UCRL-51319 (Rev. 1)

PROPERTIES OF CHEMICAL EXPLOSIVES AND EXPLOSIVE SIMULANTS

Compiled and edited by

Brigitta M. Dobratz

December 15, 1972

Prepared for U.S. Atomic Energy Commission under contract No. W-7405-Eng-48

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore

DISCLAIMER

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California/94550

UCRL-51319, Rev. 1

PROPERTIES OF CHEMICAL EXPLOSIVES AND EXPLOSIVE SIMULANTS

Compiled and edited by
Brigitta M. Dobratz

MS. date: December 15, 1972

(Supersedes UCRL-6759, Vol. 1, and UCRL-14592)

Contents

Foreword

This handbook presents information and data for high explosives of interest to programs of Lawrence Livermore Laboratory. The loose-leaf format is designed to permit easy revision and updating as new information and data become available. Thus, additions and corrections are welcomed by the compiler.

High Explosives (HE) are divided into two classes: initial detonating or primary explosives and noninitiating or secondary HEs. The primary HEs, such as azides and fulminates, are extremely sensitive to ignition by heat, shock, and electrical discharge; ignition goes to high-order detonation even for milligram quantities. Their use is therefore limited to squibs and starting materials for low-energy detonators. Since primary explosives have little application here, their properties have been specifically excluded from this compilation. Hereafter, secondary explosives are designated as HEs. Since many of the secondary high explosives (which are formulated and manufactured within the AEC complex) are mixtures, the properties of the additives and binders used have been included.

The data are the most up-to-date and accurate available to the knowledge of the compiler. Some data, however, can represent only a range, an approximation, or comparative values; this is especially true of explosive mixtures. Such cases are noted in the text as they occur. The sources of information include textbooks, journal articles, technical reports, memoranda, letters, and personal communications. Various schemes considered in the past to annotate the tables with the apposite references proved too cumbersome. However, an attempt is made in this revision and will be continued in subsequent revisions to provide precise references to the information and data presented. Data not specifically referenced were obtained from UCRL-14592*; further information and additional references can be obtained from the compiler. References are listed at the end of each section.

The compilation consists of sections on high explosives and mock explosives, code designations, data sheets on individual materials, and a bibliography. A list of abbreviations precedes the section on high explosives. The data are given in the units (metric or English) in which they were reported originally. All values and units, however, are converted to the International System of Units (S.I.)†; throughout this handbook the SI values are given in parentheses following the values in English or metric units. The units are given in the table below and on other tables and figures where used.

Reference to a company or product name in this compilation does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.

---

*Properties of Chemical Explosives, Lawrence Livermore Laboratory, Rept. UCRL-14592 (1965).

†Metric Practice Guide, American Society for Testing and Materials, Philadelphia, E 380-70 (1970).

CONVERSION FACTORS

Units and factors for conversion to SI system.

		Unit system			
	Symbol	U. S./British	cgs	SI(m/k/s)[a]	Multiplication factor
Angle			deg	rad	1.745329×10^{-2}
C-J pressure	P_{CJ}		bar	Pa	10^5
Creep compliance		1/psi (= $in.^2$/lbf)		m^2/N	1.450377×10^{-4}
Density	ρ		g/cm^3	Mg/m^3	1
Detonation velocity	D		mm/μsec	km/s	1
Heat of detonation[b]	ΔH_{det}		cal/g	J/kg	4.184×10^3
Heat of formation[b]	ΔH_f		cal/g	J/kg	4.184×10^3
			kcal/mol	kJ/mol	4.184
Initial modulus	E_0	psi		Pa	6.894757×10^3
Length			Å	m	10^{-10}
		mil		m	2.54×10^{-5}
Pressure	P	psi		Pa	6.894757×10^3
			atm	Pa	1.01×10^5
			bar	Pa	1.00×10^5
Sliding velocity	ν	in./min		m/s	4.233×10^{-4}
		ft/sec		m/s	3.048×10^{-1}
Specific heat[b]	C_p	BTU/lb-°F	cal/g-°C	J/kg-K	4.184×10^3
Temperature	T	°F		K	$[(T_F - 32)/1.8] + 273.15$
			°C	K	$T_C + 273.15$
Thermal conductivity[b]	k	BTU/hr-ft-°F		W/m-K	1.729577
			cal/cm-sec-°C	W/m-K	4.184×10^2
Thermal expansion	CTE	in./in.-°F		m/m-K	1.8
			cm/cm-°C	m/m-K	1
Vapor pressure	v.p.		mm Hg, Torr	Pa	1.333×10^2
Weight		lb		kg	4.535924×10^{-1}

[a] In this column, the abbreviations used are those of the International System of Units (SI)[2]; in this system, degrees Kelvin = K.

[b] Thermochemical BTU or calorie.

Glossary

AFNOL	polymerization product of primarily DINOL and 4,4-dinitropimeloyl chloride
AWRE	Atomic Weapons Research Establishment, U.K.
b.p.	boiling point
BDNPA	bis(2,2-dinitropropyl) acetal
BDNPF	bis(2,2-dinitropropyl) formal
BEAF	1,2-ethanediol bisdifluoronitroacetate
BKW	Brinkley-Kistiakowski-Wilson (equation of state)
BTF	benzotrifuroxan
c_b	calculated bulk sonic velocity
c_ℓ	calculated longitudinal velocity
C_p	specific heat
CAB	cellulose acetate butyrate
CEF	tris-β-chloroethyl phosphate
CJ	Chapman-Jouguet
CTE	coefficient of thermal expansion
D	detonation velocity
DATB	1,3-diamino-2,4,6-trinitrobenzene
dec.	decomposition
DFTNB	difluorotrinitrobenzene
DINOL	2,2,8,8-tetranitro-4,6-dioxa-1,9-nonane diol
DIPAM	2,2',4,4',6,6'-diaminohexanitrobiphenyl, dipicramide
DMFA	dimethylformamide
DMSO	dimethylsulfoxide
DNPA	2,2-dinitropropyl acrylate
DNPN	4,4-dinitropentanonitrile
DOP	dioctylphthalate, di-(2-ethylhexyl)-phthalate
E	energy
EDNP	ethyl 4, 4-dinitropentanoate
EGDN	ethylene glycol dinitrate
E_u	ultrasonic modulus
f	coefficient of friction
f.p.	freezing point
FEFO	bis(2-fluoro-2, 2-dinitroethyl) formal
G	complex shear modulus
H_{50}	drop weight sensitivity
HE	high explosive
HMX	1, 3, 5, 7-tetranitro-1, 3, 5, 7-tetrazacyclooctane
HNAB	2, 2', 4, 4', 6, 6'-hexanitroazobenzene
HNS	2, 2', 4, 4', 6, 6'- hexanitrostilbene
HVD	high velocity detonation

JWL	Jones-Wilkins-Lee (equation of state)
K	degrees Kelvin
k	thermal conductivity
LASL	Los Alamos Scientific Laboratory
LLL	Lawrence Livermore Laboratory
LVD	low velocity detonation
m. p.	melting point
MEK	methylethylketone
MIBK	methylisobutylketone
MW	molecular weight
N	newton (pound-force)
n	refractive index
NC	nitrocellulose
NG	nitroglycerine
NM	nitromethane
NOL	Naval Ordnance Laboratory
NONA	nonanitroterphenyl
NQ	nitroguanidine
P_{CJ}	Chapman-Jouguet pressure
PBX	plastic-bonded explosive
PENTEK	pentaerythritol
PETN	pentaerythritol tetranitrate
PR	Poisson's ratio
R	molecular refraction
RDX	1, 3, 5-trinitro-1, 3, 5-triazacyclohexane
RTV	room-temperature vulcanizing
S. I.	Systeme Internationale (International System of Units)
STP	standard temperature and pressure
T	temperature
T_g	glass transition temperature
TACOT	tetranitro-1, 2, 5, 6-tetrazadibenzocyclooctatetrene
TATB	1, 3, 5-triamino-2, 4, 6-trinitrobenzene
TEF	tris-β-chloroethylphosphate
Tetryl	2, 4, 6-trinitrophenylmethylnitramine
THF	tetrahydrofuran
TMD	theoretical maximum density
TNM	tetranitromethane
TNT	2, 4, 6-trinitrotoluene
V	volume
v	velocity
v. p.	vapor pressure
WLF	Williams-Landel-Ferry (shift equation)

α	linear coefficient of expansion
β	cubical coefficient of expansion
ΔH_{det}	heat of detonation
ΔH_f	heat of formation
Γ	adiabatic coefficient of expansion
α	linear CTE
β	cubical CTE
ϵ	dielectric constant
ν	sliding velocity
ρ	density

PROPERTIES OF CHEMICAL EXPLOSIVES AND EXPLOSIVE SIMULANTS

I. High Explosives

1. INTRODUCTION

High explosives are metastable compounds or mixtures that can react rapidly to give gaseous products at high temperature and pressure. The attendant expansion of these products is the mechanism by which explosives do useful work. As with primary explosives, reaction can be initiated by shock and heat. High explosives, however, differ from primary explosives in three ways:

1. Small unconfined charges, even though ignited, will not usually detonate high-order.
2. Electrostatic ignition is very difficult (except in explosive dust clouds).
3. Ignition of any sort requires considerably larger shocks.

2. MANUFACTURE

Pure explosives are usually synthesized by sulfuric/nitric-acid nitration of organic compounds. The product is separated from the mixed acids by filtration, then worked free of impurities and dried.

TNT is one of the few pure explosives that can be fabricated directly by melting and casting into a desired shape. Most other materials must be diluted either with TNT (thereby castable) or with plastic (thereby pressable) before they can be fabricated into useful shapes.

The procedure used for fabricating castable, TNT-containing formulations is as follows: TNT is melted and the desired solid ingredients are added with stirring. The melt is precrystallized into a slurry, and vacuum is applied just before pouring into a mold. Cracking and variations in density and composition are minimized by careful control of the cooling rate.

Plastic-bonded explosives (PBX) are pressed from "molding" powders, which may be produced in several ways. A typical preparation is by the slurry technique: powdered explosive and water are agitated in a container equipped with cover, condenser, and stirrer. A lacquer composed of the plastic (together with a plasticizer, if required) dissolved in a suitable solvent is added to the slurry. The solvent is removed by distillation, causing the plastic phase to precipitate out onto the explosive as a coating. The plastic-explosive agglomerates into "beads" as the stirring and removal of solvent are continued. Finally, water is removed from the beads by filtering and drying, leaving the molding powder. Good molding powders have a high bulk density and are free-flowing and dustless.

PBX molding powder can be pressed into usable shapes by two methods: compression molding with steel dies, or hydrostatic or isostatic pressing. In the latter method the explosive is placed in rubber sacks and subjected to fluid pressure. With either method, consolidation of the molding powder to reasonable densities (97% of theoretical) is obtained at pressures between 12,000 and 20,000 psi (83 and 138 MPa) and molding temperatures between 25 and 120°C (298 and 313 K). An important and necessary feature of molding is the use of vacuum. The molding powder is normally evacuated to a pressure of less than 1000 μ Hg (133 Pa) before pressing.

Both pressed and cast explosives are usually machined to final shape. Many intricate forms have been cut successfully. As a rule, the machining of explosives is similar to the machining of a conventional plastic, except that water is used as a cutting-tool coolant. New explosives are machined by remote control until their behavior under machining has been carefully evaluated.

Specifications

Manufacture and testing are controlled by specifications for production explosives. A list of pertinent specifications is given in Table 2-1.

Table 2.1. Specifications for manufacture and testing.

	Specification number	Title
		Explosives
BDNPA/BDNPF	WS-1141	Weapons Specification for Mixture of Bis(2,2-dinitropropyl)acetal-Bis(2,2-dinitro-propyl) formal.
Comp B	MIL-C-401	Military Specification for Composition B.
Comp-B-3	MIL-C-45113	Military Specification for Composition B-3.
FEFO	RM-253202	LLL Material Specification for Liquid Explosive Bis(2,2-dinitro-2-fluoro-ethyl) formal (FEFO).
HMX	MIL-H-45444	Military Specification for HMX.
HNAB	SS274590	Sandia Specification for Synthesis of HNAB (Hexanitroazobenzene).
LX-04	RM-252353	LLL Material Specification for LX-04 Molding Powder.
LX-07	RM-253379	LLL Material Specification for LX-07 Molding Powder.
LX-09	RM-253200	LLL Material Specification for LX-09 Molding Powder.
LX-10	RM-253511	LLL Material Specification for LX-10 Molding Powder.
LX-13	RM-253520	LLL General Specification for LX-13. (CRD)
Octol	MIL-O-45445	Military Specification for Octol.
PBX-9007	PA-PD-711	Picatinny Arsenal Purchase Description for Powder, Molding Compound Explosive (PBX). (PBX-9007).
PBX-9011	13Y-101030	LASL Material Specification for PBX-9011 Molding Powder.
PBX-9205	13Y-103317	LASL Material Specification for PBX-9205 Manufactured by the Slurry Method.
PBX-9404	13Y-103159	LASL Material Specification for PBX-9404 Molding Powder.
	RM-252336	LLL Material Specification for PBX-9404 Molding Powder.
PBX-9407	13Y-109098	LASL Material Specification for PBX-9407 Molding Powder.
PBX-9501	13Y-109643	LASL Material Specification for PBX-9501 Molding Powder.
PETN	MIL-P-387	Military Specification for Pentaerythritol Tetranitrate (PETN).
RDX	MIL-R-398	Military Specification for RDX.
Tetryl	JAN-T-339	Joint Army-Navy Specification for Tetryl (Trinitrophenylmethylnitramine).
TNT	MIL-T-248	Military Specification for TNT
XTX-8003	13Y-104481	LASL Material Specification for XTX-8003 Extrudable Explosive.
		Binders
Estane	13Y-101031	LASL Material Specification for Estane 5740 X-2.
Fluoro-elastomer	RM-252988	LLL Material Specification for Uncured Fluoro-elastomer Binder
pDNPA	RM-253201	LLL Material Specification for 2,2-Dinitropropyl-acrylate Polymer (pDNPA) Plastic Binder
Polystyrene	MIL-P-55026	Military Specification for Polystyrene, Unmodified (For Use as a Binder in Explosives).
Sylgard	13Y-104480	LASL Material Specification for Dow Corning Resin 93-022 (Aerospace Grade Sylgard 182).
		Explosive Parts and Testing
	RM-253391	LLL Specification for Mechanical Properties Testing of Plastic-Bonded High Explosive Parts.
	RM-252356	LLL General Specifications for Plastic-Bonded High Explosives.

3. NAMES AND FORMULATIONS

This section consists of Tables 3-1 through 3-4, which list the names and formulations of various explosives and energetic compounds.

Table 3-1. Pure explosive compounds.

Material[a]	Chemical name	Other designations	Color
BTF	Benzotris-[1, 2, 5] oxadiazole-[4,4,7]-trioxide	Benzotrifuroxan, hexanitrosobenzene	Buff
DATB	1, 3-Diamino-2, 4, 6-trinitrobenzene		Yellow
DIPAM	3, 3-Diamino-2, 2', 4, 4', 6, 6'-hexanitrobiphenyl	Hexanitrodiphenylamine hexite, dipicrylamine	—
DNPA	2,2-Dinitropropyl acrylate		Off-white
EDNP	Ethyl-4, 4-dinitropentanoate		Yellow
FEFO	Bis(2-fluoro-2, 2-dinitroethyl)-formal		Straw
HMX	1, 3, 5, 7-Tetranitro-1, 3, 5, 7-tetraazacyclooctane	Cyclotetramethylene tetranitramine, octogen	White
HNAB	2, 2', 4, 4', 6, 6'-Hexanitroazobenzene		Orange
HNS	2, 2', 4, 4', 6, 6'-Hexanitrostilbene		Yellow
NC (12% N)[b]	Partially nitrated cellulose	Nitrocellulose (lacquer grade), cellulose trinitrate, piroksilin	White
NC (13.35% N, min)[b]	Partially nitrated cellulose	Nitrocellulose, guncotton	White
NG	1, 2, 3-Propanetriol trinitrate	Nitroglycerin	Clear
NM	Nitromethane		Clear
NQ	Nitroguanidine	Aminomethaneamidine	White
PETN	Pentaerythritol tetranitrate	Penthrite, TEN	White
RDX	1, 3, 5-Trinitro-1, 3, 5-triazacyclohexane, hexahydro-1, 3, 5-trinitro-s-triazine	Cyclotrimethylene trinitramine, hexogen cyclonite, Gh	White
TACOT	Tetranitro-1,2,5,6-tetraazadibenzocyclooctatetrene	Tetranitrodibenzo-1, 3a, 4, 6a-tetraazapentalene	Red-orange
TATB	1, 3, 5-Triamino-2, 4, 6-trinitrobenzene		Bright yellow
*Tetryl	2, 4, 6-Trinitrophenylmethylnitramine		Yellow
*TNM	Tetranitromethane		Clear
*TNT	2,4,6-Trinitrotoluene	Trotyl, T, tol	Buff to brown

[a]Properties of materials marked with asterisks are summarized in data sheets (Section IV).

[b]Nitrocellulose is not, strictly speaking, a single chemical compound. Different grades are commercially available, the grade denoting the degree of nitration. For this handbook we cite, where possible, data characteristic of lacquer-grade nitrocellulose (12.0% N) and guncotton (13.35% N, min). Lacquer-grade nitrocellulose is not an explosive but an energy-contributing plastic binder in PBX-9404.

Table 3-2. Cast explosives: names and formulations.

Explosive[a]	Formulation (wt%)[b] TNT	RDX	Other ingredients	
Baratol	24		$Ba(NO_3)_2$	76
Boracitol	40		Boric acid	60
*Comp B, Grade A[c]	36	63	Wax	1
Comp B-3	40	60		
*Cyclotol[d]	25	75		
H-6	30	45	Wax	5
			Al	20
			$CaCl_2$	0.5
*Octol	25		HMX	75
*Pentolite[d]	50		PETN	50
Tritonal	80		Al	20

[a]Properties of materials marked with asterisks are summarized in data sheets (Section IV).

[b]The weight percent values given in the table are nominal and subject to some variation.

[c]Comp B, Grade A is formulated as a 60/40 RDX/TNT mixture, but high-quality castings usually are higher in RDX content due to the removal of a TNT-rich section at the top of the casting.

[d]There are several cyclotols and pentolites. The most common cyclotol is RDX/TNT 75/25. The most common pentolite is PETN/TNT 50/50.

Table 3-3. Plastic-bonded explosives: Names and formulations.

Explosive[a]	Other designations	Formulation		Color
		Ingredient	wt%	
*LX-04-1	PBHV-85/15	HMX Viton A	85 15	Yellow
*LX-07-2	RX-04-BA	HMX Viton A	90 10	Orange
*LX-09-0	RX-09-CB	HMX pDNPA FEFO	93 4.6 2.4	Purple
LX-09-1		HMX pDNPA FEFO	93.3 4.4 2.3	Purple
*LX-10-0	RX-04-DE	HMX Viton A	95 5	Blue-green spots on white
LX-10-1		HMX Viton A	94.5 4.5	Blue-green spots on white
*LX-11-0	RX-04-PI	HMX Viton A	80 20	White
*LX-14-0		HMX Estane 5702-F1	95.5 4.5	Violet spots on white
*PBX-9007	PBX-9007 Type B	RDX Polystyrene Di(2-ethyl-hexyl)-phthalate Rosin	90 9.1 0.5 0.4	White or mottled gray[b]
*PBX-9010		RDX Kel-F	90 10	White
*PBX-9011	X-0008	HMX Estane 5740-X2	90	Off-white
*PBX-9205		RDX Polystyrene Di(2-ethyl-hexyl)-phthalate	92 6 2	White
*PBX-9404	PBX-9404-03	HMX NC (12.0% N) Tris(β-chloro-ethyl)-phosphate	94 3 3	White or blue
*PBX-9407		RDX Exon 461	94 6	White or black[b]
*PBX-9501		HMX Estane BDNPA BDNPF	95 2.5 1.25 1.25	White

[a]Properties of materials marked with asterisks are summarized in data sheets (Section IV).

[b]Depending on graphite content.

Table 3-4. Miscellaneous explosives: Names and formulations.

Explosive[a]	Other designations	Formulation		Color
		Ingredient	wt%	
Comp C-4		RDX	91	White
		Di(2-ethylhexyl)-sebacate	5.3	
		Polyisobutylene	2.1	
		Motor oil	1.6	
EL-506A		PETN	85	Red
		Binder	15	
EL-506C		PETN	63	Red
		Binder	37	
*LX-01	NTN	Nitromethane	51.7	Clear
		Tetranitromethane	33.2	
		1-Nitropropane	15.1	
*LX-02-1	EL-506 L-3	PETN	73.5	Buff
		Butyl rubber	17.6	
		Acetyltributyl citrate	6.9	
		Cab-O-Sil	2.0	
*LX-08		PETN	63.7	Blue
		Silicone rubber	34.3	
		Cab-O-Sil	2.0	
LX-13		PETN	80	Green
		Silicone rubber	20	
MEN-II	RX-01-AC	Nitromethane	72.2	Clear
		Methanol	23.4	
		Ethylenediamine	4.4	
*XTX-8003	Extex	PETN	80	White
		Silicone rubber	20	

[a]Properties of materials marked with asterisks are summarized in data sheets (Section IV).

Table 3-5. Additives and binders.

Material[a]	Chemical name	Other designation	Color
BDNPA/BDNPF	Bis(2,2-dinitropropyl) acetal/ bis(2,2-dinitropropyl) formal 50/50 w/o		Straw
Cab-O-Sil M-5			White
DOP	Di(2-ethylhexyl)-phthalate	dioctylphthalate	Clear
Estane 5702-F1		polyurethane solution system	Light amber
Exon 461	Trifluorochloroethylene/ vinylidine chloride copolymer		White
Kel-F 800	Poly(trifluorochloroethylene)		Off-white
Kel-F 3700	Poly(trifluorochloroethylene)		Off-white
Polystyrene			Clear
Sylgard 182		Silicone resin	Light straw
TEF	Tris-β-chloroethylphosphate		Clear
Viton A	Hexafluoropropylene/ vinylidine fluoride 1:2		White

[a]Properties of these materials are summarized in data sheets (Section IV).

4. PHYSICAL PROPERTIES

This section contains information relating to selected physical constants and properties of HEs of interest. These properties are physical state and density (Table 4-1); molecular weight MW and atomic composition (Table 4-2); melting point m.p., boiling point b.p., and vapor pressure v.p. (Table 4-3 and Fig. 4-1); crystallographic and optical properties (Table 4-4).

Many properties are density-dependent. For calculations for mixtures, some useful auxiliary relationships between composition and density are as follows:

$$\rho\ (\mathrm{TMD}) = \frac{\sum m_i}{\sum (m_i/\rho_i)} = \frac{\sum (v_i \rho_i)}{\sum v_i} ,$$

$$V_i = W_i\ (\rho_0/\rho_i) = \frac{v_i}{\sum v_i} = \frac{100\ m_i/\rho_i}{\sum (m_i/\rho_i)} ,$$

$$W_i = \frac{100\ v_i \rho_i}{\sum (v_i \rho_i)} = \frac{100\ m_i}{\sum m_i} ,$$

$$\mathrm{Void}\ V_i = 1 - (\rho_0/\mathrm{TMD}) ,$$

where TMD is theoretical maximum density, m is mass, v is volume, W is weight percent, V is volume percent, ρ is theoretical density, subscript i designates the component, and ρ_0 is the actual density of the mixture.

Physical State and Density

Table 4-1. Physical States and densities.

Material	Physical state	TMD[a], ρ (g/cm^3 (Mg/m^3))	Nominal density, ρ (g/cm^3 (Mg/m^3))
AFNOL	Liquid	1.48	1.48
Baratol	Solid	2.63	2.60-2.61
BDNPA/BDNPF[2]	Liquid	1.383-1.397	—
Boracitol	Solid	—[b]	1.53-1.54
BTF	Solid	1.901	1.87
Cab-O-Sil[3]	Solid	2.3	2.2
Comp B, Grade A	Solid	1.74	1.71
Comp B-3	Solid	1.75	1.72
Comp C-4	Puttylike solid	—	1.59
Cyclotol 75/25	Solid	1.77	1.75-1.76
DATB	Solid	1.837	1.79
DIPAM[4]	Solid	1.79	—
DNPA	Solid	1.47	—
DOP	Liquid	0.9861	—
EDNP	Liquid	1.28	—
EL-506A	Solid	—	1.48
EL-506C	Solid	—	1.48
Estane[5]	Rubbery solid	—	1.18
Exon 461[6]	Solid	—	1.70
FEFO	Liquid	1.607	—
H-6	Solid	—	1.74 (cast)
HMX	Solid	1.900	1.89
HNAB-I[7]	Solid	1.795 calc. 1.799 obs.	—
HNAB-II[7]	Solid	1.744 calc. 1.750 obs.	—
HNAB-III[7]	Solid	1.718 obs.	—
HNS[8,9]	Solid	1.74	1.72
Kel-F 800[10]	Solid	—	2.02
Kel-F 3700[10]	Solid	—	1.85
LX-01	Liquid	1.23	—
LX-02	Puttylike solid	1.44	1.43-1.44
LX-04	Solid	1.889	1.860-1.870
LX-07	Solid	1.892	1.860-1.870
LX-08	Puttylike solid	1.439	≥1.42
LX-09	Solid	1.867	1.837-1.845
LX-10-0	Solid	1.896	1.858-1.868

Table 4-1. (continued)

Material	Physical state	TMD[a], ρ (g/cm^3 (Mg/m^3))	Nominal density, ρ (g/cm^3 (Mg/m^3))
LX-10-1	Solid	1.895	1.870
LX-11	Solid		1.87-1.876
LX-13	Putty curable to rubbery solid	1.558	≈1.53
LX-14	Solid	1.849	1.834
MEN-II	Liquid	1.017	—
NC (12.0% N)	Solid	—	1.58
NC (13.35% N, min)	Solid	—	1.58
NG	Liquid	1.59	—
NM	Liquid	1.13 at 20°C (293 K)	—
NQ	Solid	1.72	1.55
Octol	Solid	1.83	1.80-1.82
PBX-9007	Solid	1.697	1.66
PBX-9010	Solid	1.822	1.789
PBX-9011	Solid	1.795	1.770
PBX-9205	Solid	1.72	1.68
PBX-9404	Solid	1.865	1.831-1.844
PBX-9407	Solid	1.81	1.60-1.62[c]
PBX-9501[6]	Solid	1.855	1.843
Pentolite 50/50	Solid	1.71	1.67
PETN	Solid	1.77	1.76
Polystyrene[12]	Solid	1.12	1.05
RDX[13]	Solid	1.806	—
Sylgard 182[14]	Liquid	1.05	—
TACOT	Solid	1.85	1.61
TATB	Solid	1.938	1.88
TEF	Liquid	1.425	—
Tetryl	Solid	1.73	1.71
TNM	Liquid	1.650 at 13°C (286 K)	—
TNT	Solid	1.654	Cast: 1.5-1.6 Pressed: 1.63-1.64
Viton A[15]	Rubbery solid	—	1.815
XTX-8003	Putty curable to rubbery solid	1.556	≈1.53

[a]Theoretical maximum density.

[b]A TMD value based on boric acid and TNT is 1.52; during the vacuum casting at over 80°C (353 K), however, some of the boric acid breaks down to B_2O_3. This has the effect of increasing the TMD by an unpredictable amount.

[c]Nominal density in detonator and booster applications.

Table 4-2. Molecular weights and atomic compositions. For materials that are pure chemical compounds, molecular weights and molecular formulas are given: for those that are mixtures, an arbitrary molecular weight of 100 is assigned, and an empirical formula corresponding to this weight is given. For such mixtures, the weight percentage of an element is given by the product of the atomic weight and its subscript in the empirical formula.

Explosive	MW	Elemental composition				
		C	H	N	O	Other
Baratol	100	0.74	0.53	0.90	2.38	Ba 0.29
BDNPA/BDNPF	100					
Boracitol	100	1.23	3.79	0.53	3.97	B 0.97
BTF	252.1	6	0	6	6	
Cab-O-Sil	60.09					
Comp B, Grade A[a]	100	2.03	2.64	2.18	2.67	
Comp B-3[b]	100	2.05	2.51	2.15	2.67	
Comp C-4	100	1.82	3.54	2.46	2.51	
Cyclotol 75/25	100	1.78	2.58	2.36	2.69	
DATB	243.1	6	5	5	6	
DIPAM	454.1	12	6	8	12	
DNPA	204.1	6	8	2	6	
DOP	390.57	24	38		4	
EDNP	220.2	7	12	2	6	
EL-506A	100	2.41	4.29	1.08	3.27	
EL-506C	100	3.25	5.94	0.87	2.68	
Estane 5702F-1	100	5.137	7,500	0.187	1.758	
FEFO	320.1	5	6	4	10	F 2
Exon 461	$(213.43)_n$	4	2			Cl 3 F 3
H-6	100	1.890	2.590	1.612	2.009	Ca 0.0045 Cl 0.0090 Al 0.741
HMX	296.2	4	8	8	8	
HNAB	452.21	12	4	8	12	
HNS	450.3	14	6	6	12	
Kel-F 3700	$(116.48)_n$	2				Cl 1 F 3
LX-01-0	100	1.52	3.73	1.69	3.39	
LX-02-1	100	2.77	4.86	0.93	2.99	Si 0.03
LX-04-1	100	1.55	2.58	2.30	2.30	F 0.52
LX-07-2	100	1.48	2.62	2.43	2.43	F 0.35
LX-08-0	100	1.93	4.39	0.81	2.95	Si 0.50
LX-09-0	100	1.43	2.74	2.59	2.72	F 0.02
LX-09-1	100	1.425	2.735	2.592	2.721	F 0.0144

Table 4-2. (continued)

Explosive	MW	Elemental composition				
		C	H	N	O	Other
LX-10-0	100	1.42	2.66	2.57	2.57	F 0.17
LX-10-1	100	1.410	2.663	2.579	2.579	F 0.156
LX-11-0	100	1.61	2.53	2.16	2.16	F 0.70
LX-13 See XTX-8003						
LX-14	100	1.521	2.917	2.587	2.658	
MEN-II	100	2.06	7.06	1.33	3.10	
NC (12.0% N)	262.6	6	7	2.25	9.5	
NC (13.35% N, min)	274.1	6	7	2.5	10	
NG	227.1	3	5	3	9	
NM	61.0	1	3	1	2	
NQ	104.1	1	4	4	2	
Octol	100	1.78	2.58	2.36	2.69	
PBX-9007	100	1.97	3.22	2.43	2.44	
PBX-9010	100	1.39	2.43	2.43	2.43	Cl 0.09 F 0.26
PBX-9011	100	1.73	3.18	2.45	2.61	
PBX-9205	100	1.83	3.14	2.49	2.51	
PBX-9404	100	1.40	2.75	2.57	2.69	Cl 0.03 P 0.01
PBX-9407	100	1.41	2.66	2.54	2.54	Cl 0.07 F 0.09
PBX-9501	100	1.47	2.86	2.60	2.69	
Pentolite 50/50	100	2.33	2.37	1.29	3.22	
PETN	316.2	5	8	4	12	
Polystyrene	$(104.15)_n$	8	8			
RDX	222.1	3	6	6	6	
Sylgard 182	$(74.16)_n$	2	6		1	Si 1
TACOT	388.2	12	4	8	8	
TATB	258.2	6	6	6	6	
TEF	285.5	6	12		4	Cl 3 P 1
Tetryl	287.0	7	5	5	8	
TNM	196.0	1	0	4	8	
TNT	227.1	7	5	3	6	
Viton A	$(187.08)_n$	5	3.5			F 6.5
XTX-8003	100	1.80	3.64	1.01	3.31	Si 0.27

[a]Based on nominal composition of 63% RDX, 36% TNT, and 1% wax. The wax was assumed to have the composition CH_2.

[b]Based on nominal composition of RDX/TNT 60/40.

Table 4-3. Melting points m.p., boiling points b.p., and vapor pressures v.p.

Material	m.p. Ref.	m.p. (°C)	m.p. (K)	b.p. Ref	b.p. (°C)	b.p. (K)	v.p.[a] Ref	v.p. (mm Hg)	v.p. (Pa)
AFNOL		105-110	(378-383)			--			--
Baratol		79-80	(352-353)			--		0.1 at 100°C	(13.33 at 373 K)
BDNPA/BDNPF				2	~150 at 0.01 mm	(423 at 1.33 Pa)			
Boracitol		79-80	(352-353)			--			--
BTF		198-200	(471-473)			--			--
Comp B, Grade A		~80	(~353)			--			--
Comp B-3		79-80	(352-353)			--		0.1 at 100°C	(13.33 at 373 K)
Comp C-4		--[b]				--			--
Cyclotol 75/25		79-80	(352-353)			--		0.1 at 100°C	(13.33 at 373 K)
DATB	16	286	(559)			--			--
DIPAM	4	304	(577)			--			--
DNPA		--				--			--
DOP				17	222-230	(495-503)	17	<0.06 at 150°C 1.2 at 200°C	(<8.0 at 423 K) (159.9 at 473 K)
EDNP	18	-6	(268)	18	83 at 0.05 mm	(356 at 6.7 Pa)			--
EL-506A		--				--			--
EL-506C		--				--			--
FEFO	19	11.3-12.9	(284-286)	18	120-124 at 0.3 mm	(393-397 at 40 Pa)		2.14 × 10^{-4} at 25°C	(2.85 × 10^{-2} at 298 K)
								$\log_{10} P_{mm} = 10.33 - \frac{4171}{T(K)}$	
HMX		285-287	(558-560)			--	8	3 × 10^{-9} at 100°C	(4 × 10^{-7} at 373 K)
HNAB	20	215-216	(488-489)			--	8	1 × 10^{-7} at 100°C	(1.33 × 10^{-5} at 373 K)
	9	316	(589)			--			
HNS[c]	19	I. 313	(586)			-	4	I $\log_{10} P_{mm} = 14.084 - \frac{9347}{T(K)}$	
	19	II 318	(591)			--	8	II 1 × 10^{-9} at 100°C	(1.33 × 10^{-7} at 373 K)
LX-01-0		-54	(219)			--		29.0 at 25°C	(3866 at 298 K)
LX-02		--[b]				--			--
LX-04		Dec >250[d]	(>523)			--			--
LX-07		Dec >250	(>523)			--			--
LX-08		129-135 with decomposition	(402-408)			--			--
LX-09		Dec >280	(>553)			--			--
LX-10		Dec >250	(>523)			--			--
LX-11		Dec >250	(>523)			--			--
LX-13 See XTX-8003									
LX-14		Dec >270	(>543)			--			--
MEN II		--				--			--
NC (12.0% N)		Dec 135	(408)			--			--
NC (13.35% N, min)		Dec 135	(408)			--			--

Table 4-3. (continued)

Material	m.p. Ref.	m.p. (°C)	m.p. (K)	b.p. Ref.	b.p. (°C)	b.p. (K)	v p[a] Ref.	v p[a] (mm Hg)	v p[a] (Pa)
LX-09		Dec.>280	(>553)		--				--
LX-10		Dec.>250	(>523)		--				--
LX-11		Dec.>250	(>523)		--				--
LX-13 See XTX-8003									
LX-14		Dec.>270	(>543)		--				--
MEN II		--			--				--
NC (12.0% N)		Dec. 135	(408)		--				--
NC (13.35% N, min)		Dec. 135	(408)		--				--
NG		13.2	(286)		--			0.0015 at 20°C	(0.2 at 293 K)
NM		-29	(244)		101-101.5	(374-375)		37 at 25°C	(4933 at 298 K)
NQ	21	246-247 with decomposition	(519-520)		--				--
Octol		79-80	(352-353)		--			0.1 at 100°C	(13.33 at 373 K)
PBX-9007		Dec.>200	(>473)		--				--
PBX-9010		Dec.>200	(>473)		--				--
PBX-9011		Dec.>250	(>523)		--				--
PBX-9205		Dec.>200	(>473)		--				--
PBX-9404		Dec.>250	(523)		--				--
PBX-9407		Dec.>200	(>473)		--				--
PBX-9501	22	Dec.>240	(>513)		--				--
Pentolite 50/50		76	(349)		--			0.1 at 100 C	(13 33 at 373 K)
PETN		139-142	(412-415)		--		8	8×10^{-5} at 100°C	$(1\ 1 \times 10^{-3}$ at 373 K)
							23	$\log_{10} P_{mm}$ 14 44 - $\frac{6352}{T\ (K)}$	
Polystyrene	12	240	(513)		--				--
RDX	13	205	(478)		--			$\log_{10} P_{cm}$ 10 87 - $\frac{3850}{T\ (K)}$ from 111-130 C (384-403 K)	
TACOT	24	Dec >380	(>653)		--				--
TATB	25	Dec.>325	(598)		--				--
TEF	26	203	(476)		-				--
Tetryl		130	(403)		--				--
TNM		14 2	(287)		125.7	(399)		13 at 25°C	(1733 at 298 K)
TNT		80.9	(354)		--			0 106 at 100°C	(14 13 at 373 K)
								$\log_{10} P_{cm}$ 9 11 - $\frac{3850}{T\ (K)}$ from 200-350 C (473-623 K)	
XTX-8003		129-135	(402-408)		-				--

[a] 1 mm Hg = 1.33323×10^2 Pa

[b] No fixed melting point.

