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EXPERIMENTAL STUDY OF THE BURNING RATES OF SOME SOLID PROPELLANTS BY USING A CLOSED BOMB

Thesis by

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SUMMARY

This report represents an attempt to correlate experimental data obtained with a burning rate bomb with the data obtained from the firing of rocket charges, and to obtain burning rate curves for new propellants where insufficient data exists.

It was found that very good agreement could be obtained between experimental data obtained in a burning rate bomb and data derived from test firing of rocket charges.

A comparison was made among three different propellants which utilized Thiokol LP-3 for the fuel, and potassium perchlorate and ammonium perchlorate, separately or in combination, for the oxidizer. It was found that potassium perchlorate only gave the fastest burning rate and the ammonium perchlorate only gave the slowest burning rate, while a mixture of the two gave an intermediate value.

An investigation was made on the coning of solid propellant charges. Coning is the term applied when the burning of a solid propellant charge forms a conical burning surface. Normally a flat burning surface is expected and desired. It was found that a wide deviation in the burning rates existed between the center of the propellant and the edge in the case of the mixture of the ammonium and potassium perchlorate and the pure ammonium perchlorate oxidizers. The results also showed that the difference in burning rates between the center and edge of the charge increased as the amount of ammonium perchlorate in the oxidizer was increased. The limited investigation seemed to indicate that the fundamental variation in burning rate was the only cause of coning.

Best results were obtained from the use of a restricting material similar in nature to the propellant being investigated. In this case, a Thiokol restricting material gave the best results on the Thiokol propellants.

INTRODUCTION

The burning rate of a solid propellant may be defined as the velocity with which the burning surface recedes in a direction perpendicular to the original surface; the rate is usually measured in inches per second. Thus if a pencil-like strand of propellant, restricted from burning on the sides and one end so that the burning proceeded uniformly from one end to the other, were seven inches in length and required five seconds to burn from one end to the other, the burning rate would be 1.4 inches per second.

As a result of the delicate balance between rate of burning of a propellant and rate of discharge of the gas through the nozzle of a rocket, the burning rate and its variation with pressure is generally recognized as one of the most important characteristics of a solid propellant. Experimental determination of the burning rates of propellants by other than actual firing of rocket charges is being done by use of a burning rate bomb. The burning rate bomb owes its popularity to the use of a small sample of the propellant and the rapidity of obtaining accurate data from the results. This report represents an attempt to correlate experimental data obtained with a burning rate bomb with actual firing data, and to obtain burning rate data for new propellants for which insufficient firing data exists.

The correlation between experimental data and actual firing data is done by using a Thiokol fuel propellant with an oxidizer of ammonium and potassium perchlorate for which a tentative burning rate curve has been obtained by the firing of rocket charges. Propellants used for which no burning rate curve previously existed were also of the Thiokol type. The first of these propellants contained potassium perchlorate only as an oxidizer while the second had ammonium perchlorate only as an oxidizer. In addition to obtaining burning rate data for these specific propellants, this also provides a means of comparing the effect of the oxidizer on the burning rate.

In the process of checking experimental data with actual field burning rates, a study of restricting materials for the bomb samples has been included. The restricting of rocket propellants has been one of the many problems of rocket design and some correlation between experimental burning and actual firing may be accomplished in this field. Certainly, it is important to use a restricting material for the samples used in the burning rate bomb that will give results comparable to the actual burning rate of the propellant in field tests.

A limited investigation of the coning problem in solid rockets is also included. The investigation is limited in that it included only burning rate data for the center and edge of the rocket charge. Many other variables should be included for a complete investigation.

Previous work done by Crawford and Huggett (references "a" and "c") proved valuable as a background for this report.

EQUIPMENT AND PROCEDURE

The equipment for the work consisted of a modified version of the Crawford burning rate bomb (reference "c"). Full blueprints and pictures of the bomb are included at the end of the report. This bomb, having a volume of 238 cubic inches, has more than twice the volume of the original Crawford burning rate bomb. This larger volume was found necessary to burn larger samples with a smaller increase in pressure during burning. The bomb is constructed of a heat treated stainless steel and has been hydrostatically tested at five thousand pounds per square inch pressure. It is also equipped with a safety head containing a diaphragm which fails at 3750 pounds per square inch pressure. As may be noted from the figures, cleaning of the bomb has been facilitated by a large screw cap at the bottom. The bomb sits in a tripod equipped with casters which facilitates handling.

The cage which holds the specimen is shown in figure 17. It consists of transite plates connected by steel rods which act as conductors for the electrical circuit. The top of the cage contains four receptacles for the electrical circuit which is completed through the head of the bomb by means of four spark plugs which are connected to the cage by banana plugs (figure 18). The holes in the center of the transite plates are for alignment of the specimen, with a set screw in the bottom plate for holding the specimen upright during burning.

The complete wiring diagram is shown in figure 23. Power to the circuit is supplied at 110 volts which operates the motor of the clock.

The remainder of the circuit is 6.5 volt direct current at 6.3 amperes rectified from 110 volts by an "A" battery eliminator. The complete firing operation is controlled from the switch panel, (See photo #1) with the first switch controlling the power to the circuit. The second switch is the firing switch for igniting the charge while the third switch resets the timer at the completion of the test. The firing switch sends the current through a high resistance nichrome wire which ignites the charge. When the charge has burned through the first fuse wire, a relay sets the timer in operation. Further burning of the charge a specified distance burns the second fuse wire and another relay stops the timer. The clock is made by Standard Electric Company, has a ten inch dial, and is graduated to one one-hundredths of a second. A four wire cable connects the control panel to the bomb.

Pressure for the bomb is supplied by means of nitrogen bottles connected in parallel. The pressure gauge for the bomb is a standard calibrated gauge with a range of zero to three thousand pounds graduated to readings of twenty pounds to an accuracy of three pounds.

Determination of the burning rate of a solid propellant for a given pressure consists essentially of the following:

1) Electrical or hot wire ignition of one end of a small strand of solid propellant, which has been inhibited on its periphery and opposite end in order to force the burning to proceed cigarette-fashion from one end of the strand to the other in an uniform manner.

2) Actuation of interval timer by parting of a tiny (36 gauge) copper wire, which passes through the propellant strand at a point about

one inch from the ignited end, when the flame reaches that particular point in burning down the strand.

3) Stopping of timer by parting of second fuse wire which passes through propellant strand an accurately known distance from the first copper wire.

In the actual test procedure, three holes are drilled in the sample with a No. 60 drill, with the desired distance between the two fuse wire holes obtained accurately by a jig designed for the purpose. The jig contains guide holes at half inch intervals from zero to five inches which gives a wide range of lengths of samples. After being drilled, the specimen is placed through the holes in the center of the transite plates and fixed by means of the set screw in the lower transite plate. The igniter wire is passed through the first hole in the sample and connected from igniter terminal to ground. If the igniter wire has too much resistance, it may be necessary to use a shorter length of wire and connect it to the terminals by means of a lower resistance wire. The fuse wires are then placed through the other two holes and connected from their respective terminals to ground.

The head of the bomb is then placed on the cage and aligned by means of a post which fits in a slot in the cage. The cage is then placed in the bomb and the cap screwed on the bomb, sealing it completely. The cable is connected to the head by a Cannon plug and the timer reset to zero as the circuit may short briefly during the connection giving an initial small reading on the clock. After the electrical circuit has been completed, the bomb is pressurized by means of nitrogen bottles which have an original pressure of approximately 2200 psi. The bomb is brought to a pressure approximately ten per cent greater than that desired and then allowed to reach equilibrium. After equilibrium has been reached, the bomb is bled to the desired pressure. The bomb is then fired and the pressure recorded before firing and at the instant that the clock stops which gives the average pressure for the test. Dividing the distance between fuse wires by the time of burning gives the burning rate of the sample at that particular pressure.

Restriction of the burning of the sample to cigarette-type burning was accomplished by two methods. The first method consisted of casting directly in a plastic tube with an inside diameter of three-sixteenths of an inch. This was done by attaching a vacuum pump to one end of the tube and inserting the other end in the fluid mixture immediately after mixing of the propellant. Viscosity of the fluid mixture made this a rather slow process which was hastened, somewhat, by using short tubes. Specimens were cured by the regular method of placing them in an oven at 160° F.

The second method of restricting the sample consisted of slicing small rods from a previously cast propellant and coating with the desired restricting material. Coating was usually done by suspending the specimen in a test tube of the restricting material by a small wire. Solvent of the coating was removed by drying in an oven at 160° F. The various restricting materials used will be discussed in a later section.

DISCUSSION

The water jacket was omitted from the apparatus since only slight variation of ambient temperature was anticipated and it was felt that results of sufficient accuracy could be obtained with no control of initial temperature of bomb and propellant. The burning rate law:

$$r = a\,p^{n}$$

was used where r is in inches per second and p is the chamber pressure in pounds per square inch. This is compatible with the results obtained from the actual firing of rocket charges where the initial temperature is standardized at 80° F.

Pressure for the bomb was obtained from the use of commercial nitrogen with no emphasis placed on its purity. Previous investigation by Crawford and Huggett (reference "a") found that the small impurities of commercial nitrogen displayed no appreciable effect on the burning rate, inasmuch as results from tests made with commercial nitrogen agree with those made with pure nitrogen within the limits of experimental error. It was naturally expected that inert gases would have no effect and the small percentage of oxygen present was found to give no appreciable effect. Upper limit of the pressure range was two thousand pounds per square inch as the commercial nitrogen available was supplied at approximately twenty-two hundred pounds per square inch. However, this was satisfactory since the pressure range for the actual firing of the rocket charges varied from five hundred to fifteen hundred pounds per square inch.

No provision was made for visual observation of the burning of the charge. Other investigators (Reference "a") have used a visual method which involved a photographic film of the burning. Development and interpretation of the film required more time than the electrical method used in this report. However, the visual method would probably prove very advantageous in the study of restricting materials for propellants.

One of the primary problems was the selection of a suitable restricting material for the burning of the propellant. It was necessary that the restricting material would not fail at high pressure and would give reproducable results that were comparable with those obtained in actual firing of the propellant in the field. The propellant in the liquid phase could be drawn directly into a prepared tube and allowed to cure, or in the solid phase could be coated by a liquid solution of the liner. Therefore, the only limitation on the choice of restricting material was its strength, effect of solvent (in the case of liquid solution), and strength of bond between restricting material and propellant.

One of the first materials tested was a stainless steel tube in which propellant had been drawn by means of a vacuum and allowed to cure. The propellant cured well and seemed to bond satisfactorily, giving a normal, even pressure rise during burning. However, no burning rate was obtained since the fuse wire shorted on the stainless steel tubing during burning. Since stainless steel had given an unreliable bond with the propellant in rocket charges, no further investigation was made on stainless steel.

Tenite II, cellulose acetate butyrate, was another restricting material of the prepared tube type tested. However, the propellant did not always cure completely after being drawn into the tube. The propellant near the ends of the tube would cure properly but often a small strip parallel to the axis would remain uncured. Data obtained from these tests were naturally erratic and unreliable. No reason was found for the retardation of cure in the acetate butyrate tube. But it is possible that the presence of plasticizer in cellulose acetate butyrate inhibits cure.

