

UNCLASSIFIED

AD NUMBER

AD378656

CLASSIFICATION CHANGES

TO: unclassified

FROM: confidential

LIMITATION CHANGES

TO:
Approved for public release, distribution unlimited

FROM:
Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; NOV 1966. Other requests shall be referred to Picatinny Arsenal, Dover, NJ.

AUTHORITY

USAARDCOM ltr, 30 Sep 1983; USAARDCOM ltr, 30 Sep 1983

THIS PAGE IS UNCLASSIFIED

AD 378656

AUTHORITY: USAFARDCOM

17, 30 Sep 83



THIS REPORT HAS BEEN DELIMITED
AND CLEARL FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

SECURITY

MARKING

The classified or limited status of this report applies to each page, unless otherwise marked.

Separate page printouts MUST be marked accordingly.

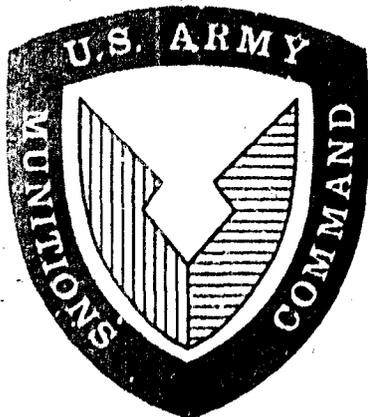
THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 AND 794. THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

CONFIDENTIAL

378656 L

COPY NO. ~~37~~ OF 100



PICATINNY ARSENAL TECHNICAL REPORT NO. 3487
**DEVELOPMENT OF NEW CATALYSTS
FOR THE
BURNING RATE CONTROL**

**OF
HIGH ENERGY SMOKELESS NITRAMINE
DOUBLE BASE PROPELLANTS (U)**

JOSEPH S. STACK

AMCMS CODE 5221.11.585

DA PROJ 1A222901A211

PICATINNY ARSENAL
DOVER, NEW JERSEY

D D C

FEB 1 1967

DOWNGRADED AT 3 YEAR INTERVALS
DECLASSIFIED AFTER 12 YEARS
DOD DIR 5200.10

CONFIDENTIAL

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

DISPOSITION

In addition to security requirements which apply to this document and must be met, each transmittal outside the Department of Defense must have prior approval of Propellants Laboratory, Picatinny Arsenal, Dover, New Jersey

When this report is no longer needed, Department of Defense agencies will destroy it in accordance with AR 380-5. Contractors will destroy it in accordance with the Industrial Security Manual or instructions furnished by the contracting officer.

DDC AVAILABILITY NOTICE

Qualified requesters may obtain copies of this report from DDC.

CONFIDENTIAL

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Section 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

Technical Report No. 3487

DEVELOPMENT OF NEW CATALYSTS
FOR THE BURNING RATE CONTROL
OF HIGH ENERGY SMOKELESS NITRAMINE
DOUBLE-BASE PROPELLANTS (U)

By

Joseph S. Stack

November 1966

Propellants Laboratory
Picatinny Arsenal
Dover, New Jersey

CONFIDENTIAL

CONFIDENTIAL

(C) TABLE OF CONTENTS

	<u>Page</u>
Abstract	1
Conclusion	2
Recommendation	3
Introduction	4
Results and Discussion	6
Experimental	14
Appendix A	17
Reference	19
TABLE I Ballistic Modifier (Lead Stannate) Analysis (C)	20
TABLE II Chemical Analysis of Ballistic Modifiers	21
TABLE III Physical Properties of Ballistic Modifiers	22
TABLE IV Ballistic Modifier (Bismuth Stannate) Analysis (C)	23
FIGURE 1 X-Ray Diffraction Patterns - Untreated and Heat Treated Lead Stannate (C)	24
FIGURE 2 X-Ray Diffraction Patterns - Lead Stannate - TDI Complexes, Lead Stannate - TDI (Reduced), Lead Stannate - TDI (Oxidized) (C)	25
FIGURE 3 X-Ray Diffraction Patterns - Lead Stannate - HDI Complex, Lead Stannate - HDI (Oxidized) (C)	26
FIGURE 4 X-Ray Diffraction Patterns - Chemical and Heat Treated Bismuth Stannate (C)	27
FIGURE 5 X-Ray Diffraction Patterns - Bismuth Stannate - HDI Complex, Bismuth Stannate - HDI (Oxidized) (C)	28
FIGURE 6 Ballistic Properties of Smokeless HMX Plastisol Propellants Containing Chemically (HDI) and Heat Treated Lead Stannate (C)	29
FIGURE 7 Ballistic Properties of Smokeless HMX Plastisol Propellants Containing Chemically (HDI) and Heat Treated Lead Stannate (C)	30

CONFIDENTIAL

CONFIDENTIAL

(C) TABLE OF CONTENTS (Cont'd)

FIGURE 8	Ballistic Properties of Smokeless HMX Plastisol Propellants Containing Chemically (TDI) and Heat Treated Bismuth Stannate (C)	31
FIGURE 9	Ballistic Properties of Smokeless HMX Plastisol Propellants Containing Chemically (HDI) and Heat Treated Bismuth Stannate (C)	32
FIGURE 10	Ballistic Properties of Extruded Smokeless Propellants Containing 54% RDX Modifiers: Lead Beta Resercylate, Cupric Salicylate (C)	33
FIGURE 11	Ballistic Properties of Extruded Smokeless Propellants Containing 56% HMX Modifiers: Lead Beta Resercylate, Cupric Salicylate (C)	34
FIGURE 12	Ballistic Properties of Extruded Smokeless Propellants Containing 54% RDX Modifier: Lead Stannate - TDI (Reduced) (C)	35
FIGURE 13	Ballistic Properties of Extruded Smokeless Propellants Containing 54% RDX Modifier: Lead Stannate - TDI (Oxidized) (C)	36
FIGURE 14	Ballistic Properties of Extruded Smokeless Propellants Containing 56% HMX Modifier: Lead Stannate - TDI (Oxidized) (C)	37
FIGURE 15	Ballistic Properties of Extruded Smokeless Propellants Containing 56% Fine HMX Modifier: Lead Stannate - TDI (Oxidized) (C)	38
FIGURE 16	Ballistic Properties of Extruded Smokeless Propellants Containing 56% HMX Modifier: Lead Stannate - TDI (Reduced) (C)	39
FIGURE 17	Ballistic Properties of Extruded Smokeless Propellants Containing 56% Fine HMX Modifier: Lead Stannate - TDI (Reduced) (C)	40
FIGURE 18	Ballistic Properties of Smokeless HMX Plastisol Propellants Modifier: Lead Stannate as received (C)	41
FIGURE 19	Ballistic Properties of a Cross-Linked Smokeless HMX Plastisol Propellant Modifier: Lead Stannate as received (C)	42
FIGURE 20	Ballistic Properties of A Smokeless HMX Plastisol Propellant Modifier: Lead Stannate - TDI (Oxidized) (C)	43

CONFIDENTIAL

CONFIDENTIAL

(C) TABLE OF CONTENTS (Cont'd)

FIGURE 21	Ballistic Properties of A Smokeless HMX Plastisol Propellant Modifier: Lead Stannate - TDI (Reduced) (C)	44
FIGURE 22	Ballistic Properties of A Cross-Linked Smokeless HMX Plastisol Propellant Modifier: Lead Stannate - TDI (Oxidized) (C)	45
FIGURE 23	Ballistic Properties of A Cross-Linked Smokeless HMX Plastisol Propellant Modifier: Lead Stannate - TDI (Reduced) (C)	46
FIGURE 24	Effect of Changes in Ball Powder/Casting Solvent Ratio Upon the Burning Rate of Smokeless HMX Plastisol Propellants Modifier: Lead Stannate - TDI (Reduced) (C)	47
FIGURE 25	Effect of Changes in Ball Powder/Casting Solvent Ratio Upon the Burning Rate of Smokeless HMX Plastisol Propellants Modifier: Lead Stannate as received (C)	48
FIGURE 26	Effect of HMX Concentration on Pressure-Temperature Dependency of Burning of High Energy Smokeless Plastisol Double-Base Propellants	49
FIGURE 27	Effect of Concentration of Lead Stannate - TDI (Oxidized) Upon Ballistic Properties of High Energy Smokeless HMX Plastisol Propellants (C)	50
FIGURE 28	Effect of Concentration of Lead Stannate - TDI (Reduced) Upon Ballistic Properties of High Energy Smokeless HMX Plastisol Propellants (C)	51
FIGURE 29	Effects of Changes in Calorific Levels Upon Ballistic Properties of High Energy Smokeless HMX Plastisol Propellants (C)	52

CONFIDENTIAL

CONFIDENTIAL

(C) ABSTRACT

Studies leading toward the development of new combustion catalysts which are very effective in reducing the temperature and pressure dependency of burning rate of high energy (230 - 240 lb-sec/lb) smokeless nitramine (RDX, HMX) propellants are discussed.

Described are the methods of manufacture, proposed reactions and analytical and X-ray diffraction data of the new combustion catalysts.

Strand burning rate data are presented for extruded and plastisol (cross-linked and uncross-linked) propellants. The results show the highly effective nature of the new combustion catalysts in reducing the variability of burning rate to changes in temperature and pressure of these propellant types. Propellants investigated have application for close support and other weapon systems where high performance and smokelessness are required.

CONFIDENTIAL

CONFIDENTIAL

(C) CONCLUSION

Two new combustion catalysts have been developed which are extremely effective in reducing the variability of burning rate to changes in temperature and combustion pressure of high energy (230 - 240 lb-sec/lb) nitrocellulose based rocket propellant formulations.

The catalysts are prepared by high temperature sintering of a complex of lead stannate and 2,4 - tolylenediisocyanate and are identified as lead stannate - TDI (Reduced) and lead stannate - TDI (Oxidized). They appear to be mixtures comprised of an ammono complex of lead or tin of unknown structure and oxides of lead and tin with and without carbon and metallic lead.

These combustion catalysts have been found to induce vastly improved burning rate behavior to high energy smokeless nitramine (RDX, HMX) double-base plastisol and extruded rocket propellants. Propellants with the new combustion catalysts have displayed substantially reduced variation in burning rate to temperatures (160°F to -40°F) and pressure over useful pressure ranges (plateau ballistics and low temperature coefficients).

CONFIDENTIAL

CONFIDENTIAL

(C) RECOMMENDATIONS

It is recommended that the high energy smokeless nitramine double-base propellants described in this report be considered as candidate propellants for advanced close support systems and other applications where smokelessness and ballistic reliability are prime requisites.

It is also recommended that research concerning the new catalyst development and their evaluation in smokeless high energy propellants be actively pursued and that the work include (1) investigations with other metal organic and inorganic combustion catalysts employing the chemical and heat treating techniques described in this report and (2) other related avenues of catalyst research.

Furthermore, it is recommended that supply sources be established for the combustion catalysts, lead stannate - TDI (Oxidized) and lead stannate - TDI (Reduced) to meet any future anticipated demands for these catalysts in propellant systems.

CONFIDENTIAL

CONFIDENTIAL

(C) INTRODUCTION

One of the critical factors effecting solid propulsion system design and operational reliability over a wide temperature range is the ballistic behavior of the propellant composition. Maximum performance is obtained with propellants which display a minimum variation of burning rate with combustion pressure and environmental temperature. For these reasons, propellants are constantly being sought which have the lowest possible burning rate vs pressure isotherm slopes and the least variation of burning rate with operational temperatures.

During the 1940's it was discovered that aliphatic lead compounds would modify the burning rate (plateau and mesa burning) of double-base compositions. Since that time investigations with ballistic modifiers has continued unceasingly and the number and types of compounds has been extended which yield ballistic modification in double-base propellants. Almost exclusively, metalo organo and inorganic compounds of lead with chelated derivatives were found to be the most effective combustion catalysts for these propellants (Ref. 1,2).

Over the past ten years, research at Picatinny Arsenal in this area has been with nitramine (RDX, HMX) nitrocellulose base propellants of high volumetric impulse of the following types:

- (a) Extruded smokeless nitramine double-base propellants.
- (b) Plastisol (cast-type) smokeless nitramine double-base propellants.
- (c) Cross-linked plastisol (cast-type) smokeless nitramine double-base propellants.

Efforts to improve the burning rate behavior of these high energy propellants with ballistic modifiers ordinarily employed in double-base systems (metalo organic and inorganic salts) met with only limited success (Ref. 3 and 4). The most efficient ballistic modification was obtained with solvent extruded type systems. Plastisol (cast type) systems, which employ Fluid Ball Powder as the polymeric binder resisted nearly all attempts at ballistic modification. For this system, lead and bismuth stannate dihydrate were found to be the most effective combustion catalysts (Ref. 3, 5, 6, 7, 8). Cross-linked plastisol (cast type) propellants resisted all attempts toward being ballistically controlled with currently known combustion catalysts.

Difficulties in effective ballistic modification of high energy smokeless nitramine double-base propellants was not unexpected since the efficiency of ballistic modification of different propellant types is known to vary because of the many factors which can influence modifying activity. The concentration, proportion, and types of propellant ingredients, the type of ballistic modifier and its relative distribution in a composition, the method of manufacture, and energy, are all significant in affecting the extent of modifying activity.

CONFIDENTIAL

The subject matter of this report covers an area of combustion catalyst research performed at the Propellant Laboratory, Picatinny Arsenal. Described are the studies made toward the development of new combustion catalysts for cross-linked and uncross-linked high energy smokeless nitramine double-base propellants which would impart to these systems the desirable ballistic quality of invariance of burning rate to changing temperature and combustion pressure conditions.

The propellants evaluated are considered thermally stable according to short term heat tests at 120°C (no deflagration after 500 minutes exposure) and they exhibited reasonably good to exceptionally good mechanical properties between 140°F and -40°F. (Tensile strength at 140°F ranged between 30 and 130 psi and elongations at maximum load at -40°F were between 20 and 60 per cent.)

CONFIDENTIAL

CONFIDENTIAL

(C) DISCUSSION

The results of investigations with the combustion catalysts are presented in three parts:

1. Synthesis and evaluation of new combustion catalysts.
2. Evaluation of new combustion catalysts as ballistic modifiers in solvent extruded type high energy smokeless nitramine double-base systems and high energy plastisol (cast type) smokeless nitramine double-base propellants.
3. Effect of composition parameters upon ballistic properties of plastisol type propellants containing the new combustion catalysts.

Synthesis and Evaluation of New Combustion Catalysts

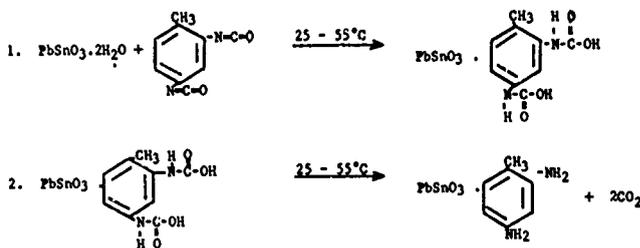
The investigation was oriented about the synthesis of organo isocyanate complexes of lead and bismuth stannate and the determination of the effects of heat treatment upon the complexes and also the original lead and bismuth stannates. Hydrated lead and bismuth stannate were selected as the metalo inorganic salts in these studies because they displayed the most effective modifying activity in higher energy plastisol type compositions in previous investigations (Ref. 3, 5, 6, 7, 8).

The following thirteen modifiers were investigated: (a) lead stannate dihydrate (as received), (b) lead stannate (heated at 450 - 500°C), (c) lead stannate - TDI complex, (d) lead stannate - TDI (oxidized), (e) lead stannate - TDI (reduced), (f) lead stannate - HDI complex, (g) lead stannate - HDI (oxidized), (h) bismuth stannate dihydrate (as received), (i) bismuth stannate (heated at 450 - 500°C), (j) bismuth stannate - TDI complex, (k) bismuth stannate - TDI (oxidized), (l) bismuth stannate - HDI complex, (m) bismuth stannate - HDI (oxidized). The nature of lead and bismuth stannate dihydrate and their heated counterparts are self-explanatory. The remaining modifiers were synthesized in the laboratory according to Procedures I, II, and III shown in Appendix A.

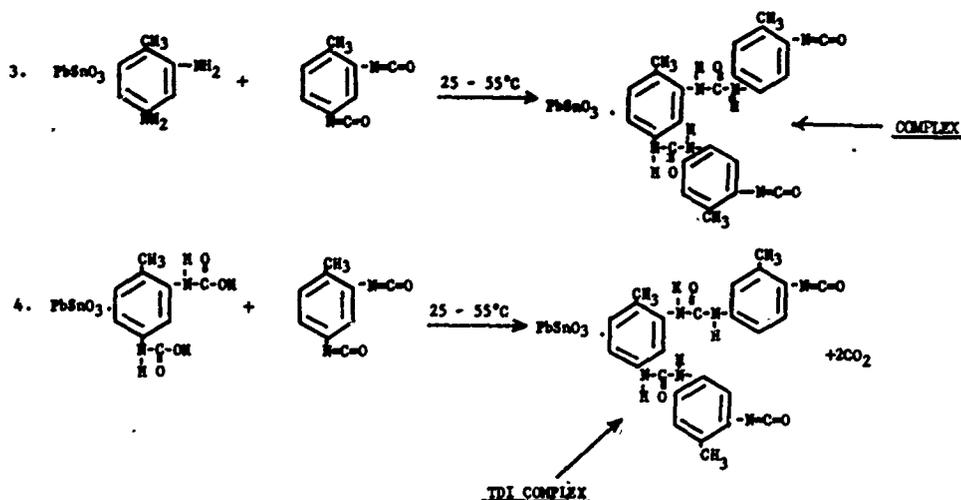
Proposed reactions for formation of the lead stannate - TDI complex and oxidized and reduced forms of lead stannate - TDI complexes are indicated below:

Reactions for Formation of Modifiers

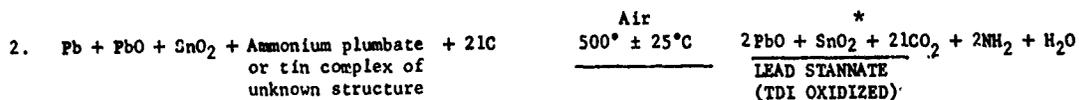
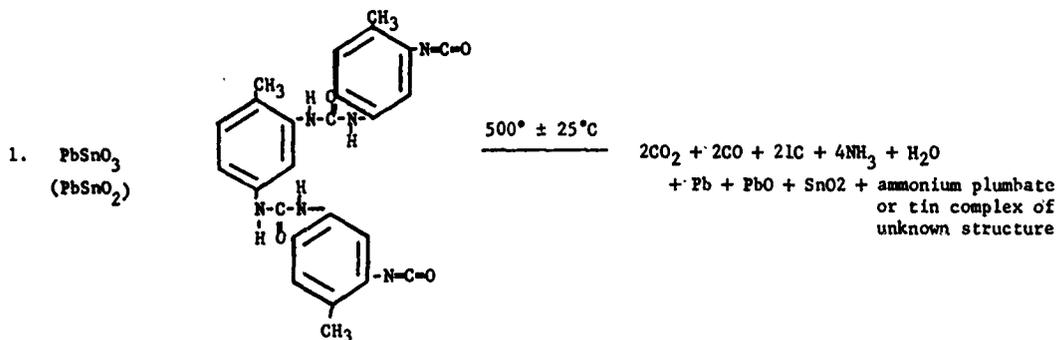
PROPOSED REACTION FOR FORMATION OF LEAD STANNATE (TDI COMPLEX)



CONFIDENTIAL



PROPOSED REACTION FOR FORMATION OF LEAD STANNATE
(2,4, TOLYLENE DIISOCYANATE OXIDIZED)

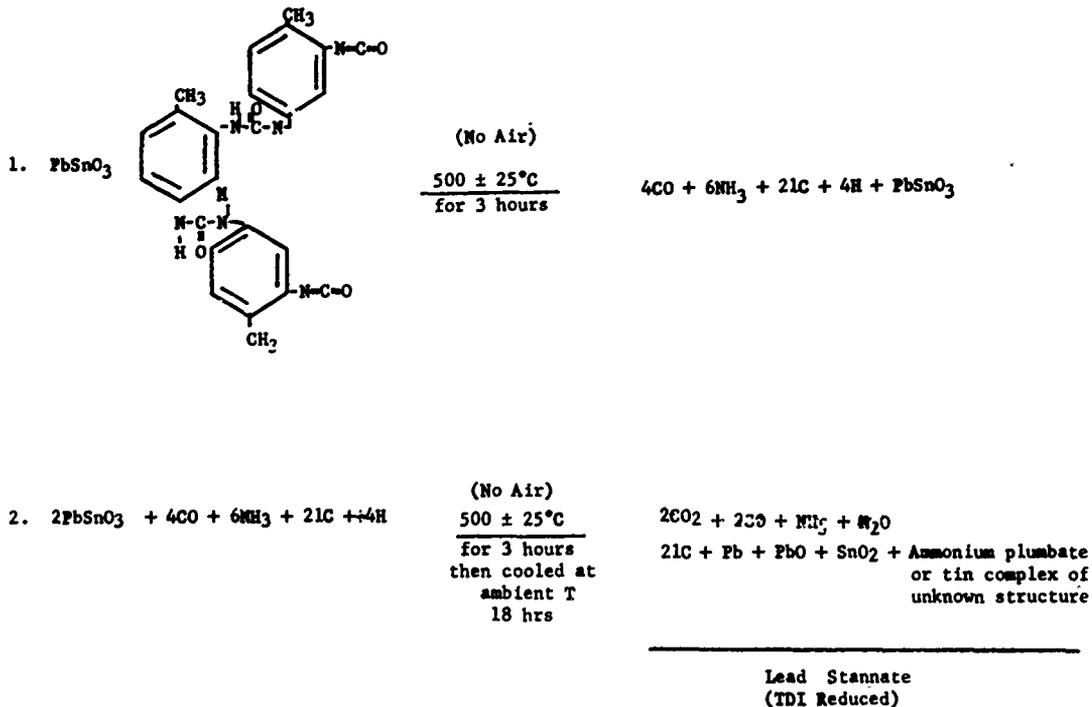


* Trace quantities of ammonium plumbate or tin complex of unknown structure.