[c] Two types of HNS are in production: HNS-I, <10 μ particle size, and HNS-II, 100-300 μ particle size

[d] Dec.: decomposes.

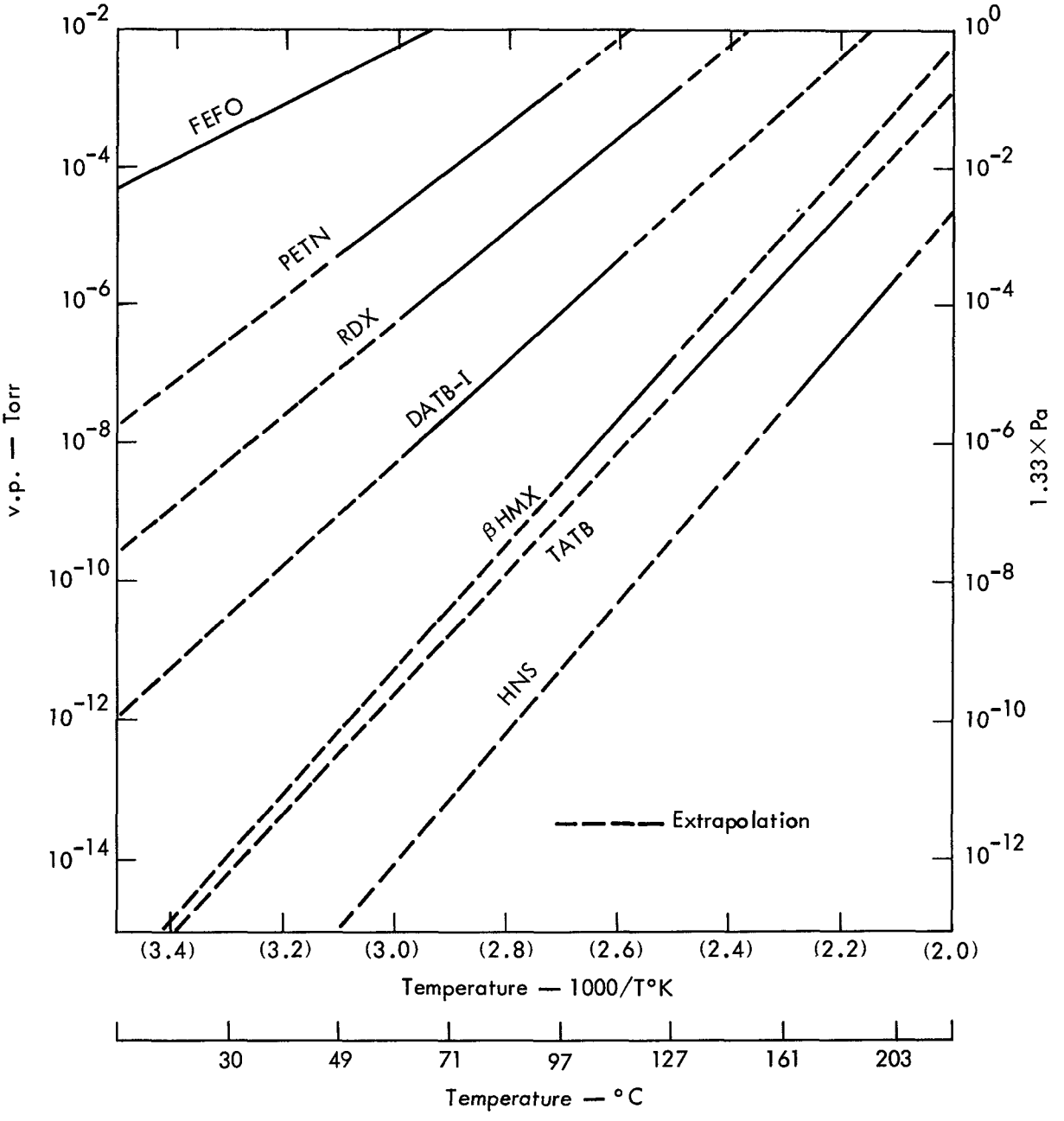


Fig. 4-1. Vapor pressure of FEFO,[27] PETN,[23] RDX,[28] DATB-I,[28] β-HMX,[28] TATB,[28] HNS.[29] Conversion factor: 1 Torr = 1.333×10^2 Pa.

Table 4-4. Crystallographic and optical properties.[a]

Material	Polymorph	Unit cell dimension (Å (10^{-1} nm))	Crystal structure	Space group	Refractive index n	Molecular refraction R
BDNPA/BDNPF[2]					1.462-1.464 at 25°C (298 K)	
BTF[29,30]		a = 9.92 b = 19.52 c = 6.52	Orthorhomic	$Pna2_1$		
Cab-O-Sil[3]			Amorphous		1.46	
DATB[16]	I	a = 7.30 b = 5.20 c = 11.63		Pc2		
DOP[17]					1.485 at 25°C (298 K)	
HMX[31-35]	II (α)	a = 15.14 b = 23.89 c = 5.91	Orthorhombic	Fdd2	α = 1.561-1.565 β = 1.562-1.566 γ = 1.72-1.74	58 calc. 55.7 obs.
	I (β)	a = 6.54 b = 11.05 c = 8.70	Monoclinic	$P2_1/c$	α = 1.589 β = 1.594 γ = 1.73	58 calc. 56.1 obs.
	III (γ)	a = 10.95 b = 7.93 c = 14.61	Monoclinic	Pc_1 P2/c, $P2_1/n$	α = 1.537 β = 1.585 γ = 1.666	58 calc. 55.4 obs.
	IV (δ)	a = 7.66 b = —— c = 32.49	Hexagonal	$P6_122$, $P6_522$		58 calc. 55.9 obs.
HNAB[7]	I	a = 10.15 b = 8.26 c = 10.06		$P2_1/c$		
	II	a = 10.63 b = 21.87 c = 7.59		$P2_1/a$		
HNS[9]		a = 20.93 b = 5.57 c = 14.67	Orthorhombic			
Kel-F 800[10]					1.46	
NQ[21]		a = 17.58 b = 24.84 c = 3.58	Orthorhombic	Fdd2	n = 16 α = 1.526 β = 1.694 γ = 1.81	25.2 calc. 22.2 obs.
PETN[36-40]	I (α) (ρ = 1.778)	a = 9.38 b = 9.38 c = 6.71	Tetragonal	$P\bar{4}2_1/c$	ω = 1.558 in Na ϵ = 1.551 light	
	II (β) (ρ = 1.716)	a = 13.22 b = 13.49 c = 6.83	Orthorhombic	Pcnb		
Polystyrene[12]		a = 21.90 b = 21.90 c = 6.63	Rhombohedral		1.59-1.60	
RDX[13,40,41,42]	I	a = 13.18 b = 11.57 c = 10.71	Orthorhombic	Pbca	n = 8 α = 1.578 β = 1.597 γ = 1.602 } at 20°C (283 K)	43.7 calc. 41.4 obs.
	II	Unstable				
Sylgard 182[14]					1.430 at 25°C (298 K)	
TATB[43-44]		a = 9.01 b = 9.03 c = 6.81	Triclinic	$P\bar{1}$	α = 1.45 β = 2.3 γ = 3.1	
Tetryl[45]		a = 14.13 b = 7.37 c = 10.61	Monoclinic	$P2_1/c$	α = 1.546 β = 1.632 γ = 1.74 calc.	
TNT[46-50]		a = 14.99 b = 40.00 c = 6.10			n = 16 α = 1.543 β = 1.674 γ = 1.717	44.3 calc. 49.6 obs.

[a]Refractive indexes and molecular refractions are at 5893 Å and 25°C (589.3 nm and 298 K) unless otherwise stated; 10 Å = 1 nm.

References

1. H. Hornig, Lawrence Livermore Laboratory, personal communication (1972).
2. M. Finger, Properties of Bis(2,2-dinitropropyl)acetal and Bis(2,2-dinitropropyl) formal, Eutectic Mixture, Lawrence Livermore Laboratory, Rept. UCID-16088 (1972).
3. Cabot Corporation, Boston, Mass., Cab-O-Sil, Rept. Cgen-7 (no date).
4. E. E. Kilmer, J. Spacecr. Rockets 5, 1216-1219 (1968).
5. B. F. Goodrich Company, Cleveland, Ohio, Estane Polyurethane Materials, Service Bulletin 64-14; Estane Polyurethane Solution Systems, Service Bulletin TSR 64-18 (1964).
6. Firestone Plastics Company, Pottstown, Penn., Exon, Sales Service Bulletin No. 20 (1956).
7. E. J. Graeber, Sandia Laboratories, Albuquerque, N. Mex., personal communication (1972).
8. A. C. Schwartz, Application of Hexanitrostilbene (HNS) in Explosive Components, Sandia Laboratories, Albuquerque, N. Mex., Rept. SC-RR-710673 (1972).
9. K. G. Shipp, J. Org. Chem. 29, 2620-2623 (1964).
10. Minnesota Mining and Manufacturing Company, St. Paul, Minn., Kel-F Elastomer – Properties and Applications (no date).
11. J. R. Humphrey, LX-10-1: A High-Energy Plastic-Bonded Explosive, Lawrence Livermore Laboratory, Rept. UCRL-51629 (1974).
12. J. Brandrup and E. H. Immergut, Eds., Polymer Handbook, Interscience, N.Y. (1966).
13. C. S. Choi and E. Prince, Acta Cryst. B28, 2857-2862 (1972).
14. Dow Corning, Hemlock, Mich., Information about Electronic Materials, Bulletin 07-123 (1964).
15. S. Dixon, D. R. Rexford, and J. S. Rugg, Ind. Eng. Chem. 49, 1687-1690 (1957).
16. J. R. Holden, Acta Cryst. 22, 545-550 (1966).
17. Food Machinery Corporation, Ohio Apex Division, Nitro, W. Va., Plasticizers, Data Sheet (1955).
18. M. Finger, Lawrence Livermore Laboratory, personal communication (1972).
19. K. G. Shipp, U.S. Naval Ordnance Laboratory, White Oak, Md., personal communication (1965).
20. G. P. Sharnin, B. J. Buzykin, and K. Kh. Shakurova, J. Org. Chem. (USSR) 6, 1039-1041 (1970).
21. W. C. McCrone, Anal. Chem. 23, 205-206 (1951).
22. T. M. Benziger, X-0242: A High-Energy Plastic-Bonded Explosive, Los Alamos Scientific Laboratory, N. Mex., Rept. LA-4872-MS (1972).
23. F. T. Crimmins, The Vapor Pressure of Pentaerythritoltetranitrate (PETN) in the Temperature Range of 50 to 98 Degrees Centigrade, Lawrence Livermore Laboratory, Rept. UCRL-50704 (1969).

24. E. I. Dupont de Nemours and Company, Technical Information on Military Specialties--TACOT (manufacturer's data sheet), E. I. DuPont de Nemours and Company, Inc., Wilmington, Del. (no date).
25. L. C. Smith, Los Alamos Scientific Laboratory, N. Mex., personal communication (1962).
26. Celanese Corporation, Chemical Division, New York, N. Y., Celluflex CEF, Products Bulletin N-46-2 (1955).
27. F. T. Crimmins, Lawrence Livermore Laboratory, personal communication (1969).
28. J. M. Rosen and C. Dickenson, J. Chem. Eng. Data 14, 120-124 (1969).
29. H. H. Cady, A. C. Larson, and D. T. Cromer, Acta Cryst. 20, 336-341 (1966).
30. E. N. Maslen, Acta Cryst. B24, 1170-1172 (1968).
31. H. H. Cady, A. C. Larson, and D. T. Cromer, Acta Cryst. 16, 617-623 (1963).
32. W. C. McCrone, Anal. Chem. 22, 1225-1226 (1950).
33. A. Filhol, Contribution to the Study of the Hexogen Molecule in the Crystalline and the Free State, Thesis, Université de Bordeaux, France (1971). (In French).
34. C. S. Choi and H. P. Boutin, Acta Cryst. B26, 1235-2340 (1970).
35. W. Selig, Explosivestoffe 17, 201-202 (1969).
36. J. E. Knoggs, Mineral. Mag. 20, 346-352 (1925).
37. A. D. Booth and F. J. Llewellyn, J. Chem. Soc. (London) 1947, 837-846 (1947).
38. J. Trotter, Acta Cryst. 16, 698-699 (1963).
39. H. H. Cady, Los Alamos Scientific Laboratory, N. Mex., personal communication (1972).
40. A. T. Bloomquist, Microscopic Examination of High Explosives and Boosters, Office of Scientific Research and Development, Rept. NDRC-B-3014 (AD-29944) (1957).
41. W. C. McCrone, Anal. Chem. 22, 954-955 (1950).
42. P. M. Harris, P. Reed, and R. E. Gluyas, Structures of Trinitro Aromatic Crystals and Related Substances, U.S. Dept. of Commerce, Rept. 156-104 (1959).
43. H. H. Cady, Microscope 14, 27 (1963).
44. H. H. Cady and A. C. Larson, Acta Cryst. 18, 485-496 (1965).
45. H. H. Cady, Acta Cryst. 23, 601-609 (1967).
46. W. C. McCrone, Anal. Chem. 21, 1583-1584 (1949).
47. F. G. J. May, B. W. Thorpe, and W. Connick, J. Cryst. Growth 5, 312 (1969).
48. W. Connick, F. G. J. May, and B. W. Thorpe, Austr. J. Chem. 22, 2685-2688 (1969).
49. D. G. Grabar, F. C. Rauch, and A. J. Fanelli, J. Phys. Chem. 73, 3514-3516 (1969).
50. L. A. Burkhardt and J. H. Bryden, Acta Cryst. 7, 135-136 (1954).

5. CHEMICAL PROPERTIES

This section gives information on heat of formation ΔH_f, heat of detonation ΔH_{det}, compatibility, and solubility.

Heat of Formation

Heat of formation ΔH_f refers to the enthalpy of the reaction

$$a\,C_{(s)} + \frac{b}{2}\,H_{2(g)} + \frac{c}{2}\,N_{2(g)} + \frac{d}{2}\,O_{2(g)} + \cdots \rightarrow C_aH_bN_cO_d$$

at 1 atm (101 kPa) and 298°C (571 K). The sign convention is such that the ΔH_f is negative when the above reaction is exothermic. Tables 5-1 and 5-2 give heats of formation of various explosive materials and of additives and binders, respectively.

Table 5-1. Heats of formation, ΔH_f, of explosives.[1]

Explosive	ΔH_f (kcal/mol)[a]	(kJ/mol)[b]	(cal/g)	(kJ/kg)[c]
Baratol	-70.8	(-295)	-708	(-2,952)
Boracitol	-257.5	(-1,076)	-2,575	(-10,755)
BTF	+144.5	(+606)	+573	(+2,399)
Comp B, Grade A[d]	+1.0	(+5.78)	+10.0	(+57.8)
Comp B-3[d]	+0.84	(+5.28)	+8.4	(+52.8)
Comp C-4[d]	+3.33	(+13.9)	+33.3	(+139)
Cyclotol 75/25	+3.01	(+13.8)	+30.1	(+138)
DATB	-29.23	(-122)	-120	(-503)
DIPAM	-20.1	(-84.1)	-44.3	(-185)
DNPA	-110	(-460)	-539	(-2,255)
EDNP	-140	(-585.8)	-635	(-2,660)
EL-506A		(-167)		(-1,669)
EL-506C		(-178)		(-1,775)
FEFO	-177.5	(-742.8)	-554.4	(-2,320)
HMX	+17.93	(+75.02)	+61	(+253)
HNAB	+57.8	(+241.8)	+128	(+535)
HNS	+13.88	(+58.1)	+30.83	(+129)
LX-01-0	-27.5	(-115.2)	-275	(-1,152)
LX-02-1[d]	-49.1	(-205.3)	-491	(-2,053)
LX-04-1	-21.5	(-90.1)	-215	(-901)
LX-07-2	-12.3	(-51.7)	-123	(-517)
LX-08[d]	-44	(-185.9)	-444	(-1,859)
LX-09-0	+1.82	(+7.61)	+18.2	(+76.1)
LX-09-1	+2.004	(+8.38)	+20.04	(+83.8)
LX-10-0	-3.14	(-13.1)	-31.4	(-131)
LX-11-0	-30.73	(-128.6)	-307.3	(-1,286)
LX-13	See XTX-8003			
LX-14	+1.50	(+6.28)	+15.0	(+62.8)
MEM-11	-74.3	(-310.7)	-743	(-3,107)
NC (12.0% N)	-216	(-904)	823	(-3,441)
NC (13.35% N, min)	-200	(-837)	730	(-3,052)
NG	-90.8	(-380)	-400	(-1,673)
NM	-27.0	(-113)	-442	(-1,853)
NQ	-23.6	(-98.7)	-227	(-949)
Octol	+2.37	(+11.9)	+25.7	(+119)
PBX-9007[d]	+7.13	(+29.8)	+71.3	(+298)
PBX-9010[d]	-7.87	(-32.9)	-78.7	(-329)
PBX-9011[d]	-4.05	(-17.0)	-40.5	(-170)
PBX-9205[d]	+5.81	(+24.30)	+58.1	(+243)
PBX-9404-3[d]	+0.08	(+0.331)	+0.8	(+3.31)
PBX-9407[d]	+11.6	(+48.4)	+116	(+484)
PBX-9501[d]	+2.3	(+9.5)	+22.8	(+95.4)
Pentolite 50/50	-24.3	(-99.4)	-243	(-993.7)
PETN	-128.7	(-593)	-407	(-1,702)
RDX	+14.71	(+61.55)	+66	(+277.1)
TACOT	+128	(+536)	+330	(+1,380)
TATB	-36.85	(-154.2)	-143	(-597.2)
Tetryl	+4.67	(+19.1)	+16.3	(+66.6)
TNM	+13.0	(+54.4)	+66	(+277)
TNT	-15	(-64.4)	-78	(-284)
XTX-8003	-44.4	(-185.9)	-444	(-1,859)

[a] For mixtures, the molecular weight is arbitrarily taken as 100 g (see Table 4-2).

[b] One kcal/mol = 4.184 kJ/mol.

[c] One cal/g = 4.184 kJ/kg.

[d] The standard enthalpies of formation of the nonexplosive components of the mixtures were estimated from bond energies.

Table 5-2. Heats of formation, ΔH_f, of additives and binders.[1]

Material	kcal/mol	(kJ/mol)	kcal/g	(kJ/kg)
BDNPA/BDNPF[a]	-46.38	(-194.1)	-0.464	(-1,941)
Cab-O-Sil	-215.94	(-903.5)	-3.597	(-15.051)
DOP[b]	-268.2	(-1,122)	-0.687	(-2,874)
Estane 5702 F-1	-95	(-397)	-0.95	(-3,975)
Kel-F 3700[b]	-161	(-674)	-1.382	(-5,783)
Polystyrene[b]	+18.9	(+79.1)	+0.181	(+757)
Sylgard 182[b]	-24.9	(-104.18)	-1.40	(-5,858)
TEF	-300	(-1,255)	-1.051	(-4,397)
Viton A	-332.7	(-1,392)	-1.778	(-7,439)

[a]Calculation.

[b]Estimate.

Heat of Detonation

Heat of detonation ΔH_{det} refers to the change in enthalpy for the high-order detonation of the explosive. Initial and final states are taken at 25°C (298 K) and 1 atm (101 kPa) pressure. The experimental values listed in Table 5-3 were determined in a detonation calorimeter; they are found to vary with density, size, and confinement of the charge as well as with calorimeter geometry. Therefore, application of these values of detonation energy to other situations represents only an approximation.

The maximum heat of detonation is a calculated value for the enthalpy of the reaction

Explosive → Most Stable Products.

The order chosen for the most stable products is H_2O, CO_2, $C_{(s)}$, and N_2 for CHNO explosives. If the explosive contains F and/or Cl, then HF and/or HCl precedes H_2O in the order. The values represent the upper limit of the chemical energy obtainable from an explosive.

In practice, the effective energy developed by a detonating high explosive is always smaller than the assumed thermodynamic maximum energy. The reason is that the actual shifting equilibrium along the adiabat until freeze-out occurs is not the one assumed here. Also, the actual entropy is higher than for 25°C (298 K) and 1 atm (101 kPa) pressure. Such codes as RUBY, BKW, and TIGER are believed to give more realistic estimates of the true composition during expansion.

Table 5.3. Heats of detonation, ΔH_{det}

Explosive	Max ΔH_{det} calculated				Experimental ΔH_{det}				Experimental conditions			
	$H_2O_{(\ell)}$		$H_2O_{(g)}$		$H_2O_{(\ell)}$		$H_2O_{(g)}$		T	Diam		ρ
	(kcal/g)	(MJ/kg)[a]	(kcal/g)	(MJ/kg)[a]	(kcal/g)	(MJ/kg)[a]	(kcal/g)	(MJ/kg)[a]	(°C(K))	(in	(mm))	(Mg/m^3)
Baratol[b]	0.74	(3.10)	0.72	(3.01)	---	---	---	---	---	---	---	---
Boracitol[c]	0.40	(1.67)	0.20	(0.84)	---	---	---	---	---	---	---	---
BTF[1,d]	1.69	(7.07)	1.69	(7.07)	1.41	(5.90)	1.41	(5.90)	25(298)	1/2	(12.7)	1.86
Comp B, Grade A	1.54	(6.44)	1.40	(5.86)	---		---		---	---	---	---
Comp B-3[1,c]	1.54	(6.44)	1.40	(5.86)	1.20	(5.02)	1.12	(4.69)	25(298)	1/3	(8.47)	1.69
Comp C-4	1.59	(6.65)	1.40	(5.86)	---	---	---	---	---	---	---	---
Cyclotol 75/25	1.57	(6.57)	1.44	(6.03)		---	---	---	---	---	---	---
DATB[1]	1.26	(5.27)	1.15	(4.81)	0.98	(4.10)	0.91	(3.81)	25(298)	1/3	(8.47)	1.80
DIPAM	1.35	(5.65)	1.27	(5.31)	---		---		---	---	---	---
DNPA	1.06	(4.44)	0.85	(3.57)	---	---	---	---	---	---	---	---
EDNP	1.23	(5.15)	0.94	(3.93)	---	---		---	---	---	---	---
El-506A	1.62	(6.78)	1.38	(5.77)	---	---	---	---	---	---	---	---
EL-506C	1.41	(5.90)	1.12	(4.69)	---	---	---	---	---	---	---	---
FEFO[2]	1.45	(6.07)	1.31	(5.82)	1.28	(5.36)	1.21	(5.06	25(298)	1/2	(12.7)	1.61
HMX[2]	1.62	(6.78)	1.48	(6.19)	1.48	(6.19)	1.37	(5.73)	25(298)	1/2	(12.7)	1.89
HNAB	1.47	(6.15)	1.42	(5.94)	---	---	---	---	---		---	---
HNS	1.42	(5.94)	1.36	(5.69)	---		---	---	---	---		---
LX-01-0	1.72	(7.20)	1.52	(6.36)	---	---	---		---	---	---	---
LX-02-1[e]	1.42	(5.94)	1.16	(4.85)	---	---	---	---	---	---	---	---
LX-04-1[1]	1.42	(5.94)	1.31	(5.49)	1.31	(5.49)	1.25	(5.23)	24(297)	1/3	(8.47)	1.88
LX-07-2	1.43	(6.23)	1.37	(5.73)			---		---		---	---
LX-08[e,1]	1.98	(8.27)	1.77	(7.41)	---		---		---	---	---	---
LX-09-0	1.60	(6.69)	1.46	(6.11)		---	---	---		---	---	---
LX-09-1	1.60	(6.69)	1.46	(6.11)	---	---	---	---	---	---	---	---
LX-10-0	1.53	(6.49)	1.42	(5.94)	---	---	---		---		---	---
LX-11-0	1.38	(5.77)	1.28	(5.36)	1.23	(5.15)	1.16	(4.85)	25(298)	1/2	(12.7)	1.88
LX-13	See XTX-8003											
LX-14	1.58	(6.61)	1.43	(5.95)	---	---	---	---	---	---	---	---
MEN-I	1.38	(5.77)	1.05	(4.39)	---		---		---	---	---	---
NC (12.0% N)	1.16	(4.85)	1.02	(4.27)		---			---	---	---	
NC (13.35% N, min)	1.16	(4.85)	1.02	(4.27)		---		---	---	---	---	---
NG	1.53	(6.65)	1.48	(6.19)	---		---		---	---	---	---
NM[2]	1.62	(6.78)	1.36	(5.69)	1.23	(5.15)	1.06	(4.44)	25(298)	1/2	(12.7)	1.13
NQ	1.06	(4.44)	0.88	(3.68)		---		---	---	---	---	---
Octol	1.57	(6.57)	1.43	(5.98)	---	---	---	---	---	---	---	---
PBX-9007	1.56	(6.53)	1.43	(5.82)			---			---	---	---
PBX-9010	1.47	(6.15)	1.36	(5.69)	---	---	---	---	---	---	---	---
PBX-9011	1.53	(6.40)	1.36	(5.69)	---	---	---	---	---	---	---	---
PBX-9205	1.46	(6.11)	1.41	(5.90)	---	---	---	---	---	---	---	---
PBX-9404[1]	1.56	(6.53)	1.42	(5.94)	1.38	(5.77)	1.28	(5.36)	25(298)	1/3	(8.47)	1.80
PBX-9407	1.60	(6.69)	1.46	(6.11)		---	---	---	---	---	---	---
PBX-9501	1.53	(6.65)	1.44	(6.03)	---		---	---	---	---	---	---
Pentolite 50/50[3]	1.53	(6.40)	1.40	(5.86)	1.23	(5.15)	1.16	(4.85)	21(294)	1	(25.4)	1.65
PETN[4]	1.65	(6.90)	1.51	(6.32)	1.49	(6.23)	1.37	(5.73)	25(298)	1/2	(12.7)	1.73
RDX[5]	1.62	(6.78)	1.48	(6.19)	1.51	(6.32)	1.42	(5.94)	23(296)	1/3	(8.47)	1.78
TACOT[1]	1.41	(5.90)	1.35	(5.64)	0.98	(4.10)	0.96	(4.02)	23(296)	1/3	(8.47)	1.74
TATB	1.20	(5.02)	1.08	(4.52)	---	---	---	---	---	---	---	---
Tetryl[1]	1.51	(6.32)	1.45	(6.07)	1.14	(4.77)	1.09	(4.56)	21(294)	1	(25.4)	1.71
TNM[d,f]	0.55	(2.30)	0.55	(2.30)	---		---	---	---	---	---	---
TNT[2]	1.41	(5.90)	1.29	(5.40)	1.09	(4.56)	1.02	(4.27)	25(298)	1/2	(12.7)	1.54
XTX-8003[1,e]	1.88	(7.89)	1.69	(7.07)	1.16	(4.85)	1.05	(4.39)	25(298)	1/2	(12.7)	1.55

[a] One cal/g = 4.184 kJ/kg

[b] $BaCO_3$ is the first product calculated

[c] B_2O_3 is the first product calculated

[d] Contains little or no hydrogen, therefore no water is formed, and values for $H_2O_{(\ell)}$ and $H_2O_{(g)}$ are identical

[e] SiO_2 is the first product calculated

[f] A very small percentage of CH_2 impurity raises these values markedly

Compatibility

Many materials have been tested for compatibility with various HEs; those listed or mentioned in this section are the most commonly used at the LLL facility for explosive testing. In Tables 5-4 and 5-5, which list adhesives and fillers, those materials rated "A" have been evaluated extensively; those rated "B" have been screened for gross incompatibility only. If these materials are used as they are supplied, that is, in the prepackaged catalyst/resin system, they are satisfactory for use as indicated. It is understood that the adhesives will be used in minimum amounts, mixed according to supplier's instructions, and used only for limited times, that is, from two to three months during environmental testing.

The results of our compatibility tests are valid only for the specific batch/lot of HE and adhesive tested. For different HEs and later lots of adhesive, even from the same suppliers, the reactivity and compatibility tests must be repeated. The supplier may change or "improve" the material without notice; this could render the material incompatible.

The compilation is not to be regarded as complete; many other materials have been evaluated but are not commonly used and therefore not included here. Table 5-6 lists adhesive tapes found to be compatible with various HEs; any other tapes should be tested before use.

Table 5-4. Adhesives: Chemical reactivity and compatibility with various high explosives.

A, compatible; OK for long-term storage.
B, compatible; OK for short-term storage (less than 30 days).
Blank, compatibility has not been checked.
1, bond strength equal to that of explosive.
2, bond strength less than that of explosive.
3, no bond strength.

Adhesive	Baratol	Comp B	EL-506	LX-04	LX-07	LX-09	LX-10	LX-11	PBX-9007	PBX-9010	PBX-9205	PBX-9404	PBX-9407	Tetryl	TNT
Adiprene L-100	A-1	A-1		A-1	A-1	A-1	A-1	A-1		A-1	A-1	A-1		A-1	A-1
Adiprene L-167	A-1	A-1		A-1	A-1	A-1	A-1	A-1		A-1	A-1	A-1		A-1	A-1
Adiprene LD-213	A-1	A-1		A-1	A-1	A-1	A-1	A-1				A-1		A-1	A-1
Aerobond 2017				A-1	A-1	--[a]	A-1	A-1				A-1			
Eastman 910	A-2	A-2	A-1	A-2	A-2	A-2	A-2	A-2		A-2	A-2	A-2		A-1[c]	A-2
Epoxies[b]															
Laminac 4116	3	3	A-1	A-1[c]	A-1[c]			A-1[c]				A-1[c]			3
3-M #465				A-2				A-2	A-2				A-2		
3-M #466				A-2				A-2	A-2				A-2		
3-M #Y9146				A-2				A-2	A-2				A-2		

[a]Do not use Aerobond 2017 with LX-09. The cure of the adhesive is inhibited by the explosive.

[b]BIPAX-2902, EPY-150, and Hysol epoxy patch kit are epoxies certified for bonding strain gauges to LX-04, LX-07, LX-09, LX-10, and PBX-9404.

[c]Does not meet environmental specifications.

Table 5-5. Fillers and coatings: Chemical reactivity and compatibility.

A, compatible; OK for long-term storage.
B, compatible; OK for short-term storage (less than 30 days).
Blank, compatibility has not been checked.

1, bond strength equal to that of explosive.
2, bond strength less than that of explosive.
3, no bond strength.

Filler or coating	Baratol	Comp B	EL-506	LX-04	LX-07	LX-09	LX-10	LX-11	PBX-9010	PBX-9205	PBX-9404
DC 93-109[a,b]				A-3	A-3	A-3	A-3	A-3			A-3
DC 93-119[c]				A-3	A-3	A-3	A-3	A-3			A-3
DC 93-120[c]				A-3	A-3	A-3	A-3	A-3			A-3
DC 93-122[a,c]				A-3	A-3	A-3	A-3	A-3			A-3
DuPont 4817 conductive silver				A-3	A-3	B-3	A-3	A-3	B-3		A-3
FDA 2 Red				A-3	A-3	A-3	A-3	A-3	A-3	A-3	A-3
FDA 3 Green				A-3	A-3	A-3	A-3	A-3	A-3	A-3	A-3
GE RTV 632[c,d]				A-3	A-3	A-3	A-3	A-3			A-3
Silastic Q 93-009[b]				A-3	A-3	A-3	A-3	A-3			A-3
Silastic Q 93-029[b]				A-3	A-3	A-3	A-3	A-3			A-3
Silastic RTV 140[d]				A-2	A-2	A-2	A-2	A-2			A-2
Silastic RTV 732[d]				A-2	A-2	A-2	A-2	A-2			A-2
Silastic RTV 891[d]				A-2	A-2	A-2	A-2	A-2			A-2

[a]Nonflowing RTV silicone rubber used mostly for potting spacers, detonators, and detonator cables.

[b]Do not attempt to use Nuocure 12, Nuocure 28, or Thermolite 12 catalysts with Silastic Q 93-109 or Q 93-029 when the material will be in contact with LX-09 or other formulations containing FEFO or DNPA.

[c]These systems contain a platinum catalyst. Do not mix them in a container which has been used to mix the more conventional RTV silicones, e.g., Silastic Q 93-009 and Q 93-029. The catalyst in these and similar RTV systems poisons the platinum catalyst and thus inhibits the cure.

[d]RTV: room-temperature vulcanizing.

Table 5-6. Adhesive tapes found to be compatible with various high explosives. Any tape not listed should be tested before use.