The third liner of the tube variety tested was Saran. The propellant was also slow in curing in this type of liner but when given the necessary time gave reproducible results that were comparable to those of the actual firing of the propellant in rocket charges. Further use of this liner was discontinued when it was decided to use Thiokol type liner which could be coated on the propellant and then allowed to cure.

One of the first of the coated type of liners to be studied was Pliobond, a commercial coating agent. The Pliobond liner consisted of two coats applied with an hour interval and then allowed to dry for several days at ambient temperature to remove solvent. However, the results of these tests were erratic and were therefore discontinued. Due to wide variation of results the bonding seemed to be inadequate.

Glyptal 1201, another commercial coating material, was tested by applying two coats with an hour interval between coats and allowing to dry for twenty-four fours at 160° F. Again, erratic results were obtained. A third coat was then applied and the specimen was allowed to dry for several days. With three coats of Glyptal, fairly good results were obtained at pressures of a thousand pounds and less. Above this pressure, the strength of bond seemed inadequate.

Vinyseal was tested in a manner similar to Pliobond. Results from these tests were good at the lower pressures (see figures 3, 4, and 5). The burning rate at higher pressures was a trifle higher than that obtained with a Thiokol base liner. At all pressures with Vinyseal coating, a small percentage of the tests had a wide variation from the average and therefore it was felt that the Thiokol type liner was the more reliable.

Attention was directed to the Thiokol type liners inasmuch as they were readily available, easily applied, and were actually used in the restricting of rocket charges. The first types tested were Thiokol LP-2 base liners designated as ambient curing and quick-setting. These restricting materials had the following compositions:

	Quick-setting	Ambient curing
Thermax	6.0	20.0
Asbestos	4.0	----
Thiokol LP-2	77.5	68.8
Diphenyl Guanidine	6.0	5.4
Lead Peroxide	6.0	5.2
Stearic acid	---	0.6

The quick-setting restricting material gave burning rates that were too high indicating failure of the liner under burning of the propellant in the bomb. The ambient curing liner gave good results but again further use was discontinued because the Thiokol base restricting material L57G was more readily available and was being used to the greatest extent on rocket charges.

L57G formed a very good bond with the propellant and gave good results that were comparable with those of the tentative burning rate curve of the propellant, obtained by static firing. There was a discrepancy between experimental and actual burning rates at higher pressures. However, the curve for the higher pressures of static firing was obtained from the results of one firing and therefore some doubt is attached to the accuracy of this curve at higher pressures. All of the experimental work done on new propellants was performed with the use of L57G as a liner. L57G had the following composition:

Thiokol LP-3	60.0
Fireclay	16.5
Thermox	14.0
Asbestos	1.5
Para quinone dioxime	4.0
Diphenyl Guanidine	4.0

The liner must be cured at 160° F for twenty-four hours.

Inasmuch as a tentative burning rate curve for JPL-100-L Propellant:

$KClO_4$	47.12
NH_4ClO_4	21.15
Thiokol LP-3	28.85
Para quinone dioxime	1.92
Diphenyl Guanidine	.96

had been obtained from range firing, this propellant was chosen for the original correlation of experimental and actual data and was also used for the investigation of restricting material. Results of the burning of this propellant are given in Tables VI and VII and plotted in figures 3, 6, and 7. Very good agreement of experimental data with the tentative curve is found to a chamber pressure of twelve hundred pounds per square inch. There is an increasing deviation above that pressure. One reason for the deviation, as stated before, is probably the fact that the tentative curve contained only one test above that pressure. A second reason could be the failure of the restricting material at higher pressures. However, all burning times with L57G were reproducable to an accuracy of ± .05 second so this does not seem to be a plausible solution.

In addition to obtaining the burning rate of the propellant at a specific pressure, the exponent "n" and coefficient "a" of the burning rate equation were obtained from the slope of the burning rate curve. These were obtained graphically by plotting the burning rate curves on log log paper.

The slope of the burning rate curves compared fairly well within the operating range of JPL-100-L. The tentative burning rate curve gave a value of "n" of 0.74 while the experimental curve gave a value of 0.78. This comparison is considered fairly good since it has been found, as will be discussed in detail later, that it is possible to get a deviation of 0.03 in the value of "n" by comparing samples from the center of a charge with those taken from the edge of the same charge. The value of "a" for the tentative curve was 0.00445 while the value of the experimental "a" was 0.00319.

The source of the propellant for the experimental work on JPL-100-L was the remaining portion of rocket charge that had been interrupted in firing. All test specimens were cut parallel to the axis. Since the charge had developed a cone in firing, samples were taken the same distance from the center and periphery of the charge in an effort to get an average burning rate.

A series of tests were made on JPL-117-D to determine a burning rate curve since none existed. JPL-117-D is a Thiokol propellant with a potassium perchlorate oxidizer:

$KClO_4$	65
Thiokol LP-3	30
Para quinone dioxime	2.1
Diphenyl Guanidine	2.9

As a result of previous work with restricting material, L57G was chosen as a liner. Samples were sliced parallel to the axis of a recently cast, unfired rocket charge.

Results of this work are given in Table VIII and plotted in figures 8 and 9. The exponent "n" for the burning rate of this propellant was .815 and the coefficient "a" was .00333.

The third type of propellant to be tested in the burning rate bomb was JPL-118 with an all ammonium oxidizer:

NH_4ClO_4	67
Thiokol LP-3	30
Para quinone dioxime	2
Diphenyl Guanidine	1

No previous burning rate curve existed for this propellant either. Again, L57G was used as a restricting material, as it had been sucessful in other experiments and would give a good basis for comparison with the all potassium oxidizer. The propellant was obtained from a rocket charge that had been interrupted in firing. As a result of the short axial length of the remaining charge, specimens were cut perpendicular to the axis.

Results obtained from burning of the JPL-118 contained more variation in burning time at the same pressure than previous tests. This was probably the result of the nature of the source of the propellant. Since the only propellant with a pure ammonium perchlorate oxidizer available was the one described in the preceding paragraph, it was necessary to use samples that contained some imperfections. Nevertheless, enough tests were made to give a fairly reliable curve which is shown in figure 10. Further tests were prevented by the unavailability of more propellant. The exponent "n" for the burning rate curve was found to be 0.247 while the coefficient "a" had a value of 0.0595. It will be observed here that the value of the exponent is unusually low for a solid propellant, which is important in burning stability.

In the process of determining the experimental burning rate curve for JPL-100-L, some consideration was given to the coning or progression of the restricted burning of the propellant. Therefore, strips were cut from a charge that had been interrupted during firing and had a definite cone. These strips were cut parallel to the axis from the center of the charge and along the periphery. The coating for these strips was L57G, applied by dipping the samples and then curing in an oven at 160° F. The results of these tests are given in Table VII and shown in figures 11 and 12. The center of the charge had a definitely slower burning rate. The exponent of the center for the burning rate law was 0.79 while the exponent for the edge of the charge was 0.76.

The results of this work were very indicative since the ratio of the burning rates at the edge and center of the charge gave the secant of the base angle of the cone which was normally found in a rocket charge that had been interrupted in firing. This is important as it shows the cause of coning is related to the difference in burning rates between the center and edge of the propellant charge.

Burning rate tests on the coning of rocket charges were also made on JPL-118. As in the case of the mixture of ammonium and potassium perchlorate oxidizer, a difference of burning rates was found between the center of the charge and edge of the charge. As would be expected from the greater angle of coning found in the propellant using ammonium perchlorate only as an oxidizer, a greater deviation was found in the burning rates between the center and edge of the charge than was found in the case of JPL-100-L. The base angle of the cone of JPL-100-L has a value between twenty and twenty-five degrees while the base angle of the cone of JPL-118 is approximately thirty-five degrees. A very close comparison was obtained between the secants of these angles and the ratios of the burning rates at the edge and center of the charge. No variation was found in the value of the exponent "n" between the center and edge of the charge of JPL-118, as both gave a value of 0.247 which coincided exactly with the average value of "n" found by using samples cut perpendicular to the axis of the charge.

In comparing the three types of propellants, it will be noted that the potassium perchlorate only oxidizer gives the fastest burning rate with the highest value of "n", and the ammonium perchlorate gives the lowest values for burning rates and exponents, while a mixture of the two give an intermediate value. The difference between burning rates at the center and edge of the charge increased with the amount of ammonium perchlorate.

CONCLUSIONS

The following conclusions may be drawn from the preceding discussion:

(1) Correlation of experimental and actual burning rates is possible with the burning rate bomb.

(2) Values of constants in burning rate law: $r = a\ p^n$

Propellant	"n"	"a"
JPL-110-L	0.78	0.00319
JPL-117-D	0.815	0.00333
JPL-118	0.247	0.0595

(3) The value of the exponent "n" decreases with an increase amount of ammonium perchlorate oxidizer.

(4) The variation of burning rate between the center and edge of the rocket charge increases for the propellants tested, with increase of ammonium perchlorate as oxidizer.

(5) Of the restricting materials used in this work, L57G gave the best performance.

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TABLE I

Propellant JPL-100-L

Restricting Material: Pliobond

P_i	P_f	P_a	t_b	r	ℓ
1000	1175	1088	3.39	.885	3"
1000	1180	1090	3.55	.845	3"
1000	1180	1090	3.34	.900	3"
1000	1180	1090	5.79	.865	5"
1000	1185	1093	5.72	.875	5"
1000	1195	1098	5.49	.910	5"
1000	1160	1080	5.50	.910	5"
1500	1660	1500	2.76	1.09	3"
1500	1700	1600	2.73	1.10	3"
1500	1690	1695	2.85	1.05	3"
1000	1170	1085	6.28	.798	5"
1000	1170	1085	6.34	.792	5"
1000	1160	1080	6.13	.817	5"
1000	1190	1095	5.97	.839	5"
1000	1140	1070	5.99	.836	5"
1000	1160	1080	6.01	.834	5"

TABLE II

Propellant JPL-100-L

Restricting Material: Vinyseal

P_i	P_f	P_a	t_b	r	ℓ
500	570	535	7.45	.402	3"
500	585	543	7.16	.418	3"
500	580	540	7.32	.409	3"
500	580	540	7.27	.413	3"
500	575	537	7.23	.415	3"
1000	1130	1065	3.84	.781	3"
1000	1135	1068	3.99	.752	3"
1000	1145	1073	3.91	.767	3"
1000	1135	1068	3.79	.790	3"
1000	1160	1080	6.78	.738	5"
1000	1150	1075	6.75	.740	5"
1000	1170	1085	6.58	.762	5"
1000	1160	1080	7.18	.696	5"
1500	1690	1595	4.76	1.05	5"
1500	1680	1590	4.76	1.05	5"
1500	1660	1580	4.88	1.03	5"
1500	1690	1595	4.85	1.03	5"
1500	1690	1595	4.79	1.03	5"
2000	2220	2110	2.33	1.28	3"
2000	2220	2110	2.28	1.32	3"
2000	2250	2125	3.80	1.32	5"
2000	2250	2125	3.98	1.26	5"
2000	2210	2105	4.04	1.24	5"
750	845	798	5.18	.578	3"
750	860	805	4.91	.611	3"
750	850	800	5.07	.593	3"

TABLE III

Propellant JPL-100-L

Restricting Material: LP-2 (Quick Setting)

P_i	P_f	P_a	t_b	r	ℓ
1020	1120	1070	3.35	.895	3"
1015	1120	1068	3.35	.895	3"
1015	1120	1068	3.36	.894	3"
1020	1140	1080	3.31	.907	3"
1020	1120	1070	3.34	.896	3"