CONFIDENTIAL

CONFIDENTIAL

PROPOSED REACTION FOR FORMATION OF LEAD STANNATE (2-4, TOLYLENE DIISOCYANATE REDUCED)



Chemical, physical, IR and X-ray diffraction analysis performed on the potential ballistic modifiers under study are shown in Tables I thru IV and Figures 1 thru 5. Though, complete analysis are not available for all the lots of combustion catalysts prepared in this investigation, the data shown is expected to be typical for these types of combustion catalysts.

The IR and x-ray diffraction data obtained indicate that heat treating or complexing the hydrates of lead or bismuth stannate with diisocyanates did not chemically alter the composition of inorganic salts as shown in Tables I and II and Figures 1 thru 5. However, by heat treating the diisocyanate complex of these salts, some changes in the composition of the basic inorganic salts (lead stannate or bismuth stannate) did occur. The chemical changes obtained varied with the type of organic fraction comprising the complex. Heat treatment of the TDI and HDI complexes of bismuth stannate resulted in the formation of a catalyst comprised of a mixture of bismuth stannate and stannic oxide. The organic fraction of these complexes was comprised essentially of a disubstituted urea without isocyanate termination. When the lead stannate - TDI complex was heated in the absence or presence of air, a chemical change occurred in the base salt resulting in the formation of catalysts comprised of lead oxide (yellow) and stannic oxide

CONFIDENTIAL

with and without carbon and metallic lead and an ammono complex of lead or tin of unknown structure. The organic fraction of the lead stannate - TDI complex was an isocyanate terminated disubstituted urea. On the other hand, the lead stannate - HDI complex when heat treated did not result in a chemical change of the inorganic salt. In the case of this complex, the organic fraction was a disubstituted urea without isocyanate termination. On the basis of these data it appears that the presence of $N=C=O$ in sufficient quantity in the organic fraction of a metal inorganic salt - isocyanate complex is necessary to promote breakdown of the salt to oxides of metals during heat treatment. The reaction in the process of heating the metal inorganic salt - isocyanate complexes is one of (1) reduction then (2) subsequent oxidation of the reduced product to the metal oxides. The $N=C=O$ in the organic fraction of the complex may (a) act as a catalyst to promote the formation of a reducing medium for reduction of the inorganic fraction of the complex or (b) during heating it may decompose and/or react with other products of decomposition and be the prime contributor of the reducing medium for the reduction of the inorganic salt.

Evaluation of New Combustion Catalysts as Ballistic Modifiers in High Energy Smokeless Nitramine Double-Base Propellants

Preliminary Studies:

The thirteen (13) combustion catalysts, namely; hydrates of lead and bismuth stannate (as received and heated at 450 - 500°C), lead and bismuth stannate TDI and HDI complexes, lead and bismuth stannate - TDI and HDI (oxidized) and lead stannate - TDI (reduced), were evaluated initially for their effectiveness as potential ballistic modifiers in high energy smokeless HMX plastisol propellants. The results of strand burning rate studies, shown in Figures 6 thru 9, indicate that only two of the combustion catalysts, lead stannate - TDI (oxidized) and lead stannate - TDI (reduced) were highly effective in reducing the dependency of burning rate with pressure for the uncross-linked HMX plastisol propellants. The remaining combustion catalysts exhibited "straight line" ballistics which bordered between being the minimum acceptable to non-acceptable in quality.

In view of the encouraging burning rate results obtained with the systems modified with lead stannate - TDI (oxidized) and (reduced), a more extensive evaluation was made with these combustion catalysts in high energy smokeless extruded and cross-linked and uncross-linked plastisol (cast type) nitramine double-base propellants.

High Energy Extruded Smokeless Nitramine Double-Base Propellants

Of the three types of high energy propellants considered for investigation, the extruded type was chosen for initial scale-up evaluation of the new combustion catalysts. With this propellant type (prepared by solvent or solvent-solventless methods), intimate distribution of the catalyst could be realized in the propellant matrix. Consequently, any ballistic information generated with these systems would, to a great extent, indicate maximum ballistic activity imparted by these catalysts in high energy systems.

CONFIDENTIAL

Two versions of solvent extruded propellants were utilized in these studies, containing 54% and 56% RDX and HMX respectively. Previous ballistic results with these systems with a combination of cupric salicylate and lead beta resorcyate as modifiers is shown in Figures 10 and 11. Pressure exponents exhibited by these systems were 0.48 (530 - 2000 psi) respectively at 70°F and temperature coefficients of pressure at 1000 psi (p/r of 2500 and 2700) of 0.16 and 0.44 between 160 and -40°F. The ballistic properties of these systems were considered the maximum activity that can be realized with currently known modifiers. These data point out the inability of usual double-base combustion catalysts to effectively control the ballistics of high energy smokeless nitramine double-base propellants.

In the evaluation of the new combustion catalysts, a direct substitution was made for the original modifiers employed in the propellants. The RDX system, modified with lead stannate - TDI (oxidized) and lead stannate - TDI (reduced), showed a vast reduction in the temperature dependency of burning rate with pressure. The data, shown in Figures 12 and 13, indicate that of the two catalysts, the reduced form of lead stannate - TDI complex was the most effective combustion catalyst. In addition to increasing the burning rate of the propellant, plateau ballistics were indicated. A burning rate isotherm slope at 70°F of 0.00 (800 - 1200 psi), and a temperature coefficient of pressure of 0.02%/°F (1000 psi, P/r 2080) between 160 and -40°F was obtained. The system with the oxidized form of lead stannate - TDI complex had a pressure exponent of 0.40 (100 - 1700 psi) at 70°F and a temperature coefficient of pressure of 0.045%/°F (1000 psi, P/r 2500) between 160 and -40°F.

Next, an evaluation was made of the combustion catalysts in 56% HMX compositions containing a bimodal distribution of filler (75% 180u and 25% 2u) and all fine HMX of 2u average particle size. Strand burning rate data for these systems, shown in Figures 14 thru 17, indicate that both the combustion catalysts, lead stannate - TDI (oxidized) and lead stannate - TDI (reduced), were highly effective in improving the ballistic properties of these propellants. In comparing the strand burning rate data, the systems with fine particle size HMX exhibited lower pressure exponents and lower temperature coefficients of pressure than similar propellants containing a bimodal distribution of HMX.

The data presented thus far show the effectiveness of the new combustion catalysts lead stannate - TDI (oxidized) and lead stannate - TDI (reduced) as ballistic modifiers for extruded type high energy smokeless RDX and HMX containing double-base propellants with calorific levels of 1137 - 1148 cal/g and specific impulses of 230 + lb-sec/lb.

High Energy Plastisol (Cast Type) Smokeless Nitramine Double-Base Propellants

The plastisol propellants evaluated are of the pourable case bonded smokeless nitramine double-base type. From a composition standpoint, the basic difference between this propellant type and the extruded version is the physical appearance of the nitrocellulose binder in finished propellants. This variation

CONFIDENTIAL

in the appearance of the binder results from differences in (1) the starting binder materials (nitrocellulose) and (2) methods of manufacture. The extruded type systems employ nitrocellulose of fibrous character. During manufacture, by either solvent or solventless techniques, it is well worked and efficiently colloidized by solvents resulting in a binder completely homogeneous in appearance. Also, because of the nature of the mixing techniques employed to manufacture these propellants, (prepared in horizontal sigma blade mixer) very thorough distribution of propellant additives can be realized within a propellant matrix.

The plastisol systems, on the other hand, employ as a binder material Fluid Ball Powder which is a regenerated form of nitrocellulose of 7 to 20 microns in diameter. The compositions of the Fluid Powder can vary from basically all nitrocellulose to a variety of liquid nitrate ester-nitrocellulose combinations. This latter type was employed as the binder ingredient in the systems reported. Plastisol propellants, because of their high fluidity are more conveniently prepared in vertical mixer types. This type of mixing provides good suspension of the propellant ingredients but does not macerate sufficiently for efficient colloidizing of the Fluid Ball Powder binder material. Actually, with these systems, colloidizing occurs between the high energy plasticizer and Fluid Ball Powder principally during the propellant cure cycle. Therefore, thorough distribution of the solvated or colloidized portion of the fluid ball powder throughout the propellant matrix is inhibited. Because of these characteristics, ballistic modification of these systems becomes more difficult.

Cross-linking of plastisol type propellants complicates ballistic modification even further. Cross-linking is desired because of its ability to improve propellant mechanical properties. However, in many cases, during the cross-linking process side reactions occur between diisocyanate cross-linkers and metallo-organic and inorganic compounds. These interactions diminish the effectiveness of ballistic modifiers in these systems. Typical burning rate data for uncrosslinked and cross-linked high energy smokeless HMX plastisol propellants catalyzed with lead stannate (as received) are shown in Figures 18 and 19. For the uncrosslinked system, straight line ballistics are indicated with a pressure exponent, "n", at 70°F of 0.40 (1000 to 1800 psi) and temperature coefficient of pressure of 0.23%/°F at 1000 psi (P/r 2500) between 160 and -40°F. The burning rate data for the cross-linked propellant shows a decided degradation of ballistic properties over the uncrosslinked system. Straight line ballistics are indicated with a pressure exponent, "n", at 70°F of 0.61 (400 - 3000 psi) and temperature coefficient of pressure of 0.44%/°F at 1000 psi and P/r 3330 between 160 and -40°F.

The highly effective modifying qualities exhibited by lead stannate - TDI (oxidized) and lead stannate - TDI (reduced) in uncrosslinked plastisol type systems are shown in Figure 6. The results of more intensive studies with these catalysts in cross-linked and uncrosslinked formulations with 30% HMX are shown in Figures 20 through 23. The uncrosslinked systems exhibited pressure ranges where burning rates were nearly independent of changes in pressure and temperature (Figures 20 and 21). Lead stannate - TDI (oxidized) and lead stannate - TDI (reduced) induced pressure exponents, "n", of 0.06 and 0.00 (800 - 1600 psi)

CONFIDENTIAL

CONFIDENTIAL

at 70°F and temperature coefficients of pressure of 0.11 and 0.07%/°F at 1000 psi (P/r 2325 and 2270) between 160 and -40°F respectively. The cross-linked systems, shown in Figures 22 and 23 also exhibited very favorable ballistics. Lead stannate - TDI (oxidized) and lead stannate - TDI (reduced) induced pressure exponents, "n", of 0.16 and 0.10 (1000 - 1800 psi) at 70°F and temperature coefficients of pressure at 1000 psi of 0.14 and 0.22%/°F (P/r 2200 and 2500) between 160 and -40°F respectively. Improvements in the ballistic properties of the cross-linked formulations were not as good as that obtained with the uncross-linked systems. However, compared to the previous ballistic properties of cross-linked compositions, the new catalysts contribute substantial improvements in burning rate control.

Effect of Composition Parameters Upon Ballistic Properties of Plastisol Type Propellants

The following parameters were investigated: changes in (1) Fluid Ball Powder/casting solvent ratio, (2) concentration of HMX, (3) concentration of combustion catalyst and (4) propellant calorific level. The burning rate results obtained in these studies are shown in Figures 24 to 29 and can be summarized as follows:

Fluid Ball Powder/Casting Solvent Ratio

The burning rates at 1000 psi of high energy smokeless HMX plastisol propellants containing lead stannate - TDI (reduced) can be varied by modifying the powder/solvent ratio (Figure 24). A 25% increase in burning rate (0.40 to 0.50 in/sec, at 70°F and 1000 psi) is reflected in the propellants with a change in powder/solvent ratio from 0.27 to 0.67. Previously the burning rates of these propellants were essentially invariant to changes in powder solvent ratio (Figure 25).

HMX Concentration

The extent of temperature dependency of burning rate with pressure of high energy smokeless HMX plastisol propellants containing lead stannate - TDI (reduced) is a function of concentration of HMX (Figure 26). As the concentration of HMX in the propellants is increased, from 0 to 35 percent in 5 percent increments, the burning rates become more independent to variations in temperature and pressure. "Straight line" ballistics are exhibited with the systems containing 0 to 25 percent HMX, "plateau" ballistics at approximately 30 percent HMX and "mesa" ballistics at concentrations of HMX greater than 30 percent.

Combustion Catalyst Concentration

The minimum concentration for effective catalysis of the smokeless propellants is approximately 2.0 percent of combustion catalysts lead stannate - TDI (oxidized) or lead stannate - TDI (reduced) (Figures 27 and 28). At 2.0% catalyst concentration, these systems exhibited pressure exponents at 70°F of 0.17 and 0.09 over pressure ranges of 700 to 1700 psi and 600 - 1350 psi respectively.

CONFIDENTIAL

(C) EXPERIMENTAL PROCEDURE

General

In the laboratory, one pound batches of propellants were prepared in the Baker Perkins (one pint capacity) vertical sigma blade mixer. The propellants were mixed under a vacuum of 2 to 4mm Hg for approximately one hour. The propellant is cast into appropriate molds and cured at 60°C for three days. Strand burning rate data was obtained by means of a Crawford Type S Strand Burner.

Laboratory Procedure for Preparation of Cross-Linked and Uncrosslinked Smokeless Nitramine Containing Plastisol Propellants

1. To casting solvent add resorcinol, if required, and Type B Fluid Ball Powder and let stand overnight at 70°F.
2. Add mixture in (1) to mixer.
3. Add HMX, modifier, "quick-gel" (Type C Fluid Ball Powder), and 2,4-toluylene diisocyanate, if required, with mixing between additions.
4. Mix at a speed of 36 rpm for approximately one hour at 25 - 30°C and a vacuum of 2-4mm Hg.
5. Cast at a viscosity of approximately 40,000 cps and cure at 60°C for three days. (Viscosity measured with Brookfield Viscometer - Spindle 6 and Setting 10).

Laboratory Procedure for Preparation of Extruded Smokeless Nitramine Containing Double-Base Propellants

The propellants are made according to small arms techniques. Mixing is performed in a horizontal Baker Perkins Sigma Blade Mixer and the Propellants solvent extruded and air dried.

CONFIDENTIAL

CONFIDENTIAL

Materials

- a. Fluid Ball Powders, Type B Lot 14528-30 and Type C Lot 2161
Supplied by Olin Mathieson Chemical Corporation
Average particle size of Ball Powder Lot 14528-30, 7 microns
Determined by Optical Count Method

<u>Composition of Fluid Ball Powders</u>	<u>Lot 14528-30</u>	<u>Lot 2161</u>
Nitrocellulose, 12.6%N, %	90.0	74.0
Nitroglycerin, %	8.0	24.0
2-nitrodiphenylamine, %	2.0	2.0
Diethylphthalate, added, %	0.2	0.1
Carbon Black, added, %	0.3	—

- b. Casting Solvent "X" (High Energy Plasticizer)
Prepared at Picatinny Arsenal
Triethyleneglycoldinitrate supplied by Propellex & Hercules Powder Co.
Butanetrioltrinitrate supplied by Amcel Propulsion Co.

<u>Composition of Casting Solvent "X"</u>	<u>%</u>
Triethyleneglycoldinitrate	65.0
Butanetrioltrinitrate	34.0
2-nitrodiphenylamine	1.0

- c. HMX (cyclotetramethylenetetranitramine)
Class E and Class A
Average particle size, 2 microns and 180 microns respectively
Determined by Optical Count Method
Supplied by Holston Ordnance Works
- d. RDX (cyclotrimethylenetrinitramine)
Class E
Average particle size, 14 microns
Supplied by Holston Ordnance Works
- e. Nitroglycerin
Supplied by Picatinny Arsenal
- f. Nitrocellulose, 12.6%N
Supplied by DuPont deNemours Inc.

CONFIDENTIAL

- g. TDI (2,4-tolylene diisocyanate)
Supplied by Eastman Organic Chemical Company
- h. Lead stannate (Lot P 10707)
Supplied by National Lead Co.
- i. Lead stannate - TDI Complex
Prepared at Picatinny Arsenal according to Procedure I outlined
in Appendix A of this report
- j. Lead stannate - TDI (Oxidized)
Prepared at Picatinny Arsenal according to Procedure II
outlined in Appendix A of this report
- k. Lead Stannate - TDI (Reduced)
Prepared at Picatinny Arsenal according to Procedure III
outlined in Appendix A of this report
- l. Lead stannate - Hexamethylene diisocyanate Complex
Prepared at Picatinny Arsenal according to Procedure I
outlined in Appendix A of this report
- m. Lead stannate - HDI (Oxidized)
Prepared at Picatinny Arsenal according to Procedure II
outlined in Appendix A of this report
- n. Bismuth stannate - TDI Complex
Prepared at Picatinny Arsenal according to Procedure I
outlined in Appendix A of this report
- o. Bismuth stannate - TDI (Oxidized)
Prepared at Picatinny Arsenal according to Procedure II
outlined in Appendix A of this report
- p. Bismuth stannate - HDI Complex
Prepared at Picatinny Arsenal according to Procedure I
outlined in Appendix A of this report

CONFIDENTIAL

- q. Bismuth stannate - HDI (Oxidized)
Prepared at Picatinny Arsenal according to Procedure II
outlined in Appendix A of this report

- r. Bismuth stannate
Supplied by Metal Thermite Corporation

- s. Cupric salicylate and lead beta resorcylate
Supplied by National Lead Co.