Manufacturer	Trade name	Number	Color
3M	Scotch Brand Electrical Tape	#33	Black
3M	Scotch Brand Mylar	#56	Yellow
3M	Scotch Brand Electrical	#57	Yellow
3M	Scotch Brand Masking	#232	Tan
3M	Scotch Brand Photo Tape	#235	Black
3M	Scotch Brand Double Sided Masking	#400	Tan
3M	Scotch Brand Tape	#420	Lead
3M	Scotch Brand Double Sided Masking	#465	Tan
3M	Scotch Brand Double Sided Masking	#466	Tan
3M	Scotch Brand Plastic	#471	Yellow
3M	Scotch Brand Plastic	#471	Red
3M	Scotch Brand Plastic	#471	White
3M	Scotch Brand Cellophane Tape	#600	Clear
3M	Scotch Brand Cellophane Tape	#850	Clear
3M	Scotch Brand Magic Mending	#810	Clear
3M	Scotch Filament Tape	#880	Pearl
3M	Scotch Brand Double Sided Masking	#Y9146	Tan
Behr-Manning	Bear Tape	#4/1	Tan
Hampton Manufacturing Company	Blue Cross Tape	----	Yellow
Mystik Tape, Inc.	Mystic Tape	#5803	Black
Okonite Company	High Voltage Rubber Tape	----	Brown
Permacel	Permacel	#29	Black
Permacel	Permacel	#32	Red
Permacel	Permacel Cellophane Tape	----	Clear
Saunders Engineering Corporation	Teflon Tape	#S15 #S16 #S18	Blue/brown
Technical Tape Corporation	Tuck Tape	----	Yellow
Technical Tape Corporation	Tuck Tape	----	Black

Table 5-7. Qualitative solubilities of pure explosives. Solubilities are expressed as follows, in terms of weight of substance dissolved at room temperature per 100 ml of solvent: i - insoluble (less than 0.1 g), sl = slightly soluble (0.1 to 5 g), s = soluble (over 5 g).

Solvent	BTF	DATB	DIPAM	DNPA	EDNP	FEFO	HMX	HNAB[6]	HNS[7]	NC	NG[8]	NM	NQ	PETN	RDX	TACOT[9]	TATB	Tetryl	TNM	TNT
Acetone	s	i	s	s	s	s	sl	s	sl	s	s	–	i	s	s	–	i	s	–	s
Benzene	s	i	–	–	–	–	–	–	–	–	s	–	i	sl	i	–	i	s	s	s
Carbon disulfide	–	i	–	–	–	–	i	–	–	–	sl	–	i	i	i	–	i	i	–	sl
Carbon tetrachloride	i	i	–	–	s	i	i	sl	–	i	sl	–	i	i	i	–	i	i	–	sl
Chloroform	–	–	sl	–	s	s	i	sl	–	i	s	–	i	i	i	i	i	sl	–	s
DMFA	s	s	s	–	s	s	sl	–	s	–	–	s	–	s	s	sl	i	–	–	s
DMSO	s	s	s	–	s	s	s	–	–	–	–	s	–	s	s	sl	i	–	–	–
Ethanol	s	i	–	–	s	s	–	–	–	s	s	s	sl	i	sl	i	i	sl	s	sl
Ethyl acetate	s	–	–	–	s	s	–	sl	–	–	s	–	i	s	i	–	i	s	–	s
Ethyl ether	s	–	–	–	s	s	i	–	–	i	s	s	i	sl	i	–	i	sl	s	sl
Nitric acid	–	–	s	–	–	–	–	–	–	–	s	–	sl	–	–	sl	–	s	–	s
Sulfuric acid	–	–	–	–	–	–	–	–	–	–	s	–	s	–	–	–	sl[10]	–	–	s
Pyridine	s	–	–	–	s	s	sl	–	–	–	s	–	–	s	sl	sl	–	–	–	s
Water	i	i	–	–	i	i	i	–	–	i	sl	s	i	i	i	i	i	i	sl	i

Table 5-8. Qualitative solubilities of additives and binders. Solubilities are expressed as follows, in terms of weight of substance dissolved at room temperature per 100 ml of solvent: i = insoluble (less than 0.1 g), sl = slightly soluble (0.1 to 5 g), s = soluble (over 5 g).

Solvent	BDNPA/ BDNPF[11]	Cab-O-Sil	DOP[12]	Estane 5702-F1[13]	Exon 461[14]	Kel-F[15]	Polystyrene[16]	Sylgard 182	TEF[17]	Viton A
Acetone	–	–	–	s	–	s	–	–	–	s
Benzene	s	–	–	–	–	–	s	–	s	–
Dichloroethane	–	–	–	s	–	–	–	–	–	–
DMFA	–	–	–	s	–	–	–	–	–	–
DMSO	–	–	–	s	–	–	–	–	–	–
Gasoline	–	–	s	–	s	–	–	–	–	–
Glycerine	–	–	i	–	–	–	–	–	–	–
MEK	–	–	–	s	s	s	–	–	s	s
MIBK	–	–	–	s	–	s	–	–	s	s
THF	–	–	–	s	–	s	–	–	–	s
Toluene	s	–	–	–	s	i	s	–	s	–
Water	i	–	i	–	–	–	–	–	i	–
Xylene	–	–	–	–	s	–	–	–	s	–

References

1. D. L. Ornellas, Lawrence Livermore Laboratory, personal communication (1974).
2. D. L. Ornellas, J. Phys. Chem. 72, 2390-2394 (1968).
3. H. W. Sexton, Armament Research and Development Establishment, Fort Halstead, United Kingdom, personal communication (1956).
4. D. L. Ornellas, J. C. Carpenter, and S. R. Gunn, Rev. Sci. Inst. 37, 907-912 (1966).
5. A. Ya. Apin and Yu. A. Lebedev, Dokl. Akad. Nauk USSR 114, 819-821 (1957).
6. D. O'Keefe, Sandia Laboratories, Albuquerque, N. Mex., personal communication (1972).
7. K. G. Shipp, J. Org. Chem. 29, 2620-2623 (1964).
8. T. Urbanski, Chemistry and Technology of Explosives (McMillan, New York, 1964-1967), vols. 1-3.
9. W. Selig, Some Analytical Methods for Explosives and Explosive Simulants, Lawrence Livermore Laboratory, Rept. UCRL-7873 Pts. 1-4 (1964-1973).
10. V. D. Gupta and B. L. Deopura, Mol. Phys. 19, 589-592 (1970).
11. M. Finger, Properties of Bis(2,2-dinitropropyl)acetal and Bis(2,2-dinitropropyl)formal, Eutectic Mixture, Lawrence Livermore Laboratory, Rept. UCID-16088 (1972).
12. Food Machinery and Chemical Corporation, Ohio-Apex Division, Nitro, W. V., Plasticizers (no date).
13. B. F. Goodrich Company, Cleveland, Ohio, Estane Polyurethane Solution Systems, Service Bulletin, TSR 64-18 (1964).
14. Firestone Plastics Company, Pottstown, Pa., Exon, Sales Service Bulletin No. 20 (1956).
15. Minnesota Mining and Manufacturing Company, St. Paul, Minn., Kel-F Elastomer – Properties and Applications, Service Bulletin (no date).
16. J. Brandrup and E. H. Immergut, Eds., Polymer Handbook (Interscience, N.Y., 1966).
17. Celanese Chemical Corporation, New York, N.Y., Celluflex CEF, Product Bulletin N-46-2 (1955).

6. THERMAL PROPERTIES

This section contains tables and information on thermal conductivity k, coefficient of thermal expansion CTE, estimated specific heat Cp, glass transition point Tg, and thermal stability.

Thermal Conductivity

Measurements of thermal conductivity made[1] on an apparatus similar to that used at the National Bureau of Standards are included in Table 6-1. Thermal conductivities as a function of temperature are given in Fig. 6-1 for 8 explosives; the straight lines represent the best fit of the data.

Table 6-1. Thermal conductivities k.

Explosive	k (BTU/hr-ft-°F)[1]	k (10^{-4} cal/cm-sec-°C)	k (W/m-K)[a]	T (°C)	T (°F)	T (K)
Baratol		11.84	(0.495)	18-75		(291-348)
Comp B-3		6.27	(0.262)	18-72		(291-345)
Comp C-4		6.22	(0.260)			
DATB		6.00	(0.251)			
LX-04	0.22	9.25	(0.380)	21.1	70	(294)
LX-07	0.23		(0.398)		70	(294)
LX-09	0.25		(0.432)		70	(294)
LX-10	0.25		(0.432)		70	(294)
LX-11	0.21 (est.)		(0.363)(est.)		70	(294)
NC (12.7% N)		5.5	(0.230)			
PBX-9010		5.14[2]	(0.215)			
PBX-9011	0.25	10.0	(0.432)		70	(294)
PBX-9404	0.25	10.1	(0.432)	21.1	70	(294)
PBX-9501		10.8[2]	(0.451)			
Polystyrene		2.51[3]	(0.105)	0		(273)
		2.78[3]	(0.116)	50		(323)
		3.06[3]	(0.128)	100		(373)
Sylgard 182		3.5[4]	(0.146)(cured)			
Tetryl (ρ = 1.53)		6.83	(0.286)			
TNT (ρ = 1.60)		6.22	(0.260)	18-45		(291-318)

[a] One cal/cm-sec-°C = 4.184×10^2 W/m-K; 1 BTU/hr-ft-°F = 0.004135 cal/cm-sec-°C = 1.729577 W/m-K. Where measurements were made in both British and metric units, only the British units were converted.

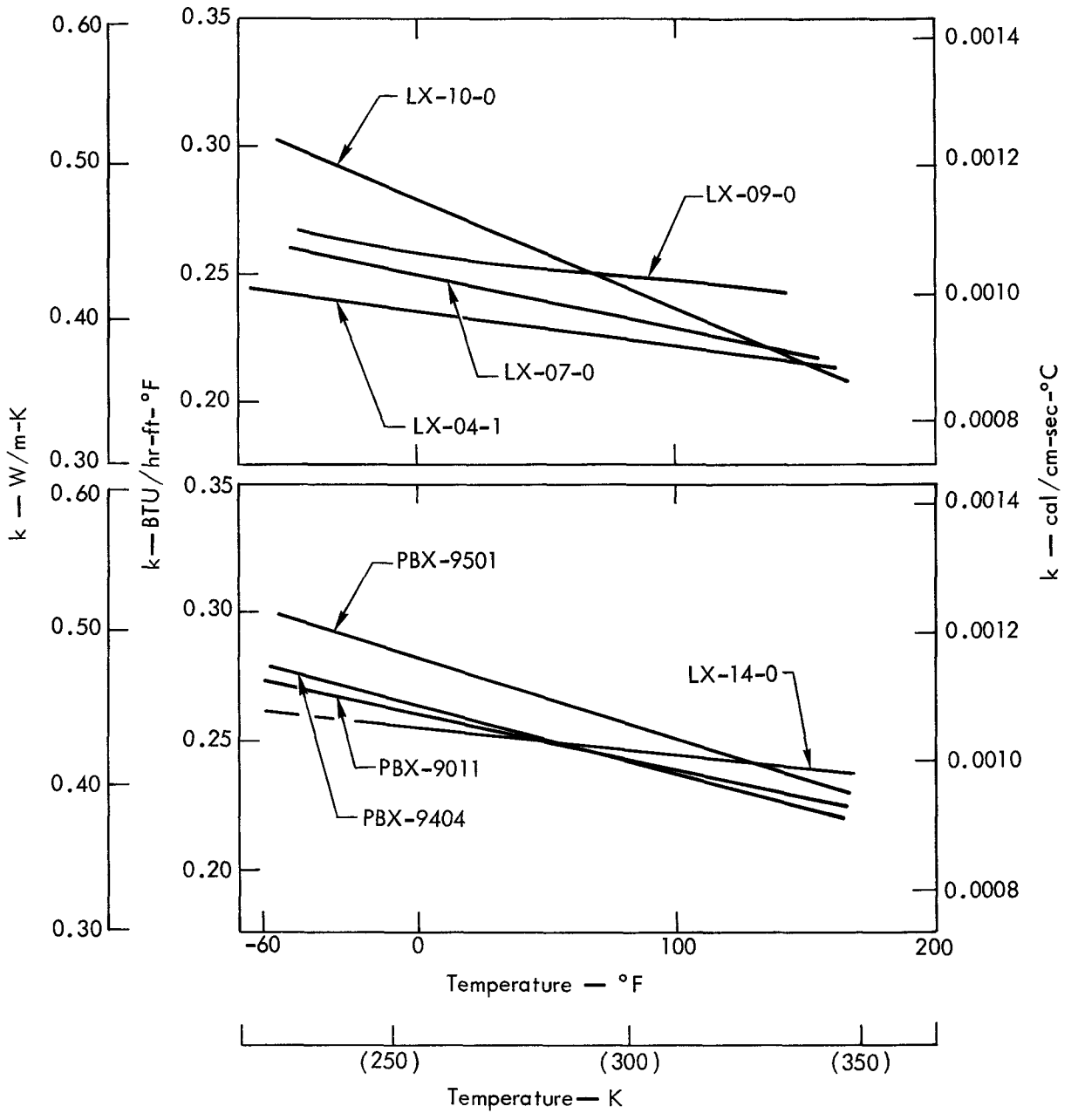


Fig. 6-1. Thermal conductivity k as a function of temperature for LX-04-1,[1] LX-07-0,[5] LX-09-0,[6] LX-10-0,[5] LX-14-0,[7] PBX-9011,[5] PBX-9404,[1] and PBX-9501.[5] Conversion factors: 1 BTU/hr-ft-°F = 1.7239577 W/m-K; 1 cal/cm-sec-°C = 4.184×10^2 W/m-K.

The thermal conductivity data[5] shown in Fig. 6-2 as a function of HMX content indicate the range of properties available with HMX/Viton explosives; see also the CTE data shown in Fig. 6-3 as a function of HMX content. Thermal conductivity k increases with increasing HMX content; CTE decreases.

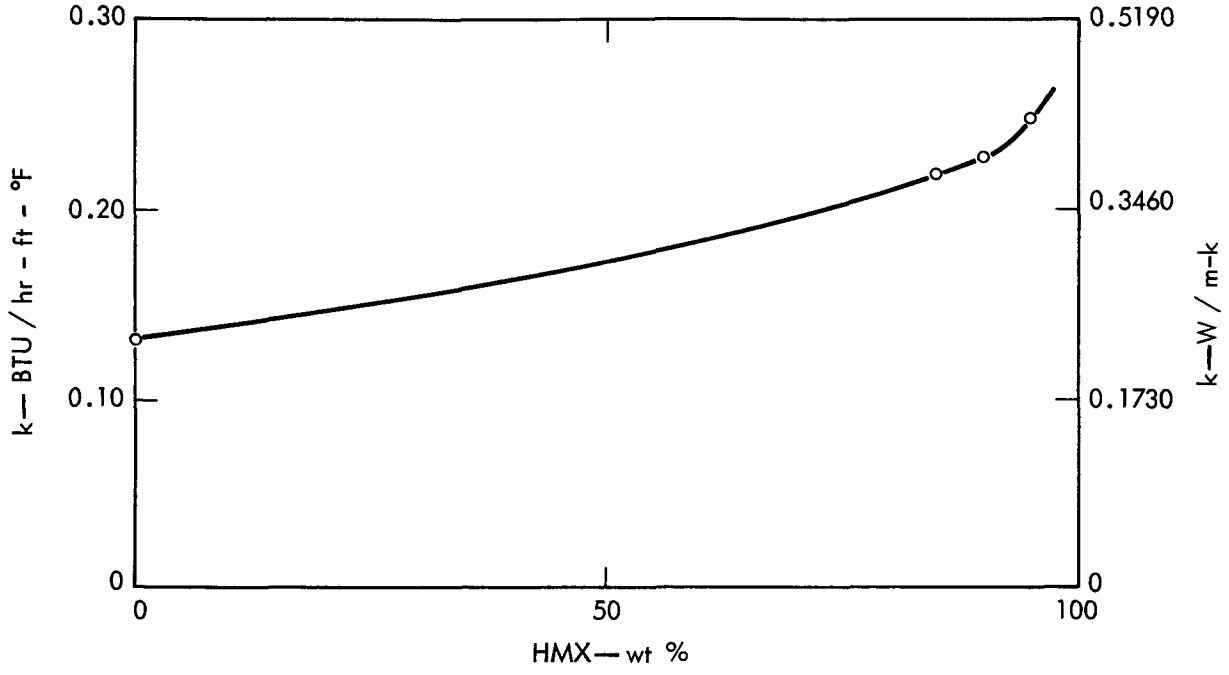


Fig. 6-2. Thermal conductivity k vs wt% HMX for HMX/Viton systems at 70°F (21°C, 294 K). Conversion factors: 1 BTU/hr-ft-°F = 1.729577 W/m-K; 1 cal/cm-sec-°C = 4.184×10^2 W/m-K.

Thermal Expansion

Thermal expansion data were obtained by the use of bulk mercury dilatometers or a linear expansion apparatus; the two methods produce comparable results.[6] Figure 6-3 shows CTE as a function of HMX content for HMX/Viton systems. Table 6-2 lists the measured linear (α) and cubic (β) expansion coefficients of explosives and binders along with their glass transition temperatures and pressed densities. The cubic expansion coefficients (β) can be calculated for isotropic materials as $\beta = 3\,\alpha$.

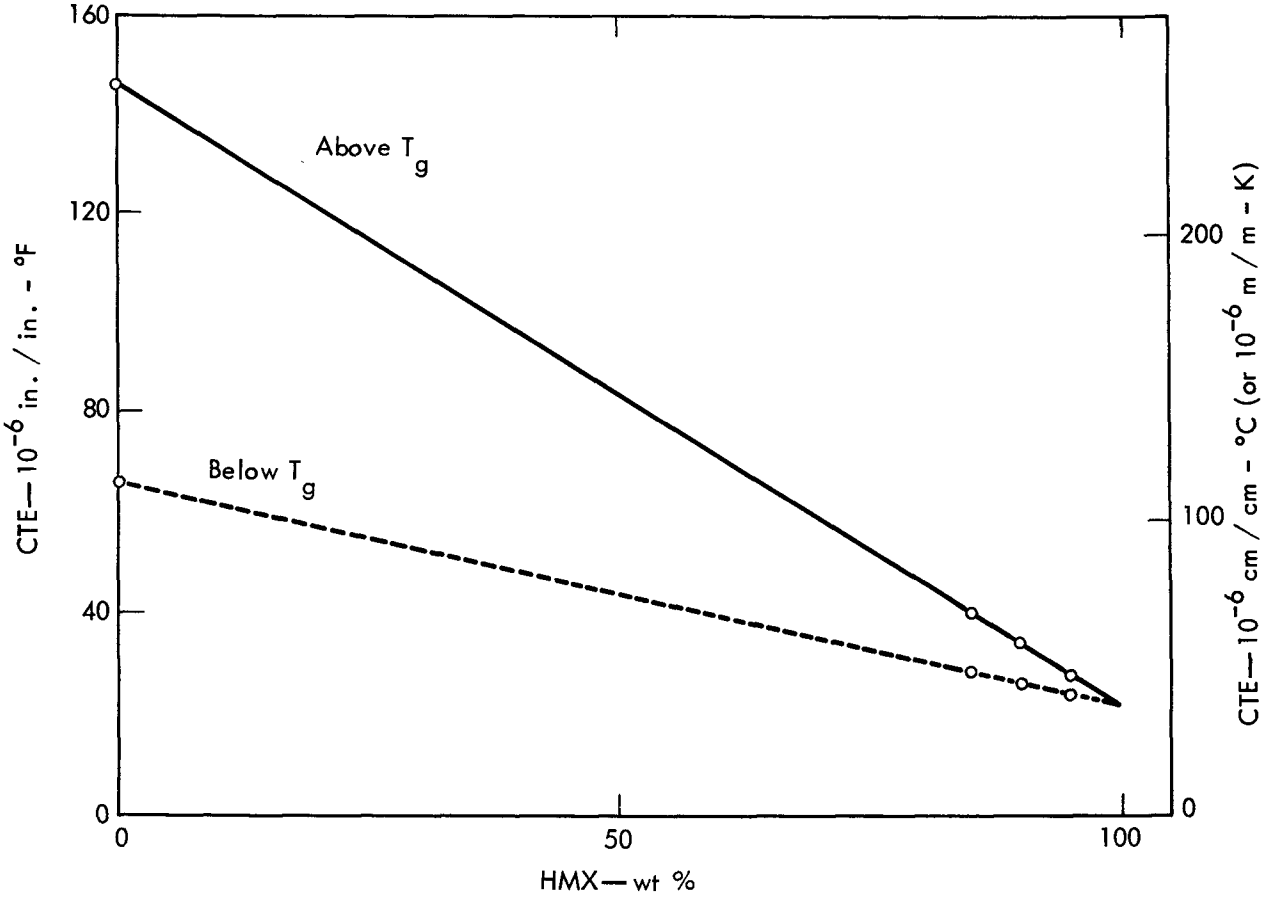


Fig. 6-3. Coefficients of thermal expansion CTE vs wt% HMX for HMX/Viton systems. Conversion factor: 1 in./in.-°F = 1.8 cm/cm-°C = 1.8 m/m-K.

Table 6.2. Explosives and binders: Coefficients of thermal expansion CTE, glass transition temperatures Tg, and pressed densities ρ.

	Linear CTE (α)[a,5]				Cubic CTE (β)[a,8]		T_g[5]		Pressed density
	(10^{-6} in/in-°F)	(10^{-6} cm/cm °C or μm/m-K)	T (°F or °C)	(K)	(10^{-6} cm/cm-°C or μm/m-K	T (°C (K))	(°F)	(K)	(g/cm^3 or Mg/m^3)
Explosives									
Baratol		33 + 0 26T	-40 to 60°C	(233 333)					
Boracitol		46 7	0 to 60°C	(273-333)					
Comp B-3		54 6 97 5	6 to 25°C 27 to 63°C	(279-298) (300-336)					
DATB		32-46 52-66	-20°C 85°C	(253) (358)					
DOP[11]		74	10-40°C	(283-313)					
Estane 5702-F1[7]							-31°C	(242)	
HMX	22 0	50 4[8]	-53 9 to 73 9°C -65 to 165°F	(219-347) (219 347)	162 5	30 to 70 (243 343)	None		
HNAB[9]		80							
HNS[9]		92							
Kel-F 3700							-51°C	(258)	
LX-02		128 7	20 to 50°C	(244-253)	385	-30 to 70 (243-343)	None above -4	(253)	
LX-04	28 5 39 5	(51 3) (71 1)	65 to -18°F -18 to 165°F	(219-245) (245 347)	228 2	-30 to 70 (243-343)	-18	(245)	1 860-1 870
LX-07	26 7 34 8	(48) (63)	-65 to -18°F -18 to 165°F	(219 245) (245 347)	182 9	30 to 70 (243-343)	-18	(245)	1 860-1 870
LX-08	104 5	(188)			565				
LX-09	27 1 31 0	(48 8) (55 8)	-65 to -20°F -20 to 165°F	(219-244) (244 347)			20	(244)	1 835 1 845
LX-10	24 8 26 2	(44 6) (47 0)	65 to 0°F 0 to 165°F	(219 255) (255 347)			-18	(245)	
LX-11	31 est 46 est	(56) (83)	-65 to -10°F 10 to 165°F	(219-249) (261 347)			18	(245)	
LX-13	See XTX-8003								
LX-14[7]	27 31	(48 5) (55 8)	<30°F >30°F	(<243) (>243)					
NC (12 7% N)		80-120							
PBX-9010		66							
PBX-9011	28 7 37 3	(51 7) (67 1)	-65 to -40°F 30 to 165°F	(219 233) (243 347)			35	(236)	
PBX 9404	28 1 32 2	(50 6) (58 0)	65 to -30°F -10 to 165°F	(219 239) (250-347)			-29	(239)	1 828-1 842
PBX-9501	30 6	(55 1)	80 to 160°F	(211-344)					
PETN[8]	46 1	(83 0)			249 2	30 to 70 (243-343)	None		
PETN[10]		76 5-89 9	20 to 90°C	(244 363)					
Polystyrene[3]		60-80	<100°C	(<373)	170-210 510-600	<100°C (<373) >100°C (>373)	100°C	(373)	
RDX[10]		63 6	20°C	(244)	191	20(244)			
Sylgard 182[5]	180 0	(324)	65 to 165°F	(219 347)					
TEF					840				
TNT		50 0 + 0 007T	Below m p						
Viton A[5]	65 0 145 2	(117) (254 8)	Below -6°F -6 to 165°F	Below 252 (252-347)	~450 728	Below 20(253) 20 to 70 (253 343)	-27°C	(246)	1 819
XTX-8003	68 8 77	(123 8) (139)	-22 to 158°F 75 to 150°F	(243 343) (297-339)	413 7	53 9 to 73 9 (219-296)			1 544

[a] One in/in-°F = 1 8 cm/cm-°C = m/m-K

Specific Heat

Specific heats C_p for the plastic components of plastic bonded explosives were estimated by means of the Kopp-Joule rule. Specific heat for the PBX was then calculated by applying the appropriate weight fractions to the specific heat of the components.

The estimates of specific heat C_p listed in Table 6-3 are believed to be accurate to ±5%. Values for specific heat at temperatures other than 20°C (293 K) for HMX-containing PBX can be estimated by the formula

$$C_p(T) = C_p(T_0) \frac{C_p(T)\ \text{HMX}}{C_p(T_0)\ \text{HMX}},$$

where $C_p(T)$ is the specific heat at a temperature other than 20°C (293 K), and $C_p(T_0)$ is the specific heat at 20°C (293 K). Similarly, substitute RDX values into the formula for RDX-containing PBX. The specific heats of HMX and RDX as a function of temperature are included in Table 6-3.

Table 6-3. Specific heats C_p.

	C_p(est.) at 20°C (293 K)[12]		C_p, experimental	
Explosive	(cal/g-°C)[a]	(kJ/kg-K)[b]	(cal/g-°C)[a]	(kJ/kg-K)[b]
Baratol[13]			0.157 at 30°C	(0.657 at 303 K)
			0.201 at 50°C	(0.841 at 323 K)
			0.403 at 70°C	(1.686 at 343 K)
			0.192 at 83-100°C	(0.803 at 356-373 K)
Comp B-3[13]			0.299 at 30°C	(1.251 at 303 K)
			0.307 at 50°C	(1.284 at 323 K)
			0.325 at 70°C	(1.359 at 343 K)
			0.333 at 83-100°C	(1.393 at 356-373 K)
DOP[11]			~0.57 at 50-150°C	(2.385 at 323-423 K)
FEFO[14]	0.25 (-73°C)	(1.05)(200 K)		
	0.36 (25°C)	(1.51)(298 K)		
	0.47 (127°C)	(1.97)(400 K)		
HMX[13]			0.265 at 20°C	(1.109 at 293 K)
			0.267 at 30°C	(1.117 at 303 K)
			0.271 at 50°C	(1.133 at 323 K)
			0.278 at 70°C	(1.163 at 343 K)
			0.286 at 90°C	(1.197 at 363 K)
			0.295 at 110°C	(1.234 at 383 K)
			0.302 at 130°C	(1.264 at 403 K)
			0.312 at 150°C	(1.305 at 423 K)
HNS[15]	0.40	(1.67)		
LX-02[16]	0.29	(1.21)		
LX-04	0.30	(1.25)		
LX-07	0.29	(1.21)		
LX-08	0.28	(1.17)		
LX-09	0.27	(1.13)		

Table 6-3. (continued).

Explosive	C_p(est.) at 20°C (293 K)[12] (cal/g-°C)[a]	(kJ/kg-K)[b]	C_p, experimental (cal/g-°C)[a]	(kJ/kg-K)[b]
LX-10	0.28	(1.17)		
LX-11[16]	0.31	(1.26)		
LX-13	0.27	(1.13)		
LX-14	0.27	(1.13)		
NC[17] (13.35% N, min.)			$(1.84 \times 10^{-2}) + (7.64 \times 10^{-4} T)$ at 298-390 K	
NG[18]			0.356 at 35-200°C	(1.490 at 308-473 K)
NM[19]			C_{sat} = 104.4 + $(6.381 \times 10^{-2} t)$ + $(3.175 \times 10^{-4} t^2)$ - $(8.131 \times 10^{-7} t^3)$ + $(4.093 \times 10^{-9} t^4)$ J/mole-°C, t in °C	
NQ[20]			C_p = 6 + 0.08 T at 200-460 K	
Octol	0.27	(1.13)		
PBX-9007	0.28	(1.17)		
PBX-9010	0.27	(1.13)	$0.247 + 0.00064t^2$ at 37-167°C (310-440 K)	
PBX-9011	0.27	(1.13)		
PBX-9205	0.28	(1.17)		
PBX-9404	0.27	(1.13)		
PBX-9407	0.27	(1.13)		
PBX-9501[21]	0.27	(1.13)	$0.238 + 0.00079T^2$ at 50-175°C (323-448 K)	
Pentolite 50/50	0.26	(1.09)		
PETN[12]			0.26 at 20°C	(1.088 at 293 K)
Polystyrene[3]			0.283 at 0°C 0.300 at 50°C 0.439 at 100°C	(1.184 at 273 K) (1.255 at 323 K) (1.837 at 373 K)
RDX[13]			0.274 at 20°C 0.278 at 30°C 0.285 at 50°C 0.289 at 70°C 0.290 at 90°C 0.293 at 110°C	(1.146 at 293 K) (1.163 at 303 K) (1.192 at 323 K) (1.209 at 343 K) (1.213 at 363 K) (1.236 at 383 K)
Sylgard 182[4]			0.34 at 25°C	(1.423 at 298 K)
TATB[19]	0.25 at 25°C	(1.05 at 298 K)		
Tetryl[20]			C_p = 15 + 0.19T at 200-403 K	
TNT[22]			$0.2463 + (8.408 \times 10^{-4} t)$ at 25-68°C (298-341 K) $0.4502 + (8.018 \times 10^{-4} t)$ at 83-117°C (356-390 K)	
Viton A[23]			0.35	(1.464)
XTX-8003[16]	0.27	(1.13)		

[a] Values are identical for BTU/lb-°F and cal/g-°C.

[b] Conversion factor: 1 cal/g-°C = 4.184 kJ/kg-K.

[c] C_{sat} = heat capacity at saturated liquid nitromethane under its own vapor pressure.

Thermal Stability

Thermal changes in materials can be measured in several ways, qualitatively and quantitatively. For HEs we generally use differential thermal analysis (DTA), thermogravimetric analysis (TGA), and tests (pyrolysis, CRT, or vacuum stability) that measure the amount of gas evolved when an HE is heated for a stated period of time at an elevated temperature. Heating rates are 10°C/min.

1. Differential thermal analysis (DTA). In the usual DTA analysis, identical containers are set up (one containing the sample and the other containing a standard reference substance) in identical thermal geometries with temperature sensors arranged so as to give both the temperature of each container and the difference in temperatures between containers. The data are displayed as a DTA thermogram in which the temperature difference is plotted against the temperature of the sample. The standard reference material chosen is one whose thermal behavior does not change rapidly. Such a plot is almost a straight line if the sample also has no rapidly changing thermal behavior (or if it is very similar to the standard material). Excursions above and below a background line are due to endo- or exothermic (heat-absorbing or heat-releasing) changes. The DTA analyses permit interpretation for phase changes, decomposition and kinetic information, melting points, thermal stability. Results are shown in Fig. 6-4. Sample sizes are of the order of 20 mg.

2. Pyrolysis. The sample is placed in a pyrolysis chamber which is then flushed with helium. When the air has been swept out, the temperature of the chamber is raised at a constant rate. Gas evolution is measured as a function of temperature by a bridge formed by two thermal conductivity cells. Data are included in Fig. 6-4, the right-hand ordinate showing the thermal conductivity response in millivolts (mV).[25] Sample sizes are of the order of 10 mg.

3. Thermogravimetric analysis (TGA). The objective in a TGA is to determine whether there are any weight changes in a sample, either when it is held at a fixed temperature or when its temperature is changed in a programmed linear fashion.

The data are generally plotted as weight vs temperature or time or as weight change vs temperature or time. The TGAs are useful for only a limited number of physical property investigations, e.g. vaporization phenomena, but they are extremely useful for obtaining information on chemical properties such as thermal stability and chemical reactions. They are also useful for obtaining kinetic data. Sample sizes are of the order of 10 mg.

The heating rate is held at ~10°C/min in nitrogen atmosphere, and weight loss is shown as a function of temperature in Fig. 6-5.[26]

4. LLL reactivity test (CRT). The sample is heated at 120°C (393 K) for 22 hr. A two-stage chromatography unit is used to measure the individual volumes of N_2, NO, CO, N_2O and CO_2 evolved per 0.25 g of explosive during this period. The test is used principally to determine the reactivity of explosives with other materials. When operated as a simple test of explosive stability, the results are expressed in terms of the sums of these volumes. Results are given in Table 6-4.