TABLE IV

Propellant JPL-100-L

Restricting Material: LP-2 (Ambient)

P_i	P_f	P_a	t_b	r	ℓ
300	340	320	10.66	.281	3"
300	340	320	10.60	.282	3"
700	790	745	5.45	.550	3"
700	785	743	5.48	.547	3"
1500	1640	1570	2.83	1.06	3"
1500	1640	1570	2.73	1.09	3"

TABLE V

Propellant JPL-100-L

Restricting Material: Saran Tubing

P_i	P_f	P_a	t_b	r	ℓ
500	560	530	6.87	.437	3"
500	560	530	6.75	.444	3"
500	560	530	6.75	.442	3"
750	840	795	3.40	.588	3"
750	840	795	3.45	.578	3"
750	845	798	3.32	.602	3"

TABLE VI

Propellant JPL-109-L

Restricting Material: L57G

P_i	P_f	P_a	t_b	r	ℓ
150	170	160	15,78	.190	3"
150	175	163	15.71	.191	3"
300	340	320	10.38	.289	3"
300	330	315	10.43	.287	3"
1000	1070	1035	4.20	.714	3"
1000	1090	1045	4.15	.722	3"
1500	1610	1555	3.14	.955	3"
1500	1610	1555	3.18	.942	3"
900	980	940	4.52	.664	3"
900	980	940	4.58	.655	3"
1200	1310	1255	3.52	.854	3"
1200	1310	1255	3.54	.848	3"
1500	1620	1560	3.02	.994	3"
1500	1620	1560	3.02	.994	3"
1500	1610	1555	2.58	1.005	3"
1500	1620	1560	3.02	.994	3"
1800	1940	1870	2.60	1.15	3"
1800	1940	1870	2.60	1.15	3"
1800	1945	1873	2.62	1.145	3"
800	880	840	4.94	.608	3"
800	880	840	4.96	.605	3"

TABLE VII

Propellant JPL-100-L

Restricting Material: L57G

Center of Charge

P_i	P_f	P_a	t_b	r	ℓ
500	550	525	4.97	.402	2"
750	810	780	3.70	.540	2"
750	820	785	3.45	.578	2"
750	820	785	3.58	.568	2"
1000	1100	1050	2.83	.707	2"
1000	1100	1050	2.83	.707	2"
1000	1100	1050	2.82	.709	2"

Edge of Charge

P_i	P_f	P_a	t_b	r	ℓ
500	560	530	4.60	.435	2"
750	825	788	3.31	.604	2"
750	820	785	3.33	.600	2"
750	815	783	3.40	.588	2"
1000	1100	1050	2.65	.755	2"
1000	1100	1050	2.70	.740	2"
1000	1100	1050	2.69	.744	2"

TABLE VIII

Propellant JPL-117-D

Restricting Material: L570

P_i	P_f	P_a	t_b	r	ℓ
300	340	320	8.30	.361	3"
300	340	320	8.41	.357	3"
500	570	535	5.35	.562	3"
500	570	535	5.30	.563	3"
500	560	530	5.34	.567	3"
760	850	805	3.99	.753	3"
760	850	805	4.02	.747	3"
760	860	810	4.01	.749	3"
1000	1110	1055	3.21	.935	3"
1000	1100	1050	3.31	.907	3"
1000	1100	1050	3.27	.917	3"
1000	1100	1050	3.26	.920	3"
1250	1380	1315	2.80	1.07	3"
1250	1380	1315	2.80	1.07	3"
1500	1610	1555	2.45	1.23	3"
1500	1610	1555	2.41	1.24	3"
1800	1940	1870	2.15	1.40	3"
1800	1920	1860	2.17	1.39	3"

TABLE IX

Propellant JPL-118

Restricting Material: L57G

Samples Cut Normal to Axis of Charge

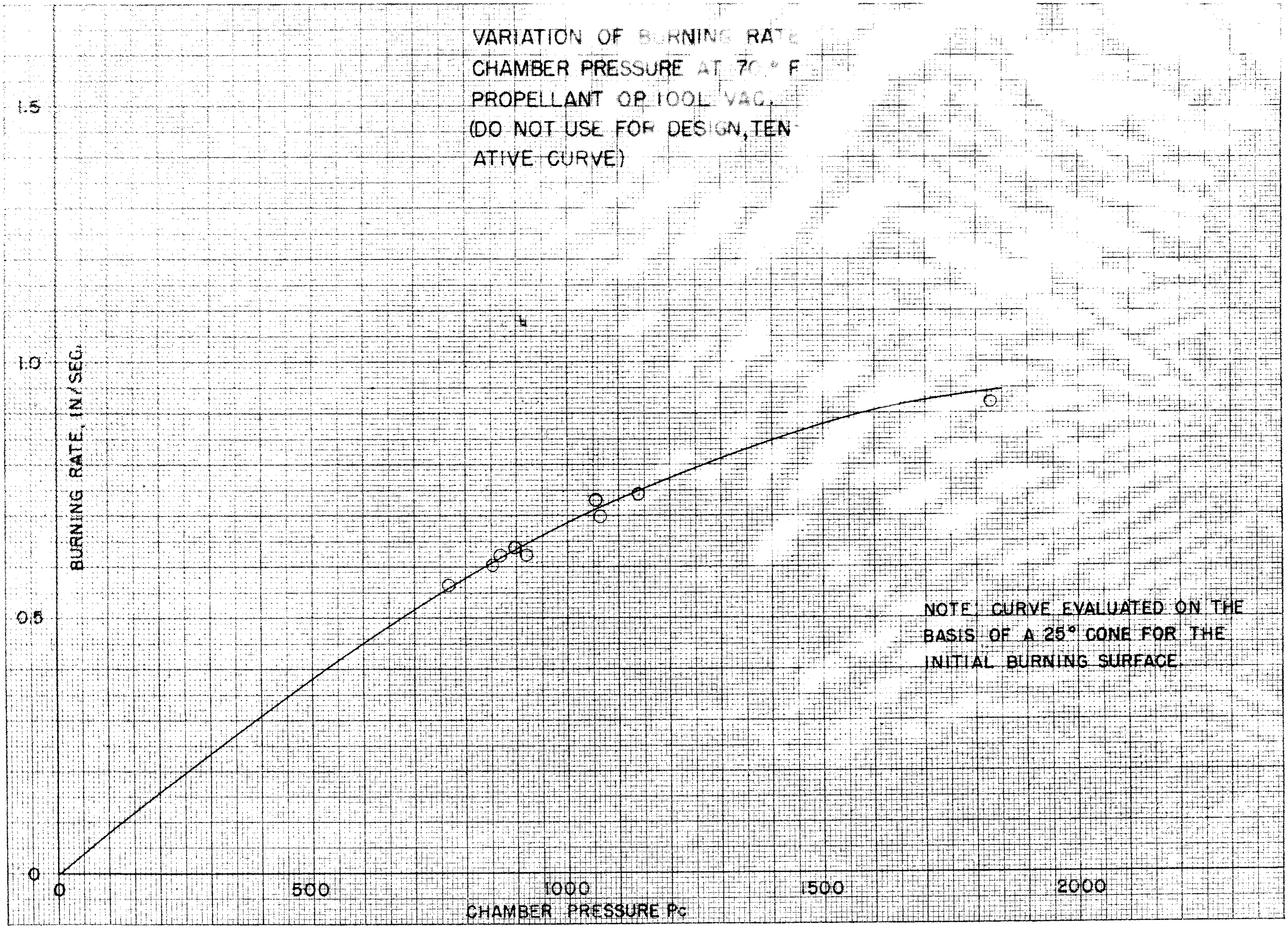
P_i	P_f	P_a	t_b	r	ℓ
500	530	515	10.57	.284	3"
1000	1040	1020	9.44	.318	3"
1000	1060	1030	9.30	.322	3"
1250	1305	1278	8.87	.338	3"
1250	1305	1278	8.88	.338	3"
1250	1310	1280	8.93	.336	3"
1250	1290	1270	8.80	.341	3"
1500	1550	1525	8.48	.354	3"
1500	1540	1520	8.52	.352	3"
1750	1810	1780	8.22	.365	3"
1800	1870	1835	8.04	.374	3"
1800	1850	1825	7.97	.376	3"

Samples from Center of Charge

P_i	P_f	P_a	t_b	r	ℓ
500	560	530	7.82	.256	3"
1000	1060	1030	6.85	.292	3"
1000	1080	1040	6.96	.287	3"
1500	1560	1530	6.30	.318	3"
1500	1560	1530	6.20	.322	3"

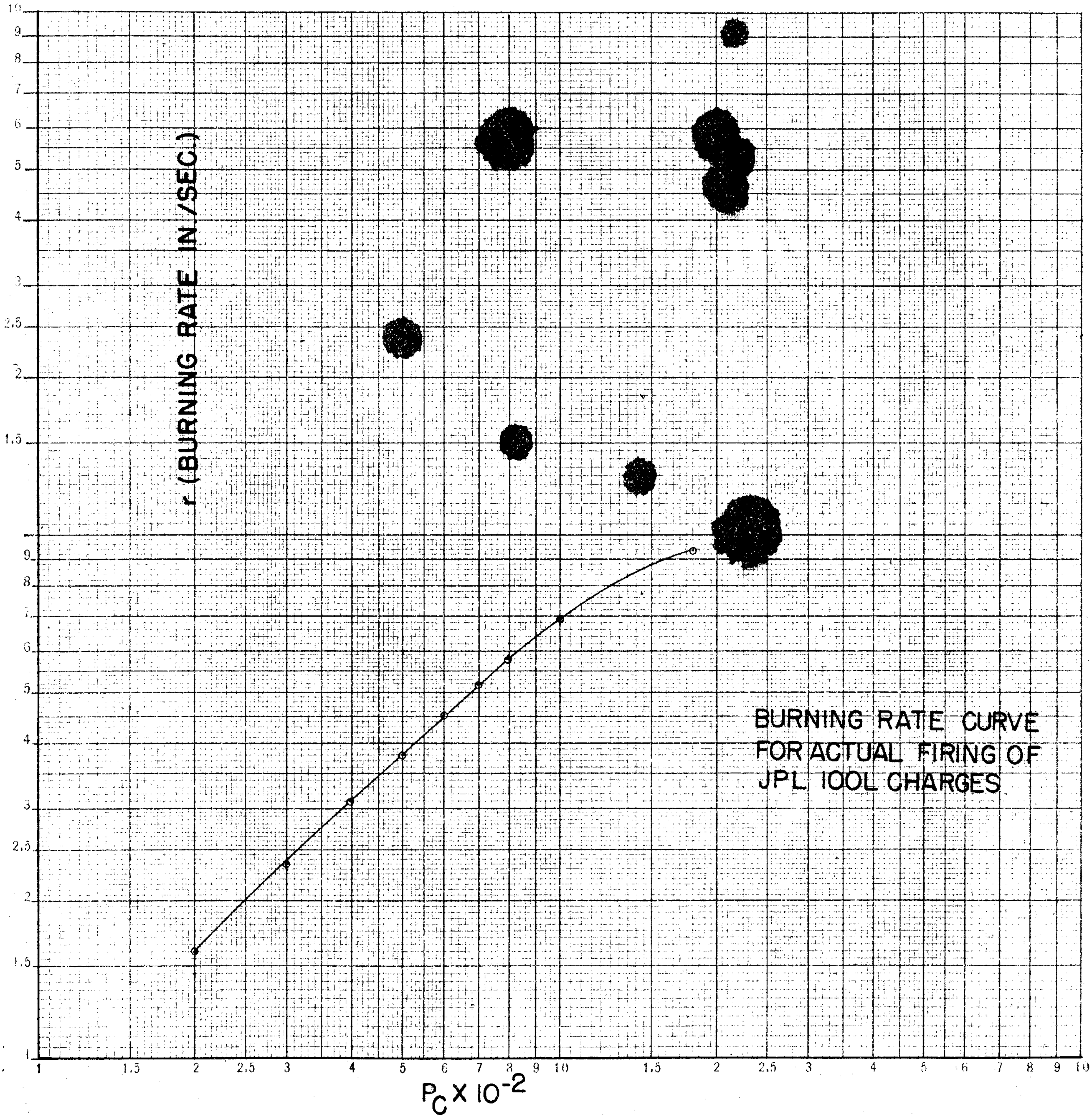
Samples from Edge of Charge

P_i	P_f	P_a	t_b	r	ℓ
500	560	530	6.24	.320	3"
1000	1070	1035	5.35	.374	3"
1000	1060	1030	5.46	.366	3"
1500	1580	1540	4.93	.406	3"
1500	1580	1540	4.89	.409	3"