- t. Carbolac, carbon black, resorcinol, 2-nitrodiphenylamine, and
triacetin are items used without purification

NOTE: The citation of trade names or manufacturers does not
constitute an official endorsement or approval of their use.

CONFIDENTIAL

(C) APPENDIX A

Procedure I

Preparation of Lead and Bismuth Stannate Complexes of 2,4-tolylene diisocyanate and Hexamethylene diisocyanate

1. Add hydrate of lead or bismuth stannate to an excess of 2,4-tolylene diisocyanate or hexamethylene diisocyanate in increments while mass is agitating.
2. Mix for one hour at 25 to 55°C.
3. Filter and wash filtercake once with acetone.
4. Place filtercake in suitable container, add acetone and agitate for 10 minutes and filter.
5. Repeat step (4) three or four times.
6. Dry Filter cake for three hours at 100°C.

NOTE: Organic matter as determined by sintering a sample of the complex from (6) in air at 450 - 500°C for one hour was as follows: lead stannate - TDI complex, 17-25%; lead stannate - HDI complex, 11.6%; bismuth stannate - TDI complex, 9.3%; bismuth stannate - HDI complex, 15.3%.

Procedure II

Preparation of Lead and Bismuth Stannate - TDI and HDI (Oxidized)

1. Place lead or bismuth stannate-isocyanate complex (obtained in procedure I, step 6) in a suitable container and heat at 450 - 500°C in a muffle furnace with door ajar until decomposition is complete (Decomposition is complete when smoking ceases). Decomposition should not be accompanied by flame.
2. Remove the sintered product in (1) from the muffle furnace and turn the mass over to permit underlying material to be near completely oxidized.
3. Place the semi-oxidized product from (2) in muffle furnace and heat for one hour at 450 - 500°C.
4. Remove from muffle furnace, cool at ambient temperature, then screen the oxidized combustion catalysts through a 400 mesh sieve.

Procedure III

Preparation of Lead Stannate - TDI (Reduced)

1. Place lead stannate - TDI complex (obtained in Procedure I, step 6) in a suitable vented vessel (container covered with aluminum foil with slits

CONFIDENTIAL

CONFIDENTIAL

on top was found workable) and heat essentially in the absence of air at 450 - 500°C in a muffle furnace with door ajar until smoking ceases. Decomposition should not be accompanied by flame.

2. Immediately after decomposition is complete (smoking ceases), close vent on vessel containing modifier and heat at 500°C \pm 25°C in the absence of air for approximately two hours. (Covering container containing modifier with aluminum foil was found suitable).

3. After heating is completed, remove covered container with lead stannate - TDI (Reduced) from muffle furnace and let cool overnight at ambient temperature.

4. Screen lead stannate - TDI (Reduced) through 400 mesh sieve.

CONFIDENTIAL

(C) REFERENCES

1. Robert P. Baumann, "Investigation of Ballistic Modifiers for High Energy Solid Rocket Propellants", Feltman Research Laboratories, Picatinny Arsenal, Technical Note No. FRL-TN-32, dated January 1961. (C)
2. Robert P. Baumann, "Investigation of Ballistic Modifiers for High Energy Solid Rocket Propellants", Feltman Research Laboratories, Picatinny Arsenal, Technical Note No. FRL-TN-127, dated February 1962. (C)
3. Robert P. Baumann, "High Volumetric Impulse Smokeless Rocket Propellants. Part I: Preliminary Investigation of HMX Cast Propellant (Plastisol)", Feltman Research Laboratories, Picatinny Arsenal, Technical Report 2601, dated March 1959. (C)
4. William G. Clark and Edward Costa, "High Volumetric Impulse Smokeless Rocket Propellants. Part II: Development of Solventless - Extruded Triple-Base Propellants", Feltman Research Laboratories, Picatinny Arsenal, Technical Memorandum 1004, dated March 1962. (C)
5. Bernard D. Strauss, "A Study of the Burning Rate Characteristics of High Energy Smokeless Nitrocellulose Plastisol Rocket Propellants", Picatinny Arsenal, Technical Memorandum 1231, dated December 1963. (C)
6. Bernard D. Strauss, "An Investigation of Burning Rate Catalysts for High Energy Smokeless Nitrocellulose Plastisol Rocket Propellants", Picatinny Arsenal, Technical Memorandum 1289, dated December 1963. (C)
7. Bernard D. Strauss, "Effect of Oxidizer Particle Size on Smokeless Plastisol Rocket Propellants", Picatinny Arsenal, Technical Memorandum 1624, dated April 1965. (C)
8. Benjamin D. Lehman, "Development of a High Energy Case Bondable Smokeless Plastisol Rocket Propellant", Picatinny Arsenal, Technical Memorandum 1748, dated October 1965. (C)
9. Robert G. Wetton and Frank J. Masuelli, "Minutes of the Second Quarterly Review (1965) of Rocket Propellant Supporting Research held at Picatinny Arsenal", 20 May 1965, Technical Memorandum 1690, Picatinny Arsenal, dated August 1965. (C)

CONFIDENTIAL

CONFIDENTIAL

TABLE I (C)
BALLISTIC MODIFIER (LEAD STANNATE) ANALYSIS (C)

Ballistic Modifier (a)	IR ANALYSIS				X-RAY DIFFRACTION				
	H ₂ O	H O H -N-C-N-	N=C-O	PbSnO ₃	Pb	PbO	PbO	SnO ₂	
Lead Stannate (as received) (740-181-43-3)	X	0	0	X	0	0	0	0	
Lead Stannate heated at 450-500°C for one hour (740-181-43-4)	X	0	0	X	0	0	0	0	
Lead Stannate - TDI complex (740-181-43-2)	X	X	X	X	0	0	0	0	
Lead Stannate - TDI (reduced) *	X	0	0	0	X	X	X	X	
Lead Stannate - TDI (oxidized) *	X	0	0	0	0	X	X	X	
Lead Stannate - HDI complex (740-181-45-6)	X	X	0	X	0	0	0	0	
Lead Stannate - HDI (oxidized) (740-181-45-5)	0	0	0	X	0	0	0	0	

(a) All modifiers screened through 400 mesh sieve

X Presence indicated

0 not indicated

* IR analysis indicates amine present

CONFIDENTIAL

CONFIDENTIAL

TABLE II (C)
CHEMICAL ANALYSIS OF BALLISTIC MODIFIERS (U)

Modifier	%Pb	%PbO	%SnO ₂	%H ₂ O	% Organic Matter	% Carbon	% Nitrogen	% Total
Lead Stannate (dihydrate) P50810 (as received)	—	52.68	38.1	9.6	—	—	—	100.4
Lead Stannate - TDI (reduced) 740-181-64-2	4.5	50.58	40.21	—	—	1.9	0.5	97.69
Lead Stannate - TDI (oxidized) 740-181-65-3	—	55.0	40.3	—	—	0.25	0.026	95.58
Lead Stannate TDI Complex 740-181-65-4	—	46.59	33.5	—	18.6	—	—	96.69
10/10/40/40 mixture C/Pb/PbO/SnO ₂ (740-181-60-3)	10.0	39.29	38.59	—	—	10.0	—	97.88

CONFIDENTIAL

CONFIDENTIAL

TABLE III (C)

PHYSICAL PROPERTIES OF BALLISTIC MODIFIERS (U)

Modifier	Impact (a) Sensitivity, in	(b) M.P., °C	Average Particle Size (c) (microns)	Hydrosonicity		
				30%	40%	50%
Lead Stannate TDI Complex (740-181-57-1)	40+	---	---	---	---	---
Lead Stannate - TDI (Reduced) (740-181-64-2)	40+	d.365	1.4	0.48	3.19	2.91 4.40
Lead Stannate - TDI (Oxidized) (740-181-65-3)	40+	---	2.1	0.47	2.56	2.04 2.69
Lead Stannate (as received) (P-50F10)	---	---	1.1	2.19	2.85	2.90 4.16

(a) P. A. Impact, 2 Kg wt.

(b) Exposed to air. Decomposes to PbO and SnO₂.

(c) Determined by optical count method.

CONFIDENTIAL

CONFIDENTIAL

TABLE IV (C)
BALLISTIC MODIFIER (BISMUTH STANNATE) ANALYSIS (C)

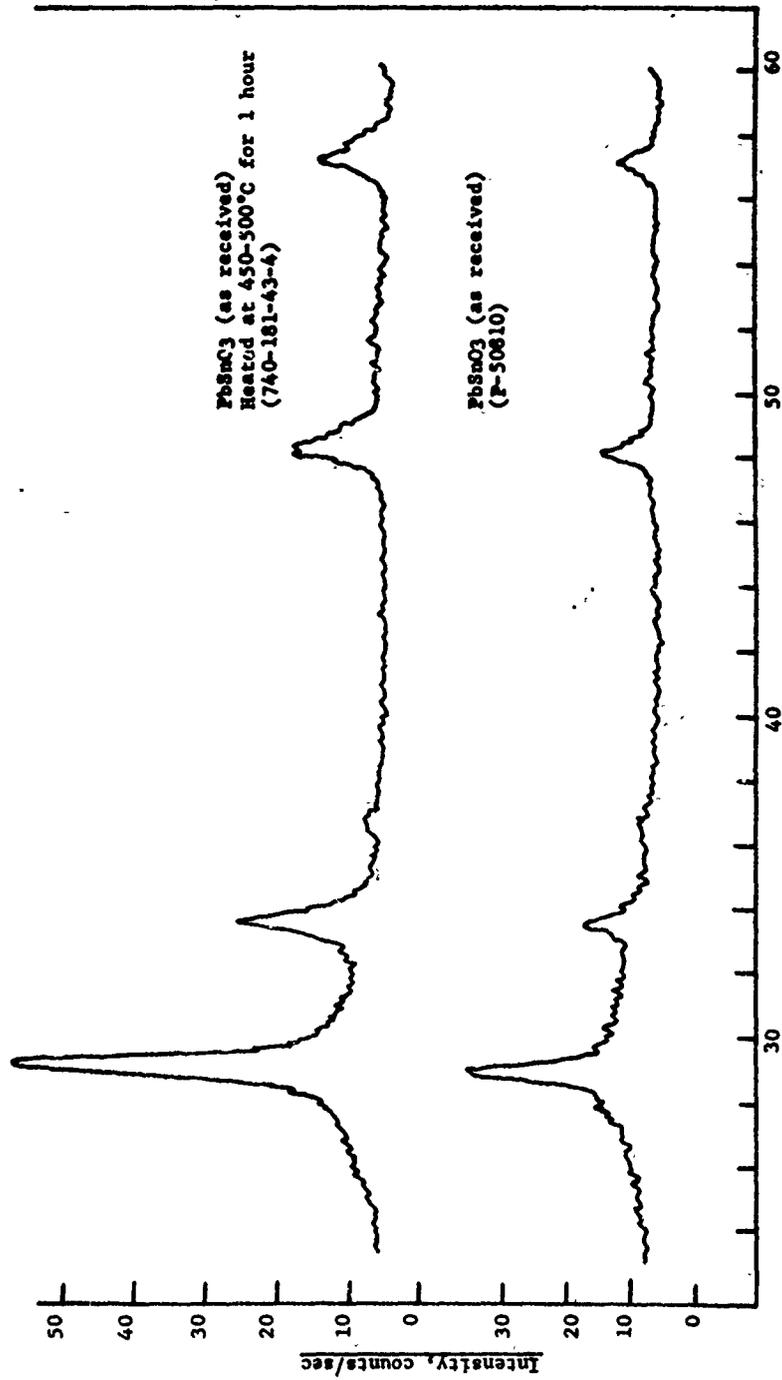
BALLISTIC MODIFIER (a)	IR ANALYSIS				X-RAY DIFFRACTION				CHEMICAL ANALYSIS		
	H ₂ O	H -C- H	N-O-O	Bd ₂ (SnO ₃) ₃	SnO ₂	Bi, %	Sn, %	O ₂ (b)	Consumables, % (c)	Total, %	
Bismuth Stannate (as received) (740-181-45-2)	X	0	0	X	0	42.59	36.60	15.7	4.0(d)	98.89	
Bismuth Stannate heated at 450-500°C for one hour (740-181-45-1)	X	0	0	X	0	45.88	37.65	15.7	---	99.23	
Bismuth Stannate - TDI Complex (740-181-45-3)	X	X	X(e)	X	0	40.91	34.16	15.7	9.3	99.07	
Bismuth Stannate - TDI (Oxidised) (740-181-45-4)	0	0	0	X	X	42.97	37.43	15.7	---	96.10	
Bismuth Stannate - HDI Complex (740-181-45-7)	0	X	0	X	0	36.91	32.30	15.7	15.3	100.21	
Bismuth Stannate - HDI (Oxidised) (740-181-45-8)	0	0	0	X	X	---	---	---	---	---	

(a) All modifiers screened thru 400 mesh sieve
 (b) Theoretical
 (c) Includes H₂O and organic matter
 (d) H₂O
 (e) Very little N-O-O indicated

X Presence indicated
 0 Not indicated

CONFIDENTIAL

**X-RAY DIFFRACTION PATTERNS
UNTREATED AND HEAT TREATED $PbSnO_3$ (C)**



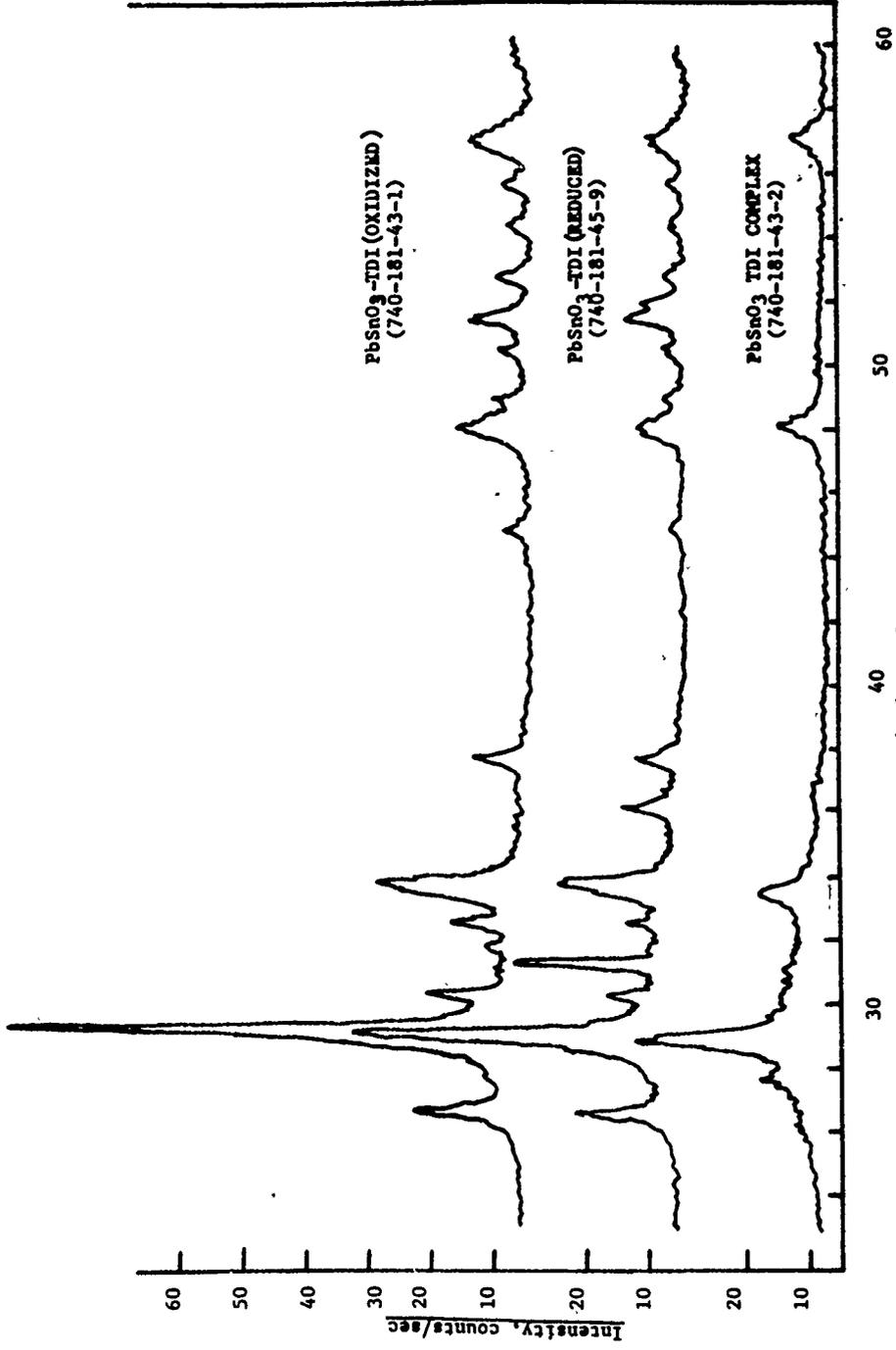
**Angle, 2θ, °
FIGURE 1 (C)**

24

CONFIDENTIAL

CONFIDENTIAL

X-RAY DIFFRACTION PATTERNS
PbSnO₃ TDI COMPLEX - PbSnO₃-TDI (REDUCED) - PbSnO₃-TDI (OXIDIZED) (C)