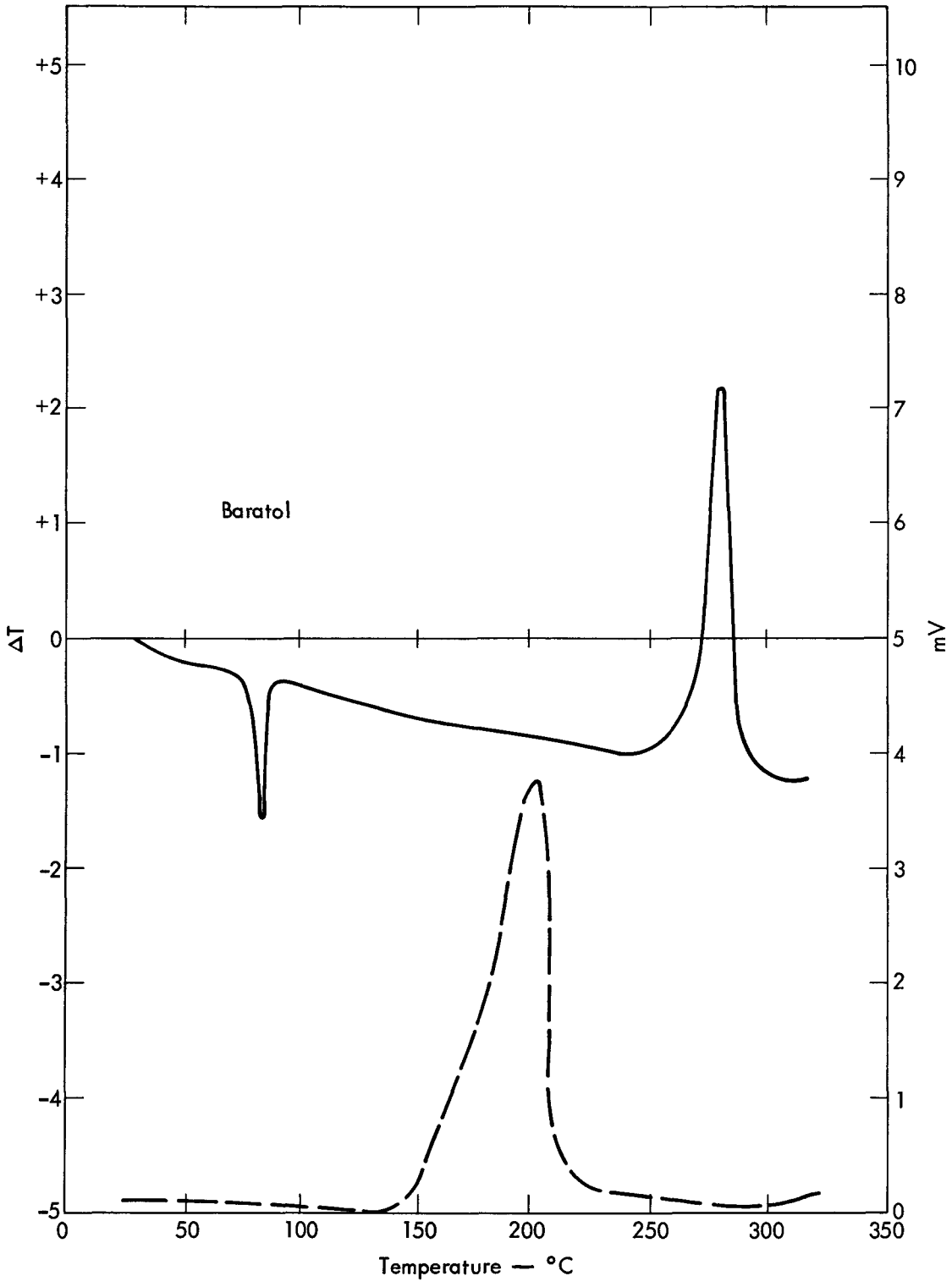


Fig. 6-4. (a) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for baratol.[24]

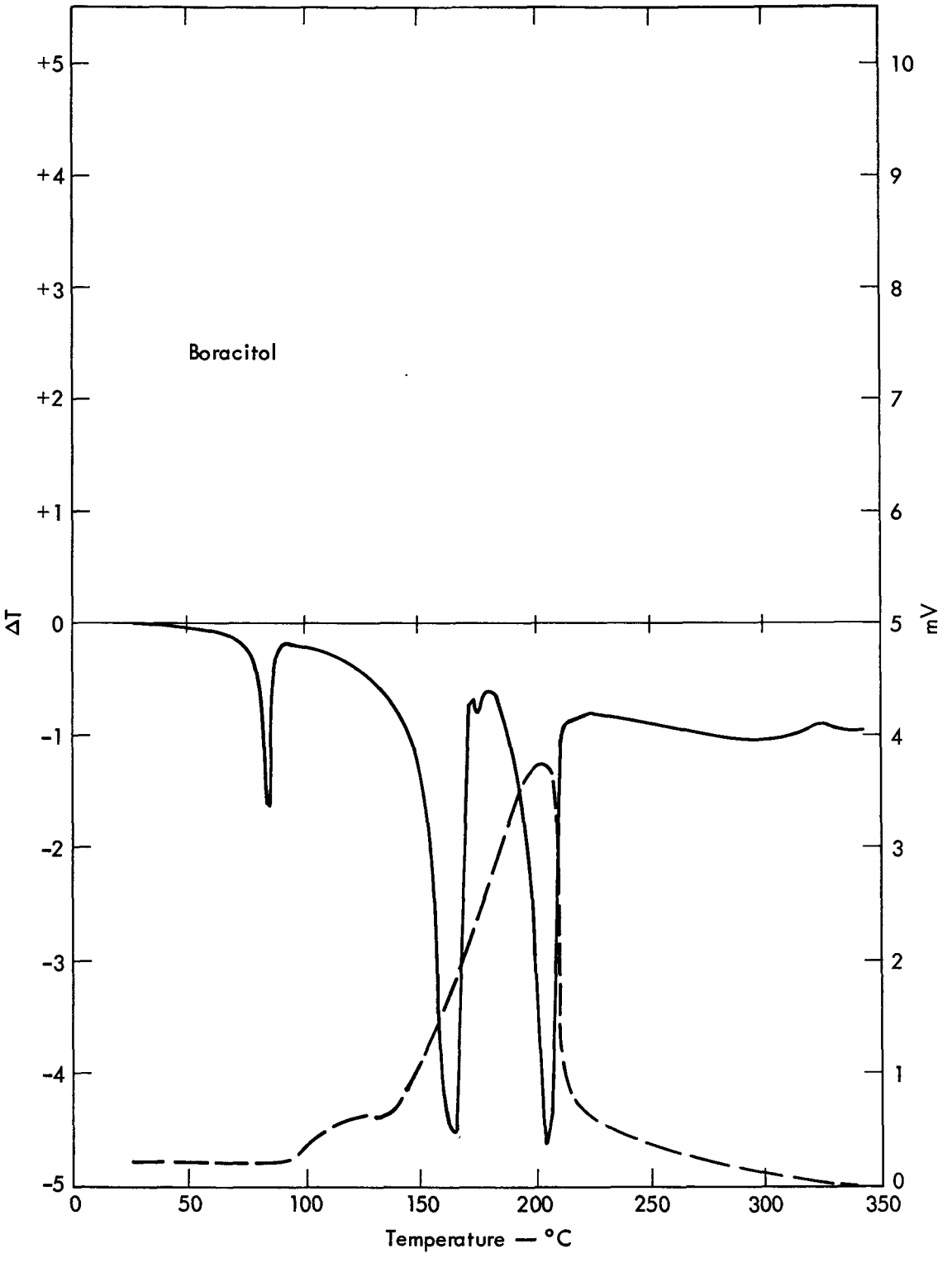


Fig. 6-4. (b) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for boracitol.[24]

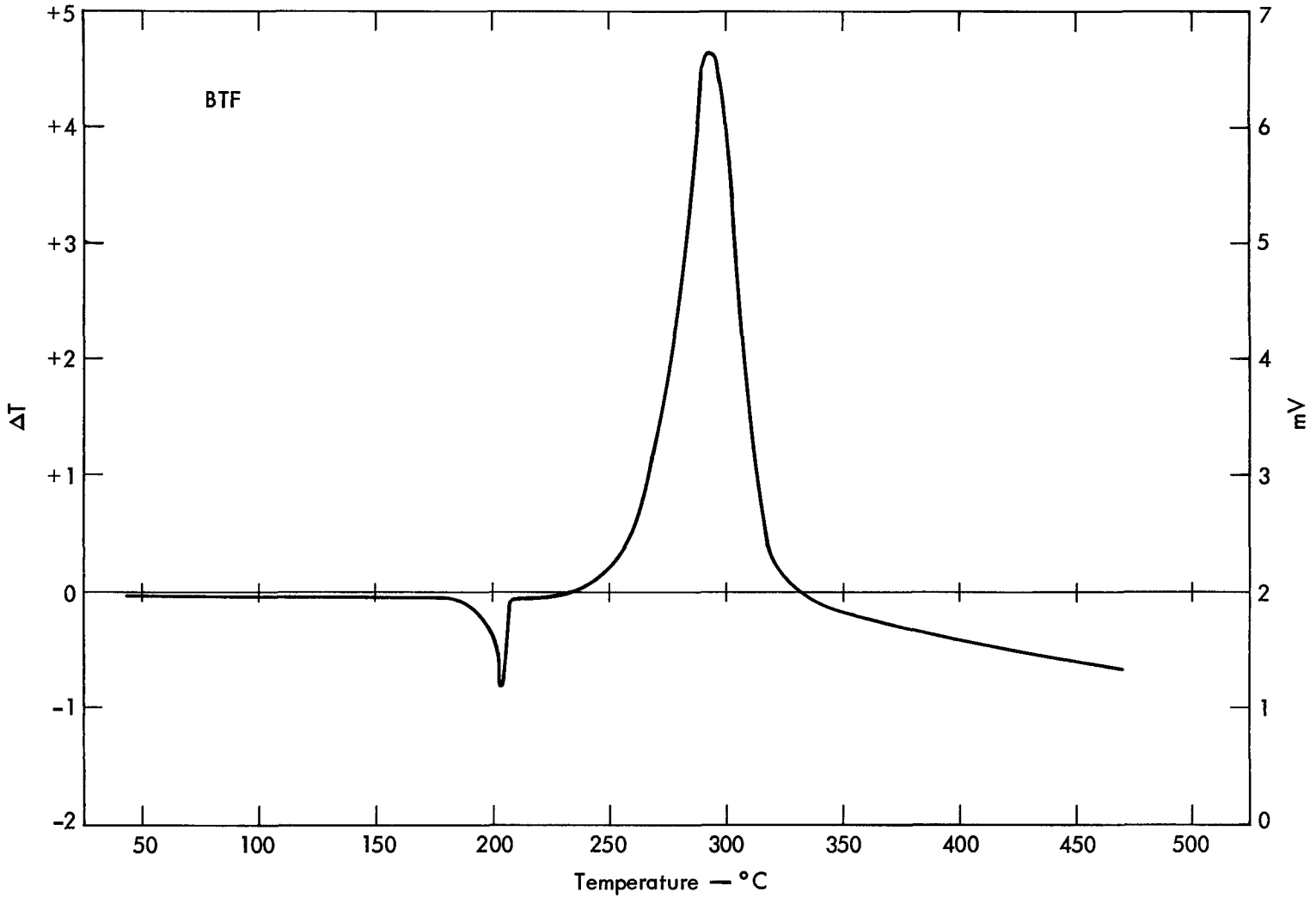


Fig. 6-4. (c) DTA curve for BTF.[24]

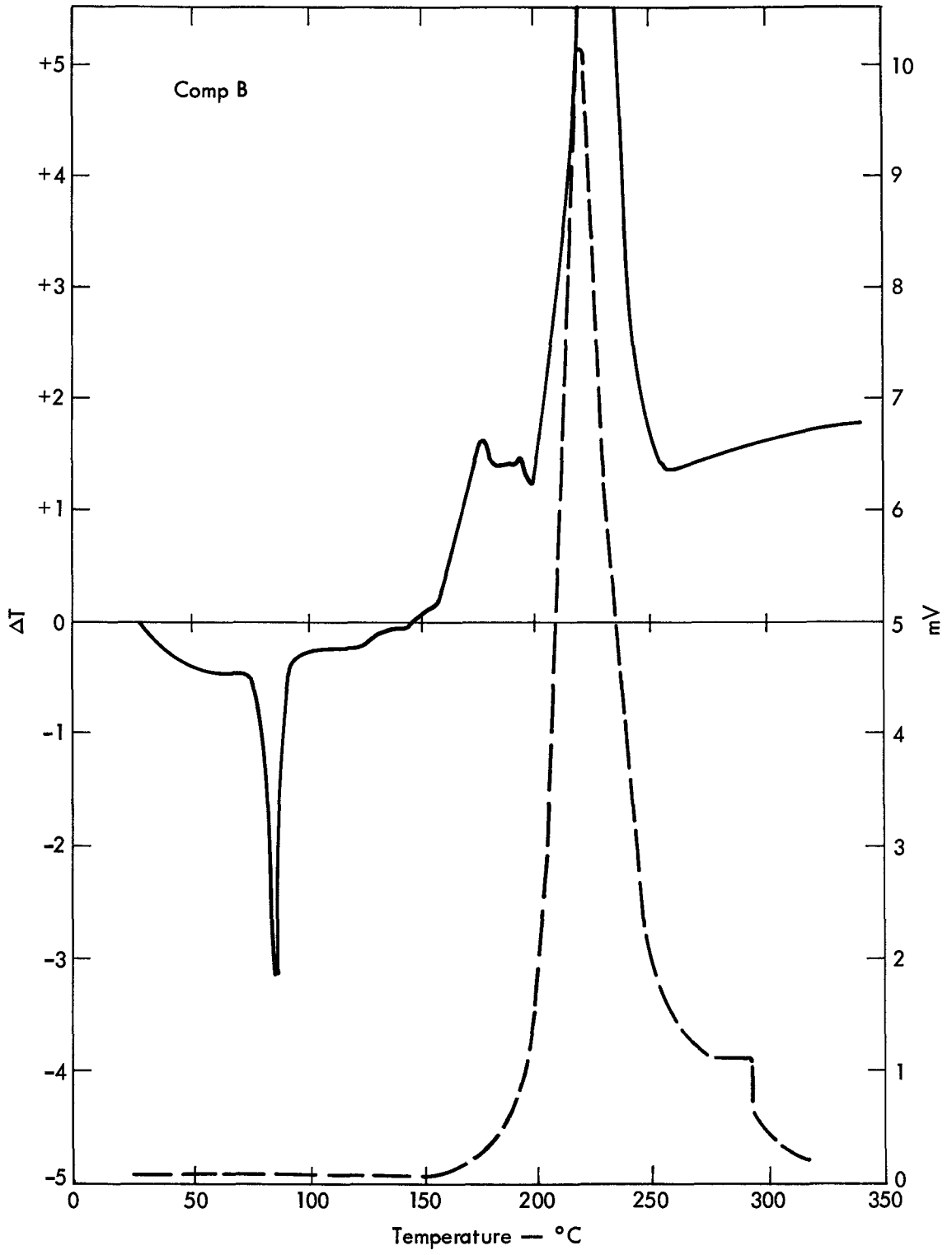


Fig. 6-4. (d) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Comp B.[24] Melting points of both TNT and RDX are lowered. The melting endotherm for RDX is almost lost in the decomposition exotherm which starts at ~150°C (423 K). Comp B is less stable than its components separately.

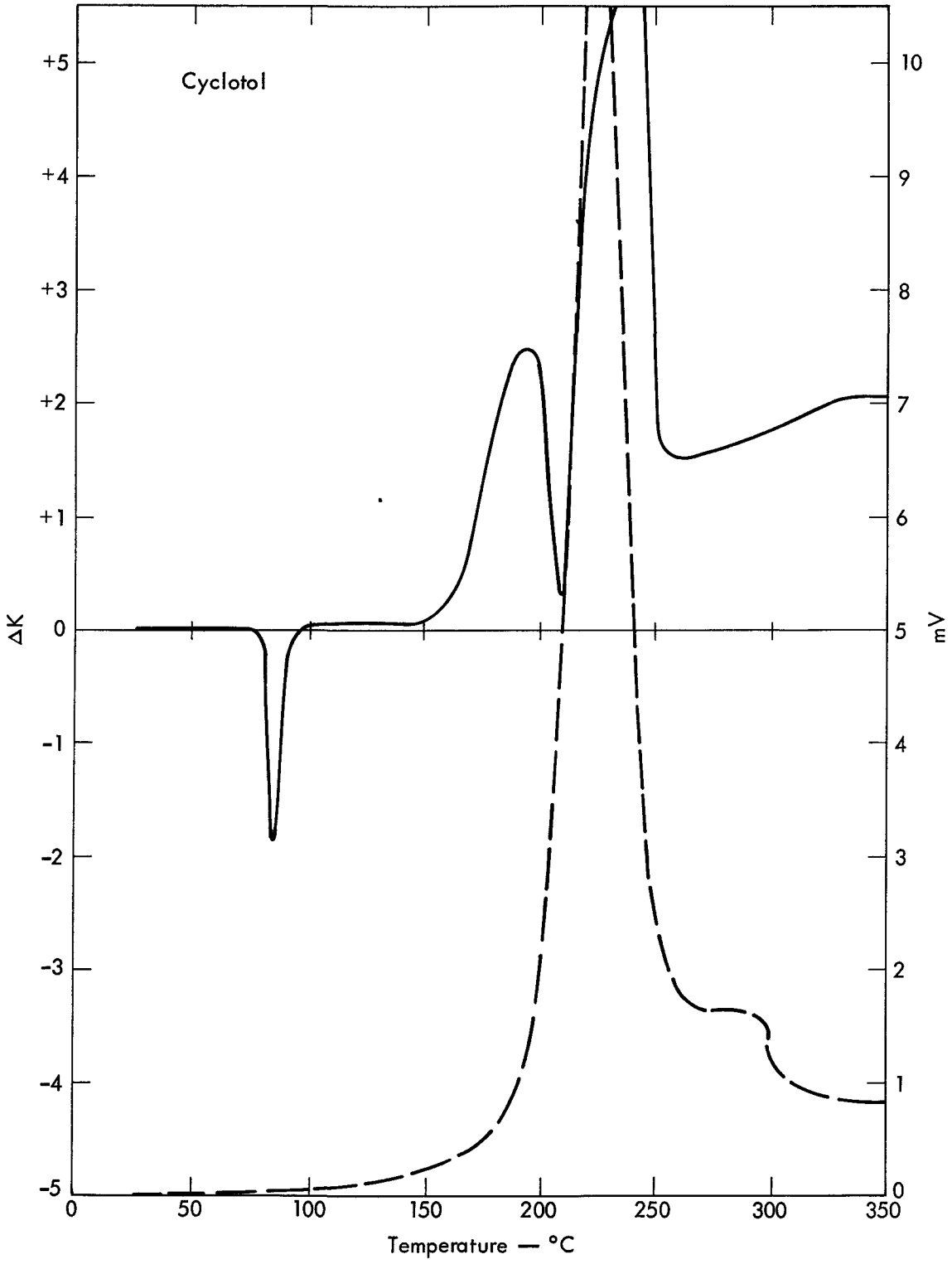


Fig. 6-4. (e) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for cyclotol.[24]

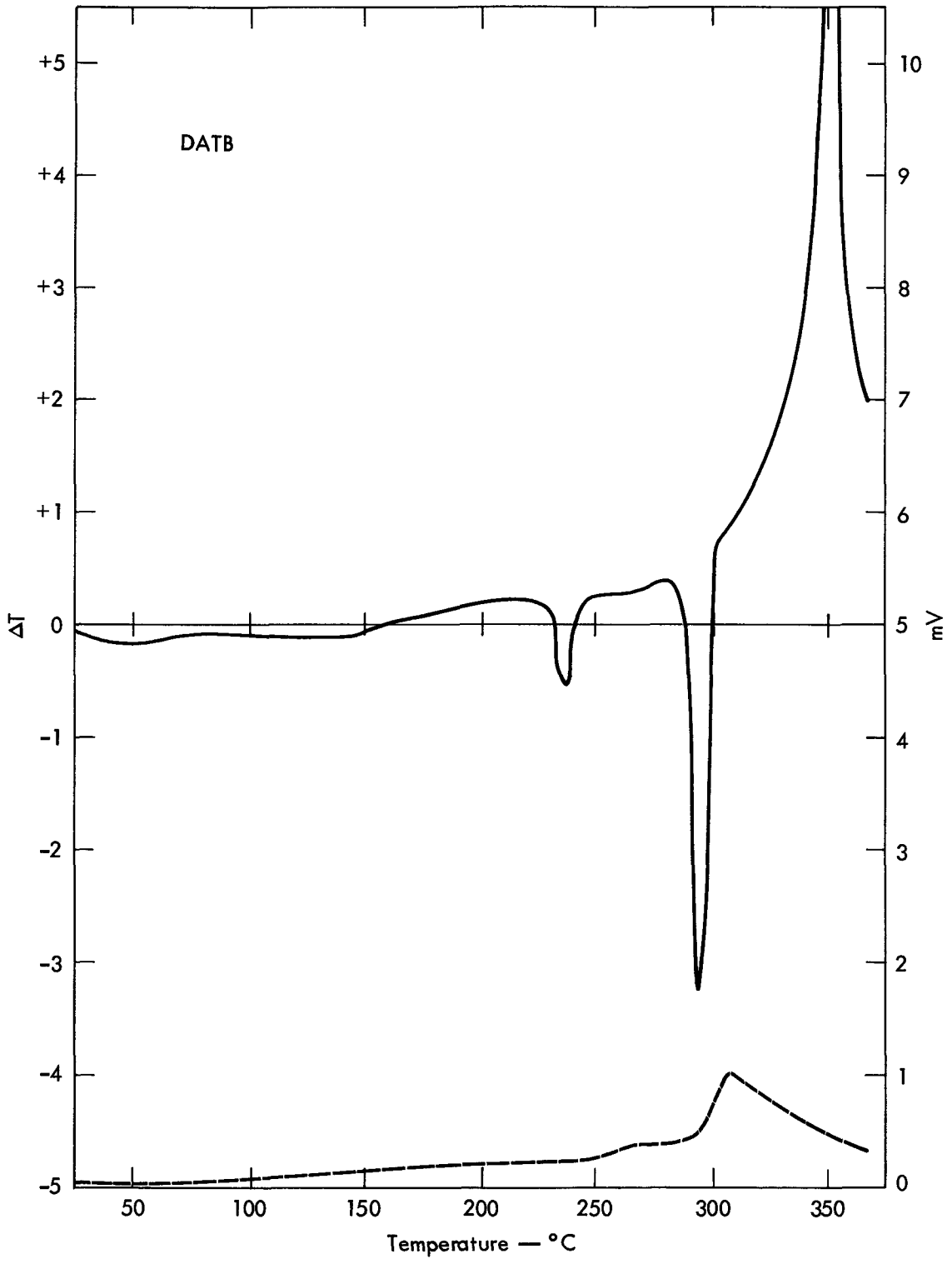


Fig. 6-4. (f) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for DATB.[24] The endotherm starting at ~220°C (493 K) is due to the I → II polymorphic transition. The melting point appears at 285°C (558 K)

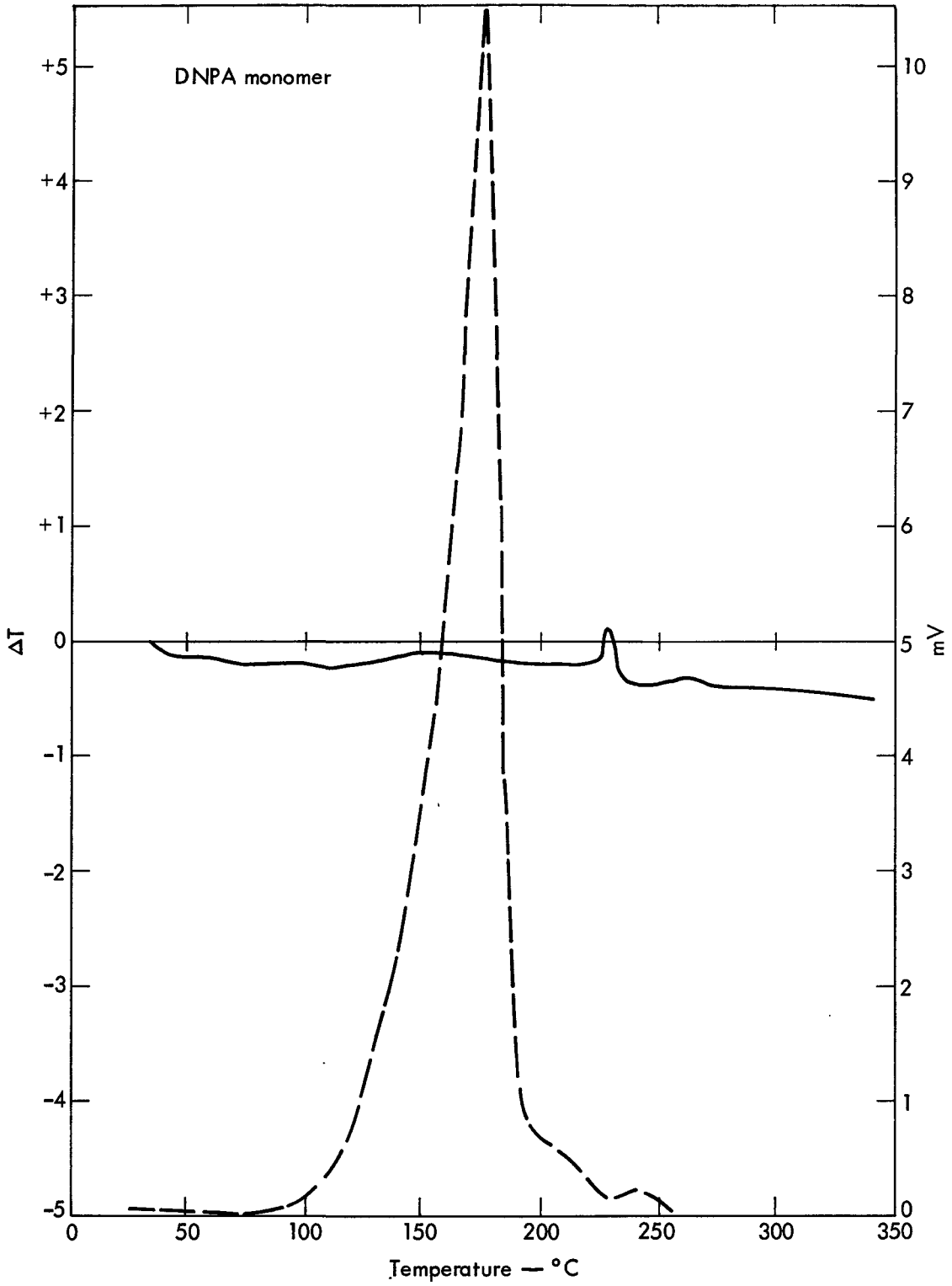


Fig. 6-4. (g) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for DNPA monomer.[24]

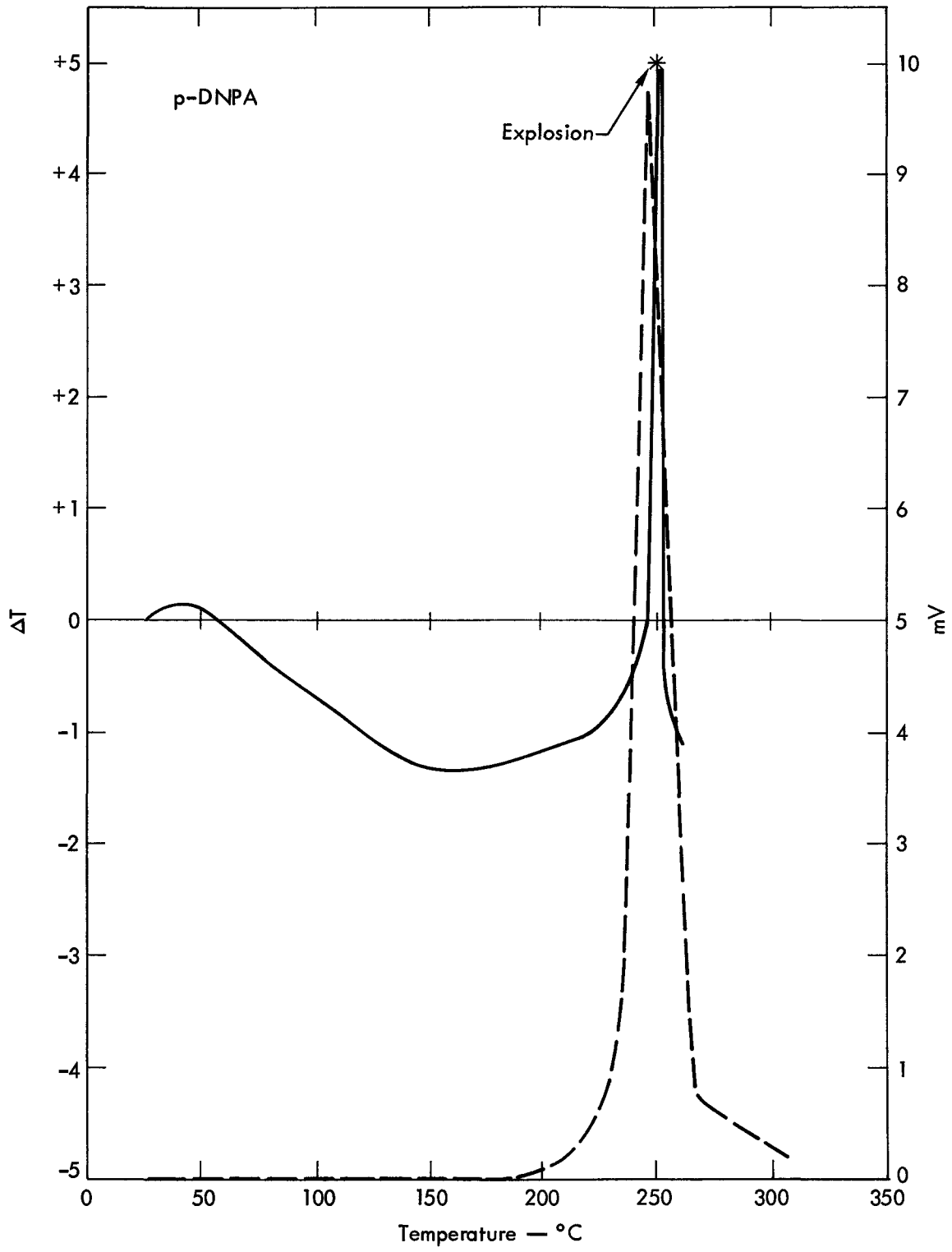


Fig. 6-4. (h) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for p-DNPA. A mild explosion usually blows the sample thermocouple out of the cell at 250°C (523 K). The small endotherm at 60°C (333 K) is due to the second-order transition of the polymer.

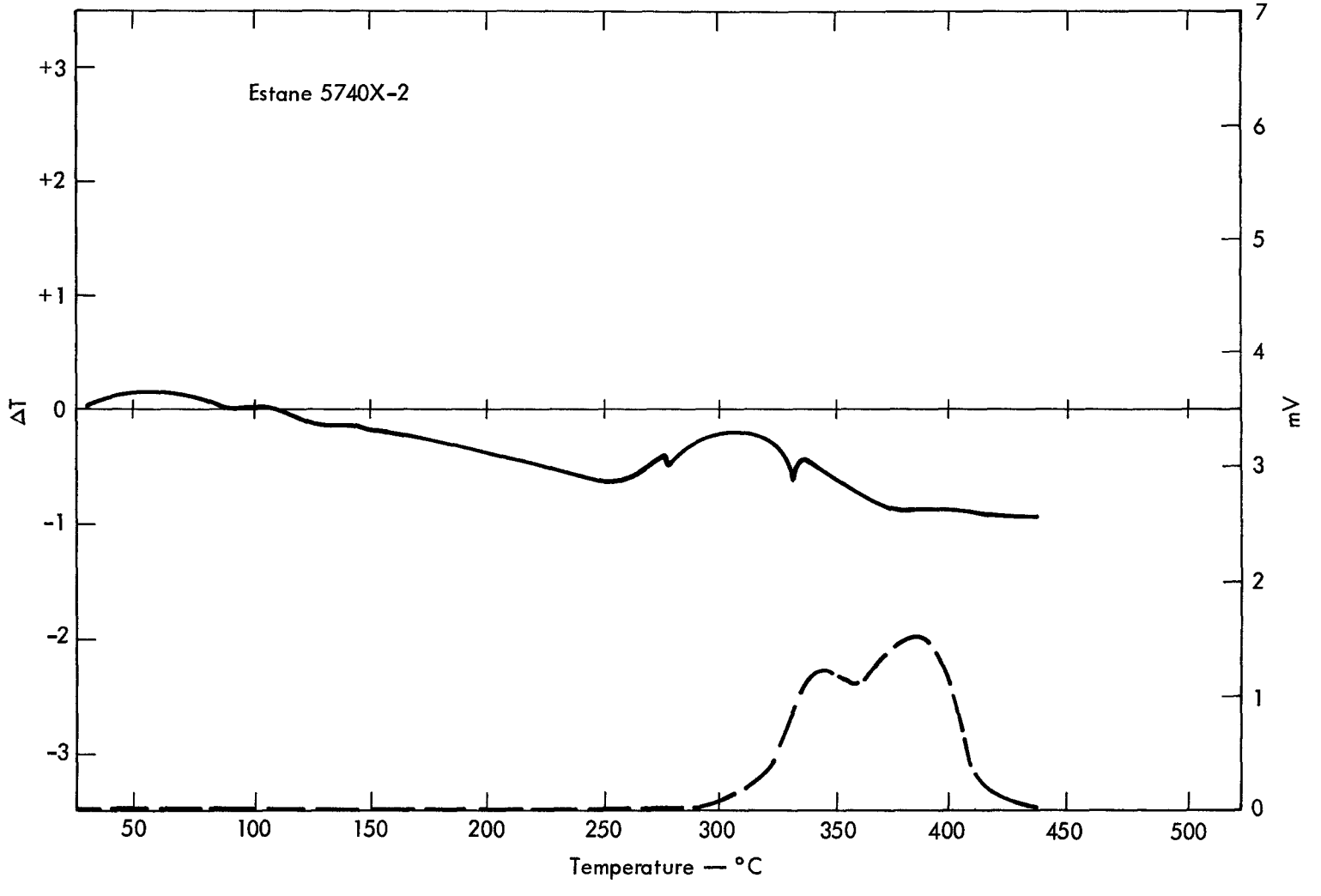


Fig. 6-4. (i) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Estane 5740 X-2.[24]

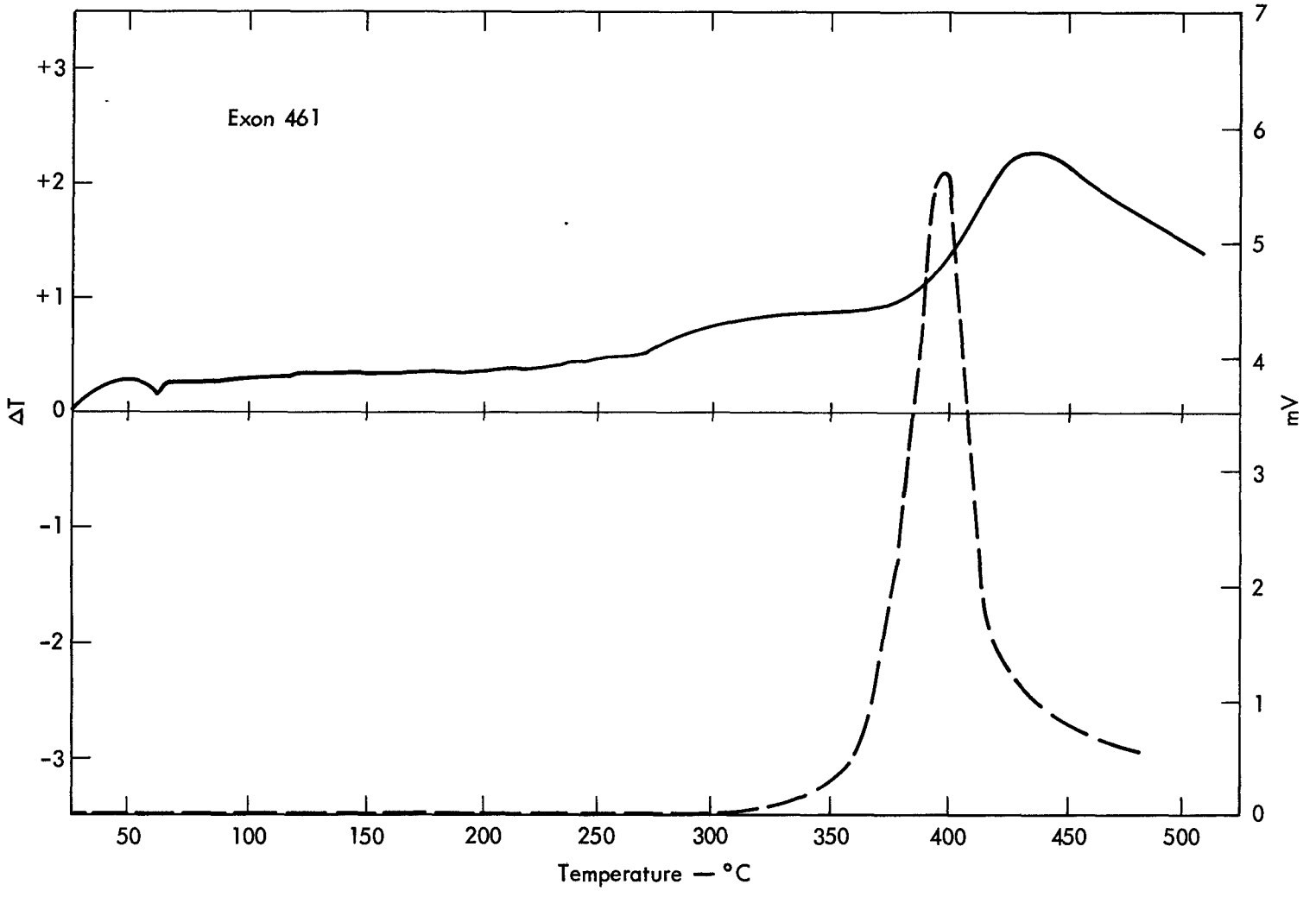


Fig. 6-4. (j) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Exon 461.[24]