VARIATION OF BURNING RATE
CHAMBER PRESSURE AT 70° F
PROPELLANT OP 100L VAC.
(DO NOT USE FOR DESIGN, TENTATIVE CURVE)

NOTE: CURVE EVALUATED ON THE BASIS OF A 25° CONE FOR THE INITIAL BURNING SURFACE.



$P_C \times 10^{-2}$
CHAMBER PRESSURE

FIG.2

CLASSIFICATION cancelled

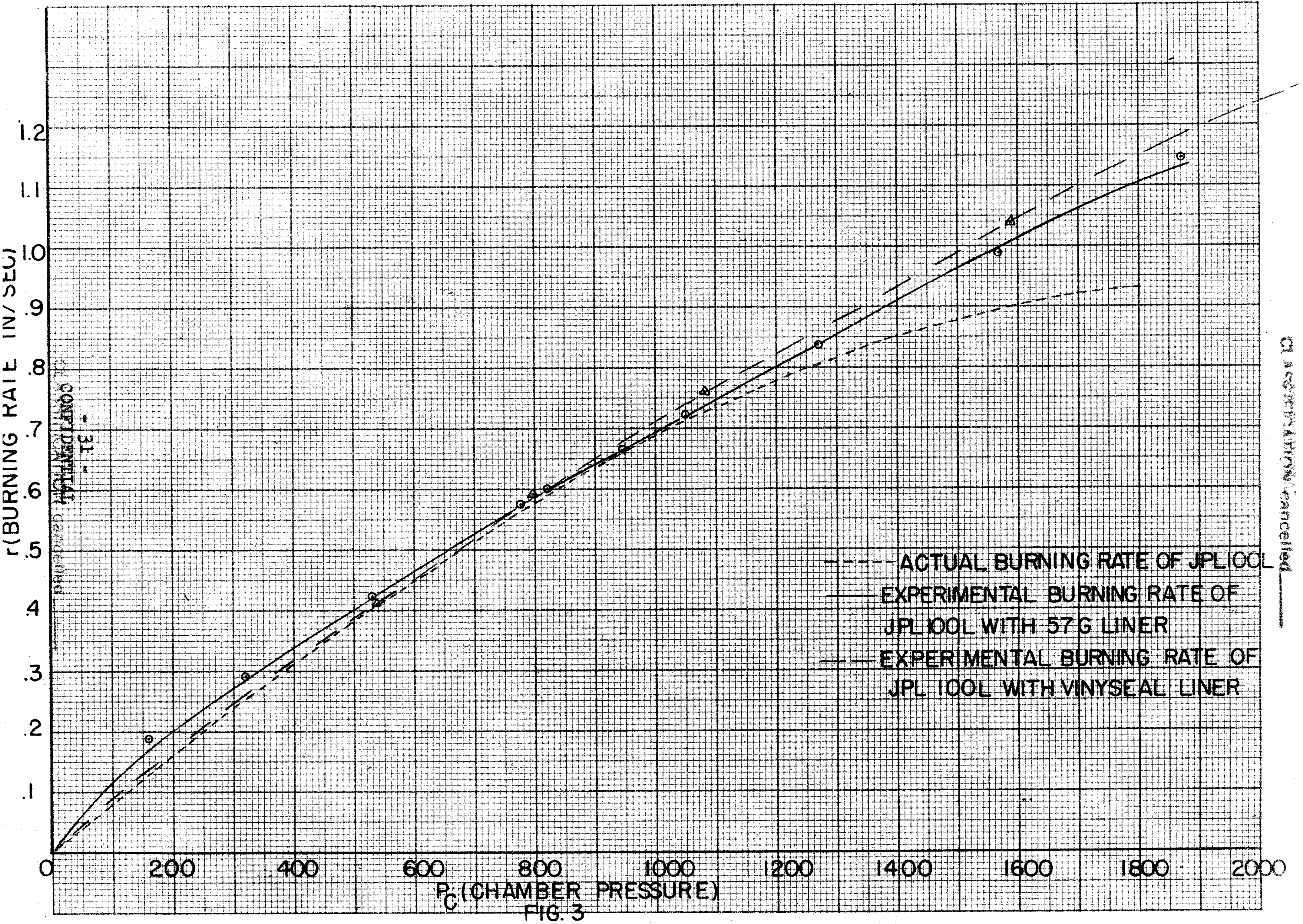
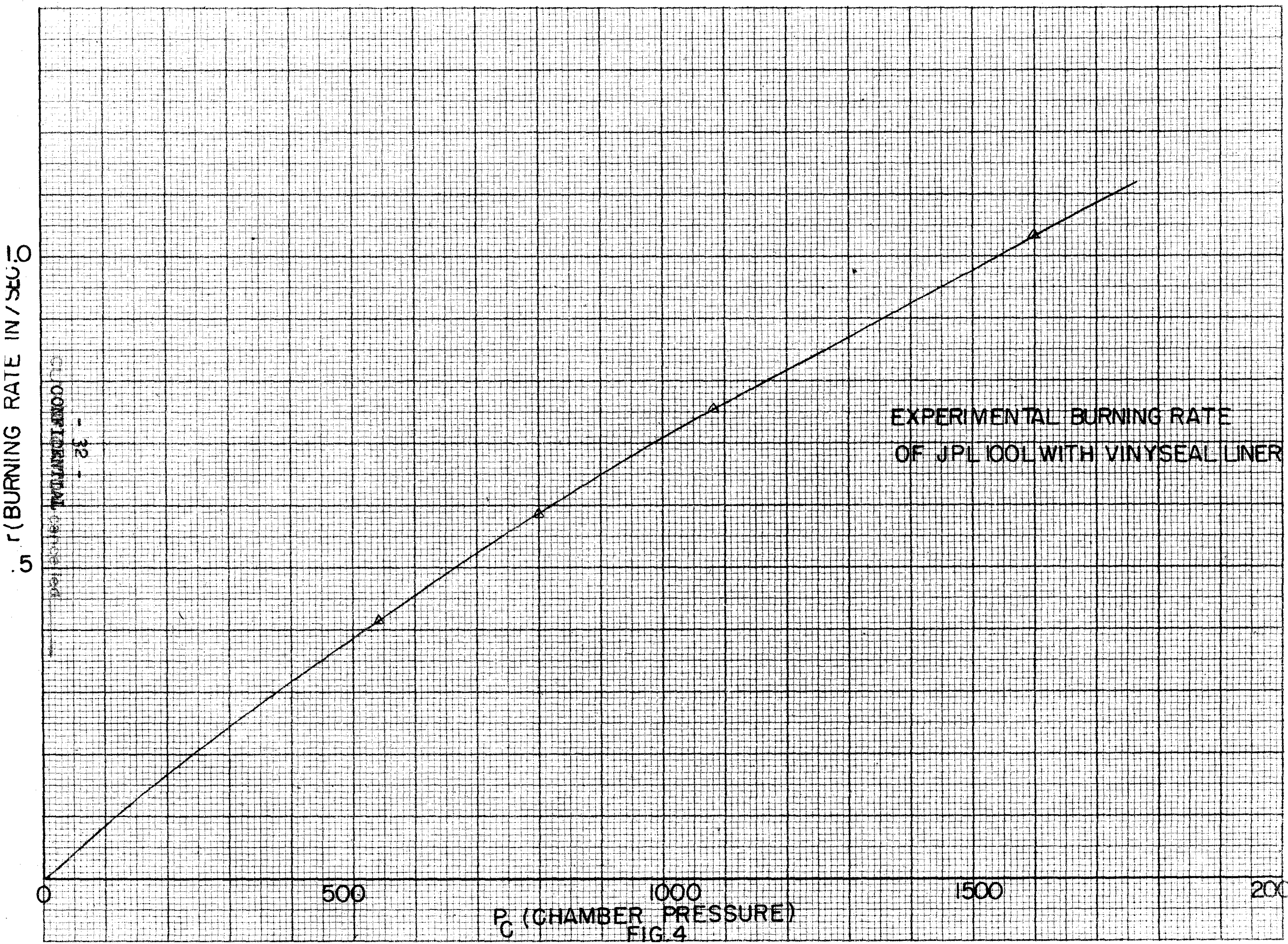