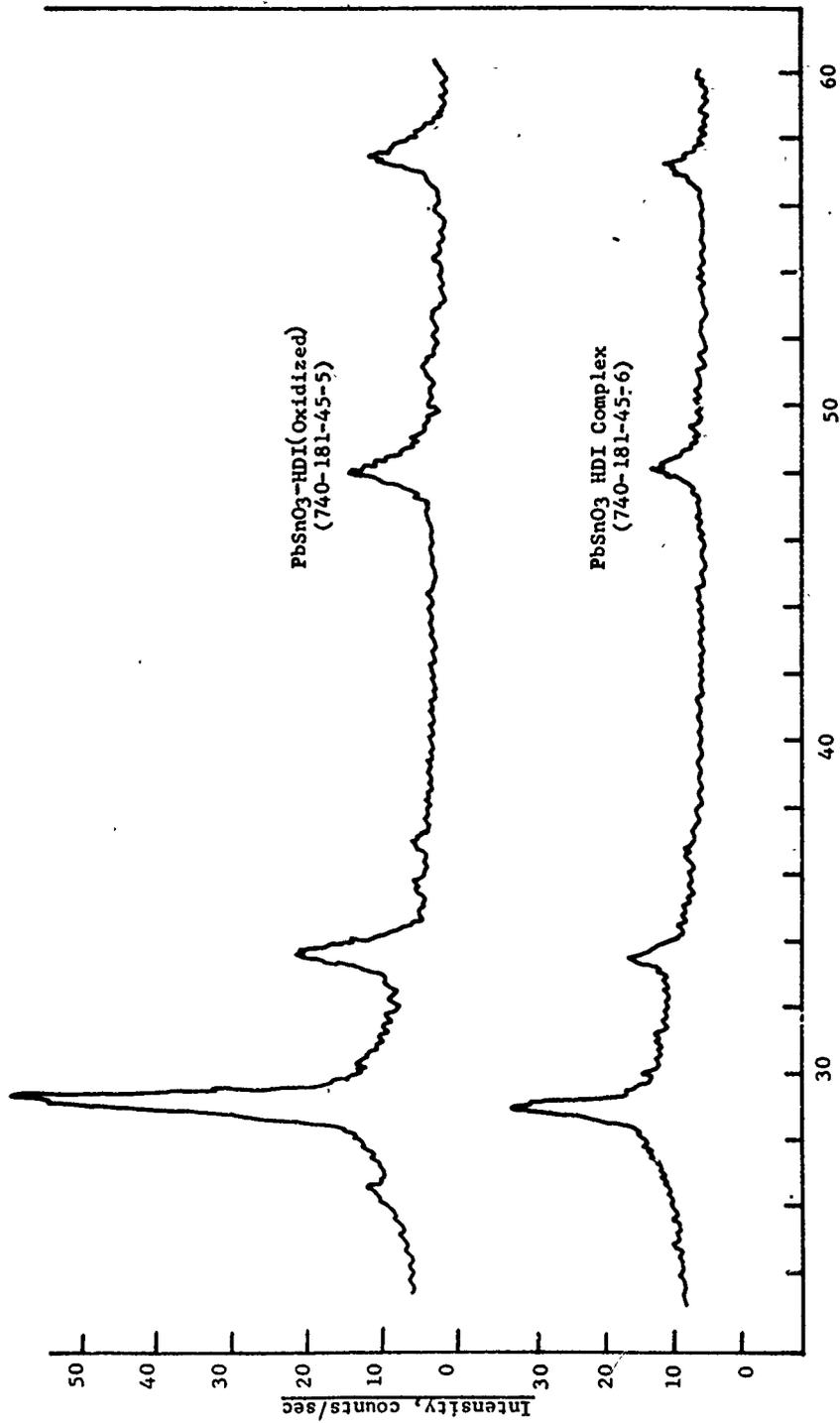


ANGLE, 2θ°
FIGURE 2 (C)
25

CONFIDENTIAL

CONFIDENTIAL

X-RAY DIFFRACTION PATTERNS
PbSnO₃ HDI COMPLEX - PbSnO₃-HDI (OXIDIZED) (C)

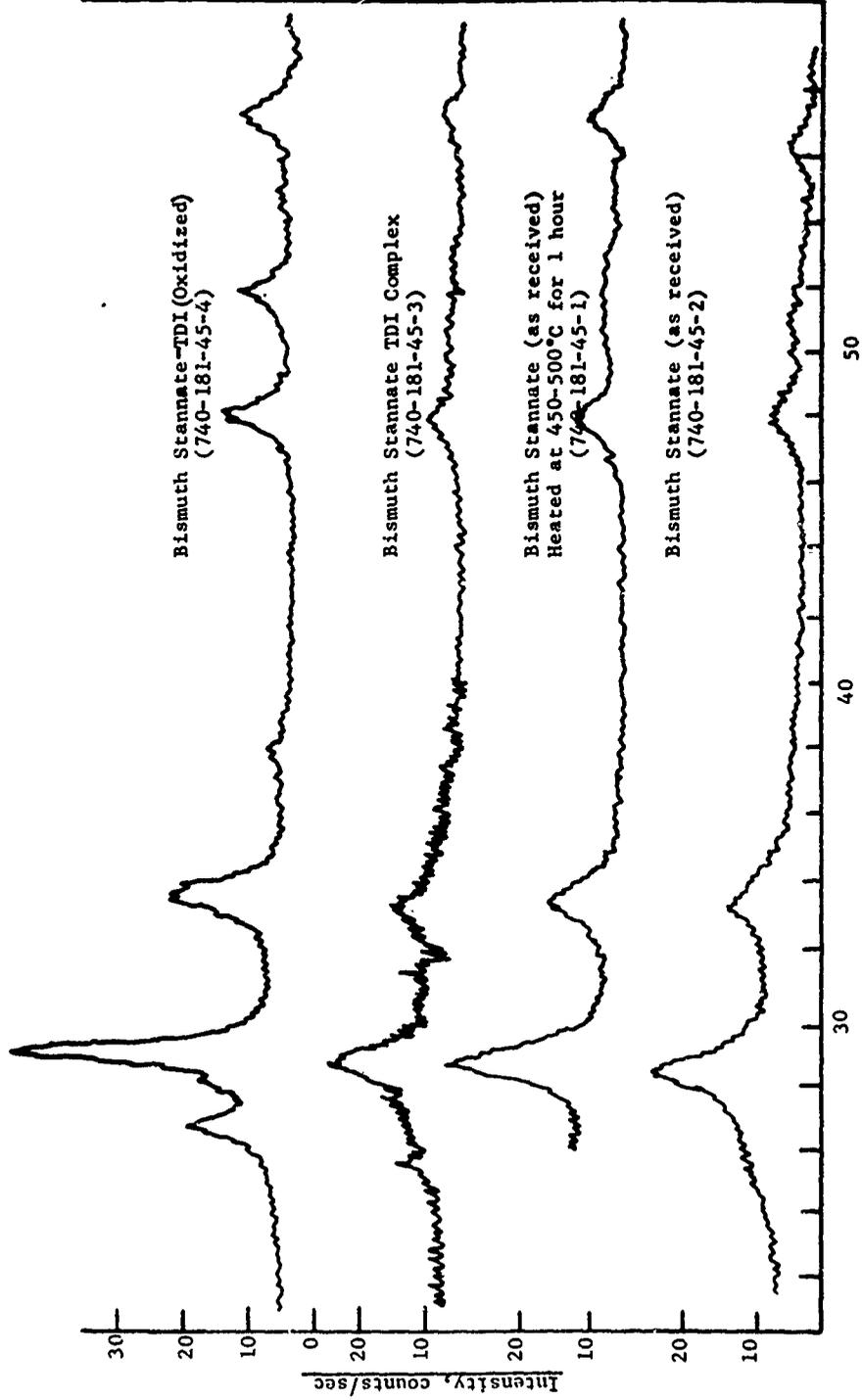


Angle, 2θ, °
FIGURE 3 (C)

CONFIDENTIAL

CONFIDENTIAL

X-RAY DIFFRACTION PATTERNS
CHEMICAL AND HEAT TREATED BISMUTH STANNATE (C)

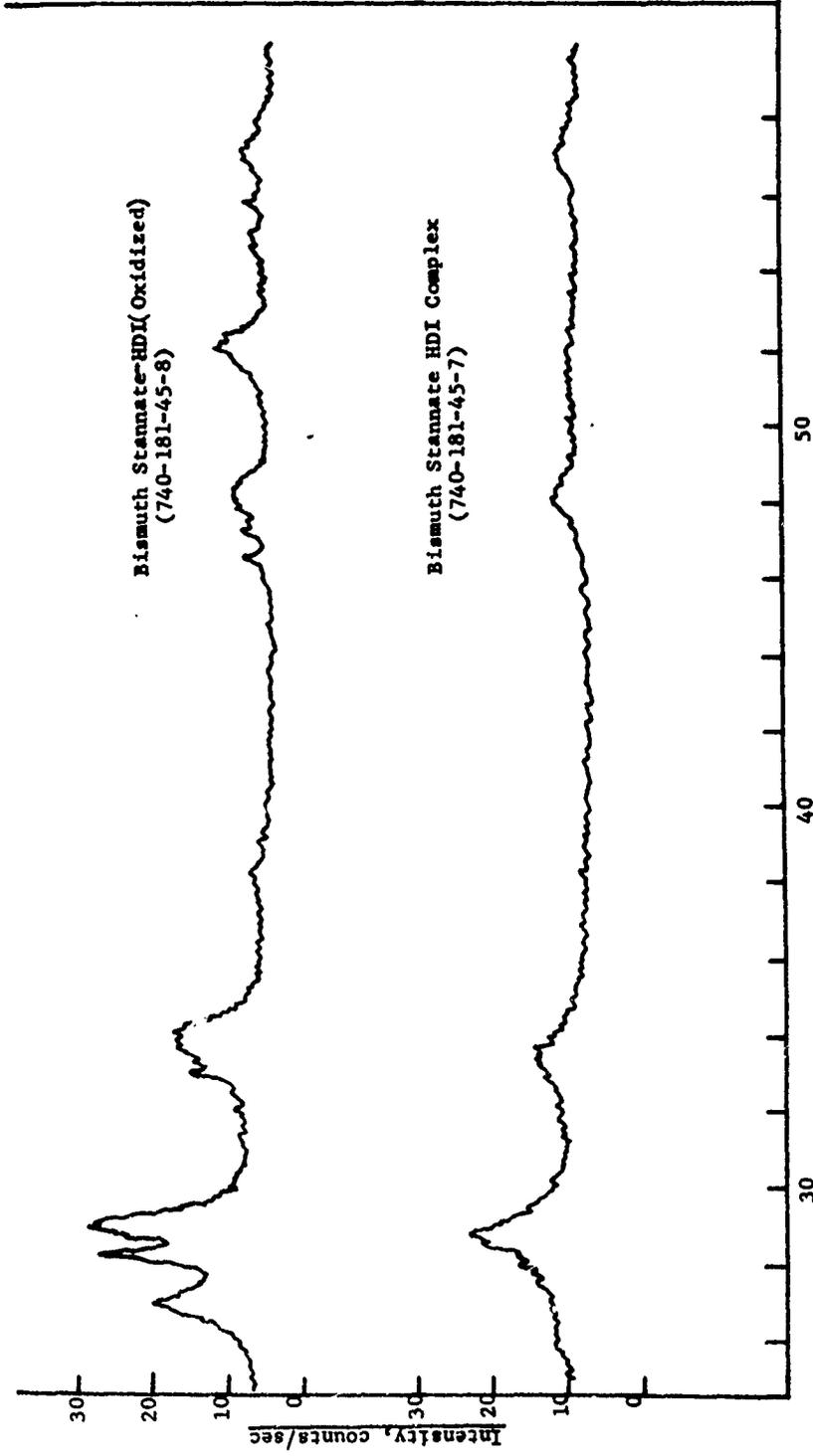


Angle, 2 θ ,
FIGURE 4 (C)

CONFIDENTIAL

CONFIDENTIAL

X-RAY DIFFRACTION PATTERNS
BISMUTH STANNATE HDI COMPLEX - BISMUTH STANNATE HDI(OXIDIZED) (C)

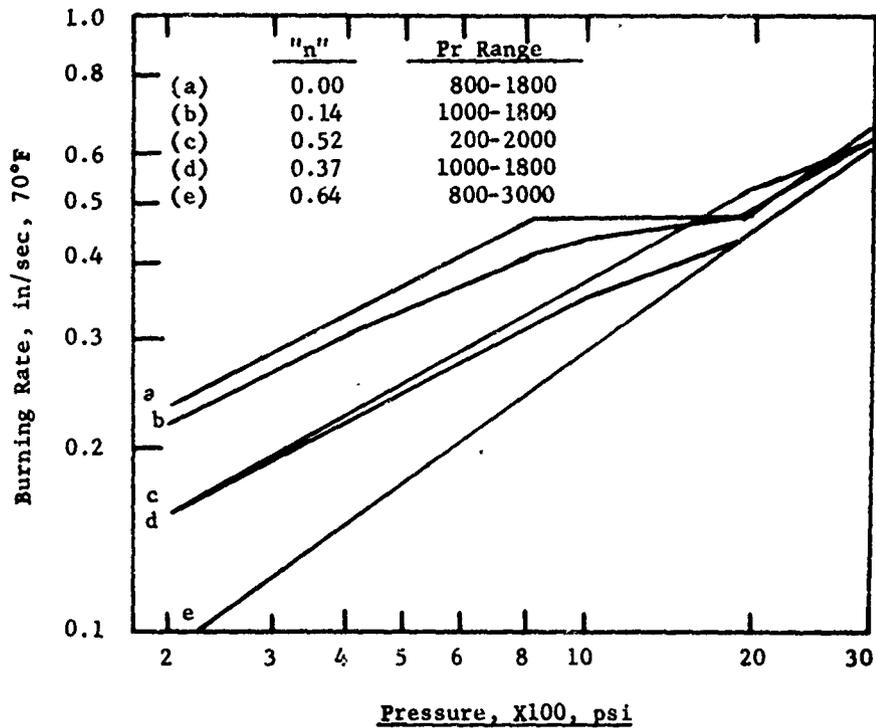


Angle, 2θ°
FIGURE 5 (C)

CONFIDENTIAL

CONFIDENTIAL

BALLISTIC PROPERTIES OF SMOKELESS HMX PLASTISOL PROPELLANTS CONTAINING CHEMICALLY (TDI) AND HEAT TREATED LEAD STANNATE (C)



INGREDIENTS

FORMULATION

Ball Powder, 14528-30	
Ball Powder, 2161	
Casting Solvent "X"	
HMX, 2u	
Ballistic Modifier	
Ball Powder/Casting Solvent Ratio	

PERCENT COMPOSITION

See a thru e

	18.5
	1.0
	46.5
	30.0
	4.0
	0.42

FORMULATION

- (a) 740-193-18-7
- (b) 740-193-18-1
- (c) 740-193-16-2A
- (d) 740-152-95-4
- (e) 740-152-95-2

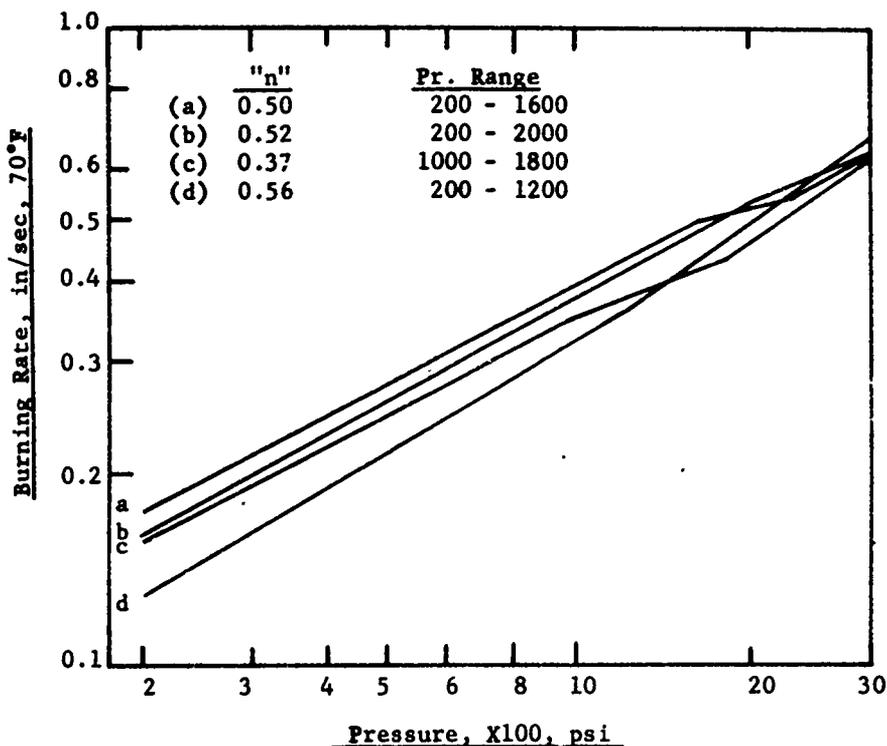
BALLISTIC MODIFIER

- Lead Stannate - TDI (reduced)
Lot 740-181-45-9
- Lead Stannate - TDI (oxidized)
Lot 740-181-43-1
- Lead Stannate (as received)
Heated at 450-500°C for one hour
Lot 740-181-43-4
- Lead Stannate (as received)
Lot P10707
- Lead Stannate - isocyanate (TDI)
Complex

FIGURE 6 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF SMOKELESS HMX PIASISOL PROPELLANTS CONTAINING CHEMICALLY (HDI) AND HEAT TREATED LEAD STANNATE (C)



INGREDIENTS

FORMULATION

Ball Powder, Lot 14528-30
 Ball Powder, Lot 2161
 Casting Solvent "X"
 HMX, 2u
 Ballistic Modifier
 Ball Powder/Casting Solvent Ratio

PERCENT COMPOSITION

See a thru d

18.5
 1.0
 46.5
 30.0
 4.0
 0.42

FORMULATION

(a) 740-193-16-2E
 (b) 740-193-16-2A
 (c) 740-152-95-4
 (d) 740-193-18-2

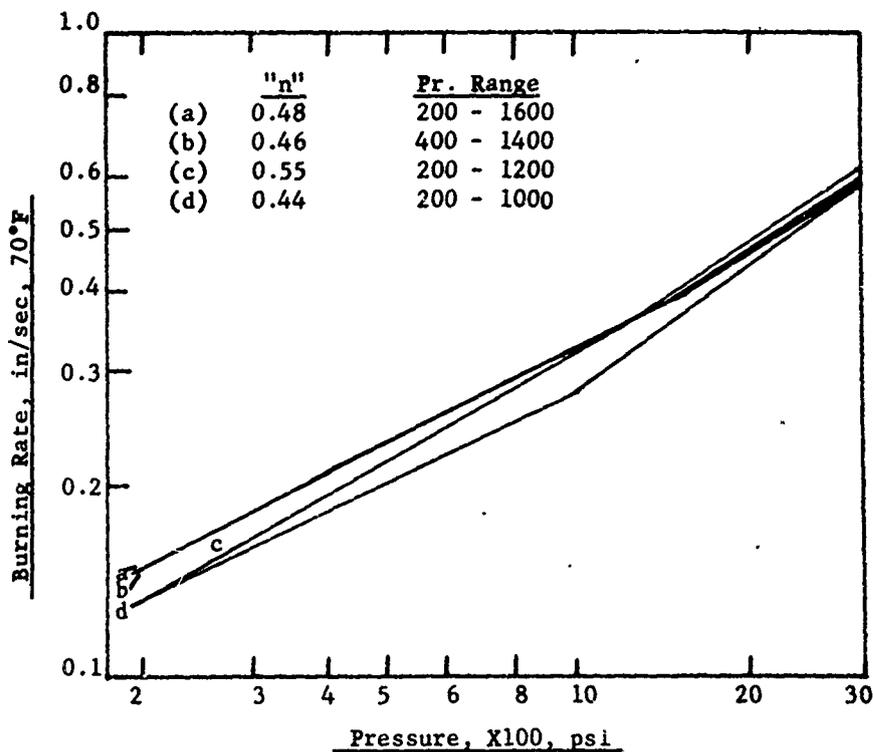
BALLISTIC MODIFIER

Lead Stannate - HDI(oxidized)
 Lot 740-181-45-5
 Lead Stannate (as received)
 Heated at 450-500°C for one hour
 Lot 740-181-43-4
 Lead Stannate (as received)
 Lot P-10707
 Lead Stannate - isocyanate (HDI)
 Complex Lot 740-181-45-6

FIGURE 7 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF SMOKELESS HMX PLASTISOL PROPELLANTS CONTAINING CHEMICALLY (TDI) AND HEAT TREATED BISMUTH STANNATE (C)



INGREDIENTS

PERCENT COMPOSITION

FORMULATION

See a thru d

Ball Powder, Lot 14528-30
 Ball Powder, Lot 2161
 Casting Solvent "X"
 HMX, 2u
 Ballistic Modifier
 Ball Powder/Casting Solvent Ratio