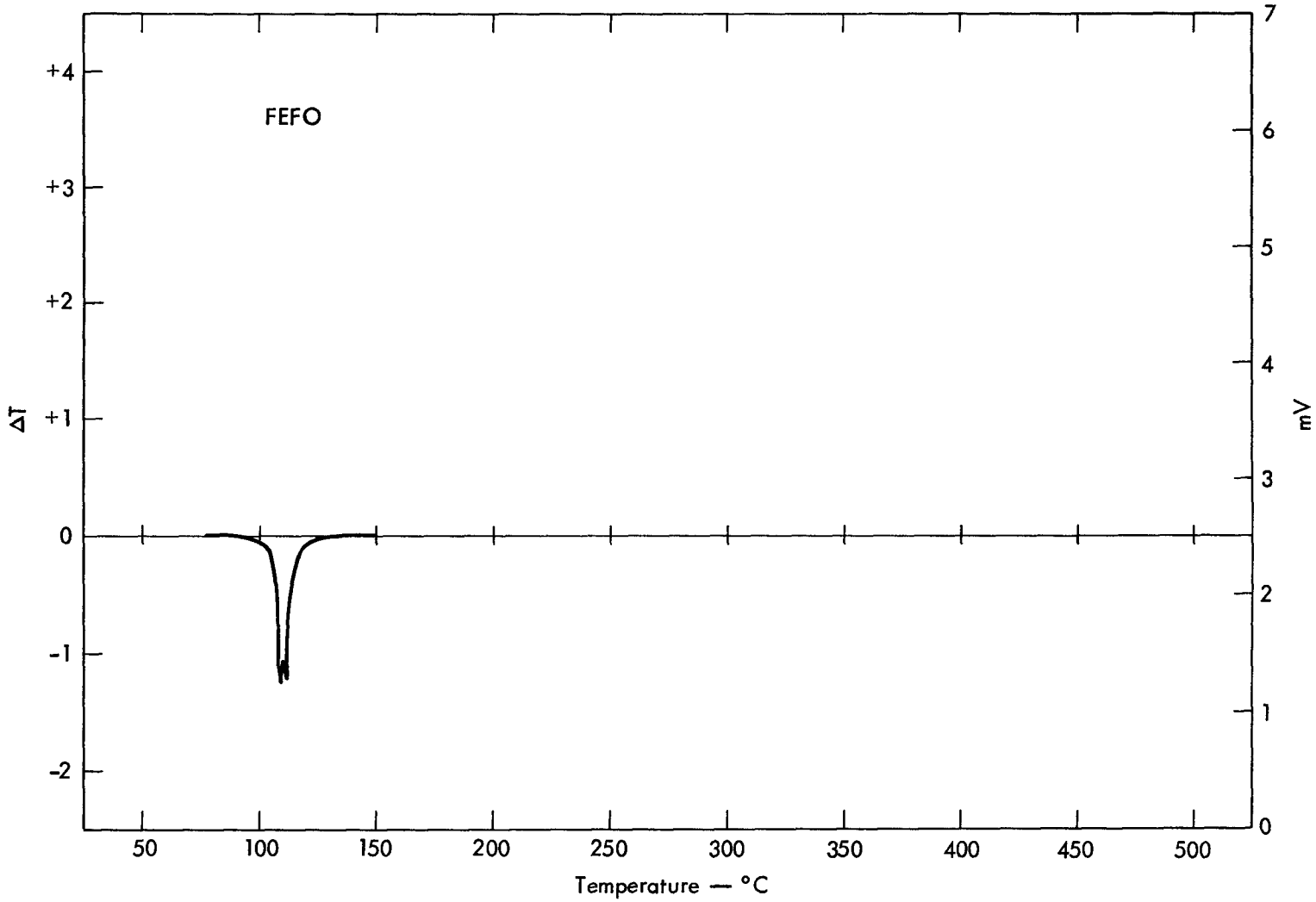


Fig. 6-4. (k) DTA curve for FEFO.[24]

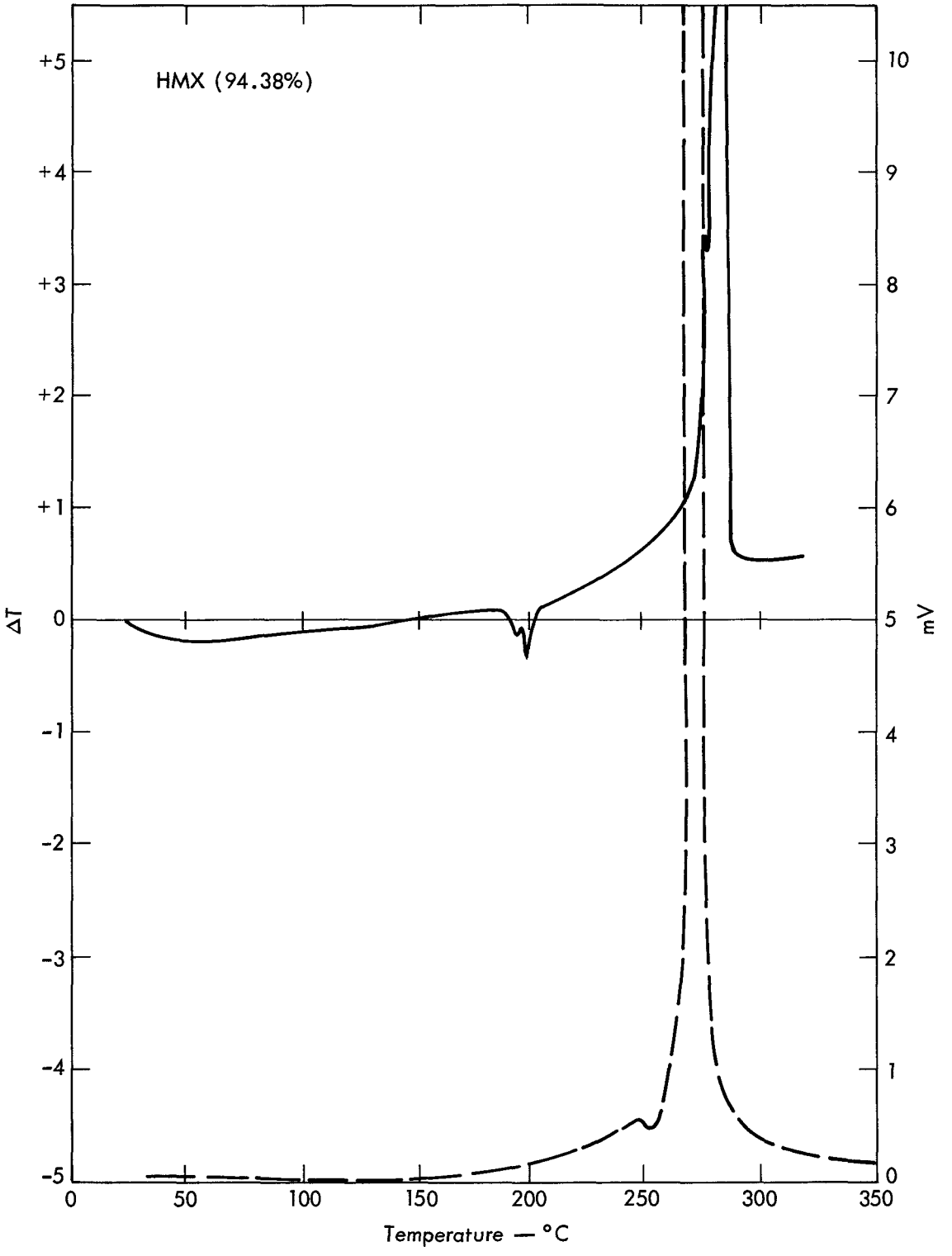


Fig. 6-4. (1) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for HMX (94.38% Holston production grade).[24] Melting point 275°C (548 K).

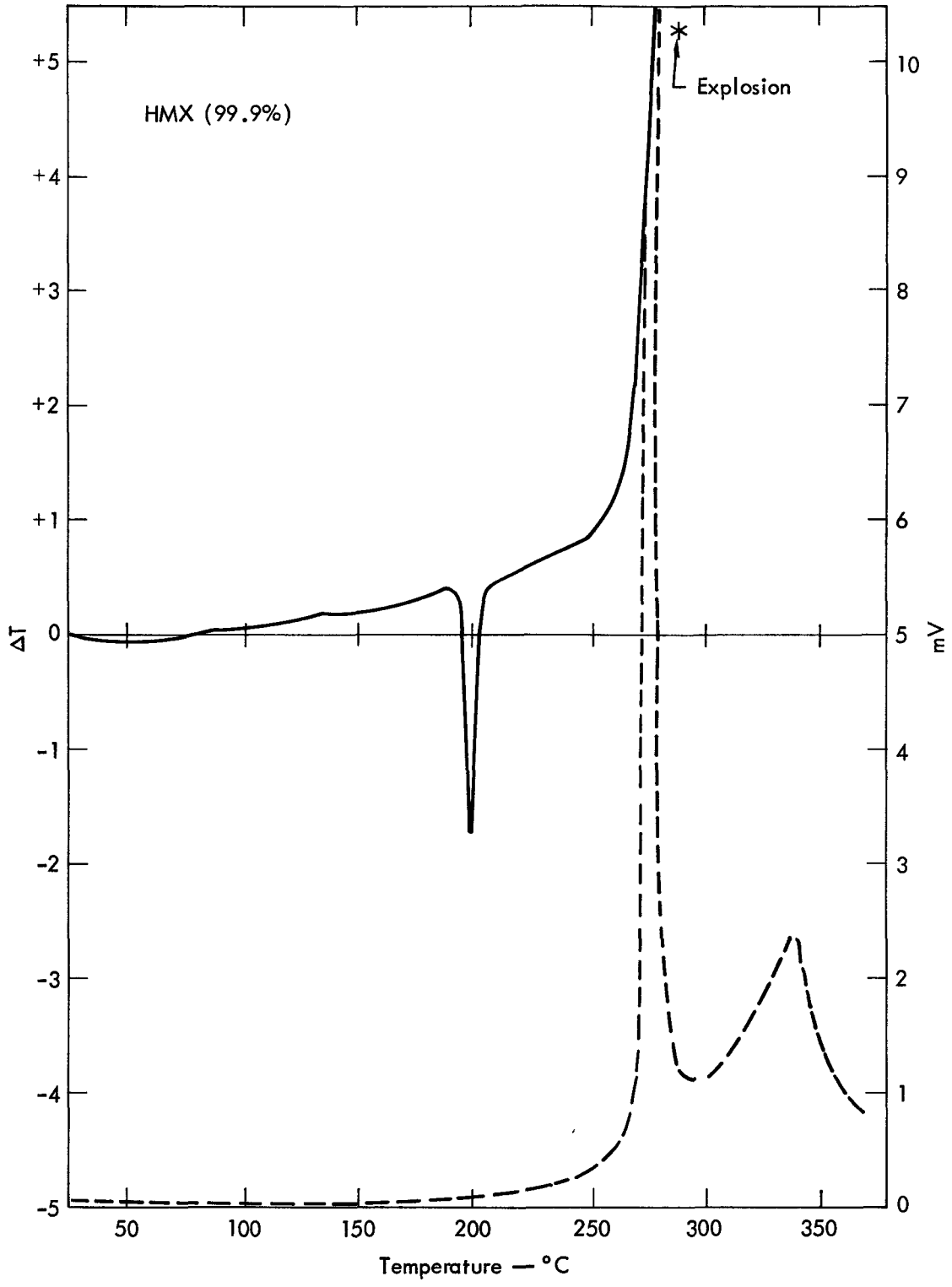


Fig. 6-4. (m) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for HMX (99.9% pure).[24] Purified by extraction and crystallization of production-grade HMX. Dry β-HMX of good purity does not show a $\beta \rightarrow \alpha$ transition. This sample shows a $\beta \rightarrow \alpha$ transition starting at 187°C (460 K), but no melting point, so the endotherm does not show on the curve.

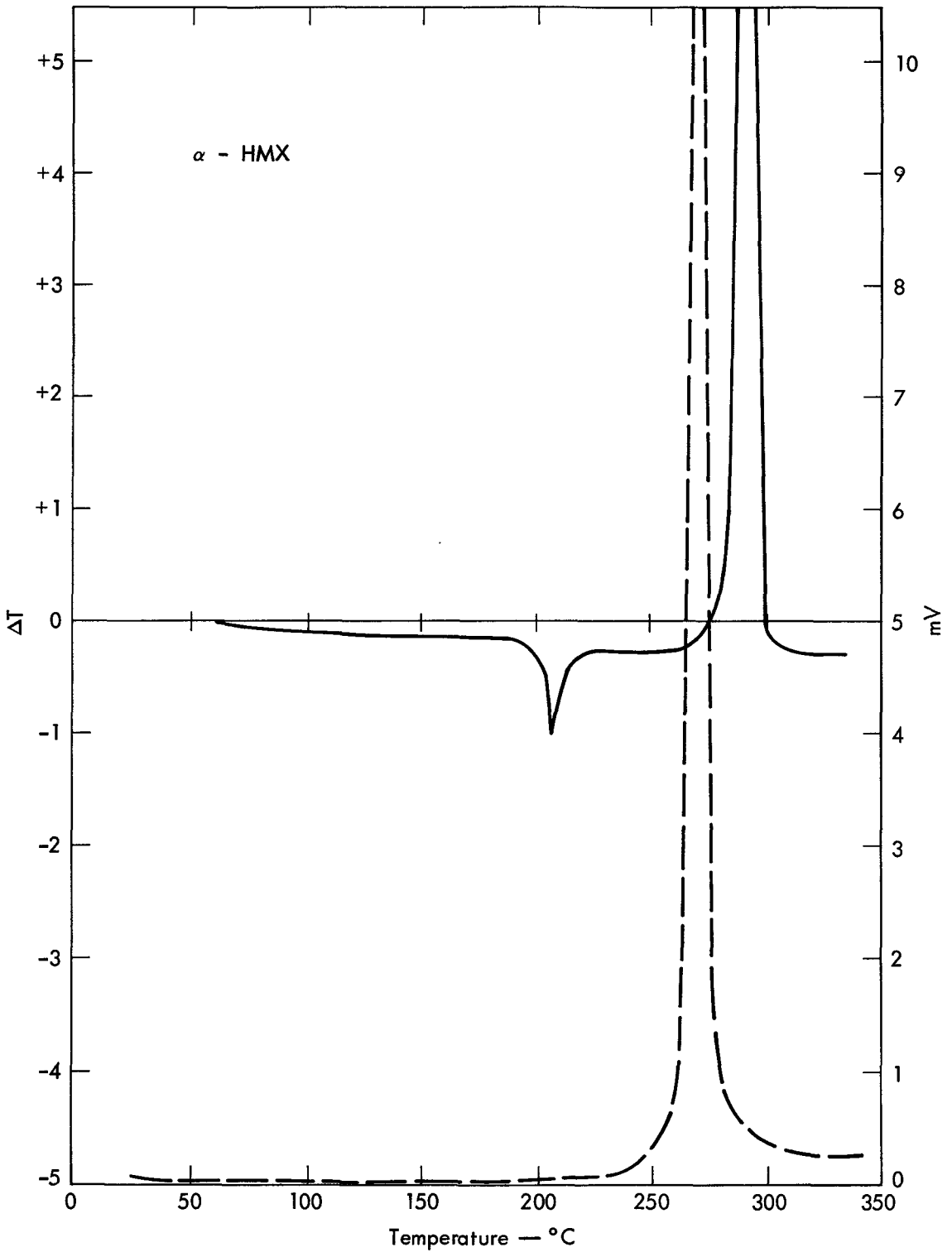


Fig. 6-4. (n) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for α-HMX.[24] Melting point 282°C (555 K).

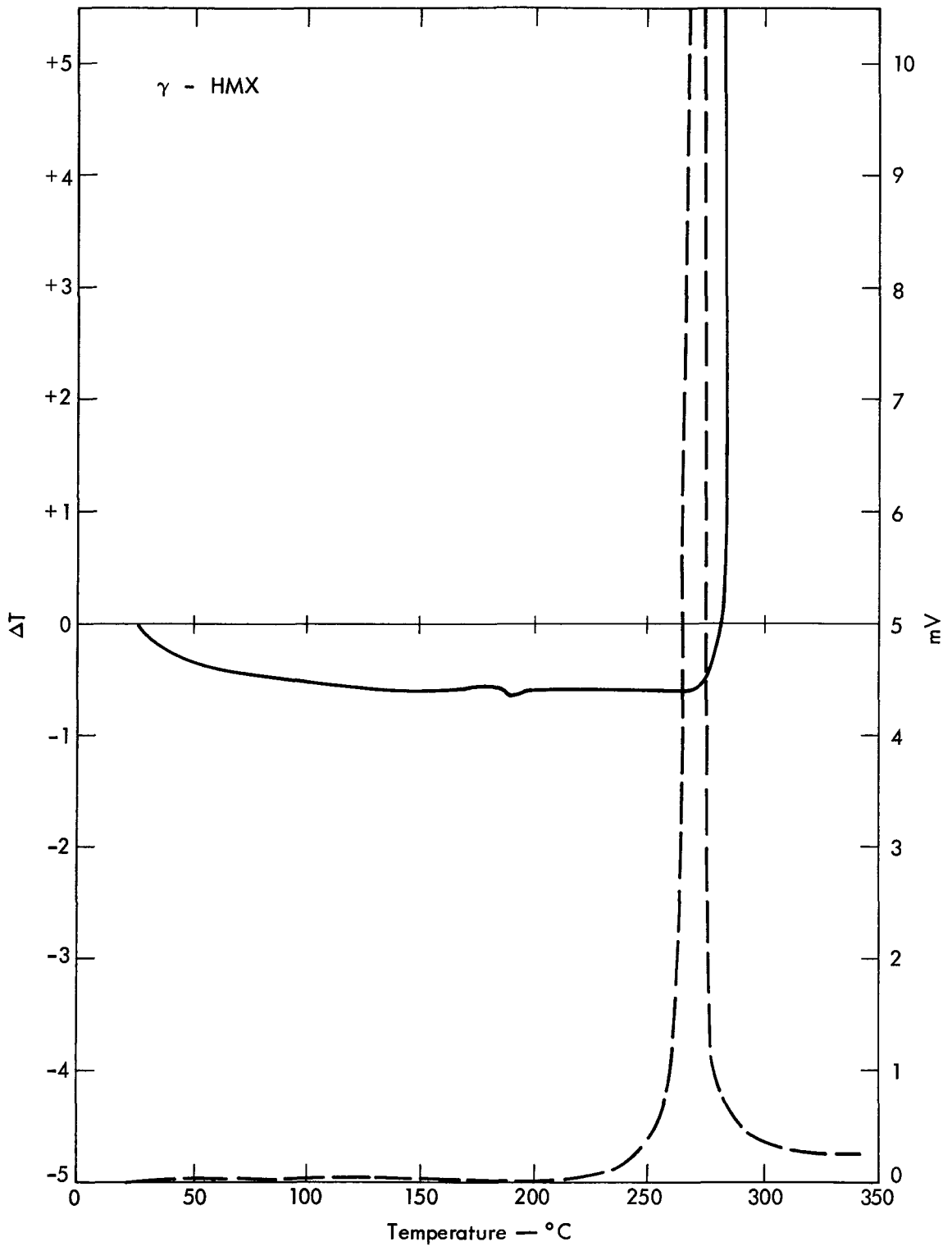


Fig. 6-4. (o) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for γ-HMX.[24] Appears to contain a small amount of β-HMX.

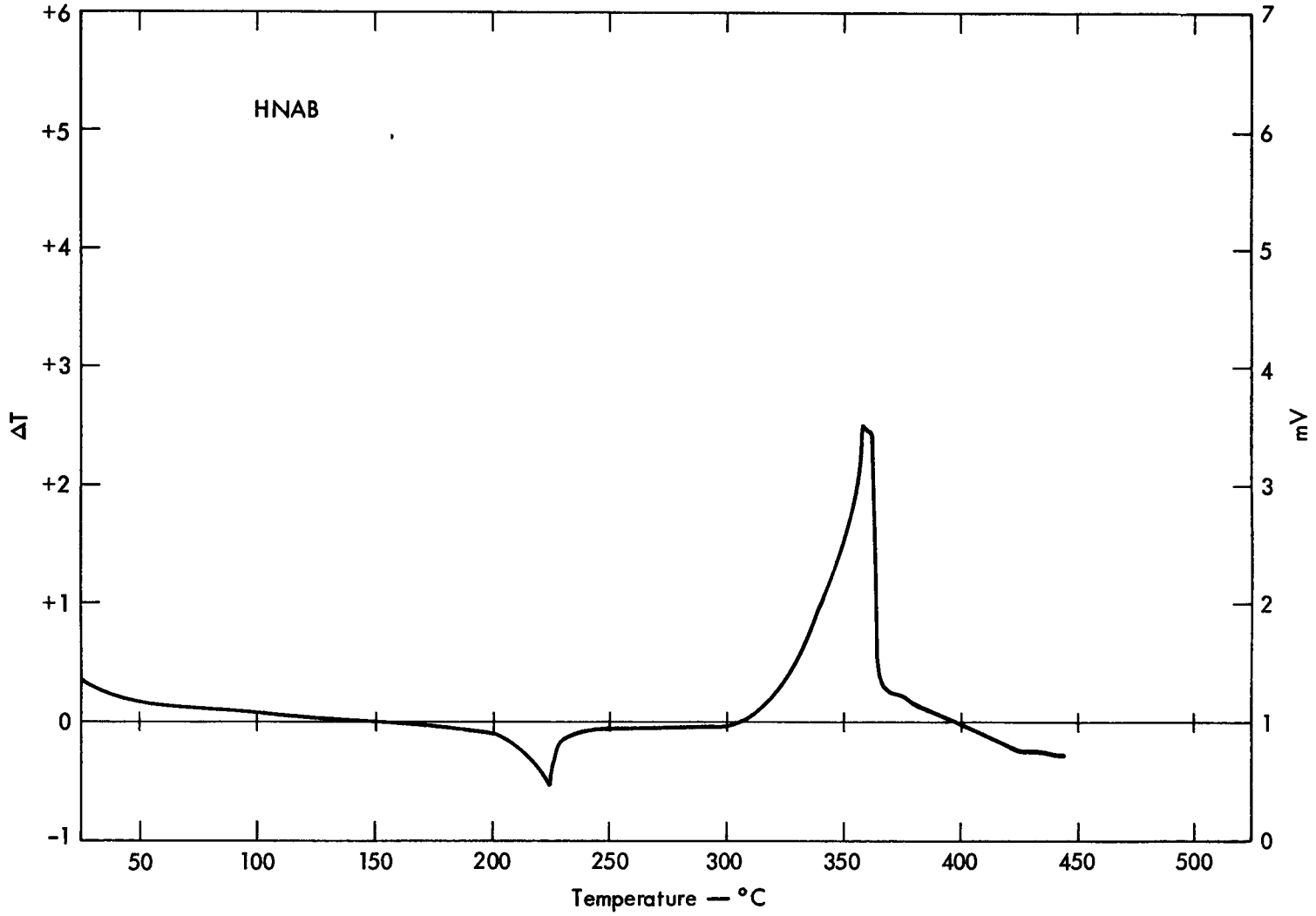


Fig. 6-4. (p) DTA curve for HNAB.[24]

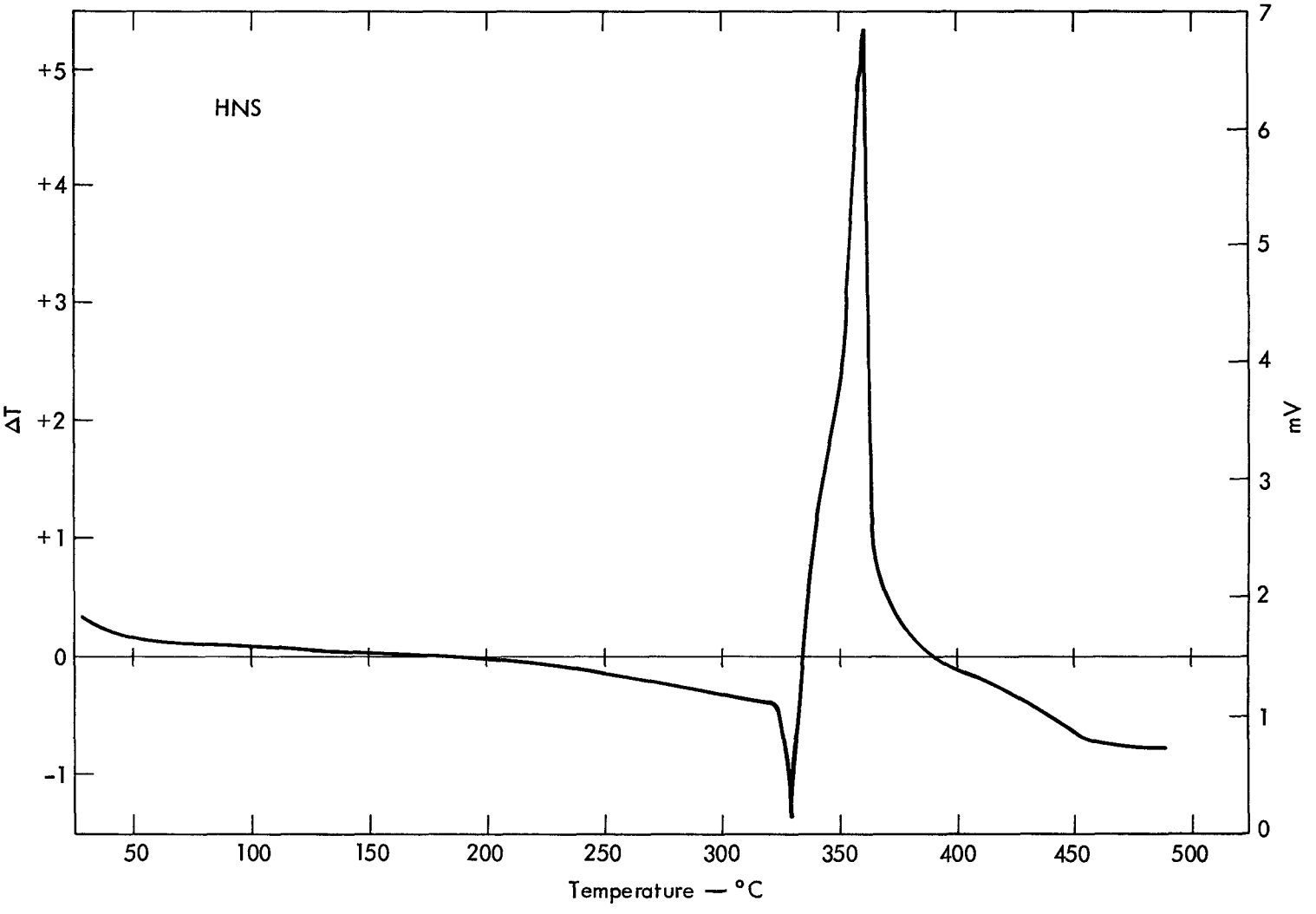


Fig. 6-4. (q) DTA curve for HNS.[24]

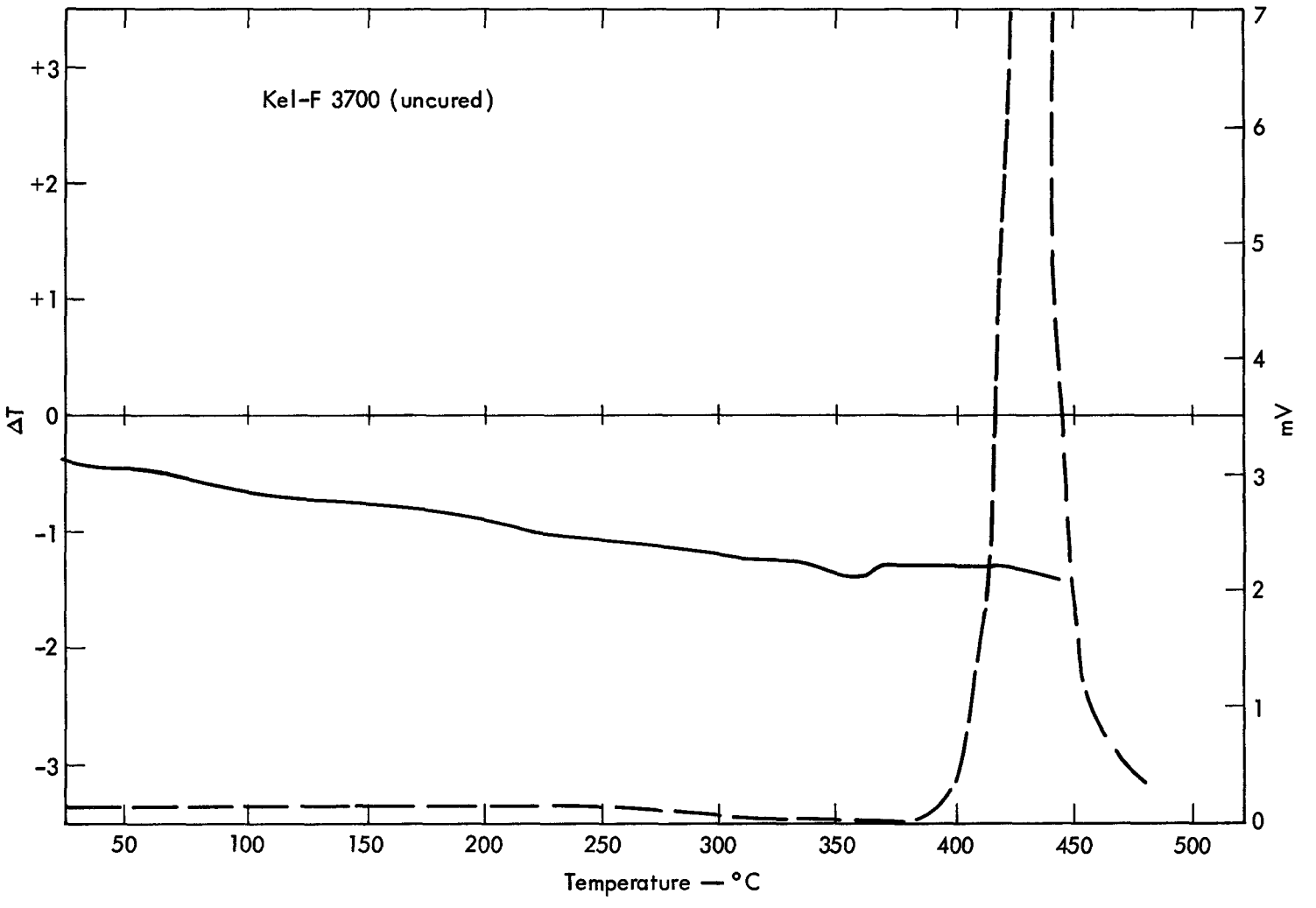


Fig. 6-4. (r) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Kel-F 3700 (uncured).[24] *Zero-line drift is due to low thermal conductivity of sample.*

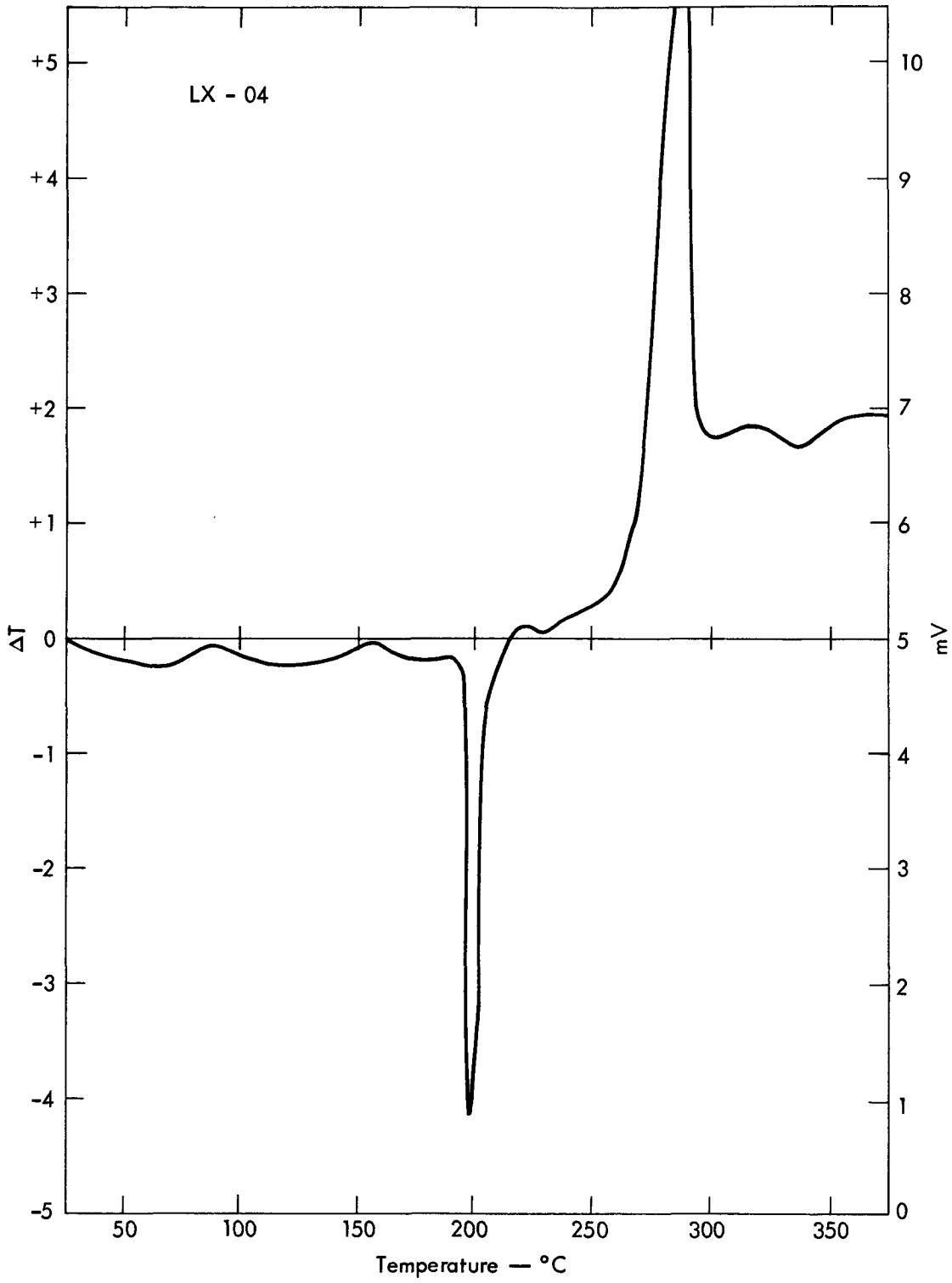


Fig. 6-4. (s) DTA curve for LX-04.[24]

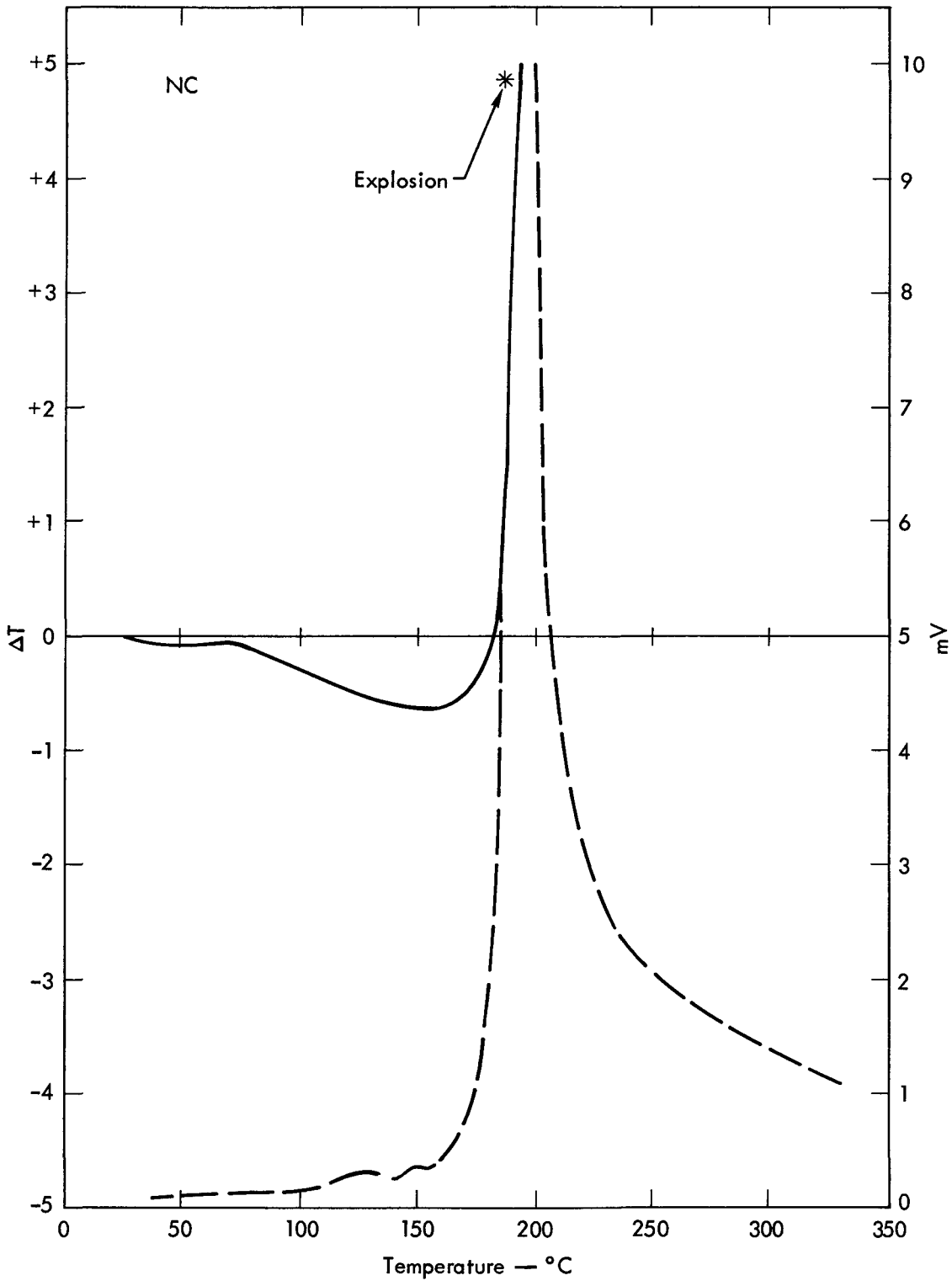


Fig. 6-4. (t) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for NC.[24] A mild explosion always blows the sample thermocouple out of the cell at 195-197°C (468-470 K).