FIG. 3

CONFIDENTIAL

CLASSIFICATION cancelled



EXPERIMENTAL BURNING RATE
OF JPL 100L WITH VINYSEAL LINER

FIG. 4

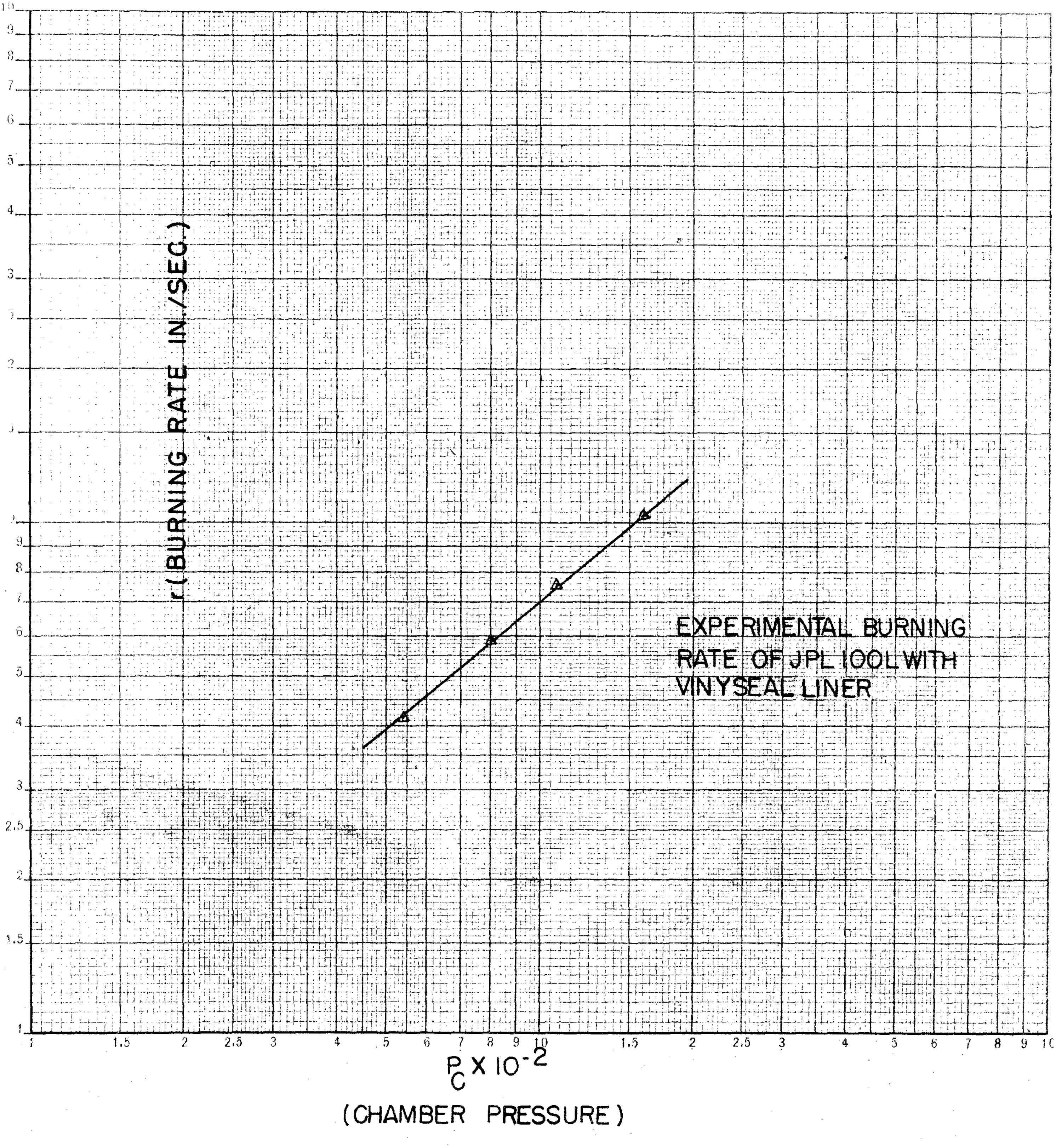
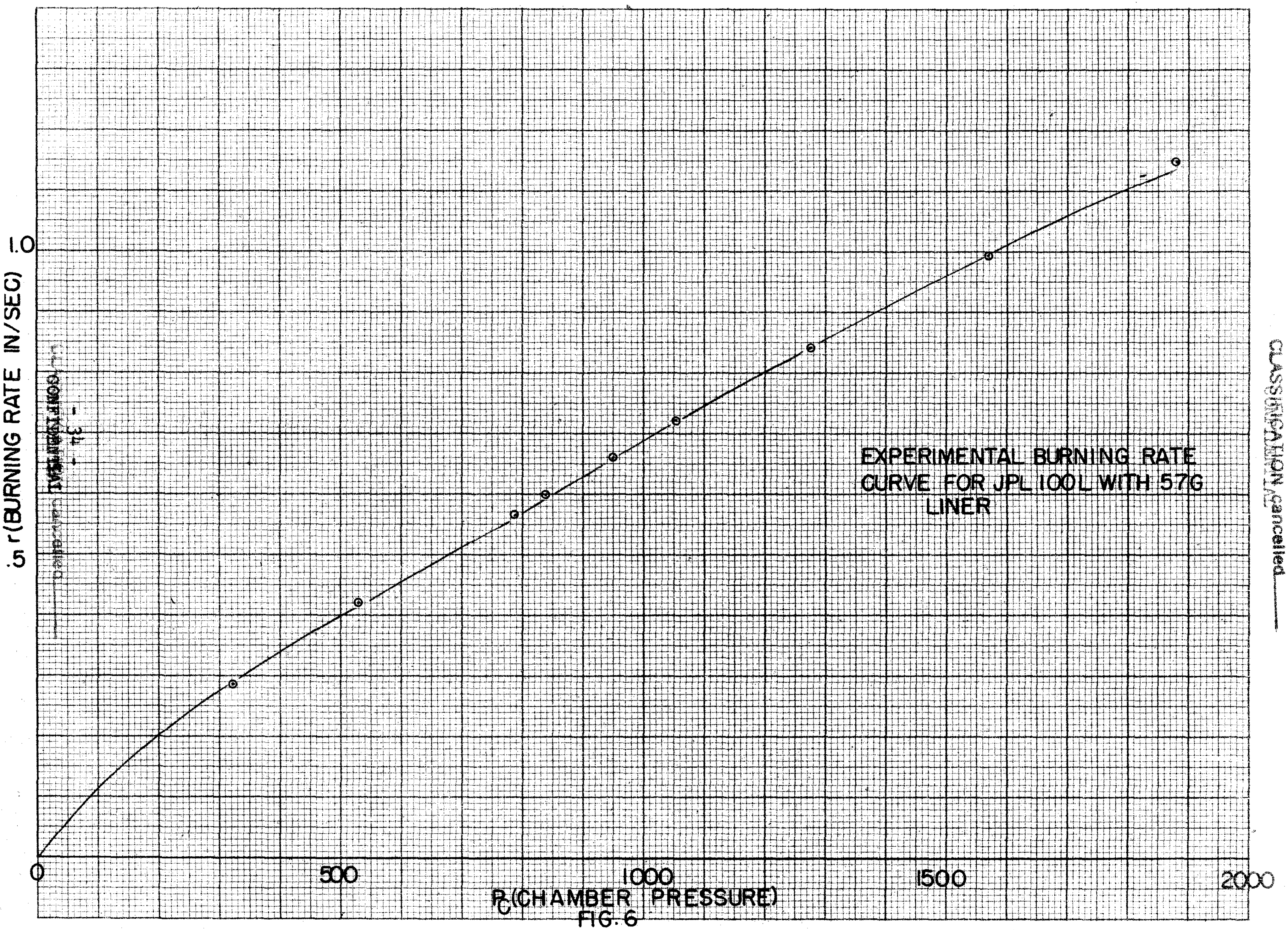

r (BURNING RATE IN./SEC.)
EXPERIMENTAL BURNING RATE OF JPL 100L WITH VINYSEAL LINER
$P_C \times 10^{-2}$
(CHAMBER PRESSURE)
1
1.5
2
2.5
3
4
5
6
7
8
9
10
1.5
2
2.5
3
4
5
6
7
8
9
10

FIG. 5



EXPERIMENTAL BURNING RATE CURVE FOR JPL 100L WITH 57G LINER

FIG. 6

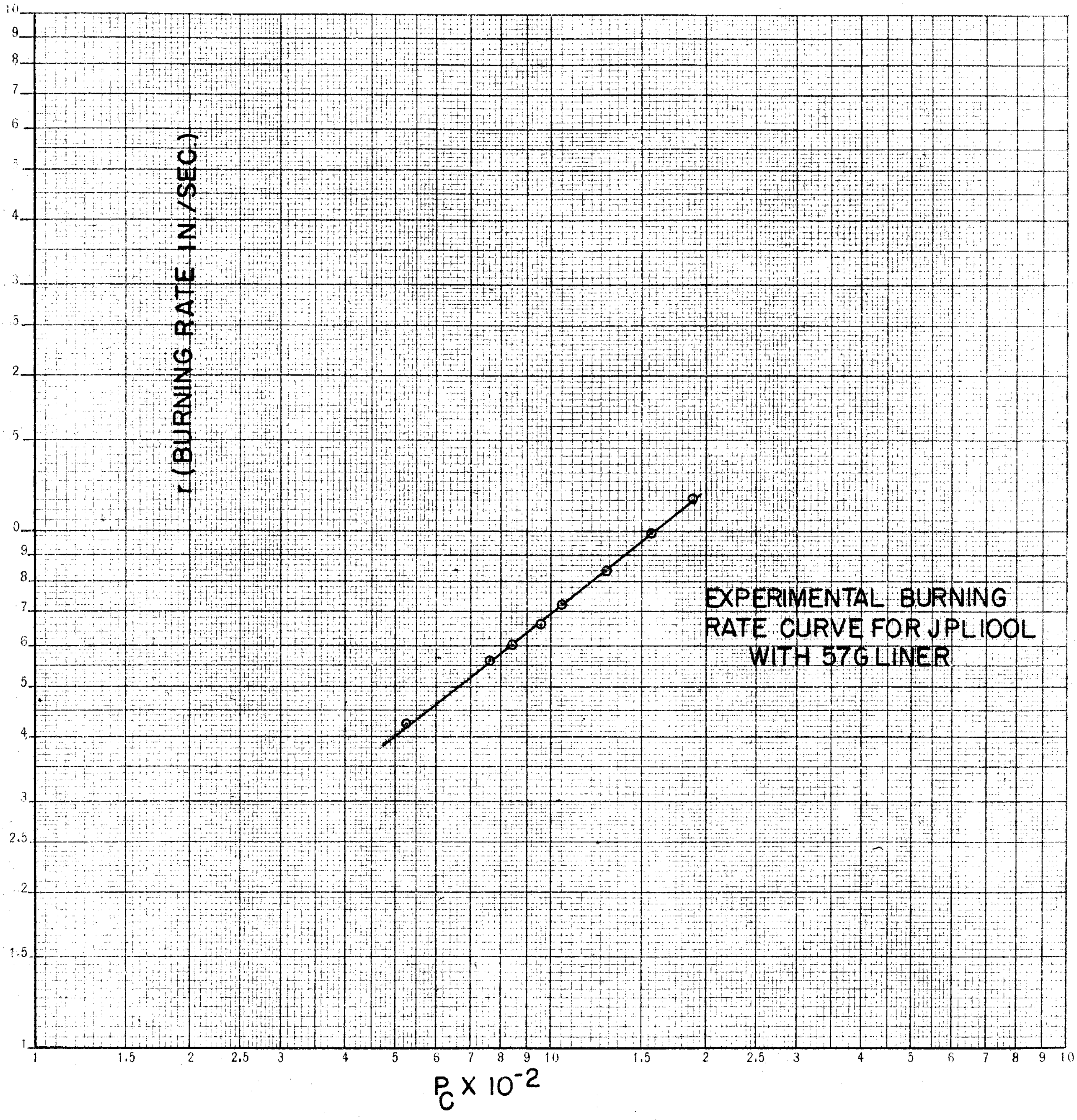
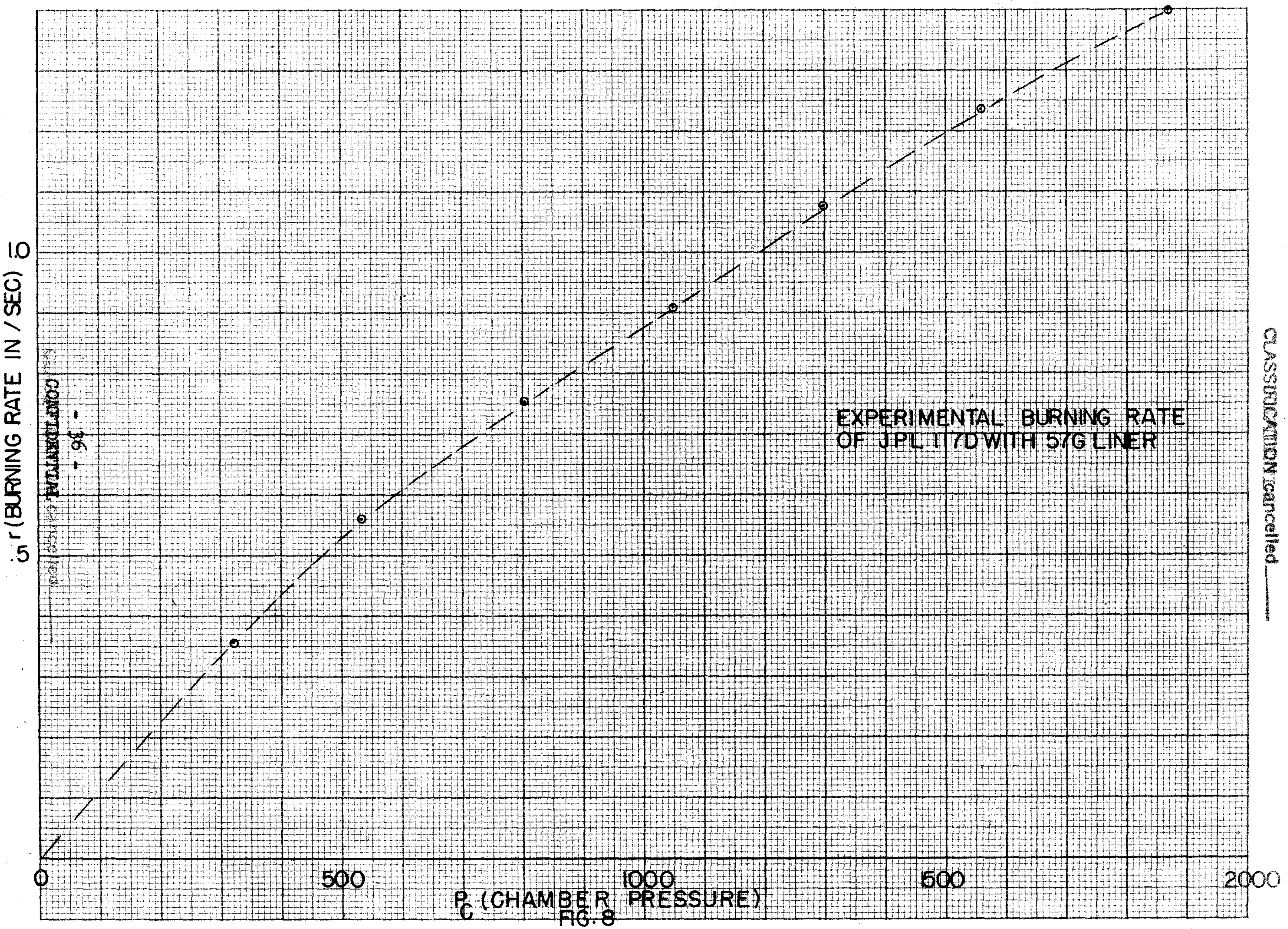