18.5
 1.0
 46.5
 30.0
 4.0
 0.42

FORMULATION

BALLISTIC MODIFIER

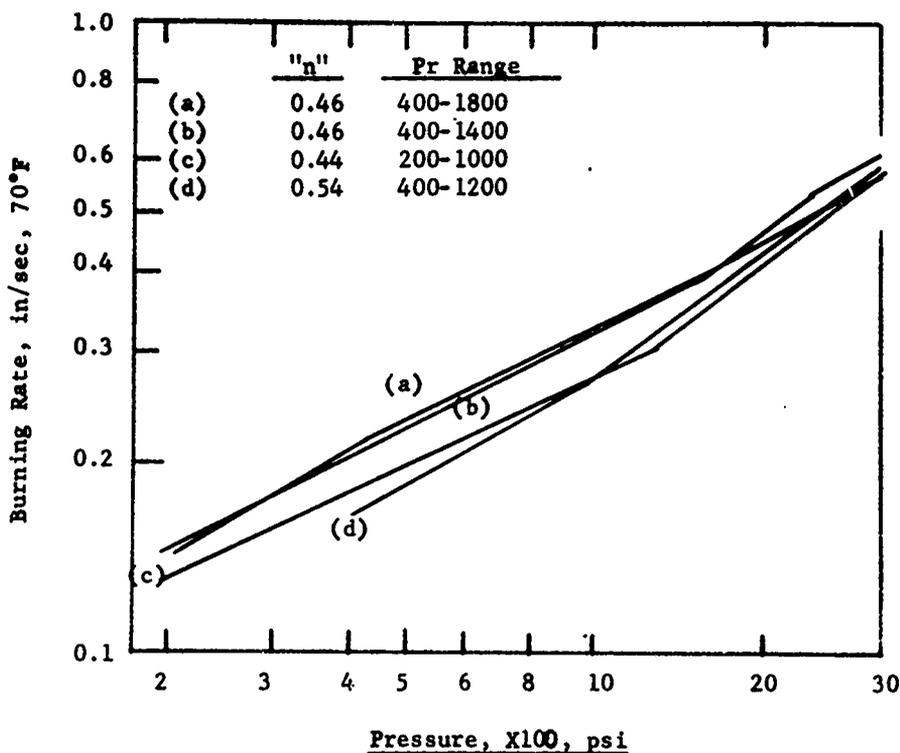
(a) 740-193-16-2B
 (b) 740-193-16-2D
 (c) 740-193-18-6
 (d) 740-193-16-2C

Bismuth stannate (as received)
 Heated at 450-500°C for one hour
 Lot 740-181-45-1
 Bismuth stannate-TDI (oxidized)
 Lot 740-181-45-4
 Bismuth stannate-isocyanate (TDI)
 Complex Lot 740-181-45-3
 Bismuth stannate (as received)
 Thermite

FIGURE 8 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF SMOKELESS HMX PLASTISOL PROPELLANTS CONTAINING CHEMICALLY (HDI) AND HEAT TREATED BISMUTH STANNATE (C)



INGREDIENTS

FORMULATION

Ball Powder, 14528-30	18.5
Ball Powder, 2161	1.0
Casting Solvent "X"	46.5
HMX, 2u	30.0
Ballistic Modifier	4.0
Ball Powder/Casting Solvent Ratio	0.42

PERCENT COMPOSITION

See a thru d

FORMULATION

- (a) 740-193-18-5
- (b) 740-193-16-2B
- (c) 740-193-16-2C
- (d) 740-193-18-4

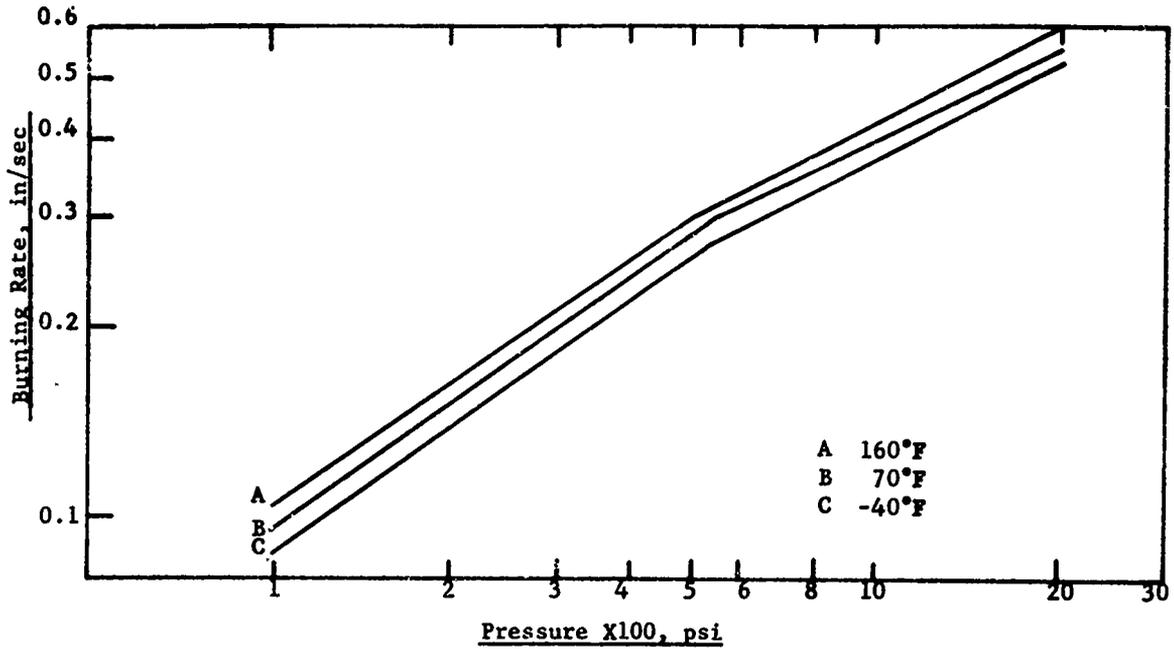
BALLISTIC MODIFIER

- Bismuth Stannate - HDI(OXIDIZED)
Lot 740-181-45-8
- Bismuth Stannate (as received)
Heated at 450-500°C for one hour.
Lot 740-181-45-1
- Bismuth Stannate (as received)
Thermite
- Bismuth Stannate - isocyanate
(HDI) complex
Lot 740-181-45-7

FIGURE 9 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF EXTRUDED SMOKELESS PROPELLANTS CONTAINING 54% RDX (MODIFIERS: LEAD BETA RESORCYLATE, CUPRIC SALICYLATE) (C)



INGREDIENTS

FORMULATION

Nitrocellulose, 12.6% N
 Nitroglycerin
 RDX, 14u
 Triacetin
 2-Nitrodiphenylamine
 Lead beta resorcyate
 Cupric salicylate
 Carbolac I, added

PERCENT COMPOSITION

5313

19.9
 16.7
 54.0
 4.2
 1.0
 2.1
 2.1
 0.03

Heat of Explosion, cal/gm

Expt 1104

πp at Constant p/r
 From -40°F to 160°F

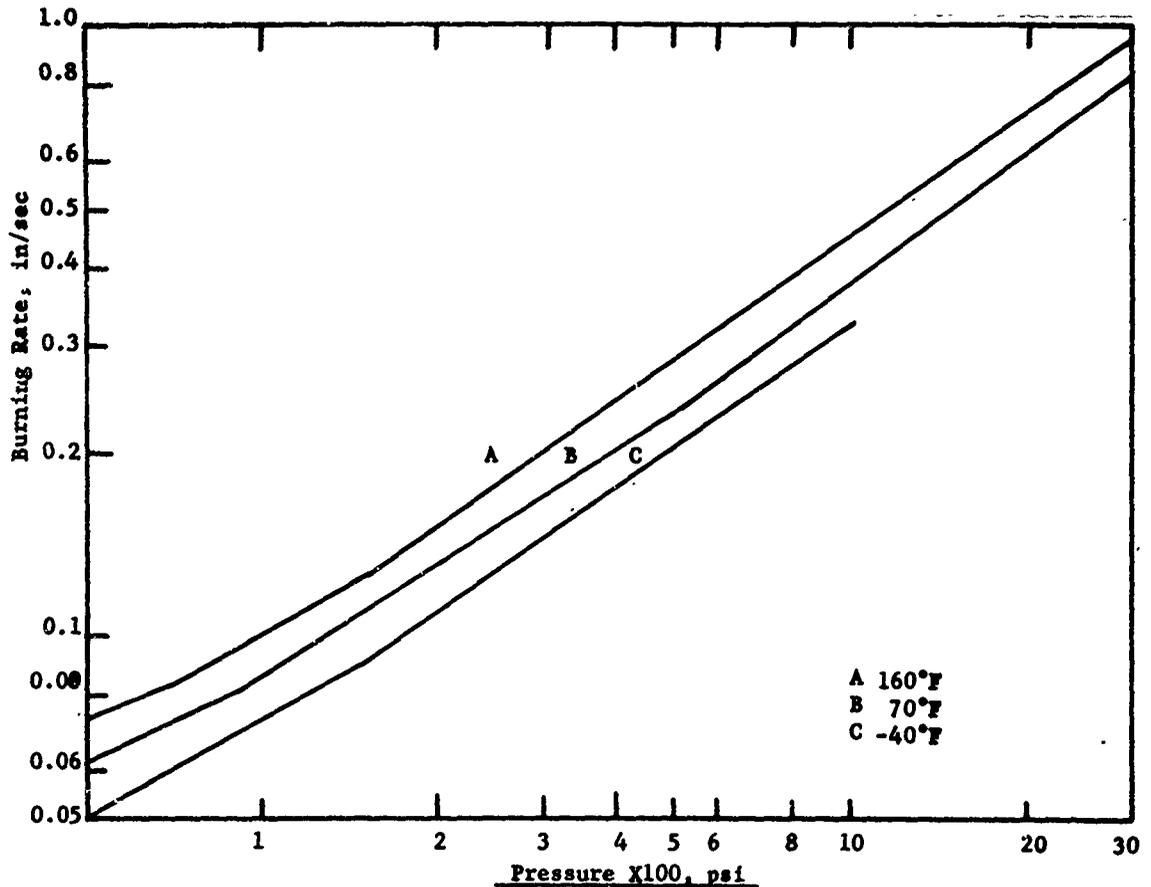
Press, at 70°F	p/r	$\pi p, \%/^{\circ}F$
1000	2500	0.16

Press range, psi	Pressure Exponent, 70°F
530-2000	Slope, "n" 0.48

FIGURE 10 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF EXTRUDED SMOKELESS PROPELLANTS CONTAINING 56% HMX (MODIFIERS: LEAD BETA RESORCYLATE CUPRIC SALICYLATE) (C)



INGREDIENTS

FORMULATION

Nitrocellulose, 12.6% N	20.0
Nitroglycerin	15.0
HMX: 75% 180 micron, 25% 2 micron	56.0
Triacetin	4.0
2-Nitrodiphenylamine	1.0
Lead beta resorcyate	2.0
Cupric salicylate	2.0
Carbon black, Added	0.03

PERCENT COMPOSITION

3118

Heat of Explosion, cal/gm

Expt 1121

np at Constant p/r
From -40°F to 160°F

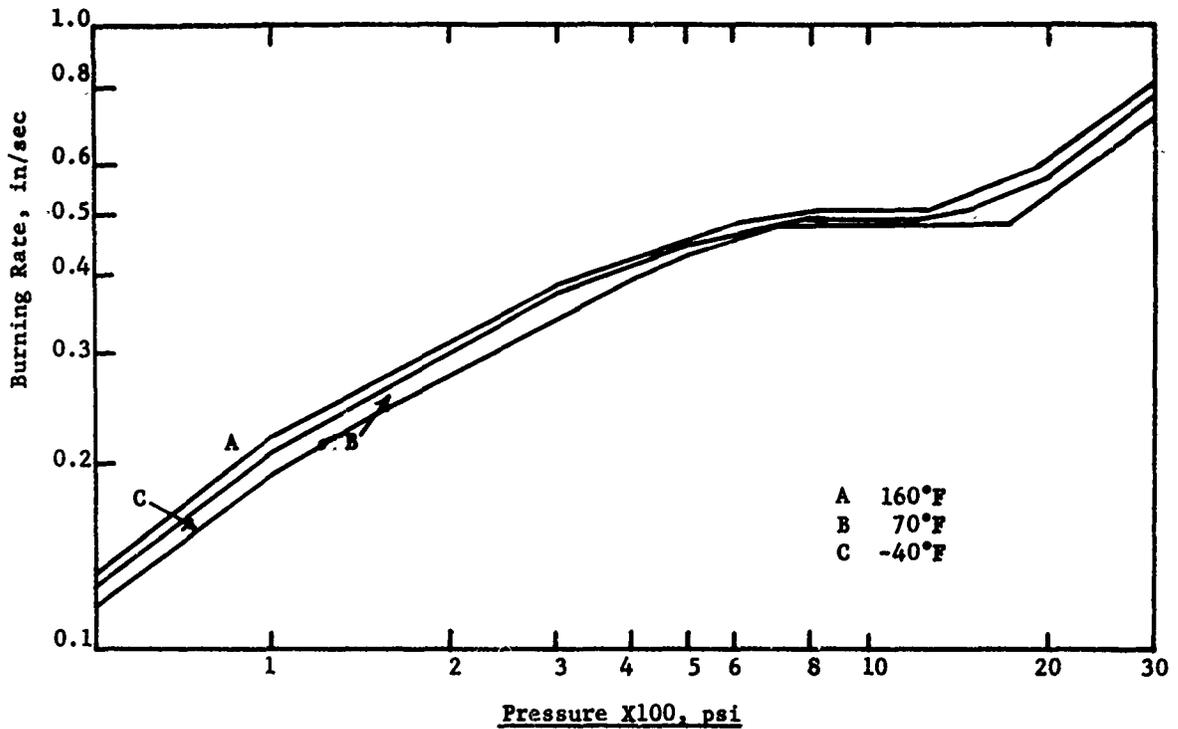
Pressure Exponent, 70°F
Press range, psi Slope, "n"
500-3000 0.71

Press, at 70°F p/r np, %/°F
1000 2700 0.44

FIGURE 11 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF EXTRUDED SMOKELESS PROPELLANTS CONTAINING 54% RDX (MODIFIER: LEAD STANNATE - TDI (REDUCED)) (C)



<u>INGREDIENTS</u>	<u>PERCENT COMPOSITION</u>
<u>FORMULATION</u>	<u>740-172-26-2 (5313)</u>
Nitrocellulose, 12.6% N	19.9
Nitroglycerin	16.7
RDX: 14 micron average	54.0
Triacetin	4.2
2-Nitrodiphenylamine	1.0
Lead Stannate - TDI (Reduced) (740-181-45-9)	4.2
Carbolac I, Added	0.03

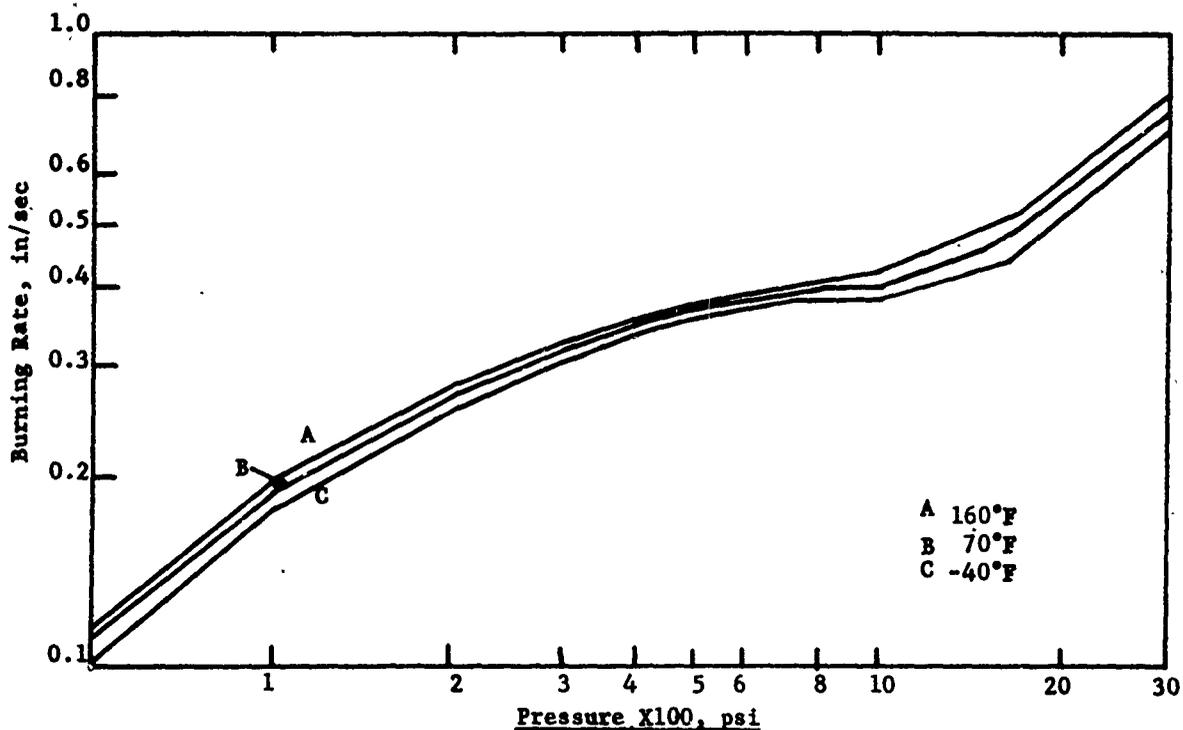
Heat of Explosion, cal/gm
Expt 1145

<u>mp at Constant p/r</u>			<u>Pressure Exponent, 70°F</u>	
<u>From -40°F to 160°F</u>			<u>Press range, psi</u>	<u>Slope, "n"</u>
<u>Press, at 70°F</u>	<u>p/r</u>	<u>mp, %/°F</u>	800-1200	0.00
1000	2080	0.02		

FIGURE 12 (c)

CONFIDENTIAL

BALLISTIC PROPERTIES OF EXTRUDED SMOKELESS PROPELLANTS CONTAINING 54% RDX (MODIFIER: LEAD STANNATE - TDI(OXIDIZED) (C))



<u>INGREDIENTS</u>	<u>PERCENT COMPOSITION</u>
<u>FORMULATION</u>	<u>740-172-26-1 (5313)</u>
Nitrocellulose, 12.6% N	19.9
Nitroglycerin	16.7
RDX: 14 micron average	54.0
Triacetin	4.2
2-Nitrodiphenylamine	1.0
Lead Stannate - TDI(Oxidized) (740-181-46-1)	4.2
Carbolac I, Added	0.03