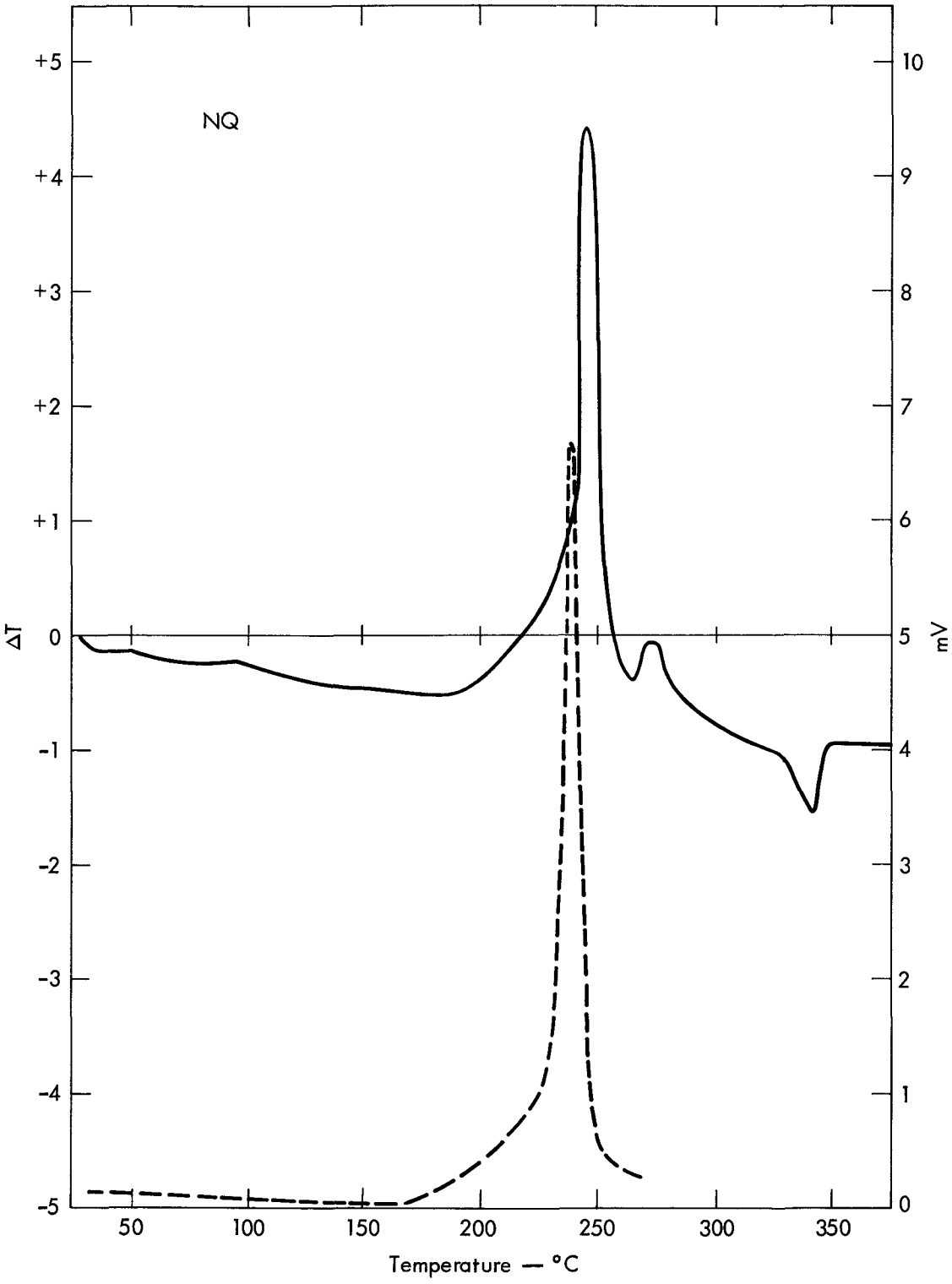


Fig. 6-4. (u) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for NQ.[24]

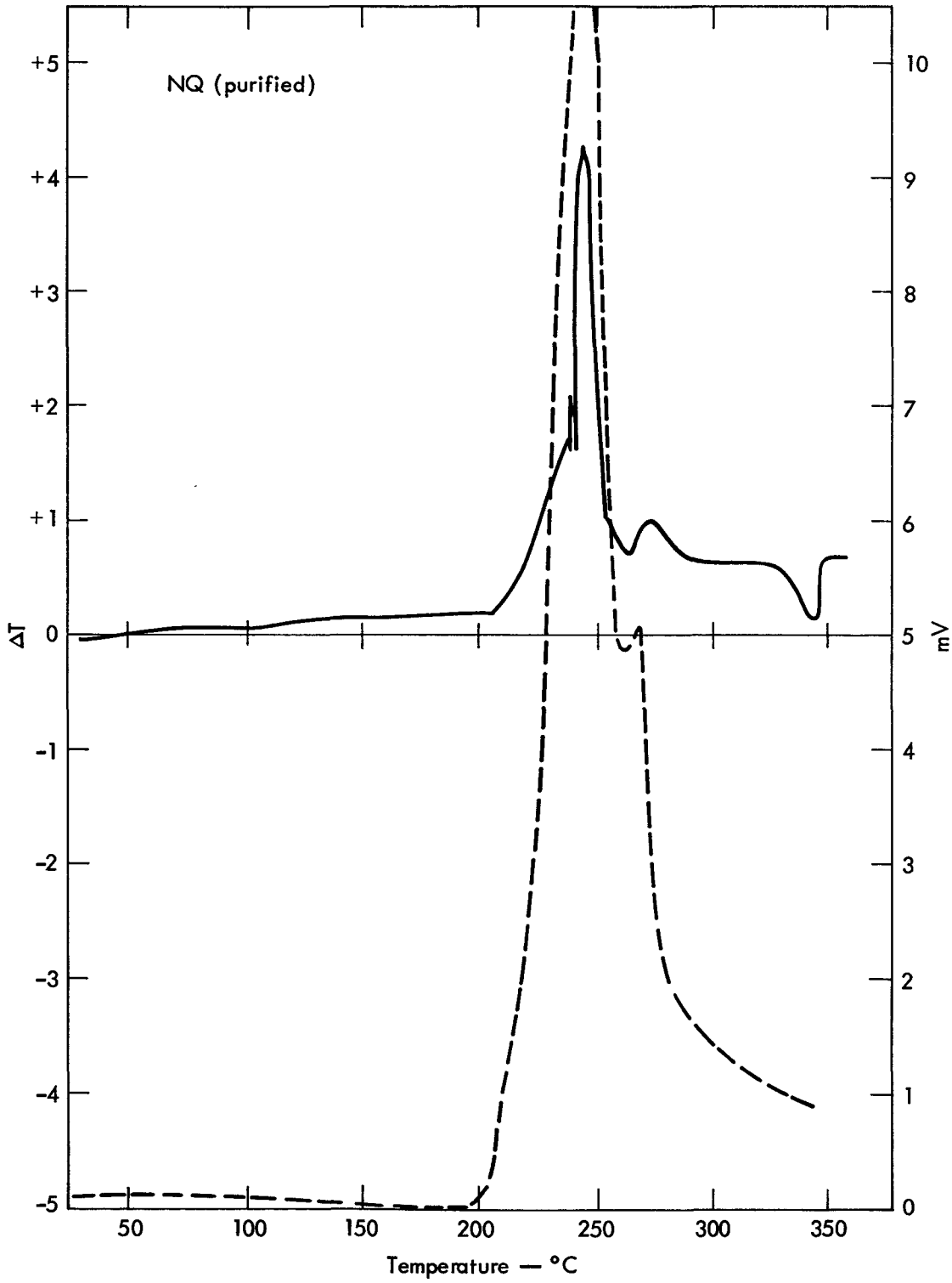


Fig. 6-4. (v) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for NQ (purified).[24] The melting point of the sample is superimposed on the decomposition exotherm. The decomposition in the liquid phase is extremely violent.

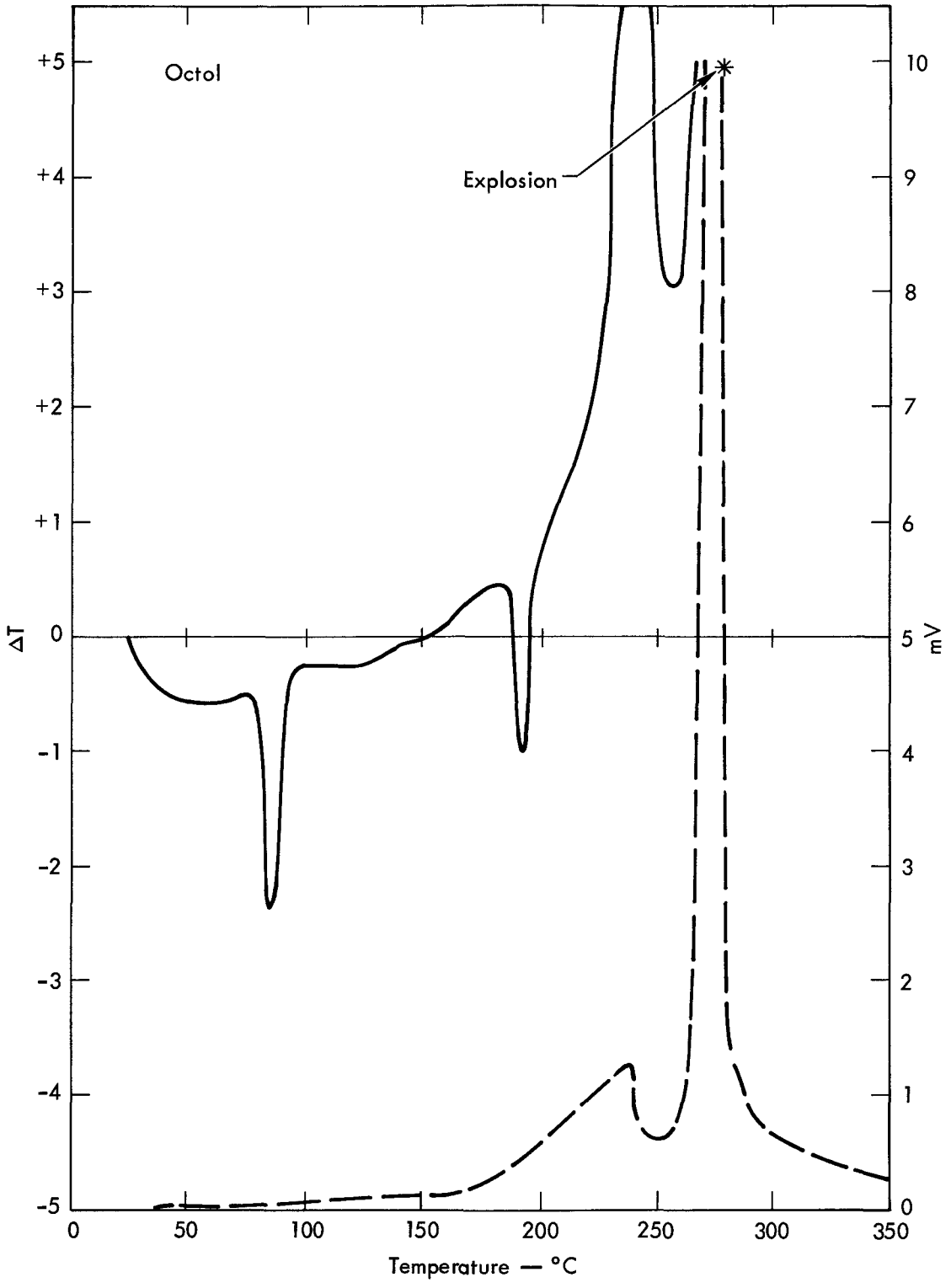


Fig. 6-4. (w) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for octol.[24] The endotherms were due to the melting of TNT and to the $\beta \rightarrow \delta$ transition of HMX. The pyrolysis curve shows an almost perfect volatilization curve for TNT before the HMX decomposition.

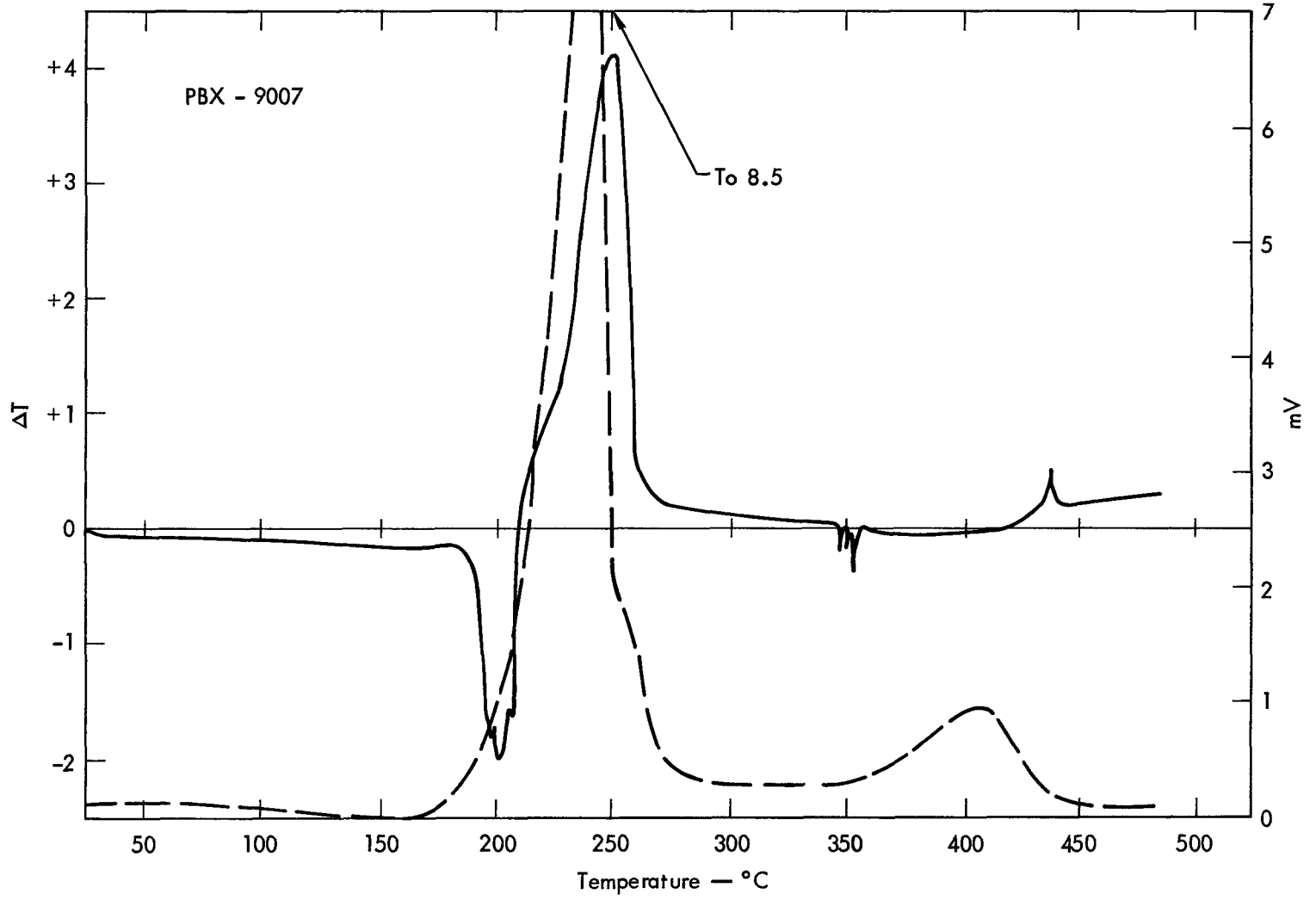


Fig. 6-4. (x) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PBX-9007.[24]

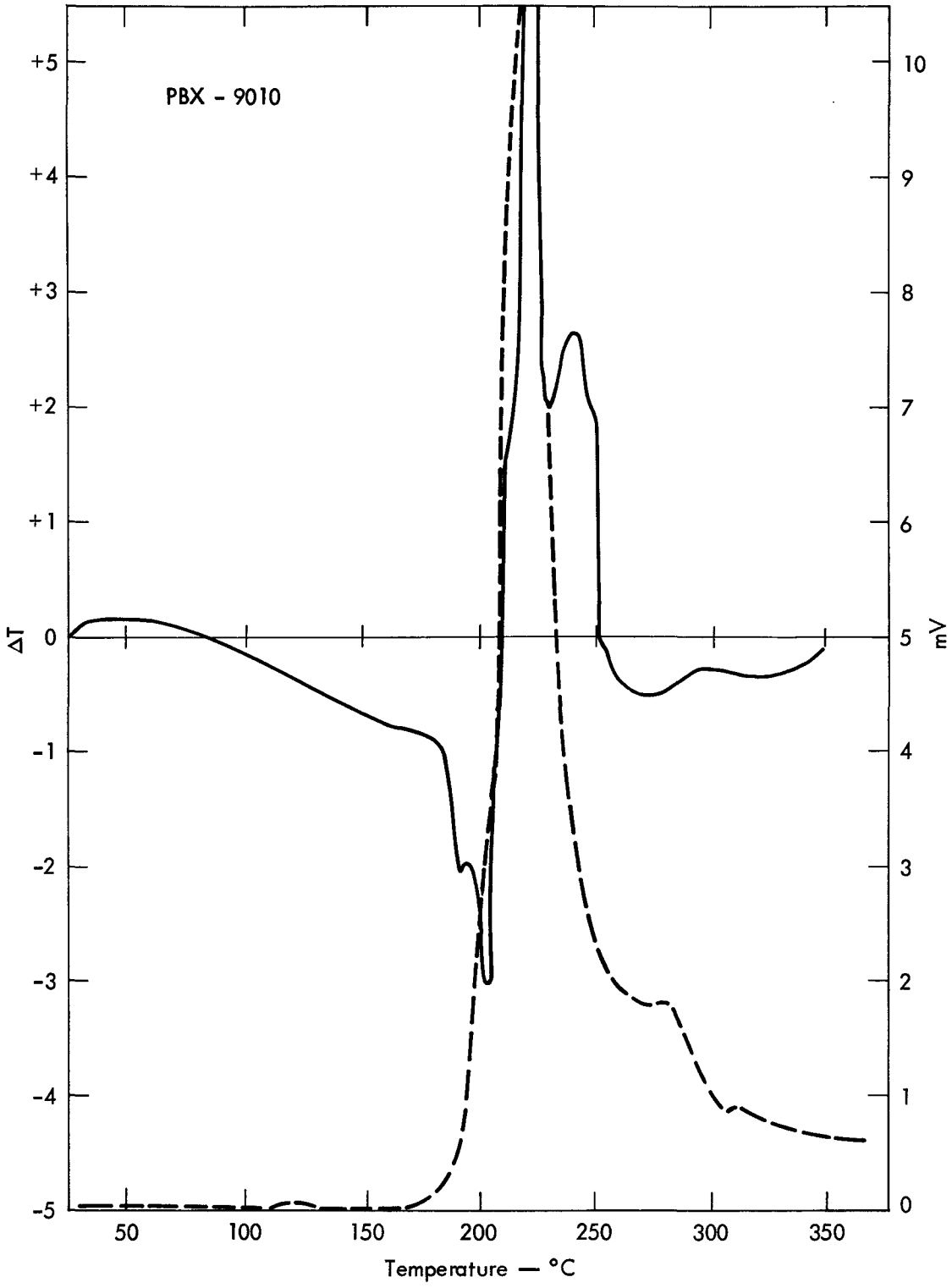


Fig. 6-4. (y) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PBX-9010.[24]

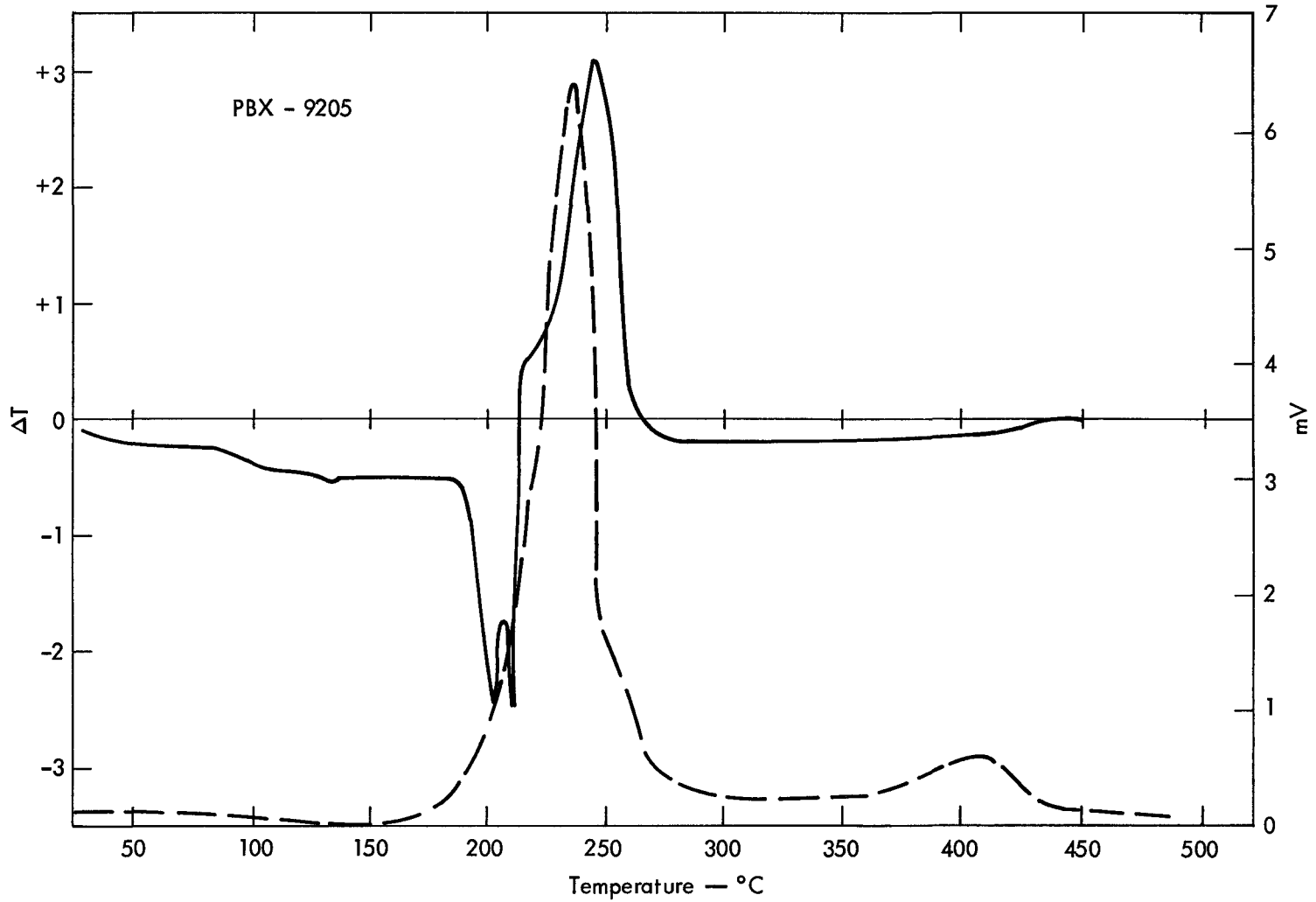


Fig. 6-4. (z) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PBX-9205.[24]

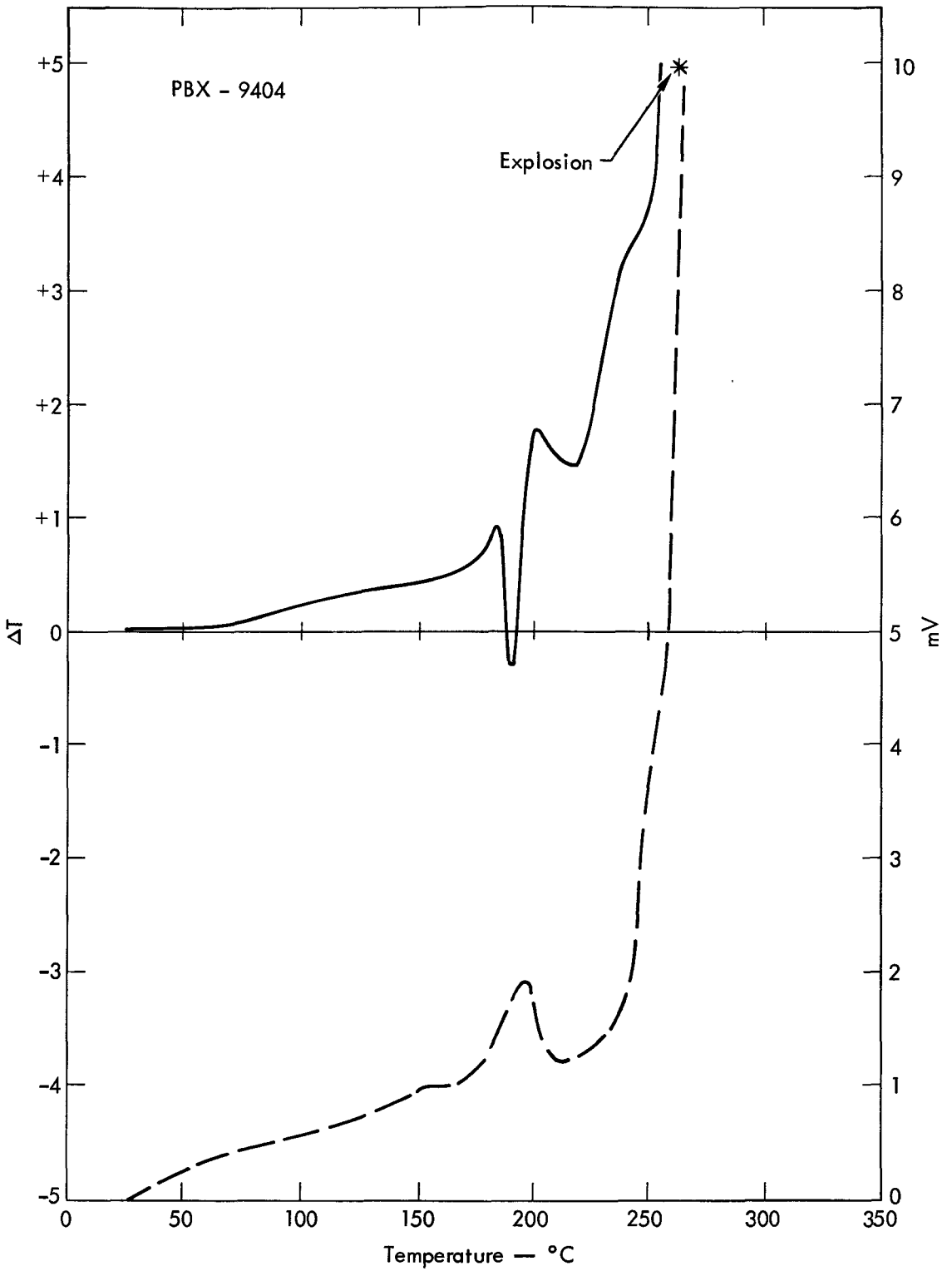


Fig. 6-4. (aa) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PBX-9404.[24] Stabilized with diphenylamine. Solvent evolution and decomposition are integrated in the pyrolysis curve; however, the DTA curve shows that true decomposition begins at ~75°C (348 K). The HMX $\beta \rightarrow \delta$ transition is superimposed on the NC/CEF decomposition exotherm. Some samples of PBX-9404 show a small endotherm at 150°C (423 K).