r (BURNING RATE IN./SEC.)
10
9
8
7
6
5
4
3
2.5
2
1.5
0.
9
8
7
6
5
4
3
2.5
2
1.5
1
1
1.5
2
2.5
3
4
5
6
7
8
9
10
1.5
2
2.5
3
4
5
6
7
8
9
10
EXPERIMENTAL BURNING
RATE CURVE FOR JPL 100L
WITH 57G LINER
$P_C \times 10^{-2}$
(CHAMBER PRESSURE)

FIG.7



EXPERIMENTAL BURNING RATE
OF JPL 117D WITH 57G LINER

FIG. 8

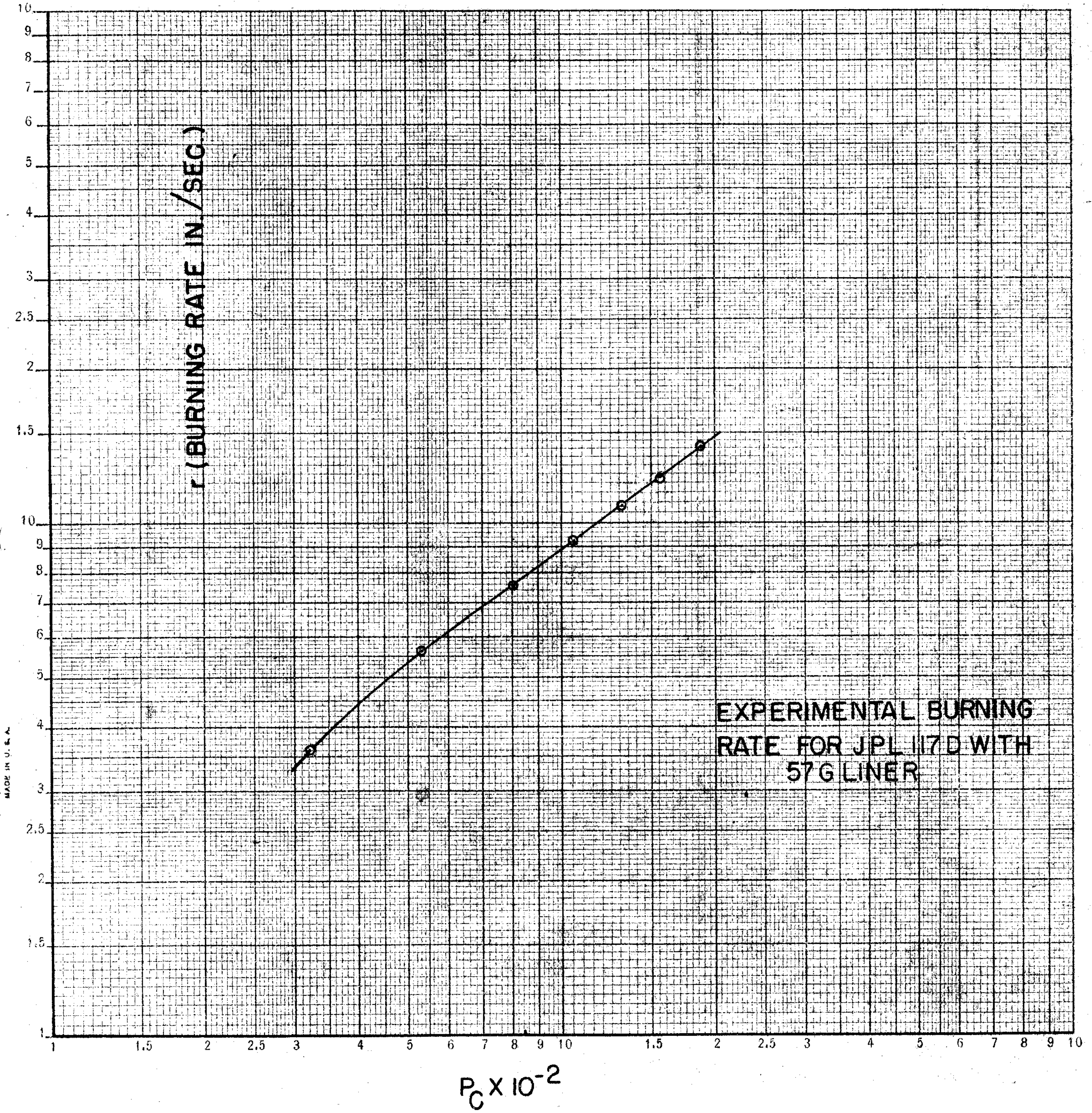
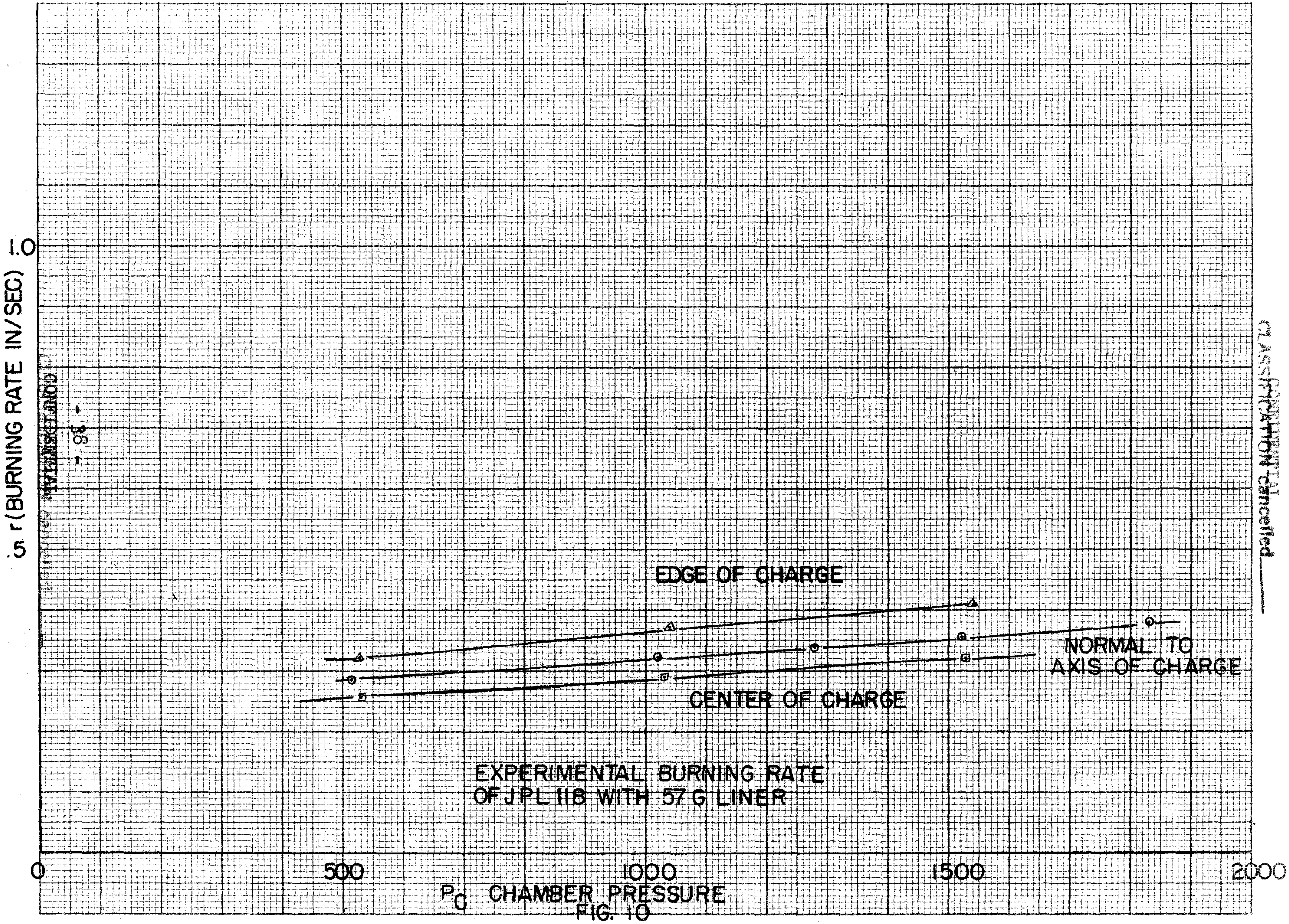
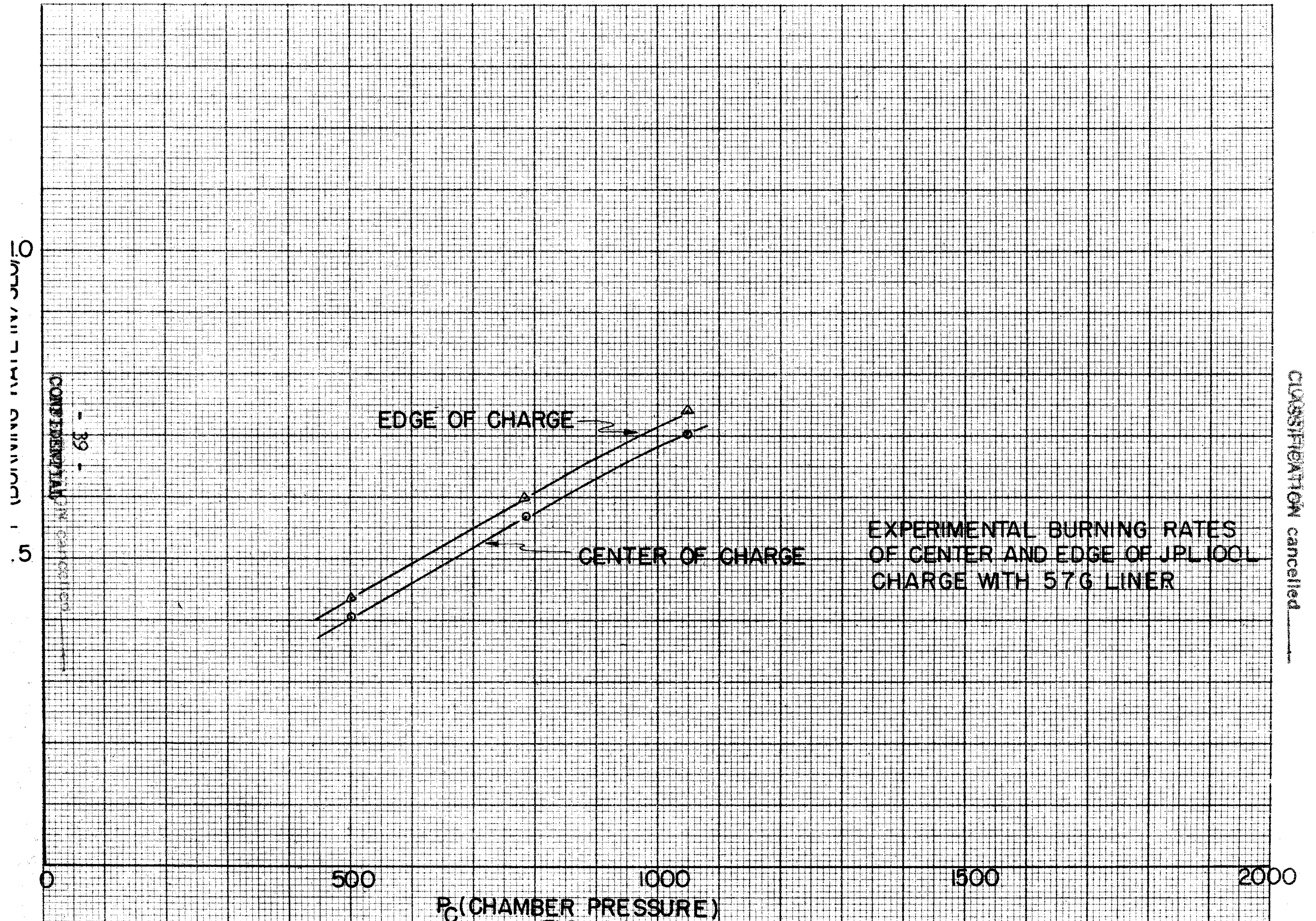