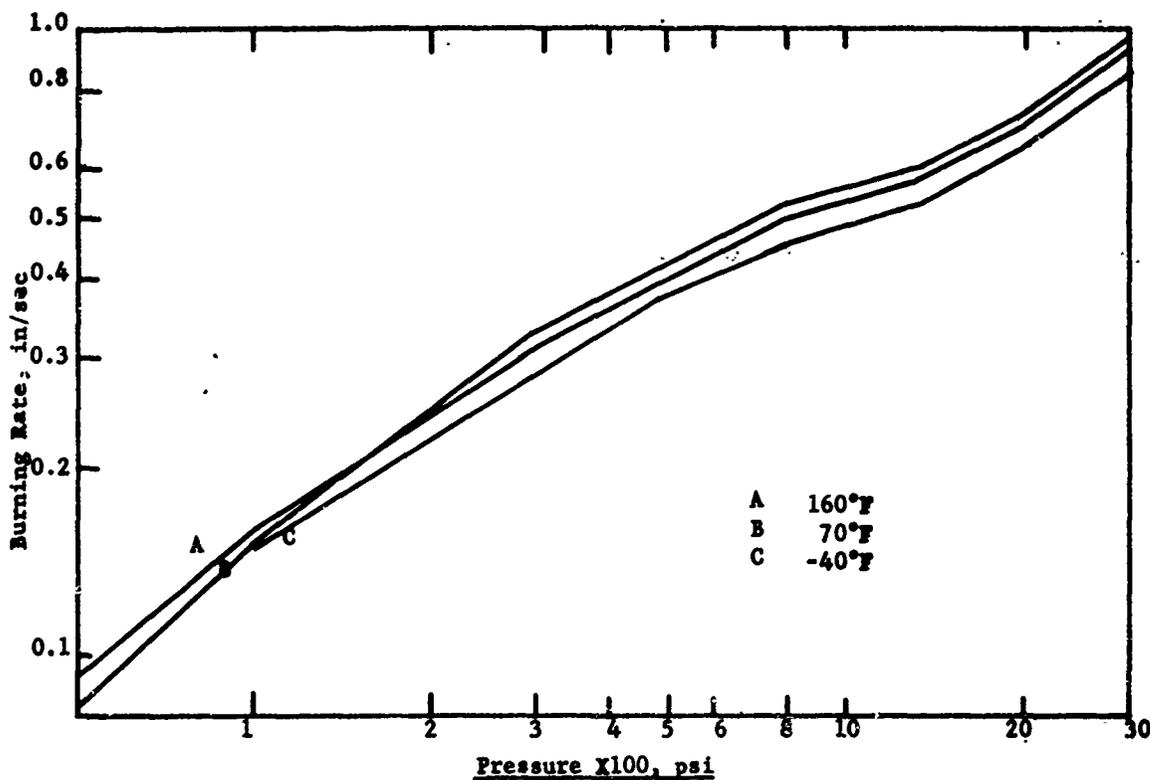
Heat of Explosion, cal/gm
 Expt 1147

<u>πp at Constant p/r</u>			<u>Pressure Exponent, 70°F</u>	
<u>From -40°F to 160°F</u>			<u>Press range, psi</u>	<u>Slope, "n"</u>
<u>Press, at 70°F</u>	<u>p/r</u>	<u>πp, %/°F</u>		
1000	2500	0.045	800-1000	0.00
			1000-1700	0.40

FIGURE 13 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF EXTRUDED SMOKELESS PROPELLANTS CONTAINING 56% HMX (MODIFIERS: LEAD STANNATE-TDI(OXIDIZED)) (C)



<u>INGREDIENTS</u>	<u>PERCENT COMPOSITION</u>
<u>FORMULATION</u>	
740-172-26-3 (5118)	
Nitrocellulose, 12.6% N	20.0
Nitroglycerin	15.0
HMX: (79% 180 micron, 25% 2 micron)	56.0
Triacetin	4.0
2-Nitrodiphenylamine	1.0
Lead stannate-TDI(Oxidized) (740-181-46-1)	4.0
Carbolac I, Added	0.03

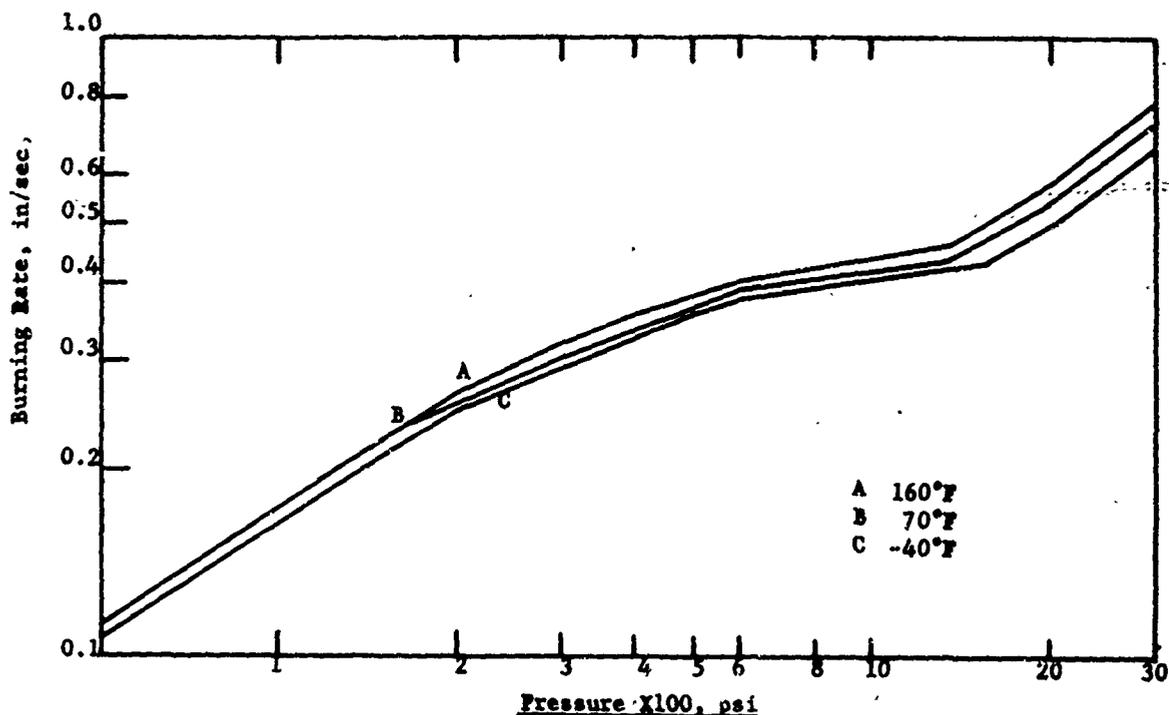
Heat of Explosion, cal/gm
Expt 1148

<u>RD at Constant p/r</u>			<u>Pressure Exponent, 70°F</u>	
<u>From -40°F to 160°F</u>			<u>Press range, psi</u>	<u>Slope, "n"</u>
<u>Press. at 70°F</u>	<u>p/r</u>	<u>RD, %/°F</u>	800-1300	0.23
1000	1920	0.09		

FIGURE 14 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF EXTRUDED SMOKELESS PROPELLANTS CONTAINING 56% FINE HMX (MODIFIER: LEAD STANNATE-TDI(OXIDIZED))(C)



INGREDIENTS

FORMULATION

Nitrocellulose, 12.6% M
 Nitroglycerin
 HMX: 2 micron average
 Triacetin
 2-Nitrodiphenylamine
 Lead stannate-TDI(Oxidized)
 (740-181-45-1)
 Carbon black, Added

PERCENT COMPOSITION

740-172-26-5 (5128 fine)
 20.0
 15.0
 56.0
 4.0
 1.0
 4.0
 0.03

Heat of Explosion, cal/gm

Expt 1144

np at Constant p/r

From -40°F to 160°F

Press. at 70°F

1000

p/r

2380

np, %/°F

0.05

Pressure Exponent, 70°F

Press range, psi

600-1300

Slope, "n"

0.11

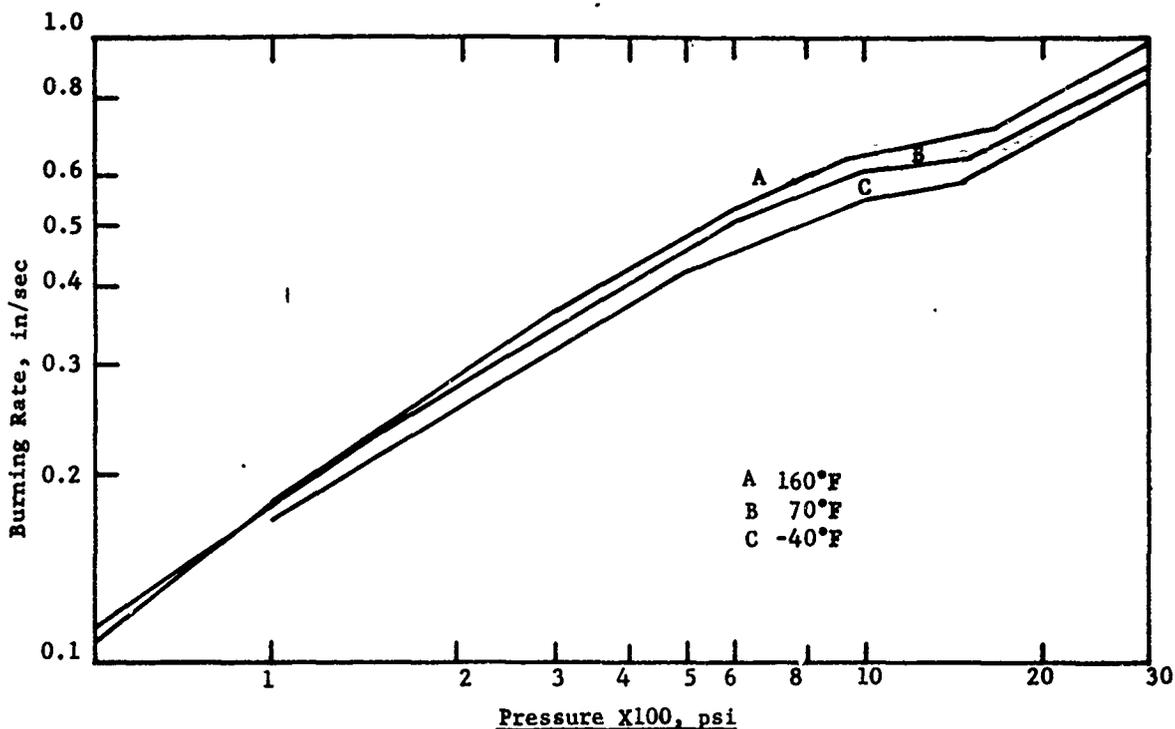
FIGURE 15 (C)

38

CONFIDENTIAL

CONFIDENTIAL

BALLISTIC PROPERTIES OF EXTRUDED SMOKELESS PROPELLANTS CONTAINING 56% HMX (MODIFIER: LEAD STANNATE -TDI(REDUCED)) (C)



INGREDIENTS

FORMULATION

Nitrocellulose, 12.6% N

Nitroglycerin

HMX: 75% 180 micron, 25% 2 micron

Triacetin

2-Nitrodiphenylamine

Lead stannate -TDI(Reduced)

(740-181-45-9)

Carbon black, Added

PERCENT COMPOSITION

740-172-26-4 (5118)

20.0

15.0

56.0

4.0

1.0

4.0

0.03

Heat of Explosion, cal/gm

Expt 1143

πp at Constant p/r

From -40°F to 160°F

Pressure Exponent, 70°F

Press range, psi

1000-1500

Slope, "n"

0.14

Press, at 70°F

1000

p/r

1650

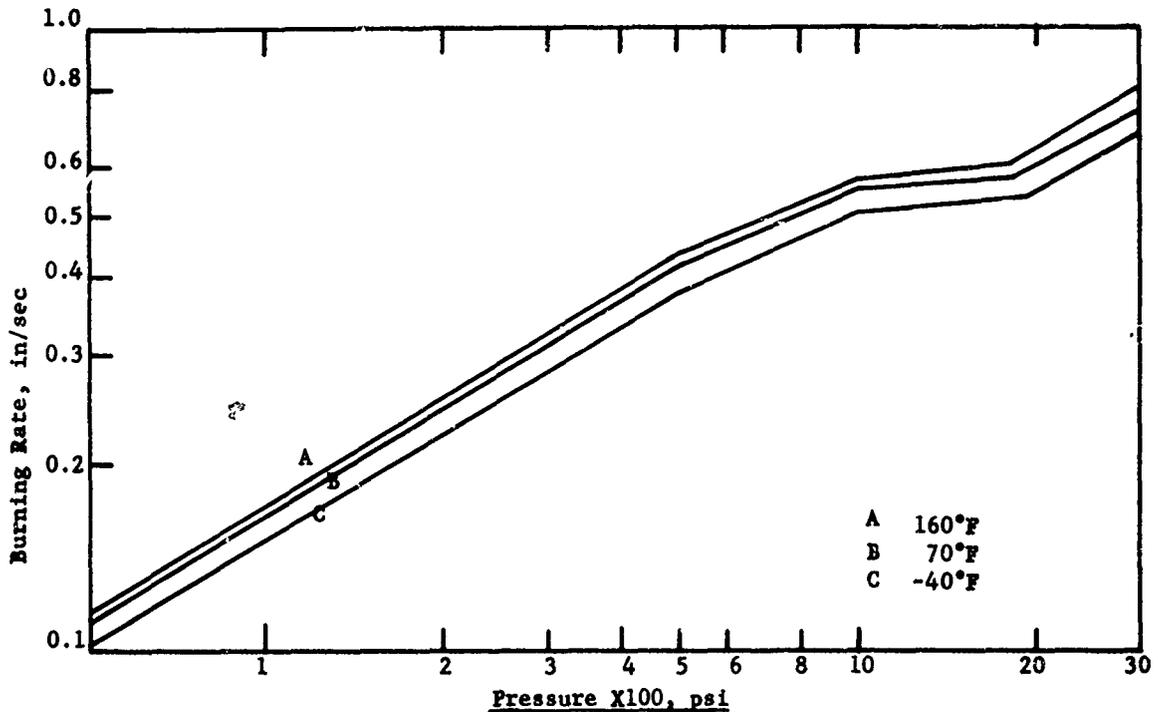
πp , %/°F

0.12

FIGURE 16 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF EXTRUDED SMOKELESS PROPELLANTS CONTAINING 56% FINE HMX (MODIFIER: LEAD STANNATE - TDI(REDUCED)) (C)



INGREDIENTS

FORMULATION

Nitrocellulose, 12.6% N
 Nitroglycerin
 HMX: 2 micron average
 Triacetin
 2-Nitrodiphenylamine
 Lead stannate -TDI(Reduced)
 (740-181-45-9)
 Carbon black, Added

PERCENT COMPOSITION

740-172-26-6 (5118 fine)
 20.0
 15.0
 56.0
 4.0
 1.0
 4.0
 0.03

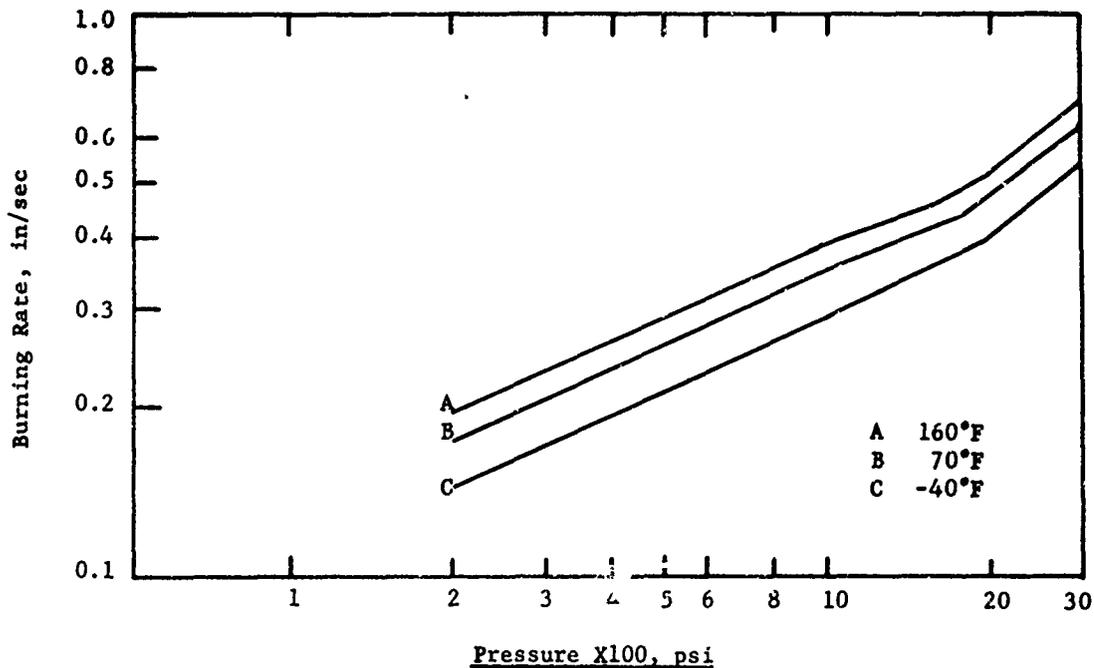
Heat of Explosion, cal/gm
 Expt 1137

<u>mp at Constant p/r</u>			<u>Pressure Exponent, 70°F</u>	
<u>From -40°F to 160°F</u>			<u>Press range, psi</u>	<u>Slope, "n"</u>
<u>Press, at 70°F</u>	<u>p/r</u>	<u>mp, %/°F</u>	6000-1800	0.08
1000	1850	0.07		

FIGURE 17 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF SMOKELESS HMX PLASTISOL PROPELLANTS (MODIFIER: LEAD STANNATE (AS RECEIVED)) (C)



INGREDIENTS

FORMULATION

Fluid Ball Powder, Type B (14528-30)
 Fluid Ball Powder, Type C (2161)
 Casting Solvent "X"
 HMX, 2u
 Lead Stannate, P10707

PERCENT COMPOSITION

<u>740-193-21-2A</u>	
Fluid Ball Powder, Type B	18.5
Fluid Ball Powder, Type C	1.0
Casting Solvent "X"	46.5
HMX, 2u	30.0
Lead Stannate	4.0

mp at Constant p/r
 From -40°F to 160°F

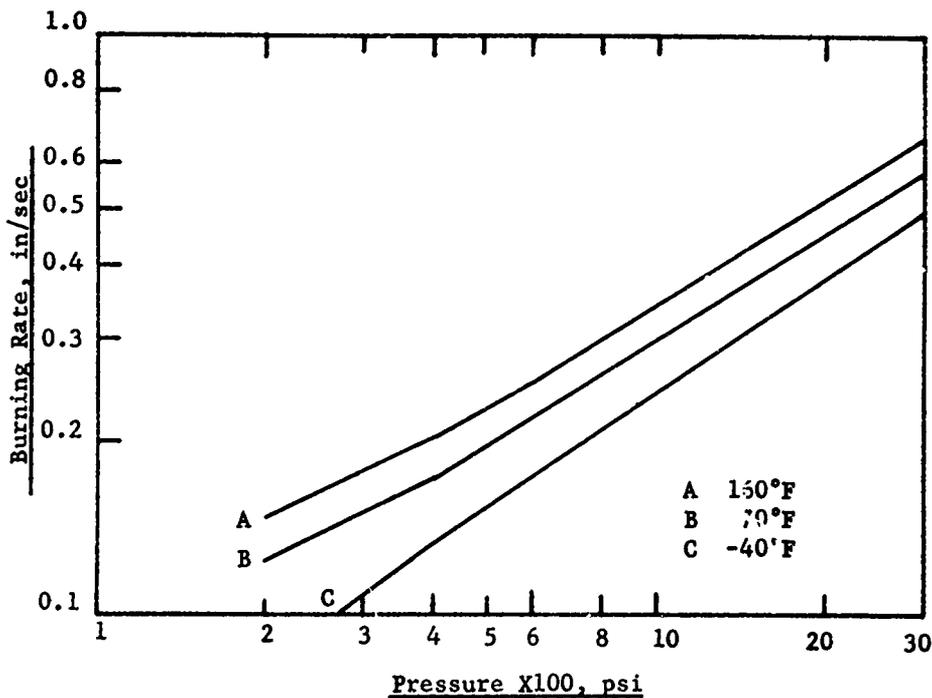
<u>Press. at 70°F</u>	<u>p/r</u>	<u>mp %/°F</u>
1000	2500	0.23

