PYROTECHNIC RED FLAMES



A. $SrCl_2$ arc in air
B. Anhydrous $SrCl_2$ arc in dry nitrogen
C. Pyrotechnic flame: $Sr(NO_3)_2$ /Mg/Polyvinyl chloride, 80/20/20
D. Pyrotechnic flame: $Sr(NO_3)_2$/ Mg/Phenol-formaldehyde 60/40/10
E. $Sr(NO_3)_2$ arc in air.

FIG 33

M-33360/1

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REVISION

1

TITLE: Long Range Research on Pyrotechnics Burning Characteristics of Binary Mixtures

AD-B803 228

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c Binary Propellants 22 11

c Pyrotechnics (NOT ABSTRACTED) Prop 11

22 3
2 5

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SUBJECT HEADINGS:
Pyrotechnics

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