r (BURNING RATE IN./SEC.)
10
9
8
7
6
5
4
3
2.5
2
1.5
1
1.5
2
2.5
3
4
5
6
7
8
9
10
EXPERIMENTAL BURNING RATE FOR JPL 117 D WITH 57 G LINER
$P_C \times 10^{-2}$

FIG. 9



EXPERIMENTAL BURNING RATE
OF JPL 118 WITH 57 G LINER

FIG. 10



EXPERIMENTAL BURNING RATES OF CENTER AND EDGE OF JPL 100 L CHARGE WITH 57G LINER

FIG. 11

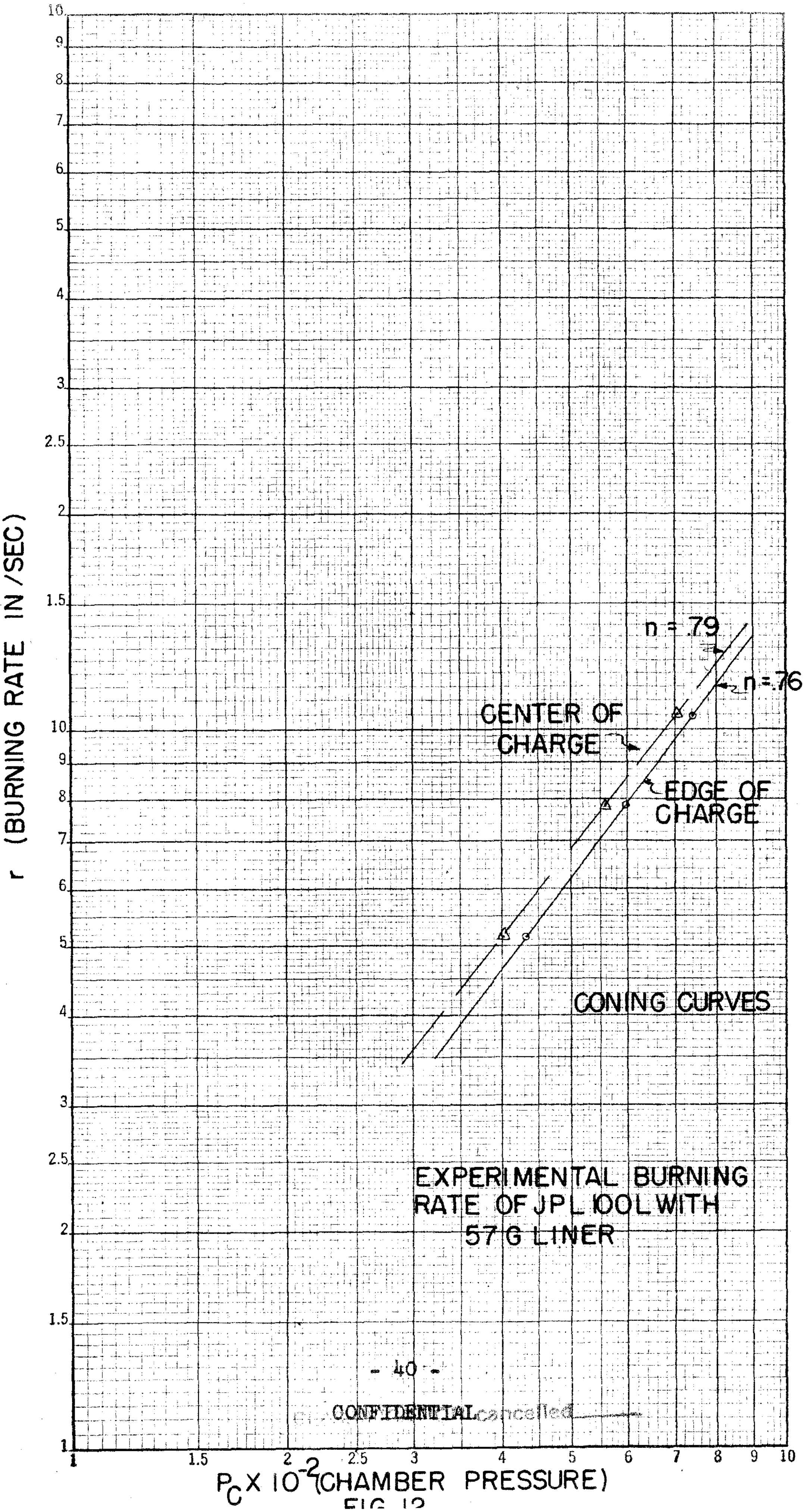
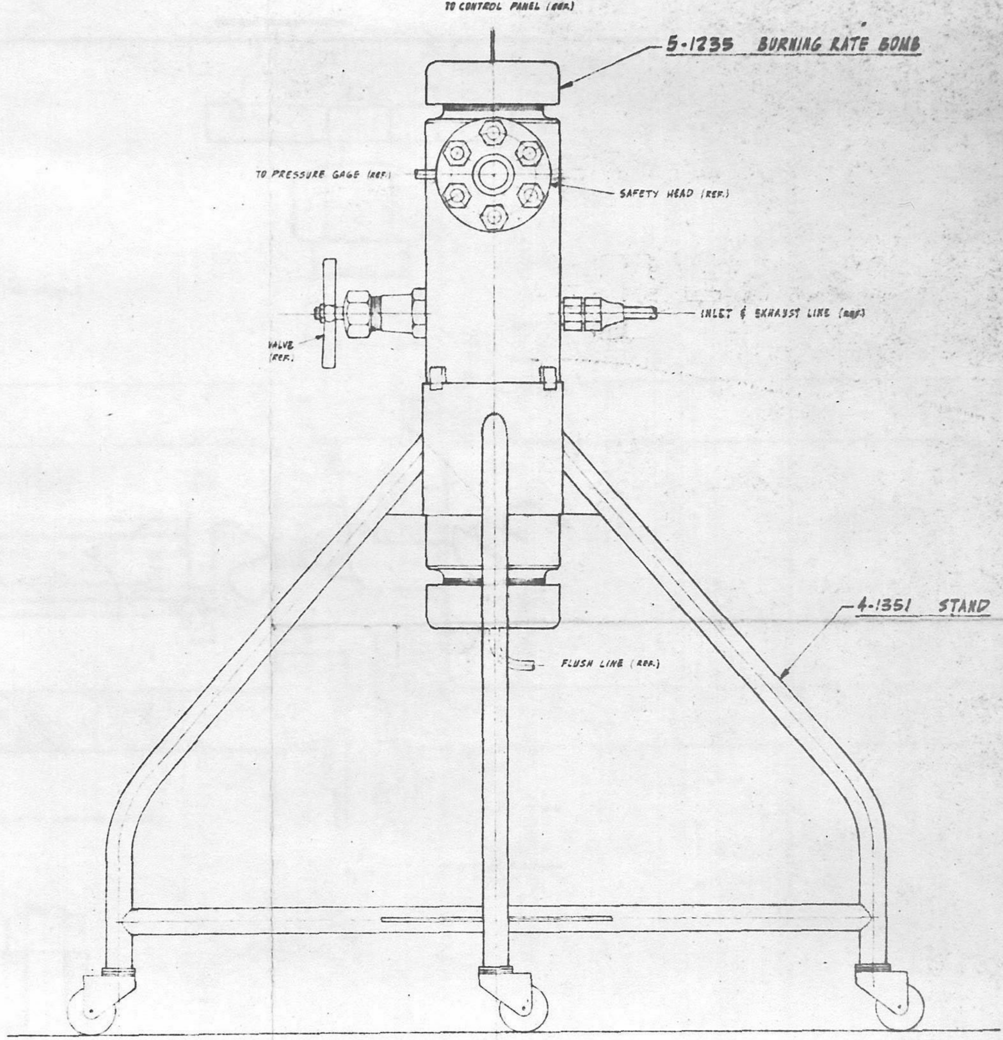

r (BURNING RATE IN /SEC)
10
9
8
7
6
5
4
3
2.5
2
1.5
10
9
8
7
6
5
4
3
2.5
2
1.5
1
1
1.5
2
2.5
3
4
5
6
7
8
9
10
n = .79
n = .76
CENTER OF CHARGE
EDGE OF CHARGE
CONING CURVES
EXPERIMENTAL BURNING RATE OF JPL 100L WITH 57 G LINER
$P_C \times 10^{-2}$ (CHAMBER PRESSURE)

FIG 12



PART	DESCRIPTION	REQ.
4-1353*	DRILL JIG	1
4-1351	STAND	1
5-1235	BURNING RATE BOMB	1
4-1352	ASSEMBLY	—

* NOT SHOWN ON DWG.; TO BE USED IN DRILLING POWDER GRAIN.