<u>Pressure Exponent, 70°F</u>	
<u>Press Range, psi</u>	<u>Slope "n"</u>
1000-1800	0.40

FIGURE 18 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF A CROSSLINKED SMOKELESS HMX PLASTISOL PROPELLANT MODIFIER: LEAD STANNATE (AS RECEIVED) (C)



INGREDIENTS FORMULATION

Fluid Ball Powder, Type B, 14528-30
 Fluid Ball Powder, Type C, 2161
 Casting Solvent "X"
 HMX, 2u
 2,4-tolylene diisocyanate, added
 Resorcinol, added
 Lead Stannate, P-10707 (as received)
 Ball Powder/Casting Solvent Ratio

PERCENT COMPOSITION 740-193-49-1

18.5
 1.0
 46.5
 30.0
 1.5
 0.5
 4.0
 0.42

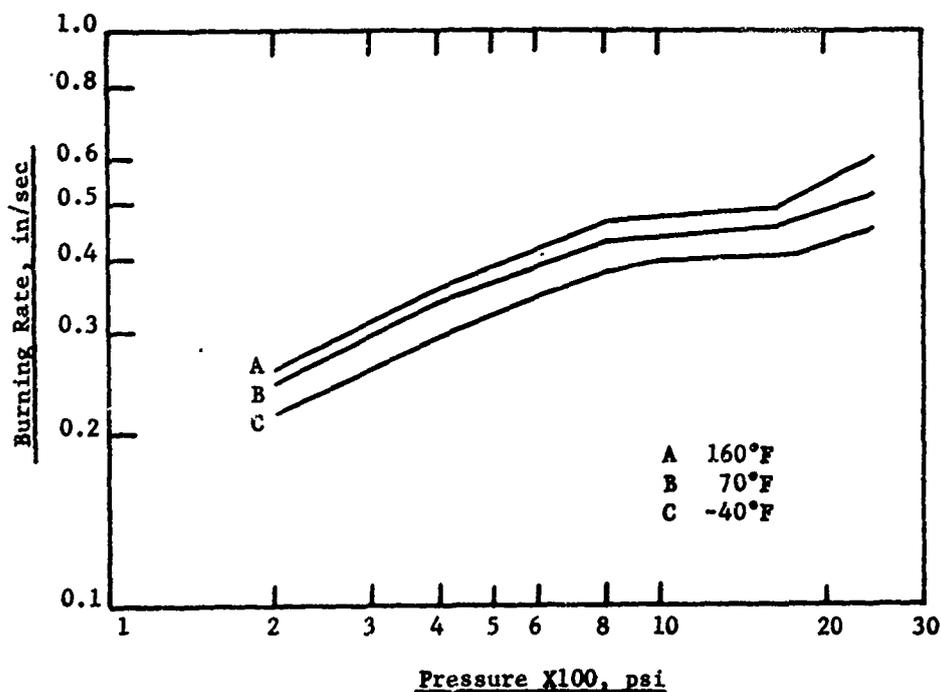
πp at Constant p/r From -40°F to 160°F		
Press. at 70°F	p/r	$\pi p, \%/^{\circ}F$
1000	3330	0.44

Pressure Exponent, 70°F	
Press range, psi	Slope, "n"
400-3000	0.61

FIGURE 19 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF A SMOKELESS HMX PLASTISOL PROPELLANT (MODIFIER: LEAD STANNATE - TDI(OXIDIZED)) (C)



INGREDIENTS

PERCENT COMPOSITION

FORMULATION

740-193-48-A

Fluid Ball Powder, Type B, (4528-30)	18.5
Fluid Ball Powder, Type C, (2161)	1.0
Casting Solvent "X"	46.5
HMX, 2u	30.0
Lead Stannate - TDI(Oxidized) (740-181-65-3)	4.0

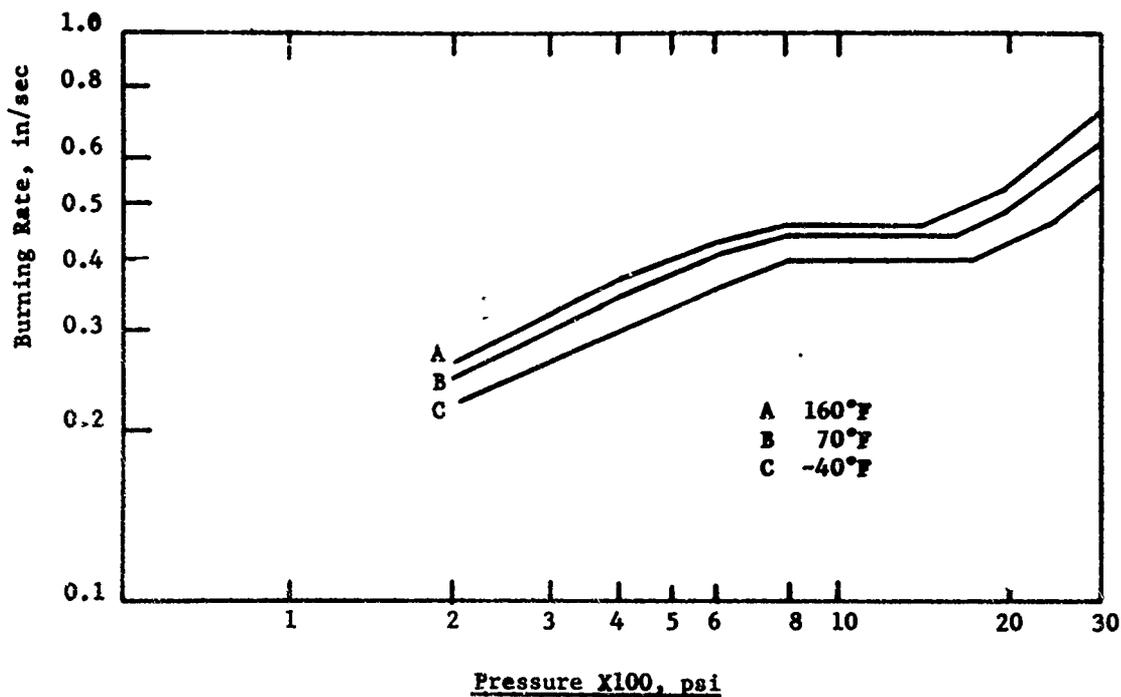
<u>np at Constant p/r</u> <u>From -40°F to 160°F</u>		
<u>Press. at 70°F</u>	<u>p/r</u>	<u>np, %/°F</u>
1000	2325	0.11

<u>Pressure Exponent, 70°F</u>	
<u>Press range, psi</u>	<u>Slope, "n"</u>
800-1600	0.06

FIGURE 20 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF A SMOKELESS HMX PLASTISOL PROPELLANT (MODIFIER: LEAD STANNATE - TDI (REDUCED)) (C)



INGREDIENTS

FORMULATION

Fluid Ball Powder, Type B (14528-30)
 Fluid Ball Powder, Type C (2161)
 Casting Solvent "X"
 HMX, 2u
 Lead Stannate - TDI (Reduced)
 (740-181-64-2)

PERCENT COMPOSITION

740-193-48-B

Fluid Ball Powder, Type B (14528-30) 18.5
 Fluid Ball Powder, Type C (2161) 1.0
 Casting Solvent "X" 46.5
 HMX, 2u 30.0
 Lead Stannate - TDI (Reduced) 4.0

<u>mp at Constant p/r</u>		
<u>From -40°F to 160°F</u>		
<u>Press. at 70°F</u>	<u>p/r</u>	<u>mp, %/°F</u>
1000	2270	0,071

<u>Pressure Exponent, 70°F</u>	
<u>Press range, psi</u>	<u>Slope, "n"</u>
800-1600	0.00

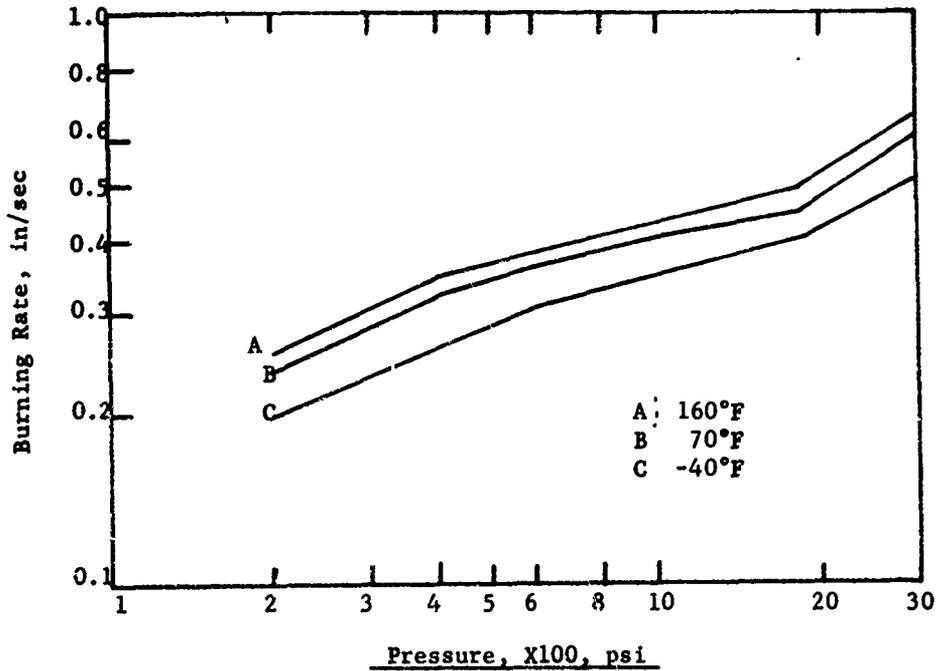
FIGURE 21 (C)

44

CONFIDENTIAL

CONFIDENTIAL

BALLISTIC PROPERTIES OF A CROSS-LINKED SMOKELESS HMX PIASISOL PROPELLANT MODIFIER: LEAD STANNATE - TDI(OXIDIZED) (C)



INGREDIENTS

FORMULATION

Fluid Ball Powder, Type B, 14528-30
 Fluid Ball Powder, Type C, 2161
 Casting Solvent "X"
 HMX, 2u
 2, 4-tolylene diisocyanate, added
 Resorcinol, added
 Lead Stannate - TDI(Oxidized)
 (740-181-47-3)
 Ball Powder/Casting Solvent Ratio

PERCENT COMPOSITION

740-193-24-1

18.5
 1.0
 46.5
 30.0
 1.5
 0.5
 4.0
 0.42

$\frac{\pi p}{r}$ at Constant $\frac{p}{r}$
 From -40°F to 160°F

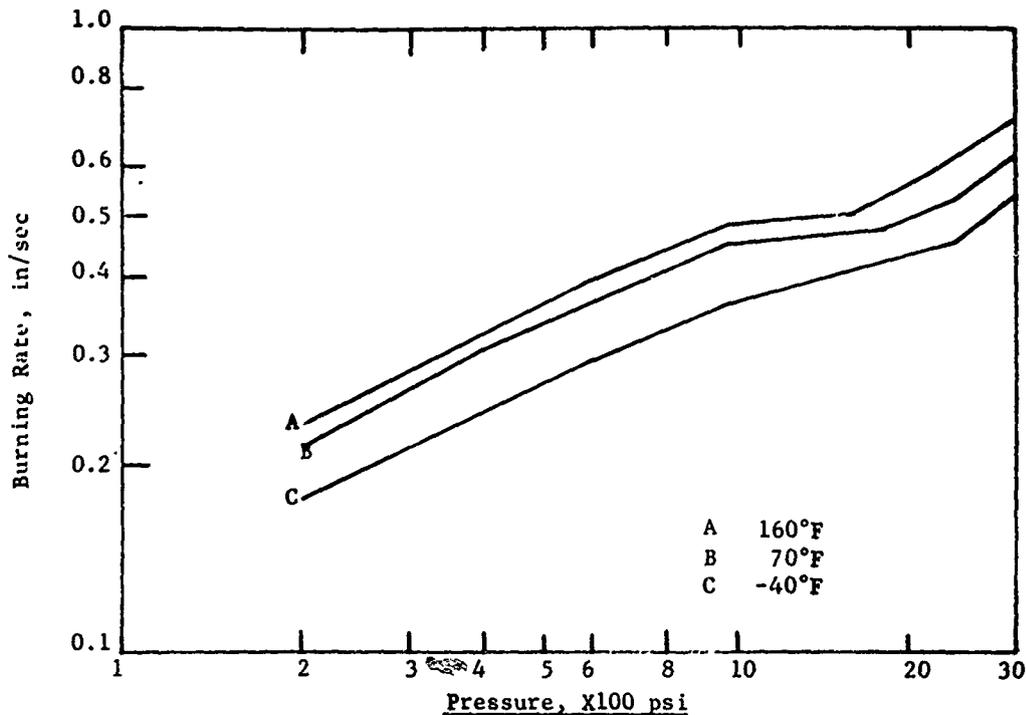
$\frac{\pi p}{r}$ at 70°F
 1000 $\frac{p}{r}$ 2500 $\frac{\pi p}{r}$, %/°F 0.14

Pressure Exponent, 70°F
 Press Range, psi Slope, "n"
 1000 - 1800 0.16

FIGURE 22 (C)

CONFIDENTIAL

BALLISTIC PROPERTIES OF A CROSS-LINKED SMOKELESS HMX PLASTISOL PROPELLANT MODIFIER: LEAD STANNATE - TDI (REDUCED) (C)



INGREDIENTS

FORMULATION

Fluid Ball Powder, Type B, 14528-30
 Fluid Ball Powder, Type C, 2161
 Casting Solvent "X"
 HMX, 2u
 2, 4-tolylene diisocyanate, added
 Resorcinol, added
 Lead Stannate - TDI (Reduced)
 (740-181-47-4)
 Ball Powder/Casting Solvent Ratio

PERCENT COMPOSITION

740-193-24-2

18.5
 1.0
 46.5
 30.0
 1.5
 0.5
 4.0
 0.42

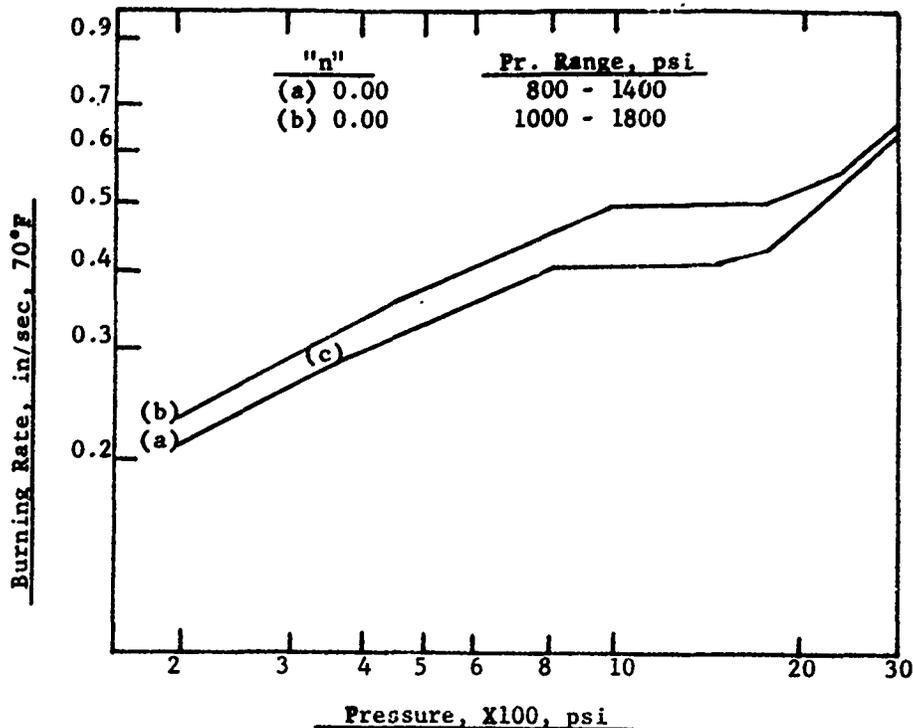
<u>mp at Constant p/r</u>		
<u>From -40°F to 160°F</u>		
<u>Press at 70°F</u>	<u>p/r</u>	<u>mp, %/°F</u>
1000	2220	0.22

<u>Pressure Exponent, 70°F</u>	
<u>Press Range, psi</u>	<u>Slope, "n"</u>
1000 - 1800	0.10

FIGURE 23 (C)

CONFIDENTIAL

EFFECT OF CHANGES IN BALL POWDER/CASTING SOLVENT RATIO UPON THE BURNING RATE OF SMOKELESS HMX PLASTISOL PROPELLANTS MODIFIER: LEAD STANNATE - TDI (REDUCED) (c)



INGREDIENTS

FORMULATION

Ball Powder, Lot 14528-30
 Ball Powder, Lot 2161
 Casting Solvent "X"
 HMX, 2u
 Lead Stannate - TDI(reduced)
 (Lot 740-181-46-3)

PERCENT COMPOSITION

740-193-23-1B (a)

740-193-23-7B (b)

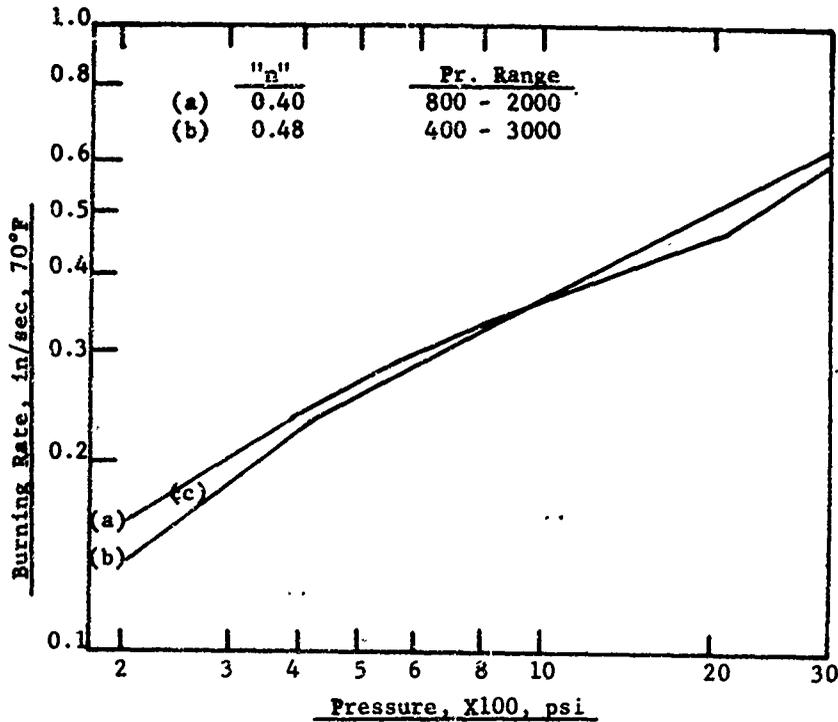
Ball Powder, Lot 14528-30	13.0	25.5
Ball Powder, Lot 2161	1.0	1.0
Casting Solvent "X"	52.0	39.5
HMX, 2u	30.0	30.0
Lead Stannate - TDI(reduced)	4.0	4.0

- (a) Powder/Solvent Ratio 0.27
 (b) Powder/Solvent Ratio 0.67
 (c) Burning rates for systems with P/S ratios of 0.33, 0.42, 0.49, 0.556 and 0.58 fall between that obtained for (a) and (b).