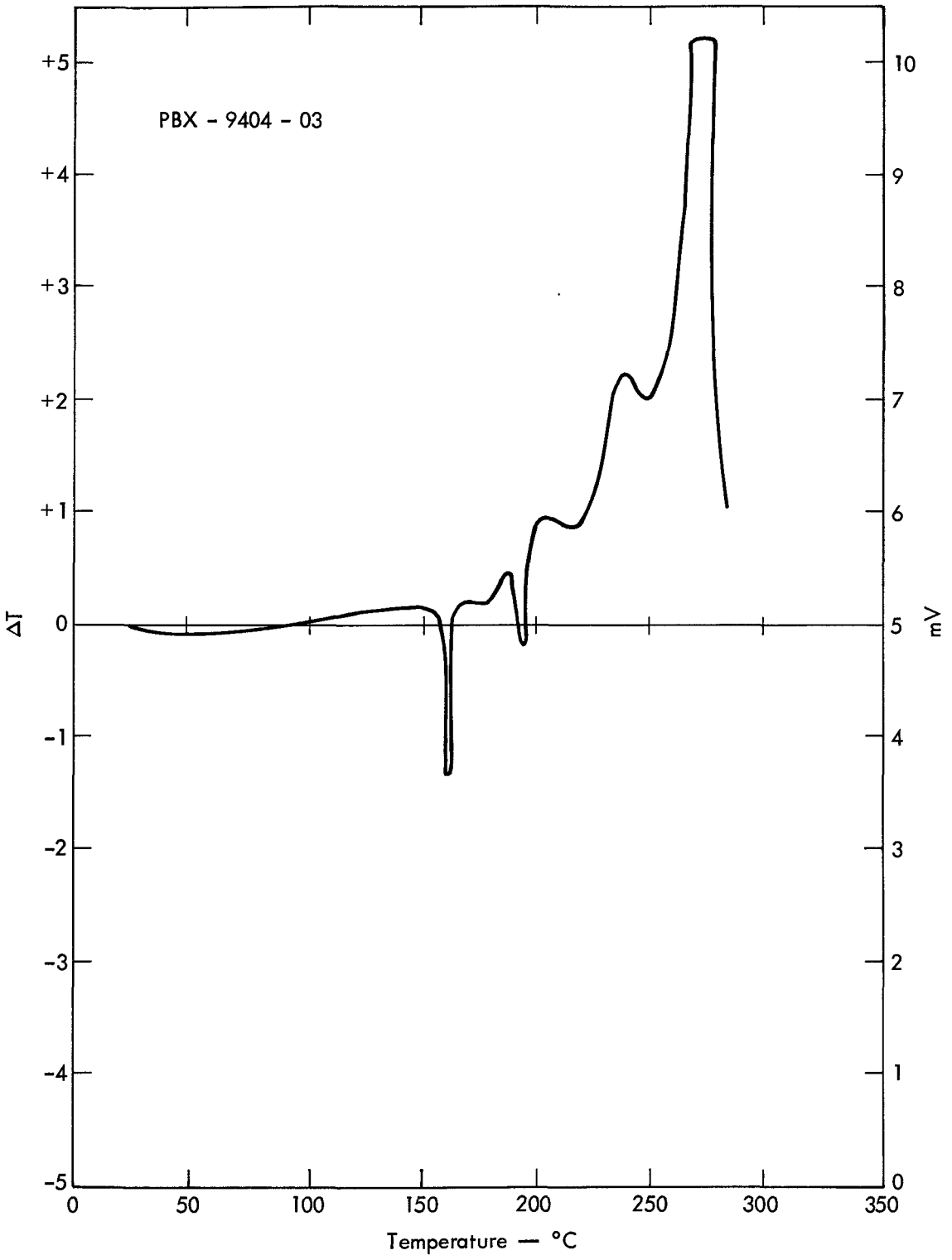


Fig. 6-4. (bb) DTA curve for PBX-9404-03.[24]

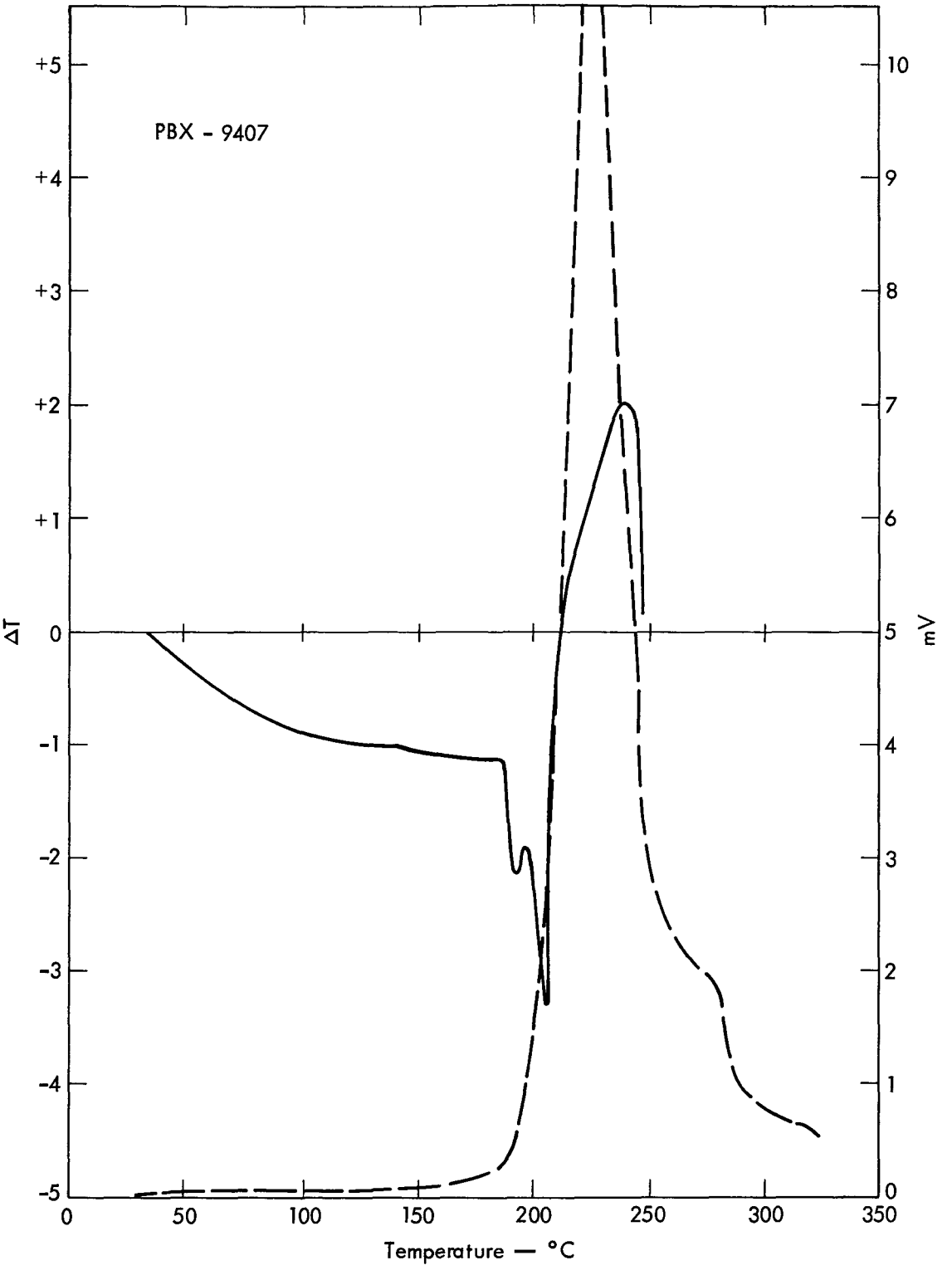


Fig. 6-4. (cc) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PBX-9407.[24]

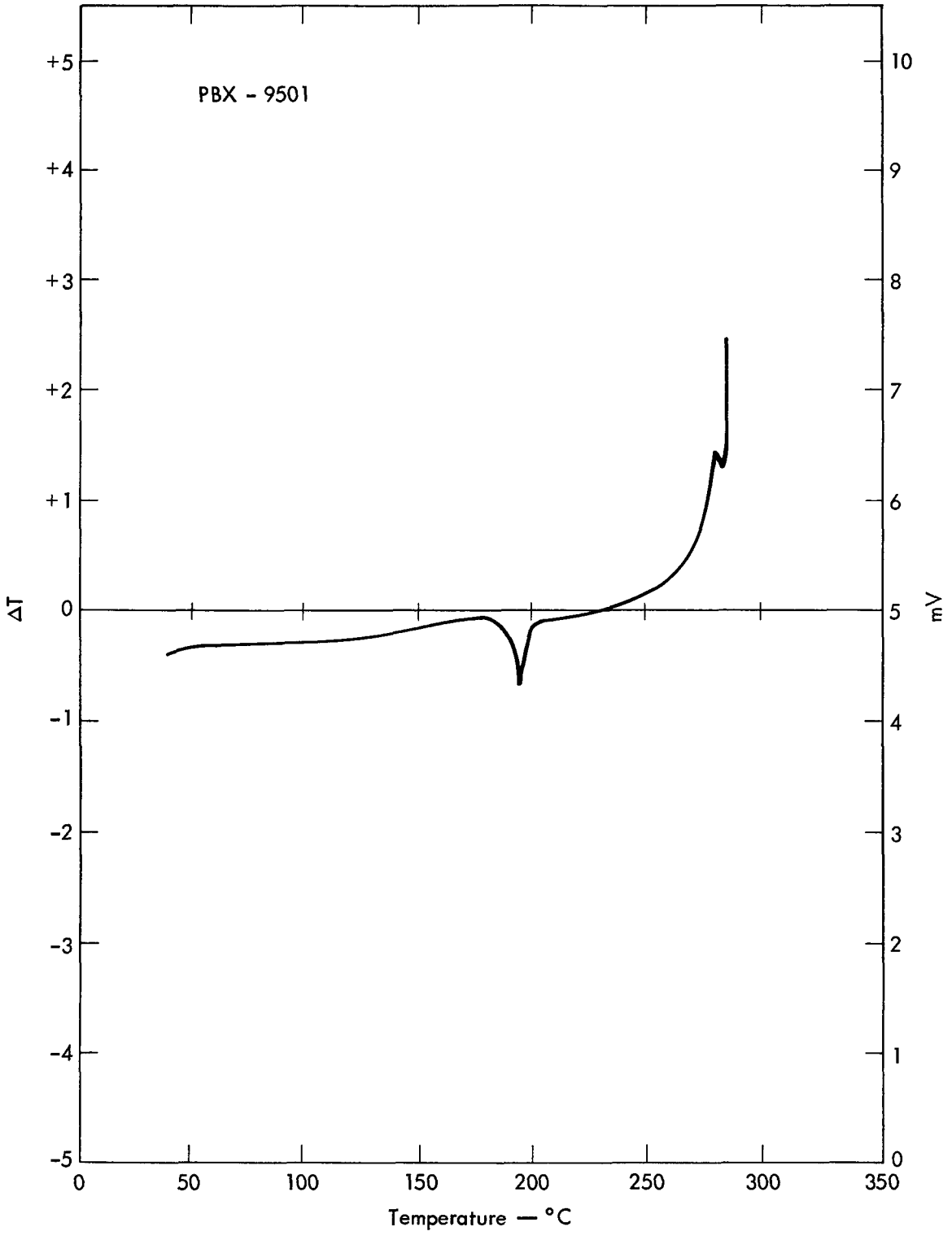


Fig. 6-4. (dd) DTA curve for PBX-9501.[24]

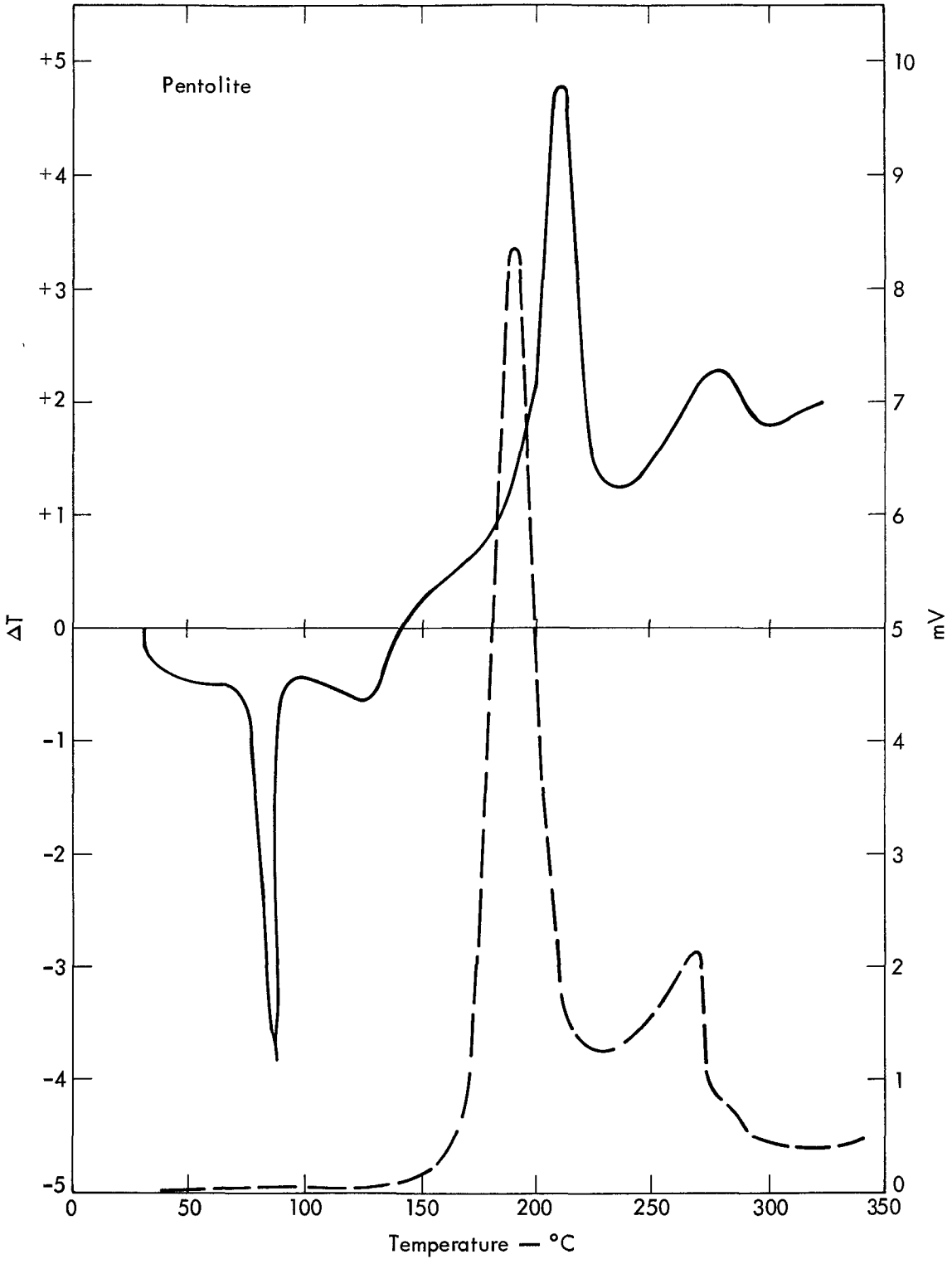


Fig. 6-4. (ee) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for pentolite.[24]

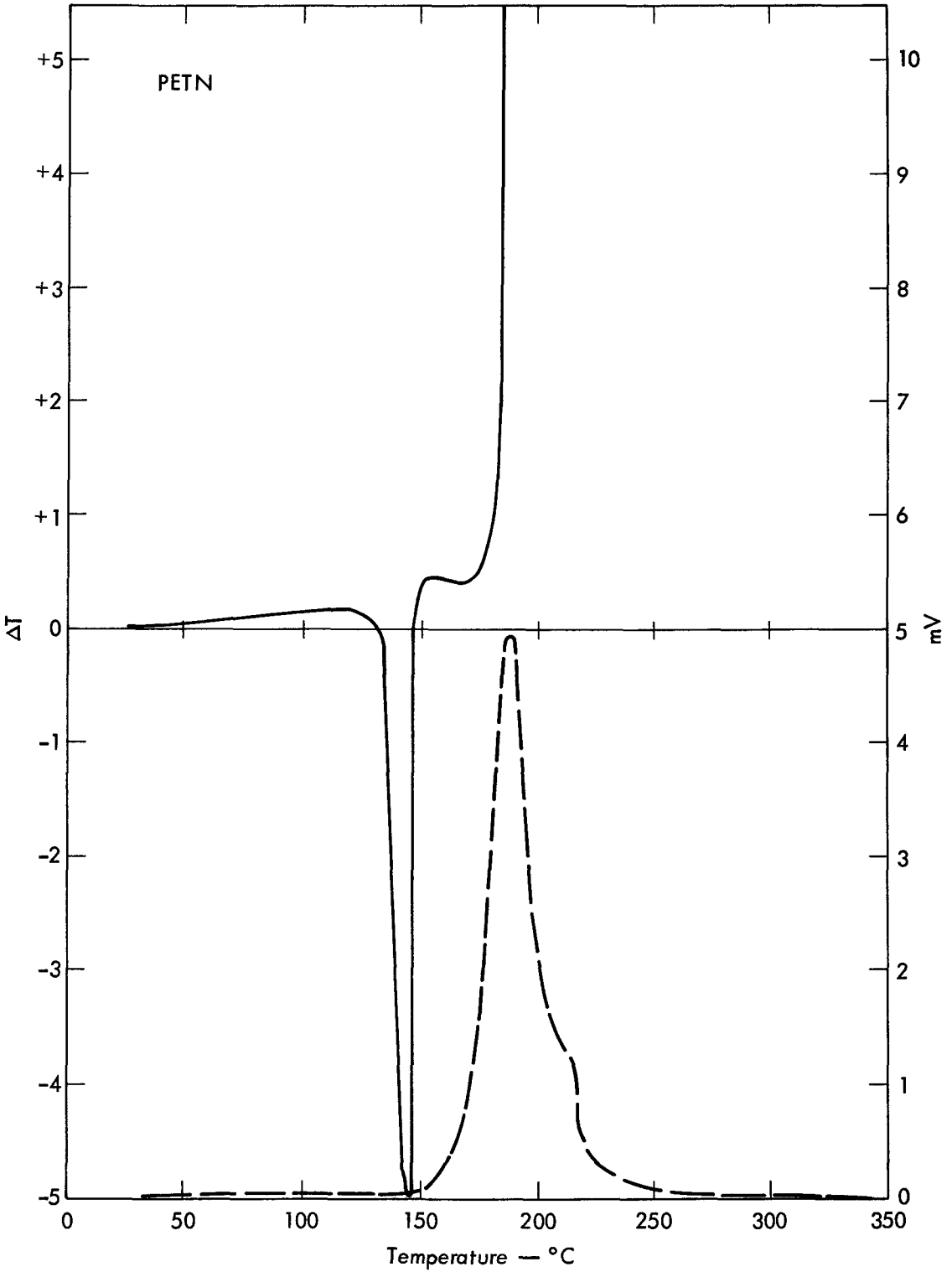


Fig. 6-4. (ff) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PETN.[24] The small pyrolysis at 132°C (405 K) represents a small evolution of trapped air from the imperfect crystal.

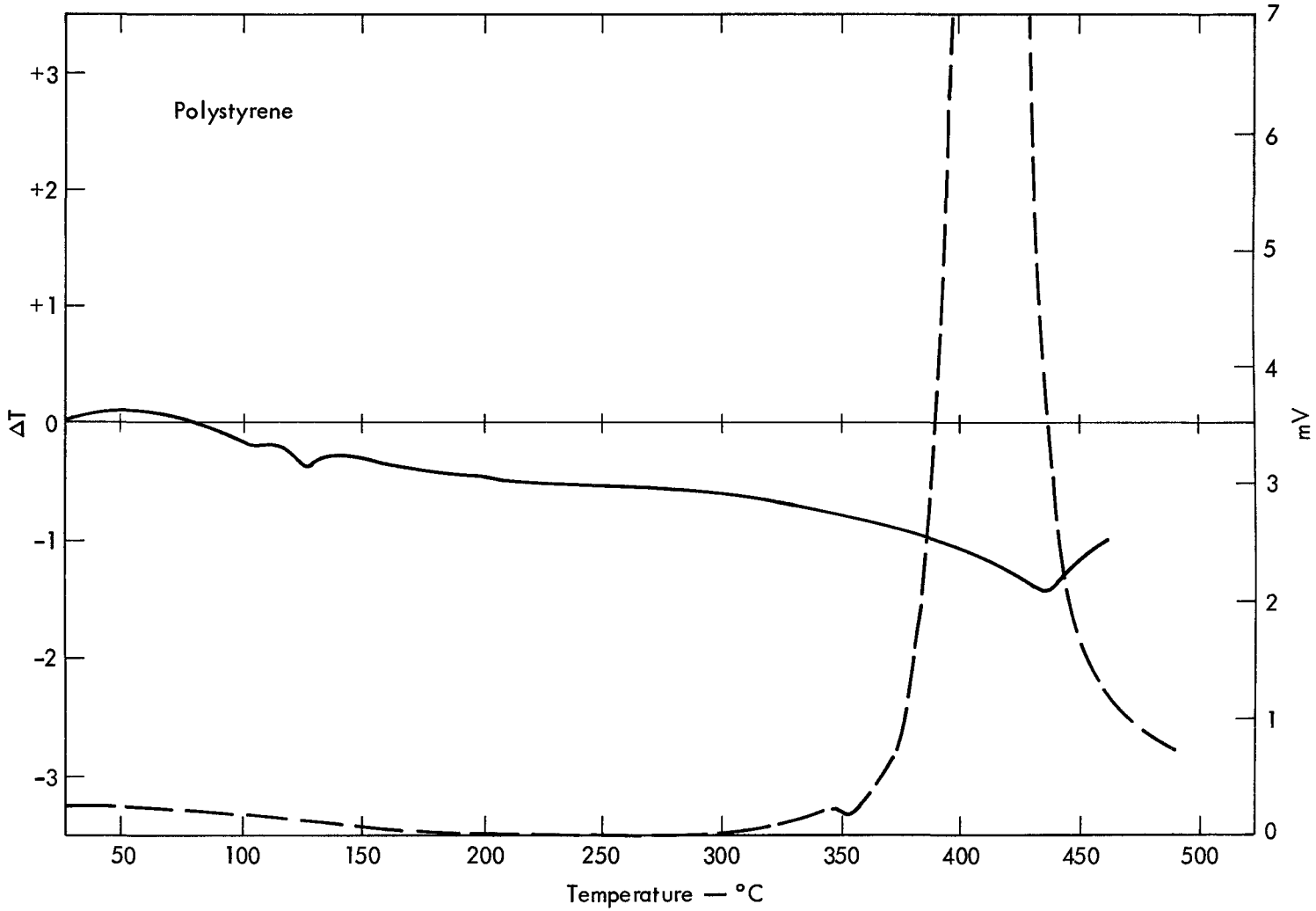


Fig. 6-4. (gg) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for polystyrene.[24] The ASTM softening point is ~90-100°C (363-383 K).

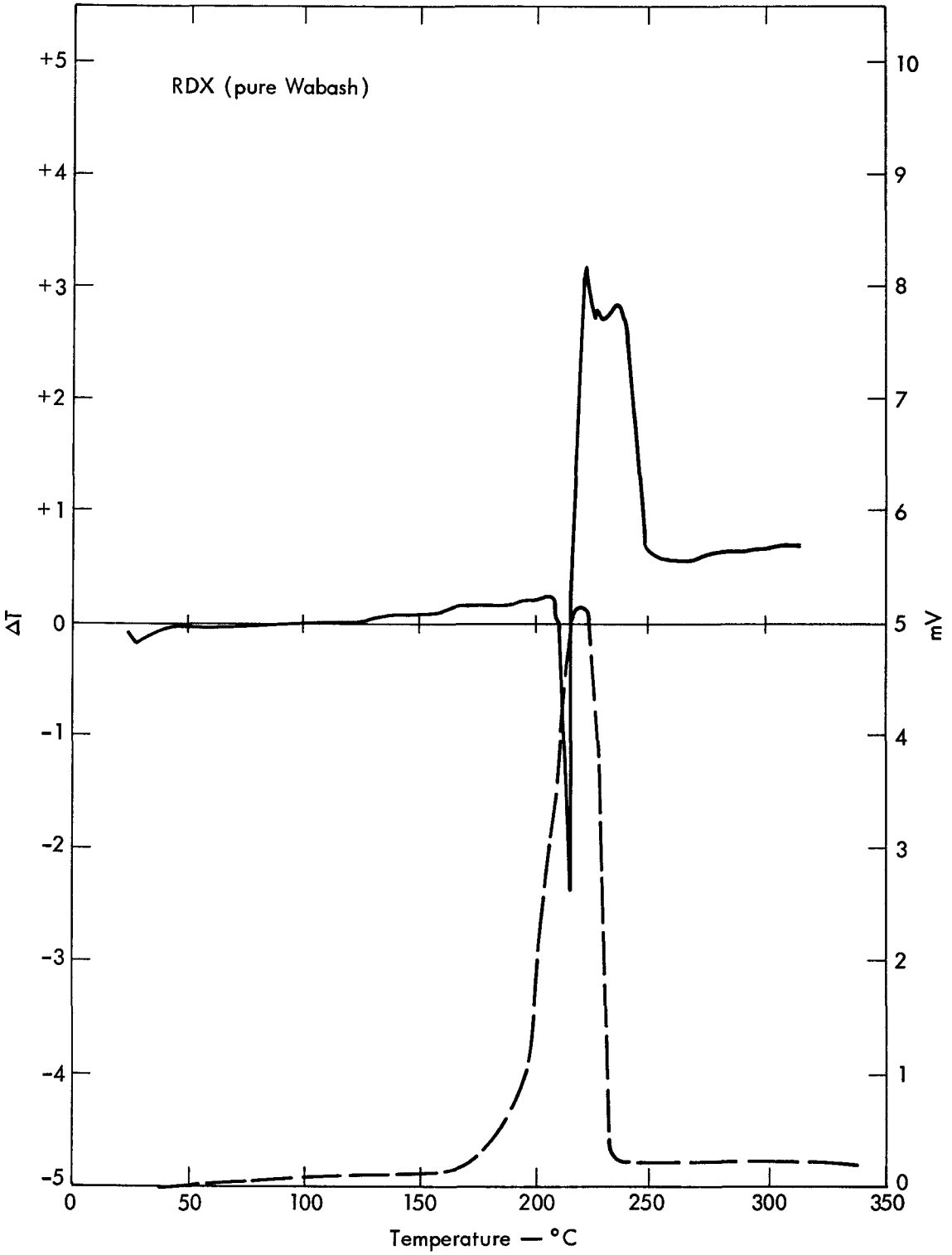


Fig. 6-4. (hh) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for RDX (pure Wabash grade).[24] Gas evolution below the melting point is primarily sublimation.

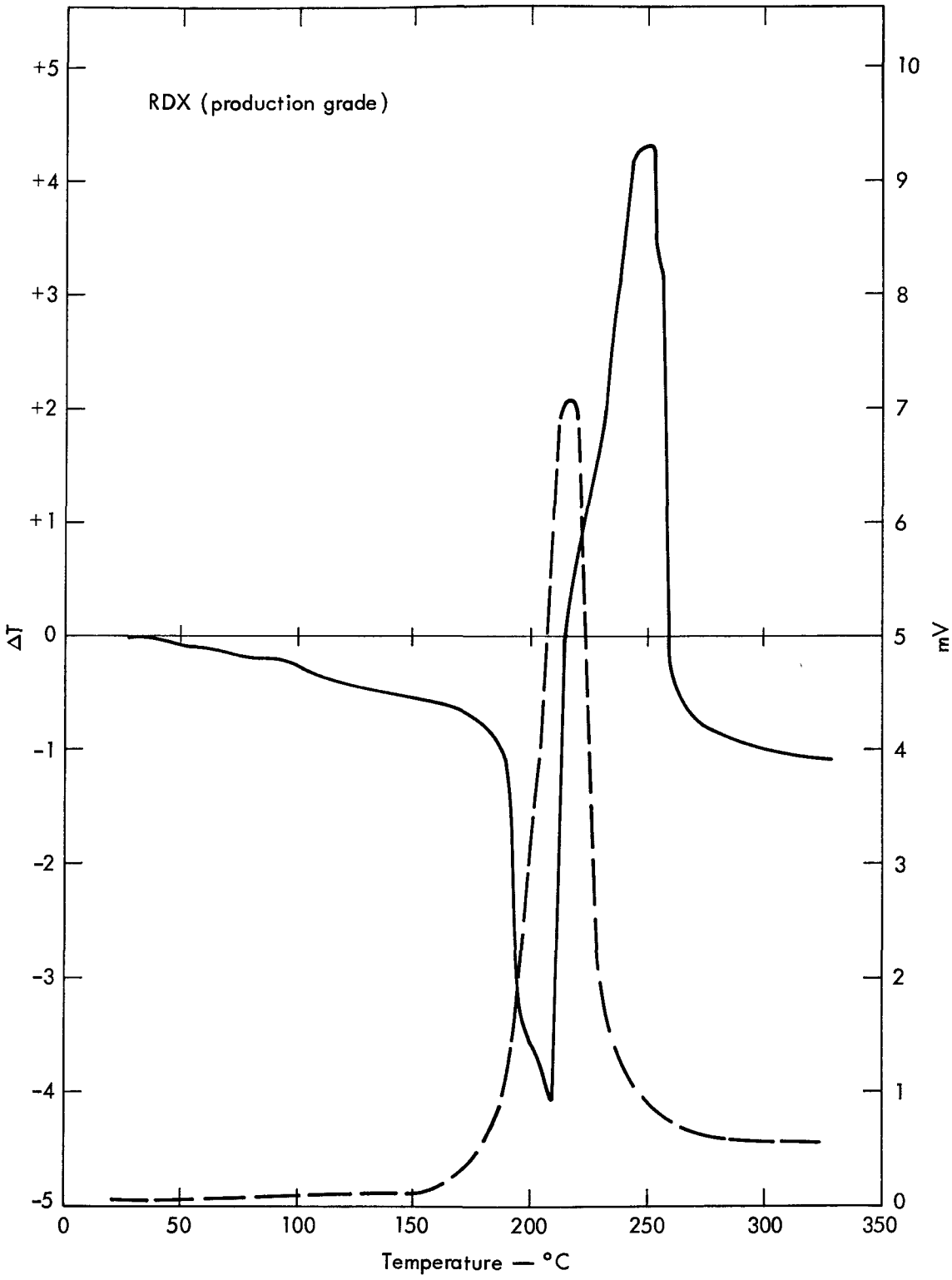


Fig. 6-4. (ii) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for RDX (Holston production grade).[24] The sample contained several percent of HMX, which shows up as lowered melting point, broader endotherm, and lower gas-evolution temperature.

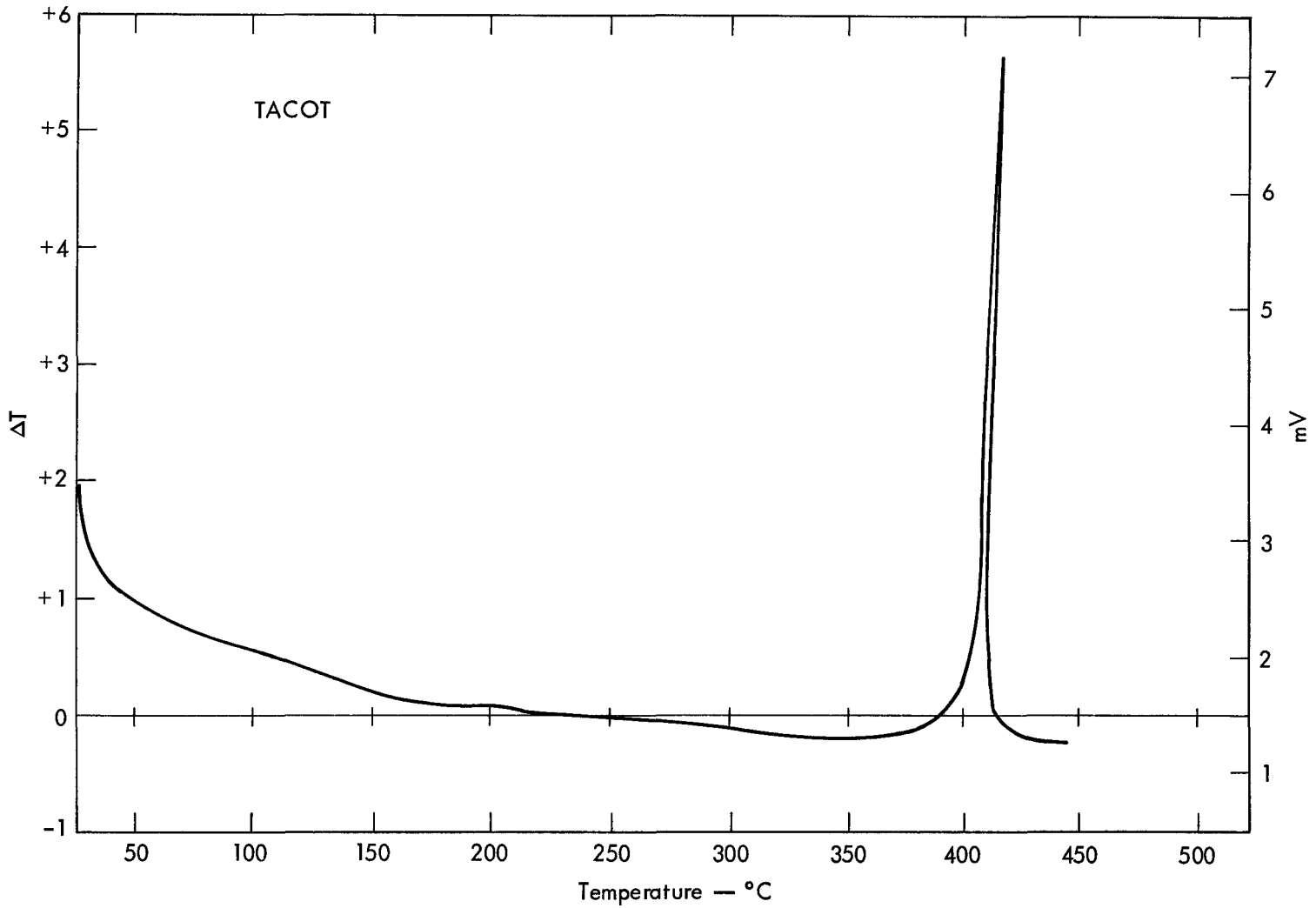


Fig. 6-4. (jj) DTA curve for TACOT.[24]

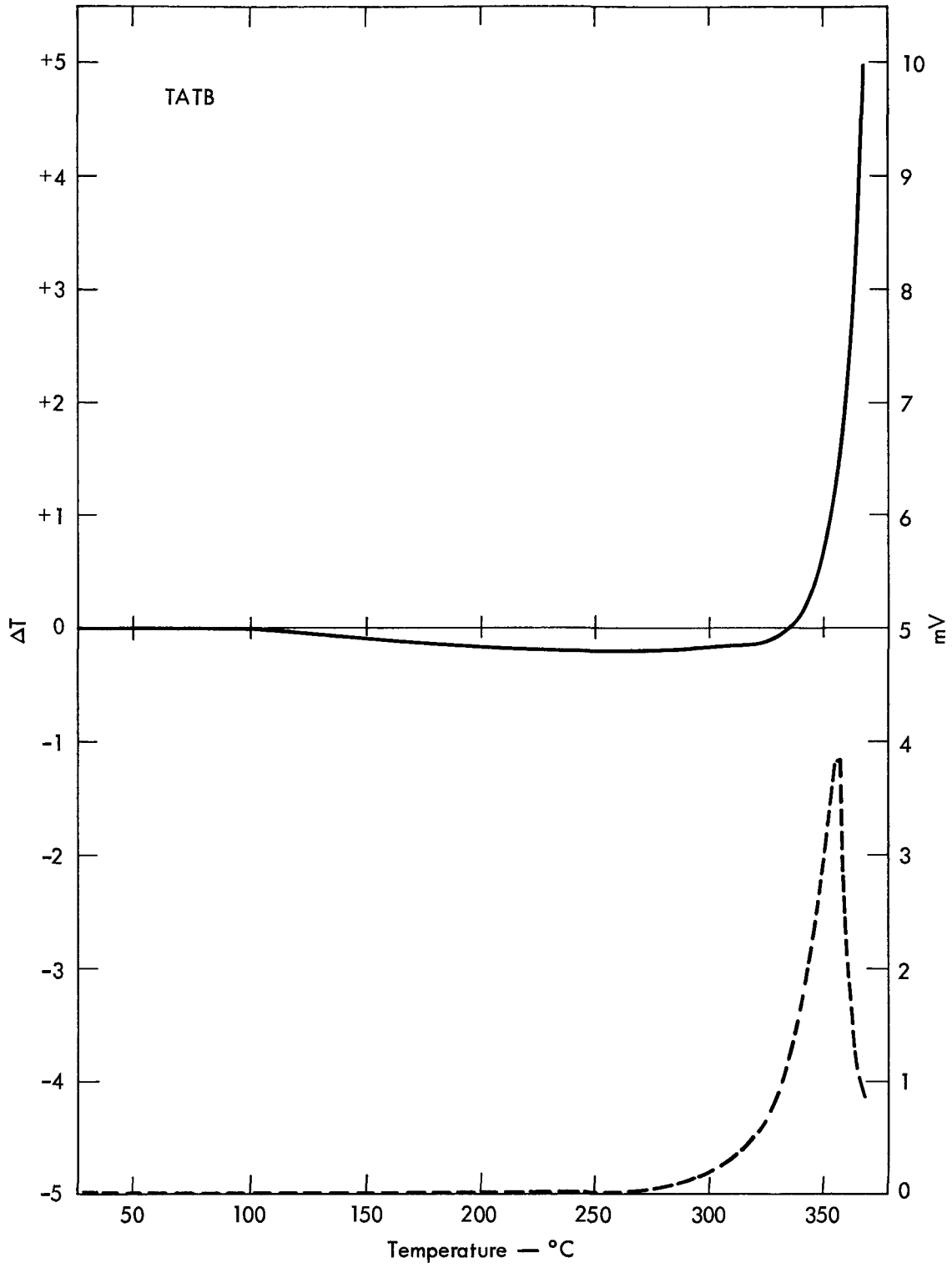


Fig. 6-4. (kk) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for TATB.[24] The sample appears to be completely stable to at least 250°C (523 K).