LETTER	DATE	CHANGE	BY	CHKD.	APVD.

TOLERANCE ± .010 UNLESS OTHERWISE NOTED

21259
DEC 31 '46

JET PROPULSION LABORATORY, GALCIT **CALIFORNIA INSTITUTE OF TECHNOLOGY**

PROJECT DESIGNATION ORDCIT SECTION 8 PROJECT CLASSIFICATION

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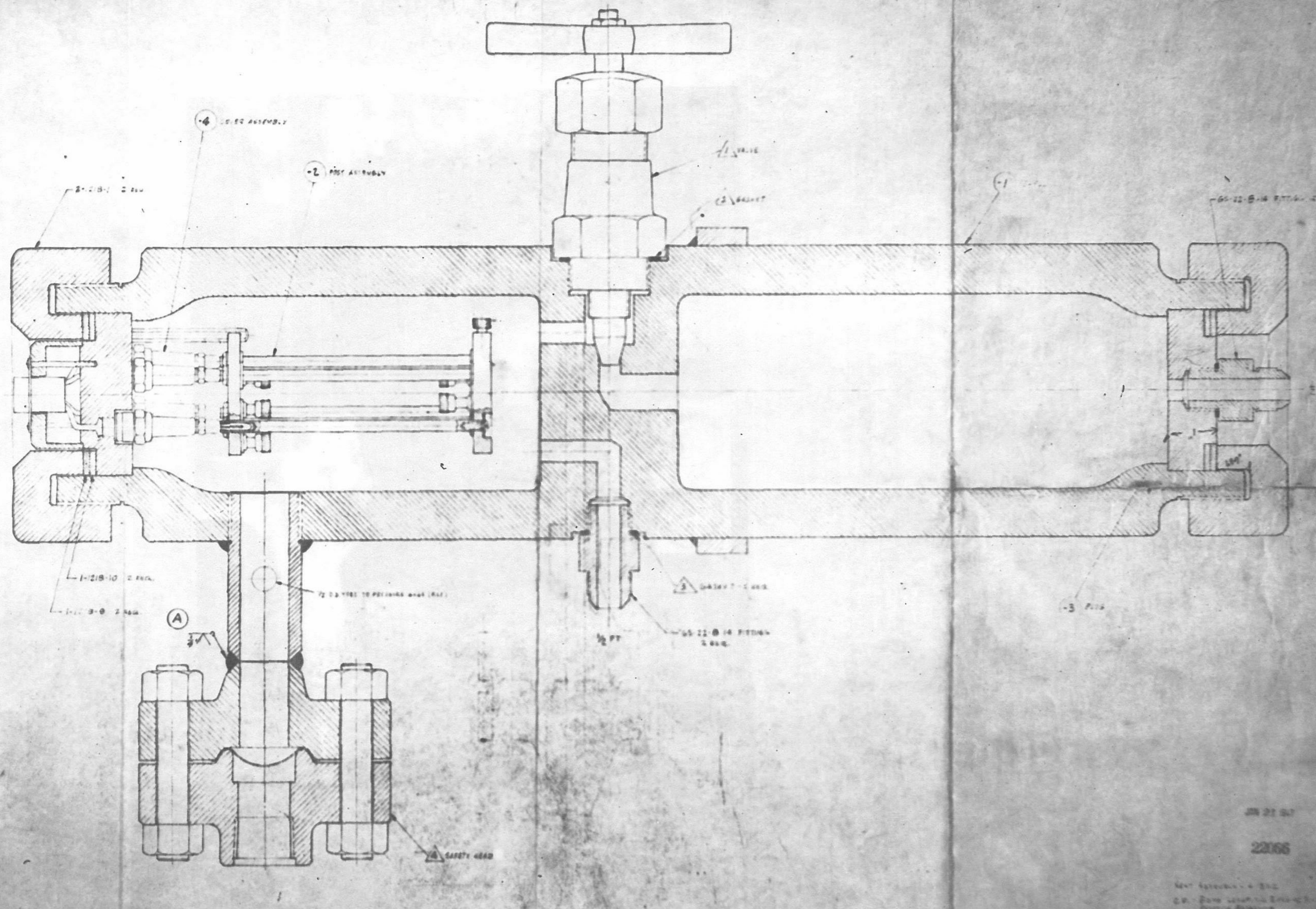
LAST DASH NO.	—	MATERIAL —
DWN.	O'HARA	12-5-46
CHK.	[illegible]	12-26-46
APPD.	[illegible]	[illegible]
ENG.	SHAFER	12-30

ASSEMBLY - PRESSURE RESERVOIR AND CRAWFORD BURNING RATE BOMB - WITH STAND

SCALE 1/4

4-1352
DRAWING NO.

CLASS CONFIDENTIAL Cancelled



PART	DESCRIPTION	REQ.
4	SAFETY HEAD - BLACK-SIVALLS & BRYSON 1"-5600#/□" BURST PRESSURE; WELDED BASE, THREADED HOLD-DOWN	1
3	GASKET - COPPER - .062 × .880 I.D. × 1.125 O.D.	2
2	GASKET - COPPER - .062 × 1.06 I.D. × 1.375 O.D.	1
1	VALVE - CRANE #22257 GLOBE 1"	1
1-1218-10	GASKET	2
1-1218-9	SPACER	2
2-1218-1	COVER	2
GS-22-B-14	AD-1/2 PT	2
-4	LEVER ASSEMBLY	1
-3	PLUG - LOWER	1
-2	POST ASSEMBLY	1
-1	SHELL	1
S-1218	ASSEMBLY	—

LTR	DATE	CHANGE	BY	CHKD.	APPD.
A	1/7/47	WELD TO SAFETY HEAD 3/8" WAS 1/4"	GRGAHD		

TOLERANCES ± .01 UNLESS OTHERWISE NOTED

JAN 21 '47

22066

JET PROPULSION LABORATORY, GALCIT — CALIFORNIA INSTITUTE OF TECHNOLOGY

PROJECT DESIGNATION — SECTION — PROJECT CLASSIFICATION

PRESSURE RESERVOIR
& CRAWFORD BURNING RATE BOMB

S-1218-A

CLASS CONFIDENTIAL Cancelled

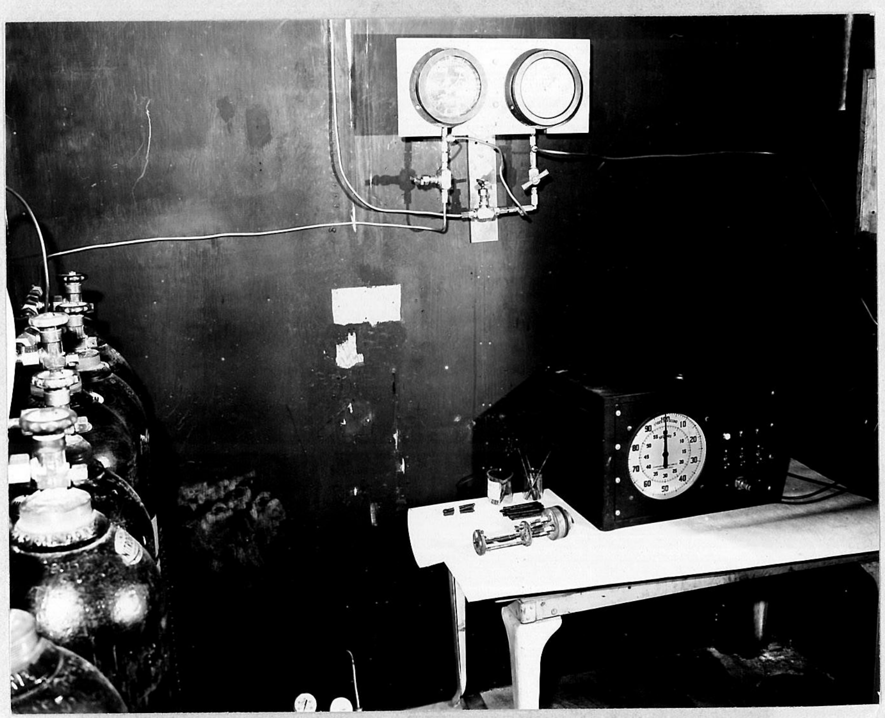


Photo 1

Photo 2

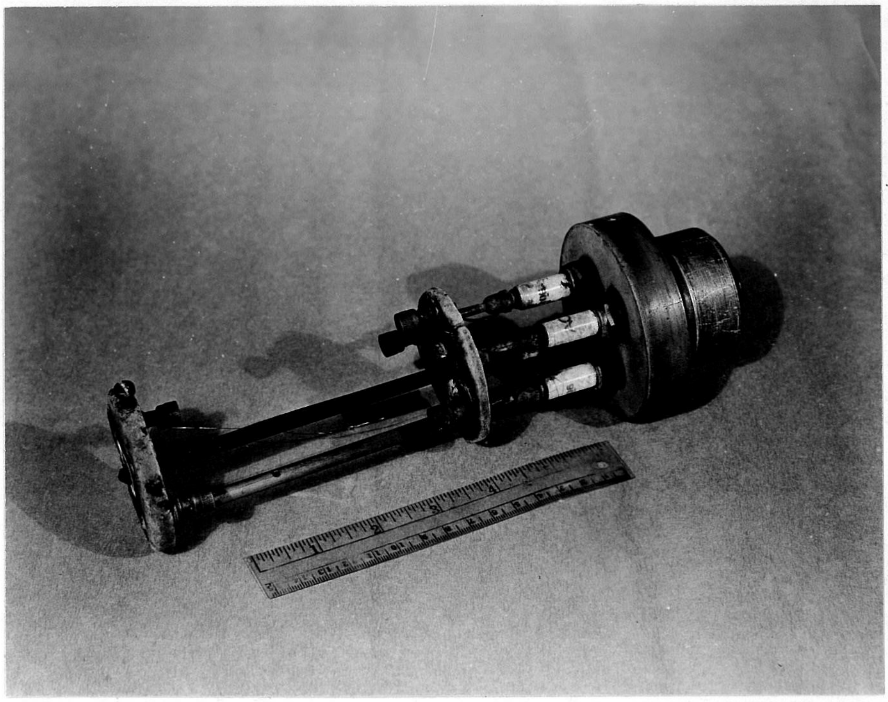


Photo 3