FIGURE 24 (c)

CONFIDENTIAL

EFFECT OF CHANGES IN BALL POWDER/CASTING SOLVENT RATIO UPON THE BURNING RATE OF SMOKELESS HMX PLASTISOL PROPELLANTS MODIFIER: LEAD STANNATE (AS RECEIVED) (C)



<u>INGREDIENTS</u>	<u>PERCENT COMPOSITION</u>	
<u>FORMULATION</u>	<u>740-193-6</u>	
	<u>1</u>	<u>5</u>
Ball Powder, Lot 14528-30	13.0	23.3
Ball Powder, Lot 2161	1.0	1.0
Casting Solvent "X"	52.0	41.7
HMX, 2u	30.0	30.0
Lead Stannate (as received) (Lot P10707)	4.0	4.0
Ball Powder/Casting Solvent Ratio 0.27		0.58

- (a) Burning rates for system with 0.27 ball powder/casting solvent ratio.
- (b) Burning rates for system with 0.58 ball powder/casting solvent ratio.
- (c) Burning rates at 1000 psi are similar for systems with ball powder/casting solvent ratios of 0.27, 0.33, 0.42, 0.49, 0.556 and 0.58.

FIGURE 25 (C)

CONFIDENTIAL

EFFECT OF HMX CONCENTRATION ON PRESSURE - TEMPERATURE DEPENDENCY
OF BURNING RATE OF HIGH ENERGY SMOKELESS PLASTISOL
DOUBLE-BASE PROPELLANTS (C)

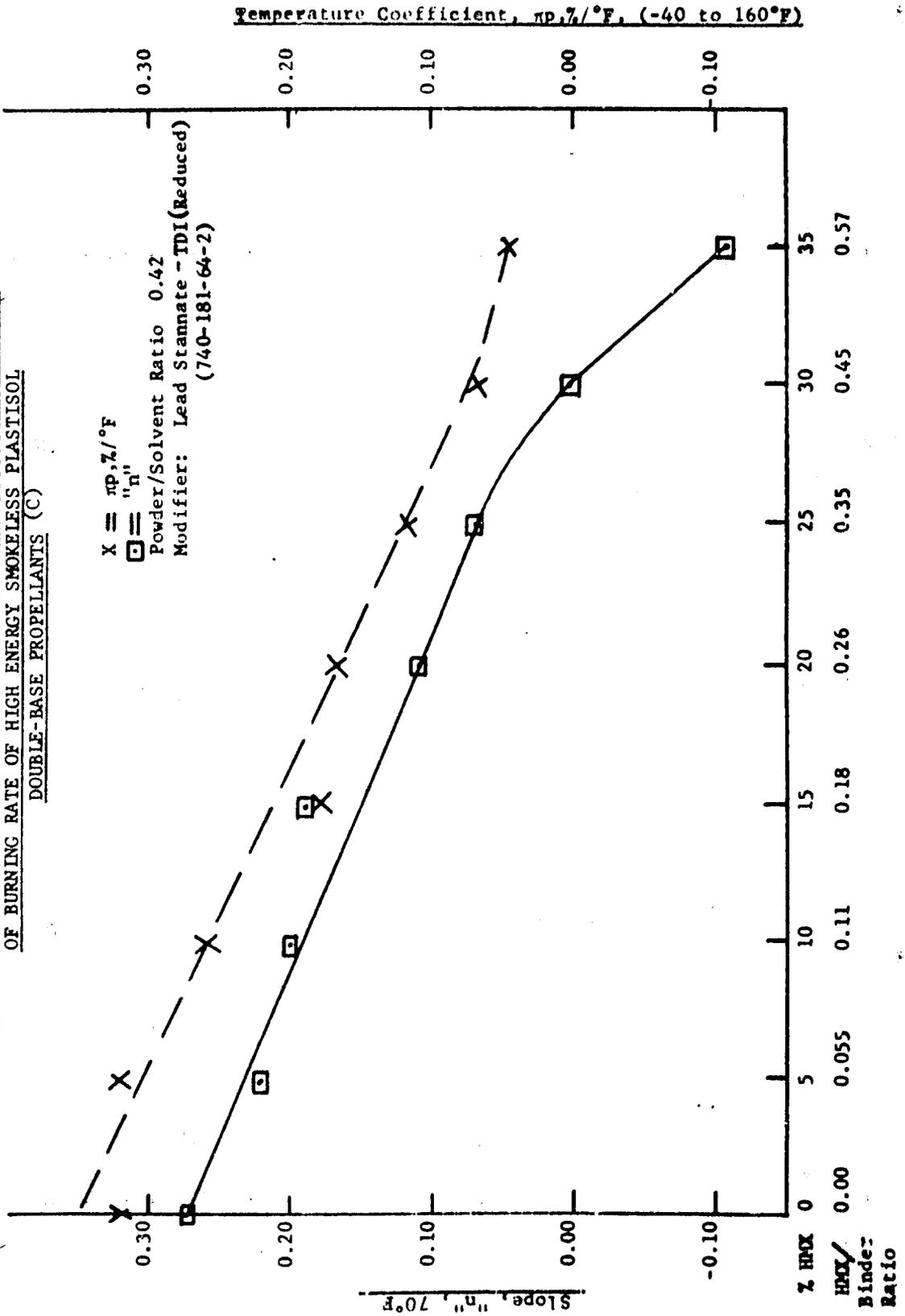
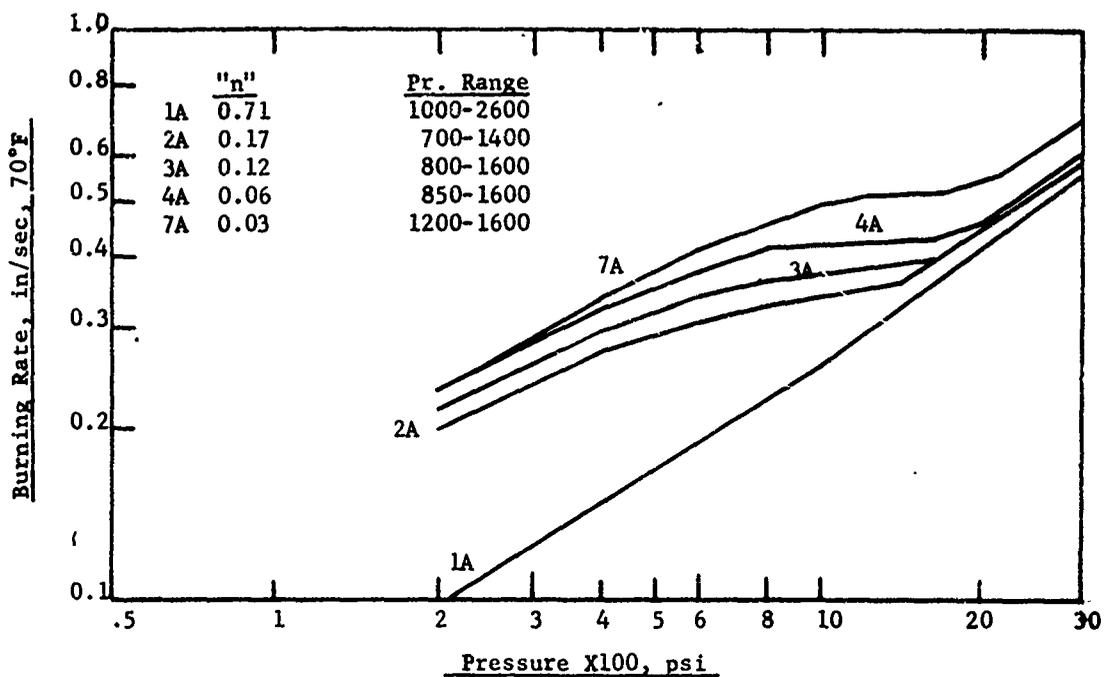


FIGURE 26 (C)

CONFIDENTIAL

CONFIDENTIAL

EFFECT OF CONCENTRATION OF LEAD STANNATE TDI (OXIDIZED) UPON BALLISTIC PROPERTIES OF HIGH ENERGY SMOKELESS HMX PLASTISOL PROPELLANTS (C)



INGREDIENTS

FORMULATION

Ball Powder, 1428-30	18.5	18.5	18.5	18.5	18.5
Ball Powder, 2161	1.0	1.0	1.0	1.0	1.0
Casting Solvent "X"	46.5	46.5	46.5	46.5	46.5
HMX, 2u	33.0	32.0	31.0	30.0	27.0
Lead Stannate- TDI(Oxidized) (740-181-65-3)	1.0	2.0	3.0	4.0	7.0
Ball Powder/Casting Solvent Ratio	0.42				

PERCENT COMPOSITION

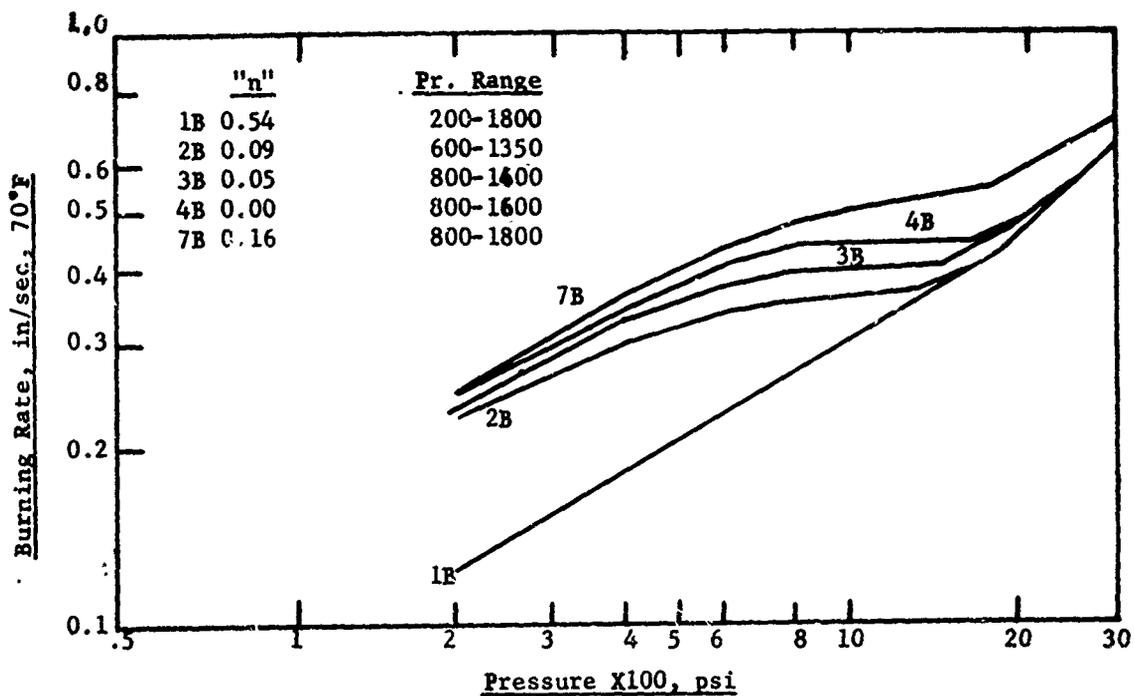
740-193-56

	<u>1A</u>	<u>2A</u>	<u>3A</u>	<u>4A</u>	<u>7A</u>
Ball Powder, 1428-30	18.5	18.5	18.5	18.5	18.5
Ball Powder, 2161	1.0	1.0	1.0	1.0	1.0
Casting Solvent "X"	46.5	46.5	46.5	46.5	46.5
HMX, 2u	33.0	32.0	31.0	30.0	27.0
Lead Stannate- TDI(Oxidized) (740-181-65-3)	1.0	2.0	3.0	4.0	7.0
Ball Powder/Casting Solvent Ratio	0.42				

FIGURE 27 (C)

CONFIDENTIAL

EFFECT OF CONCENTRATION OF LEAD STANNATE TDI (REDUCED) UPON BALLISTIC PROPERTIES OF HIGH ENERGY SMOKELESS HMX PLASTISOL PROPELLANTS (C)



INGREDIENTS

PERCENT COMPOSITION

FORMULATION

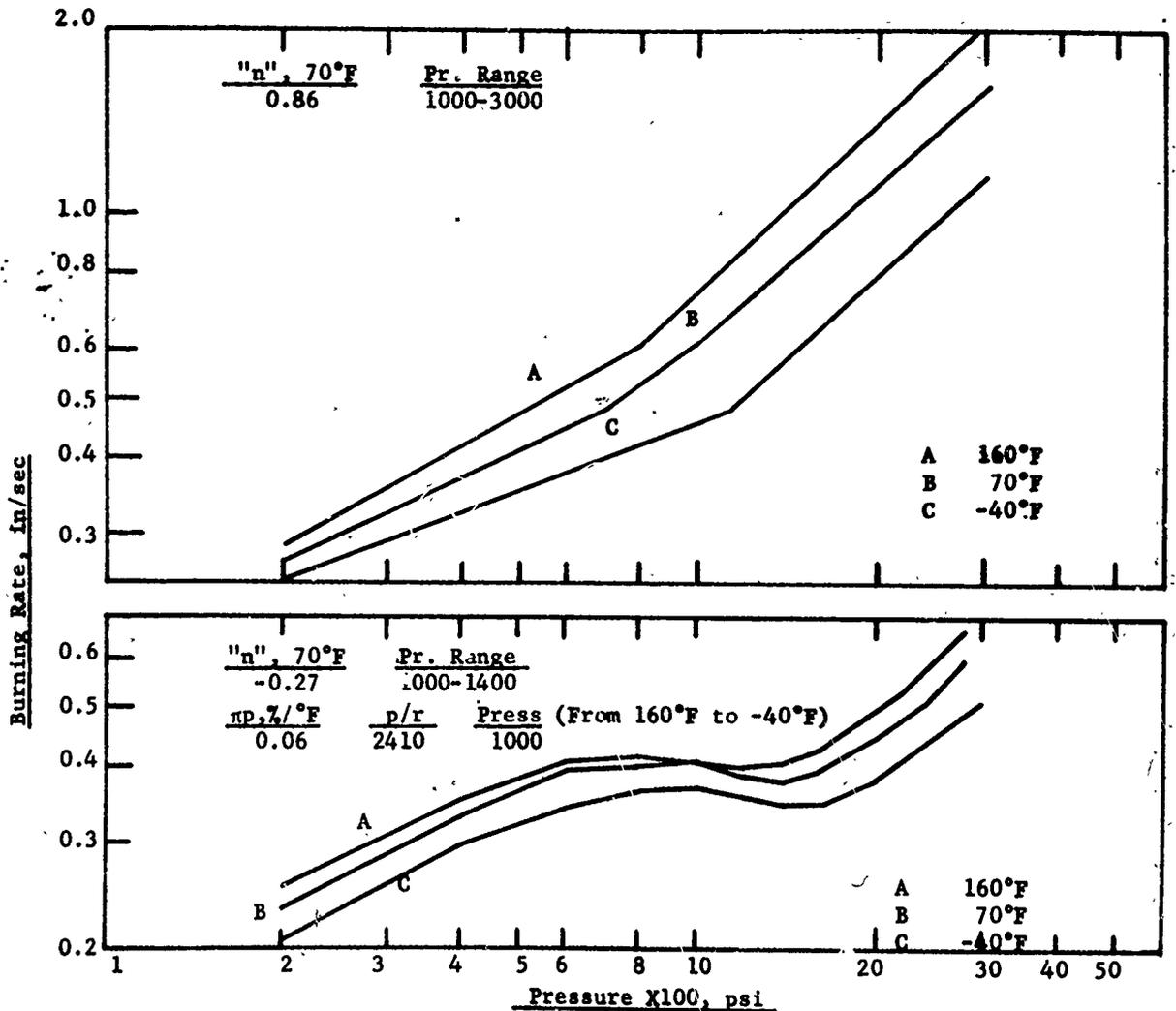
740-193-56

	<u>1B</u>	<u>2B</u>	<u>3B</u>	<u>4B</u>	<u>7B</u>
Ball Powder, 14528-30	18.5	18.5	18.5	18.5	18.5
Ball Powder, 2161	1.0	1.0	1.0	1.0	1.0
Casting Solvent "X"	46.5	46.5	46.5	46.5	46.5
HMX, 2u	33.0	32.0	31.0	30.0	27.0
Lead Stannate - TDI (Reduced) (740-181-64-2)	1.0	2.0	3.0	4.0	7.0
Ball Powder/Casting Solvent Ratio	0.42				

FIGURE 28 (C)

CONFIDENTIAL

EFFECTS OF CHANGES IN CALORIFIC LEVELS UPON BALLISTIC PROPERTIES OF HIGH ENERGY SMOKELESS HMX PLASTISOL PROPELLANTS (U)



FORMULATION	740-193-62-1	740-193-51-1B
Ball Powder, 14528-30	13.0	13.0
Pall Powder, 2161	1.0	1.0
Casting Solvent "X"	---	52.0
HMX, 2u	30.0	30.0
Lead Stannate - TDI (Reduced) (740-181-64-2)	4.0	4.0
Nitroglycerin	52.0	---
Ball Powder/Casting Solvent Ratio	0.27	0.27
Q, cal/g	1420	1000

FIGURE 29 (c)

CONFIDENTIAL

Security Classification

DOCUMENT CONTROL DATA - R&D		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION
Picatinny Arsenal, Dover, New Jersey		Confidential
		2b. GROUP
		4
3. REPORT TITLE		
Development of New Catalysts for the Burning Rate Control of High Energy Smokeless Nitramine Double-Base Propellants (U)		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
5. AUTHOR(S) (Last name, first name, initial)		
Stack, Joseph S.		
6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1966	52	9
8a. CONTRACT OR GRANT NO.	8a. ORIGINATOR'S REPORT NUMBER(S)	
a. PROJECT NO. 1A222901A211	Picatinny Arsenal Technical Report No. 3487	
c. AMCMS Code 5221.11.585	8b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10. AVAILABILITY/LIMITATION NOTICES		
Qualified requesters may obtain copies of this report from DDC		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY	
13. ABSTRACT		
<p>(C) Studies leading toward the development of new combustion catalysts which are very effective in reducing the temperature and pressure dependency of burning rate of high energy (230 - 240 lb-sec/lb) smokeless nitramine (RDX, HMX) propellants are discussed.</p> <p>Described are the methods of manufacture, proposed reactions and analytical and X-ray diffraction data of the new combustion catalysts.</p> <p>Strand burning rate data are presented for extruded and plastisol (cross-linked and uncross-linked) propellants. The results show the highly effective nature of the new combustion catalysts in reducing the variability of burning rate to changes in temperature and pressure of these propellant types. Propellants investigated have application for close support and other weapon systems where high performance and smokelessness are required.</p>		

DD FORM 1473
1 JAN 64

CONFIDENTIAL

Security Classification

~~CONFIDENTIAL~~
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Combustion Catalysts Burning Rate Control Smokeless Nitramine Propellants Extruded Propellants Plastisol Propellants Cross-Linked Propellants RDX HMX						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.