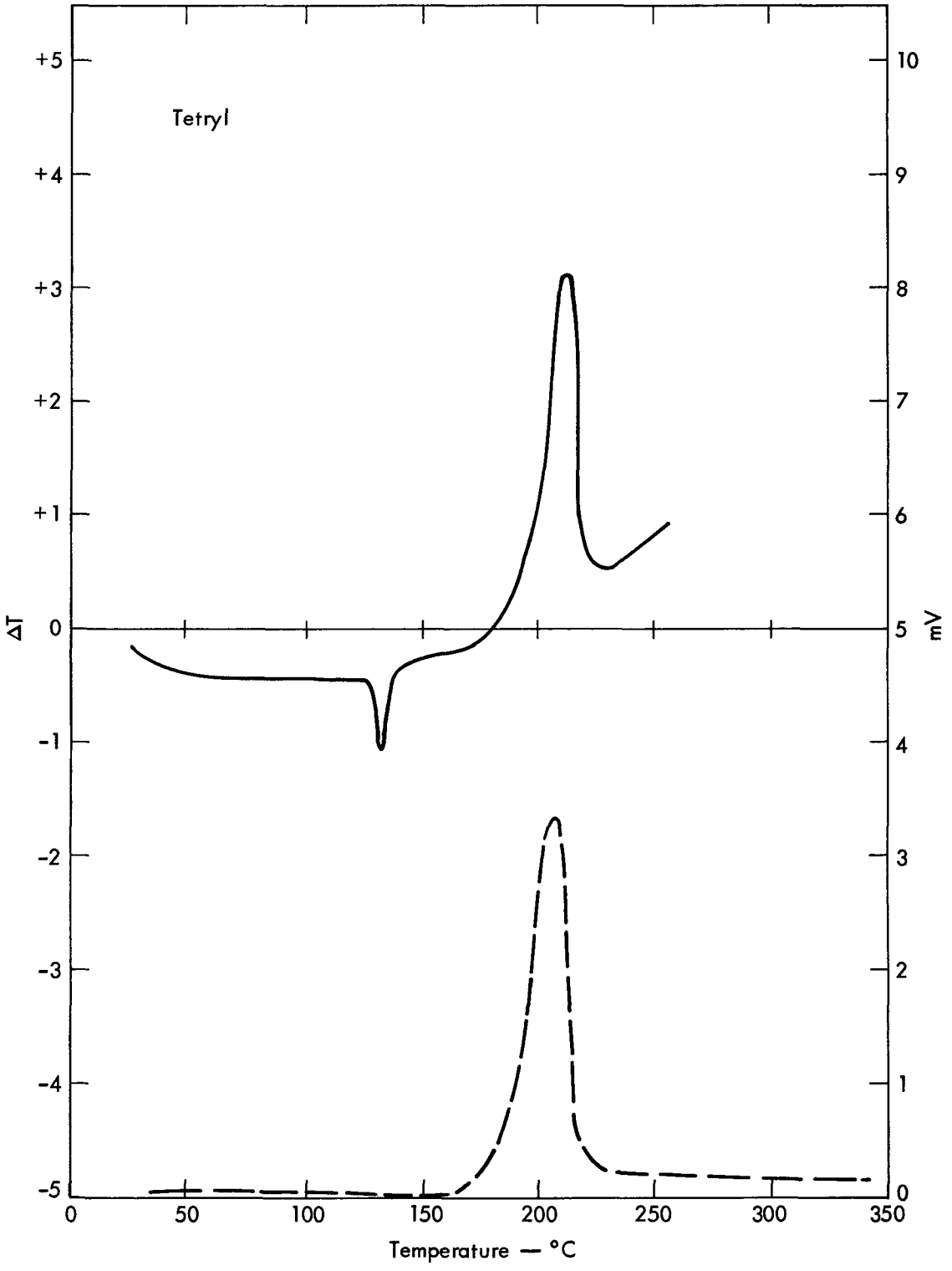


Fig. 6-4. (11) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for tetryl.[24] Reportedly melts at 130°C (403 K) and explodes at 187°C (460 K). This sample started to melt at 128°C (401 K) but did not undergo rapid decomposition until about 198°C (471 K).

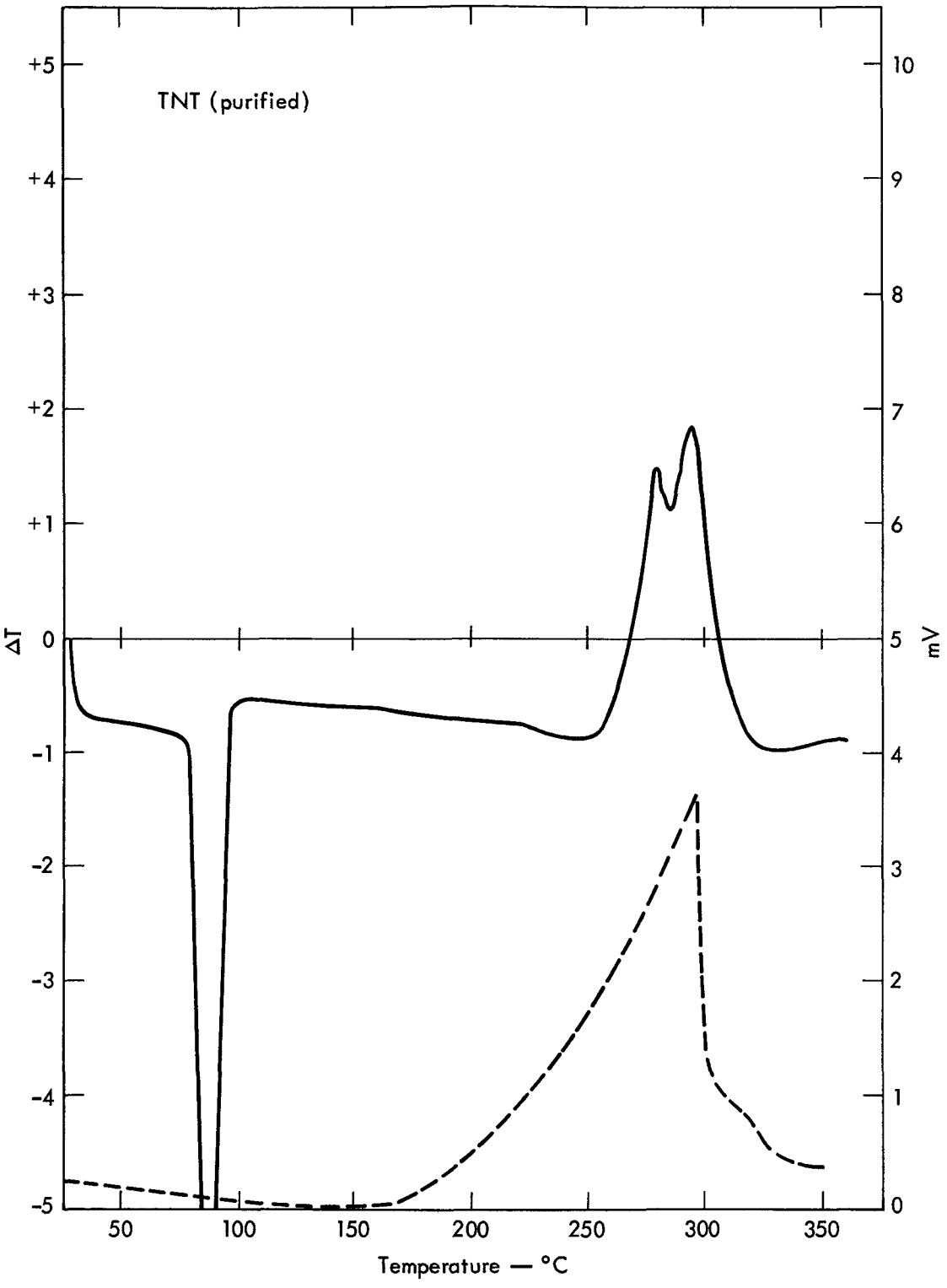


Fig. 6-4. (mm) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for TNT (purified).[24]

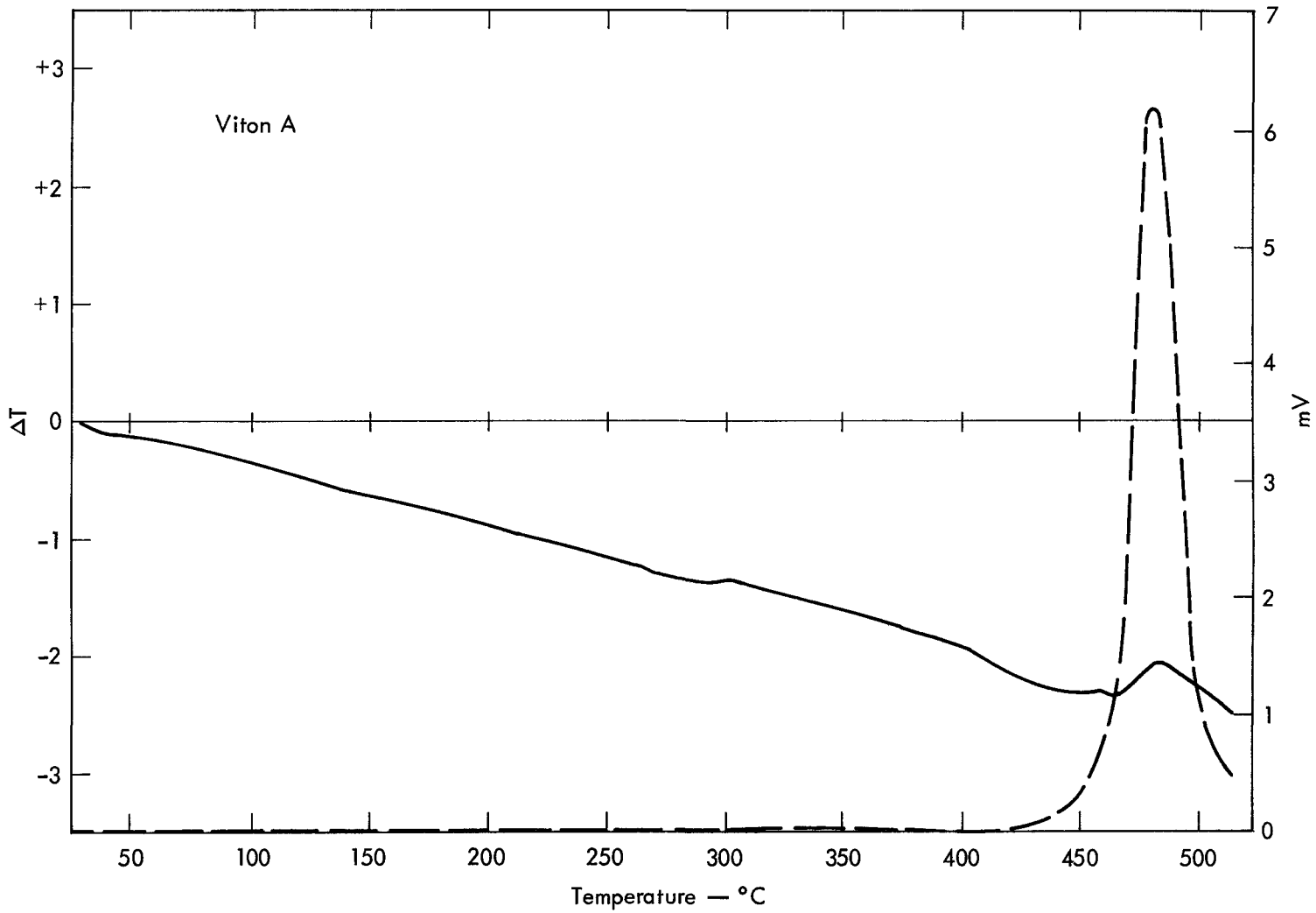


Fig. 6-4. (nn) DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Viton A.[24]

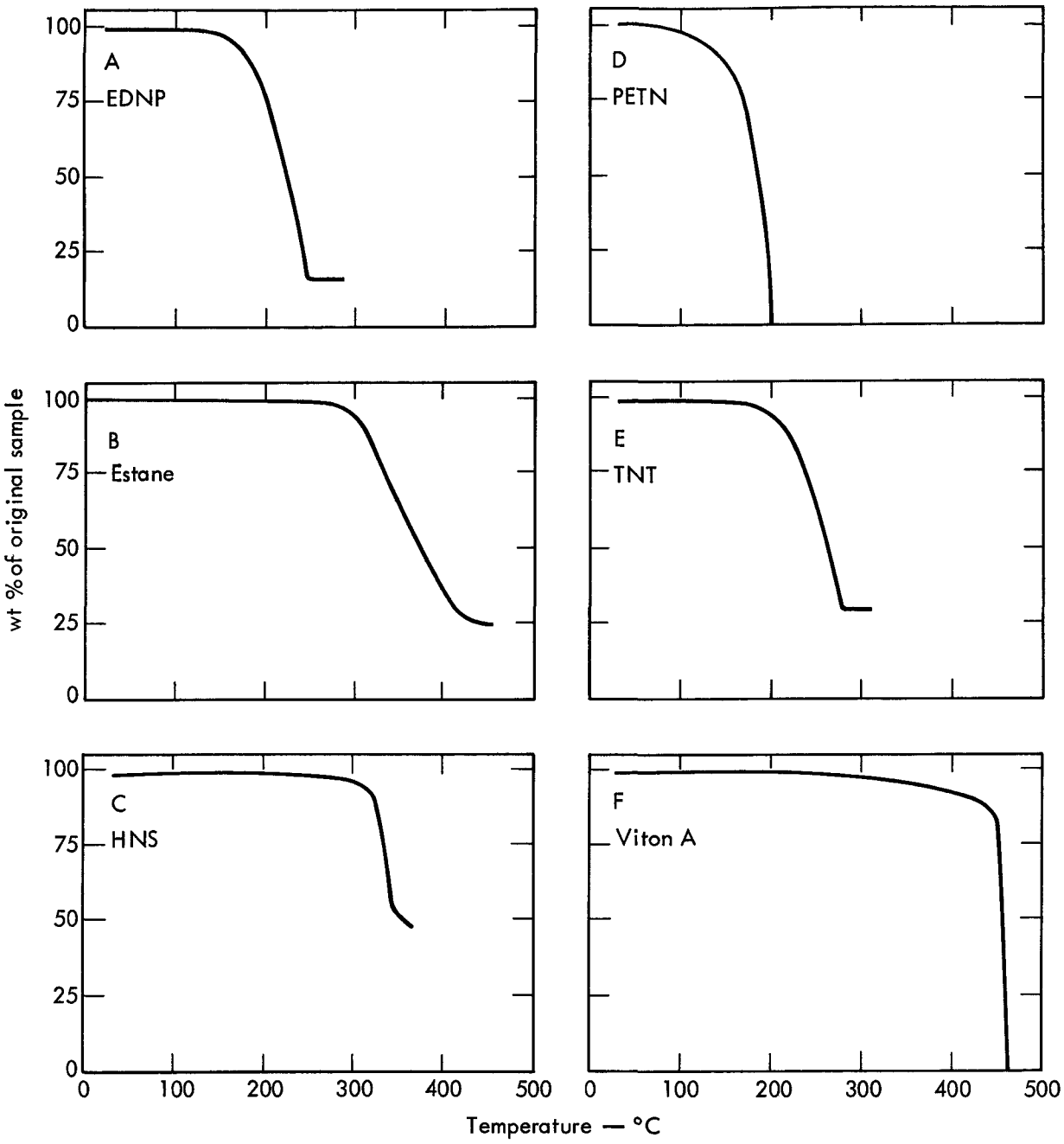


Fig. 6-5. TGA curves for explosives and binders.[26]

Table 6.4. Thermal stabilities of various explosives.

Explosive	LLL reactivity test (cm^3 gas STP/0.25 g evolved in 22 hr at 120°C (393 K))	Vacuum stability test (cm^3 gas STP/g evolved in 48 hr at 120°C (393 K))
Baratol	0.015-0.02	0.19
Boracitol	-	0.02-0.04
BTF	0.24-0.40	-
BTF (purified)	0.05	-
Comp B, Grade A	0.051	0.05-0.16
Comp B-3	0.033	0.27
Comp C-4	0.026	-
Cyclotol 75/25	0.014-0.04	0.25-0.94
DATB	<0.03	<0.03
DNPA	0.04-0.06	-
FEFO	0.04-0.10	-
HMX	<0.01	0.07
HNS	0.01	-
LX-01	1.8[a]	-
LX-02	0.3-0.6	-
LX-04	0.01-0.04	-
LX-07-2	0.01-0.04	-
LX-09-0	0.03-0.07	-
LX-10-0	0.02	-
LX-10-1	0.04-0.06	-
LX-11	0.01-0.04	-
LX-13	See XTX-8003	
LX-14	0.02	0.025
NC (12.0% N)	1.0-1.2	5.0
NQ	0.02-0.05	-
Octol	-	0.18
PBX-9007	0.03-0.07	-
PBX-9010	0.02-0.04	0.2-0.3[c]
PBX-9011	0.024	-
PBX-9205	0.025	-
PBX-9404	0.36-0.40	3.2-4.9
PBX-9407	0.06	-
PBX-9501[11]	0.07	0.8
Pentolite 50/50	-	3.0[b]
PETN	0.10-0.14	-
RDX	0.02-0.025	0.12-0.9
TACOT	-	-
TATB	-	-
Tetryl	0.036	-
TNT	0.00-0.012	~0.005
XTX-8003	<0.02[b]	-

[a]Measured at 80°C (353 K) because of the high volatility of the material

[b]Measured at 100°C (373 K).

[c]Ref. 2.

5. Vacuum stability test. The sample is heated for 48 hr at 120°C (393 K). A simple manometric system is used to measure the total volume of all gases evolved, including water and residual solvents. The results are expressed on the basis of 1 g of explosive. For reference purposes, 1 cm^3 of evolved gas per gram of explosive represents about 0.2% decomposition (see Table 6-4).

Thermal Stability of Larger Explosive Charges

For large amounts of explosive, the results from small-scale thermal-stability tests are not strictly applicable. There is a maximum safe temperature that should not be exceeded for large charges: it is the point at which thermal energy from slow chemical decomposition is being given off at a rate greater than it can be dissipated. It is referred to as the self-heating temperature and is dependent on the amount of explosive, its environment, and the time it will be held at the elevated temperature. For example:

1. Twenty-five pounds (11.34 kg) of LX-04-1 may be held at 190°C (463 K) for no more than 10 min and at 220°C (493 K) for no more than 1 min.

2. Calculations indicate that ~13,000 lb (~6 tons) of molten TNT may be unsafe. Information on problems of this nature can be obtained from members of the Organic Materials Division.

References

1. K. A. Peterman, Lawrence Livermore Laboratory, personal communication (1964).
2. A. Popolato, Los Alamos Scientific Laboratory, Albuquerque, N. Mex., personal communication (1974).
3. J. Brandrup and E. H. Immergut, Eds., Polymer Handbook, (Interscience, N. Y., 1960).
4. Dow Corning, Hemlock, Mich., Information About Electronic Materials, Dow Corning Bulletin 07-123 (May 1964).
5. R. L. Murray, Lawrence Livermore Laboratory, personal communication (1972).
6. W. G. Moen, Lawrence Livermore Laboratory, personal communication (1964).
7. W. H. Kirkwood, Lawrence Livermore Laboratory, personal communication (1974).
8. M. Finger, Lawrence Livermore Laboratory, personal communication (1965).
9. A. C. Schwartz, Application of Hexanitrostilbene (HNS) in Explosive Components, Sandia Laboratories, Albuquerque, N. Mex., Rept. SC-RR-710673 (1972).
10. H. H. Cady, J. Chem. Eng. Data 17, 369-371 (1972).
11. Food Machinery Corporation, Ohio Apex Division, Nitro, W. V., Plasticizers, Data Sheet (1955).
12. D. L. Ornellas, Lawrence Livermore Laboratory, personal communication (1974).
13. R. Velicky, C. Lenchitz, and W. Beach, Picatinny Arsenal, Dover, N. J., Rept. PA-TR-2504 (January 1949). Enthalpy data were plotted and C_p was recalculated by D. L. Ornellas, Lawrence Livermore Laboratory (1974).
14. R. Shaw, Stanford Research Institute, Palo Alto, Calif., personal communication (1973).
15. S. Marantz and G. T. Armstrong, J. Chem. Eng. Data 13, 118-121 (1968).
16. D. G. Miller, Lawrence Livermore Laboratory, personal communication (1964).
17. L. J. Decker, J. R. Ward, and E. Freedman, Thermochim. Acta 8, 177-183 (1974).
18. Army Materiel Command, Properties of Explosives of Military Interest, U.S. Army Materiel Command, Rept. AMCP-706-177 (1967).
19. H. A. Berman and E. D. West, J. Chem. Eng. Data 14, 107-109 (1969).
20. G. Krien, H. Licht, and J. Zierath, Thermochim. Acta 6, 465-472 (1973).
21. T. W. Benziger, X-0242: A High-Energy Plastic Bonded Explosive, Los Alamos Scientific Laboratory, N. Mex., Rept. LA-4872-MS (1972).
22. H. Cady and W. Rogers, Los Alamos Scientific Laboratory, Los Alamos, N. Mex., Rept. LA-2696 (July 1962).
23. E. I. Du Pont de Nemours and Co., Service Bulletin, (no date).
24. R. N. Rogers, Los Alamos Scientific Laboratory, personal communication (1974).
25. R. N. Rogers, S. K. Yasuda, and J. Zinn, Anal. Chem. 32, 672-678 (1960).
26. B. Shroyer, Lawrence Livermore Laboratory, personal communication (1974).

7. MECHANICAL PROPERTIES

High explosives are viscoelastic materials. Their mechanical properties are functions of time, temperature, and loading rate. In any one material they vary because of differences in raw material from one lot to another, differences in pressing conditions, and differences in the machining procedures used to fabricate the materials. Therefore, the data in this section are not intended to provide exact numerical values but rather to demonstrate general trends and to make comparisons between different materials. For more refined calculations to predict the behavior of materials, each individual lot of HE must be characterized.

To characterize materials over the entire temperature range from -65 to 165°F (219-347 K), it is necessary to make certain assumptions:

1. The material is homogeneous.
2. The material is isotropic.
3. Linear elastic and viscoelastic theory can be used to characterize explosives.
4. Poisson's ratio (PR) is independent of time and temperature. (Poisson's ratio for most solid HEs falls in the range from 0.25 to 0.30.)
5. The material is thermorheologically simple (i. e., the time-temperature postulate holds).
6. The "failure envelope" (see Fig. 7-8) provides an adequate criterion of failure.
7. The material does not age.

These assumptions have been explored experimentally and found to be reasonable.

The first step to be undertaken when looking for data on mechanical properties is to examine the time-scale of the specific problem. A schematic plot of stress vs time (Fig. 7-1) is useful for indicating the kind of data needed.

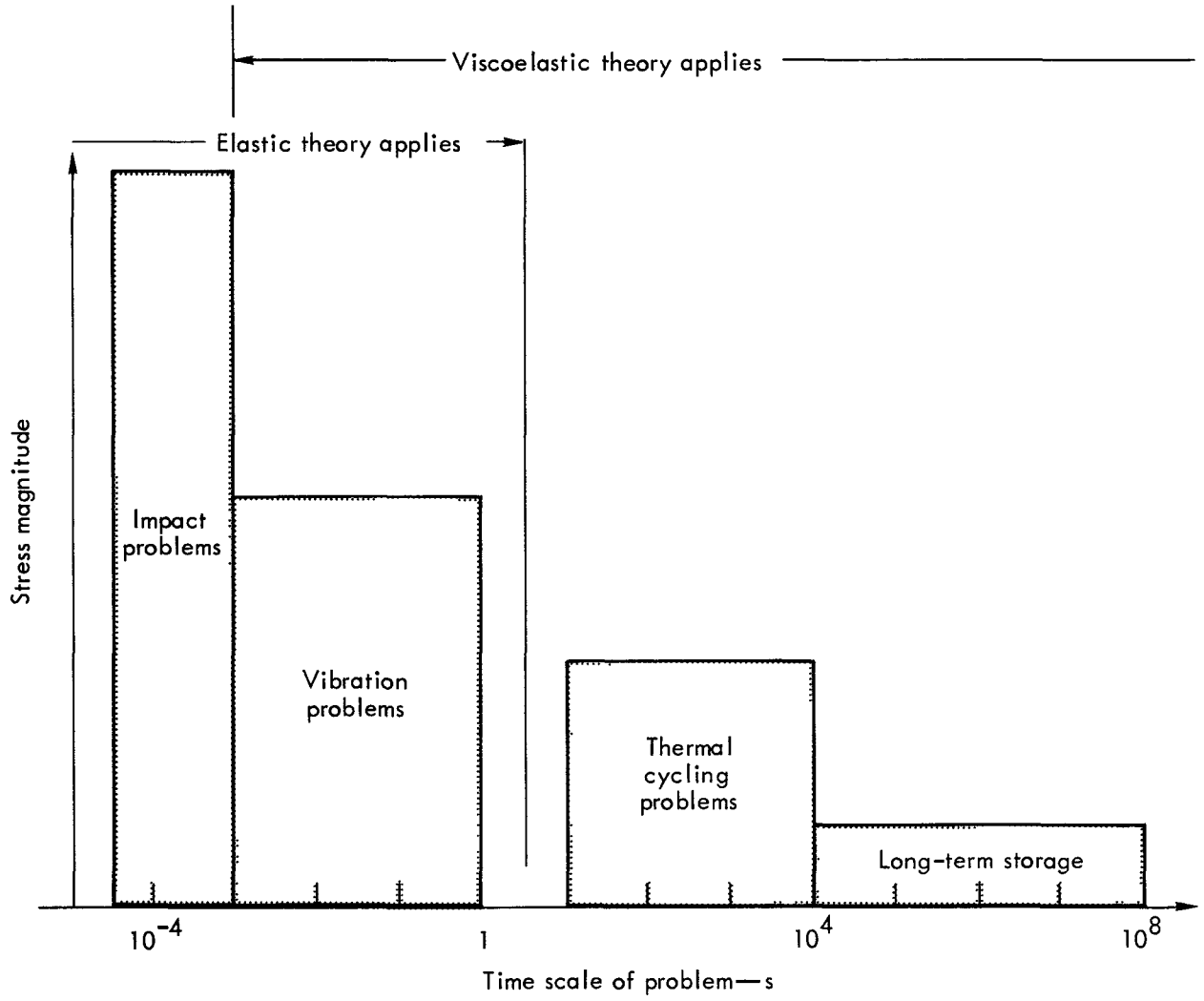


Fig. 7-1. The time-scale of the problem indicates the appropriate theory, which in turn indicates the kind of data to be collected. For elastic characterization, use initial modulus E_0 as in Fig. 7-3 or ν as in Table 7-1. For viscoelastic characterization, use creep curves as in Figs. 7-4 to 7-6. Failure criteria apply to both characterizations (Fig. 7-8).

Dynamic effects become important in a material when the time-scale of observation approaches the transit time of a wave velocity across a characteristic dimension of the sample. This shift from static to dynamic considerations is said to occur when the loading rate exceeds approximately 1 sec^{-1}. Static-dynamic stress-strain relationships in compression are shown in Fig. 7-2 for LX-04, LX-10, and PBX-9501.

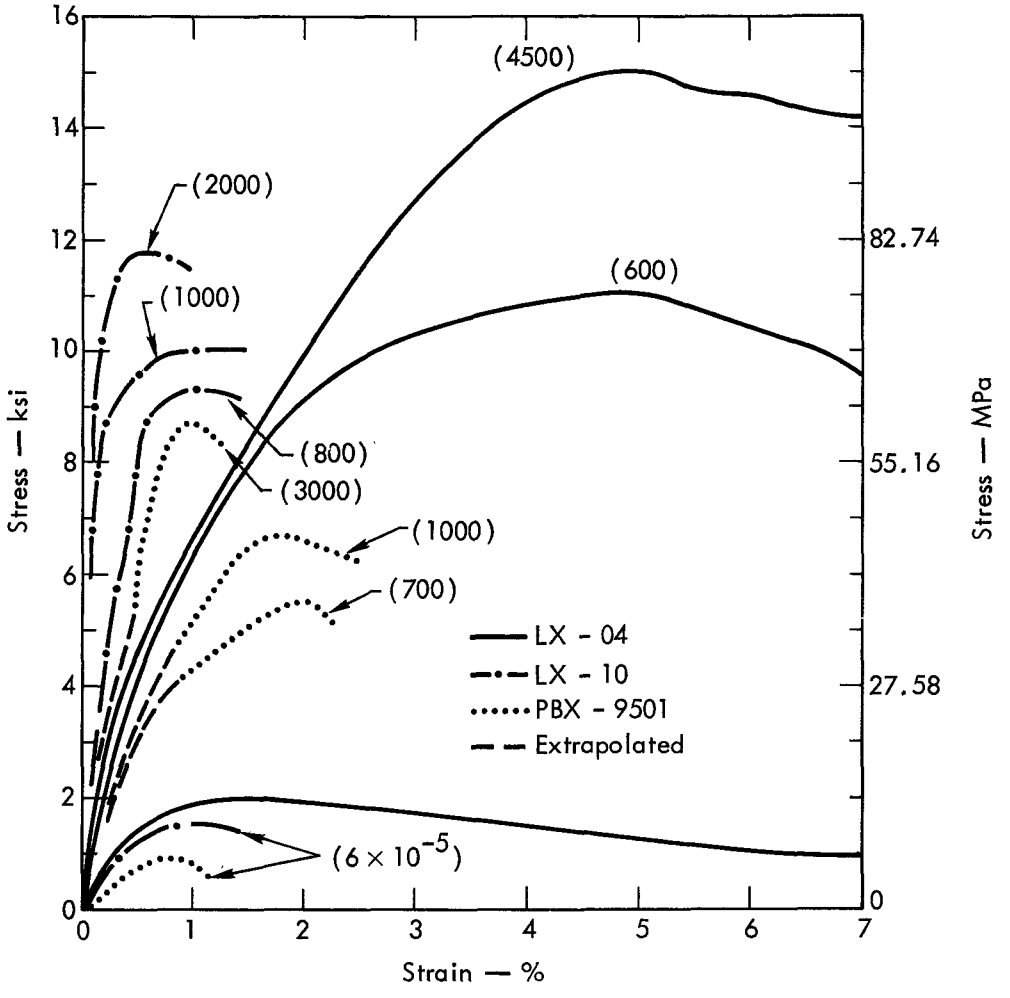


Fig. 7-2. Compressive stress-strain curves for LX-04, LX-10, and PBX-9501 at various strain rates.[1,2] Conversion factor: 1 psi = 6.894757 kPa. Numbers in parentheses are loading rates in s^{-1}.

Other considerations in the material properties are the crystallinity of the binder and the effects of adhesives. The crystallinity of the binder is controlled by its carbon content; increased crystallinity increases the stiffness of the material and decreases the temperature-sensitivity of the mechanical properties.[3] When HE assemblies are joined together with adhesives, the compliance of the adhesive must be considered. Most adhesives used with HEs are stronger but more compliant than the explosive. If clean surfaces and recommended assembly procedures are used, the bond will usually be stronger than the HE. If the assembly is to be subjected to stress analysis, the adhesive bond should be modeled as a thermoviscoelastic material; however, data are not currently available to make this characterization.[3]

A series of codes for linear thermoviscoelastic analysis has been developed to predict thermal, mechanical, and failure behavior of HEs when subjected to arbitrary thermal and mechanical boundary conditions.[4] Members of the Nonmetallic Materials Group of W Division can supply copies of the codes and assist in generating a viscoelastic model of the problem to be analyzed. As noted above, different characterizations of material are required for different kinds of problems.

Static Mechanical Properties

In this section, experimental data are given for characterization of static mechanical properties: initial modulus E_0 (Fig. 7-3), creep (Figs. 7-4 and 7-5), compression creep (Fig. 7-6), stress-strain data (Fig. 7-7), failure envelopes (Fig. 7-8), friction (Table 7-1 and Figs. 7-9 and 7-10), and complex shear (Fig. 7-11). The failure envelopes were obtained under isothermal, monotonically increasing tension loads.

Initial Modulus

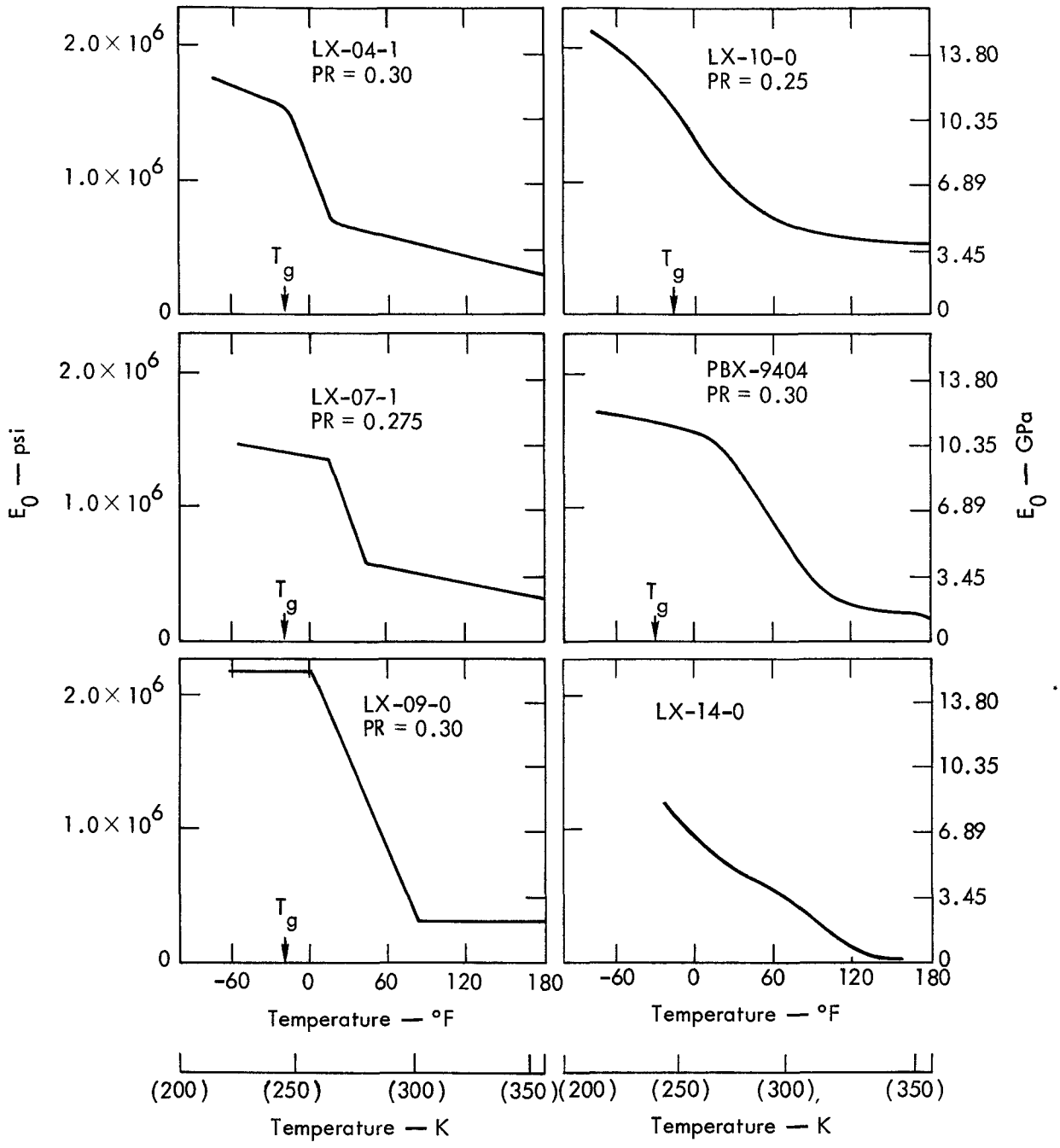


Fig. 7-3. Initial longitudinal modulus E_0 vs temperature for several explosives. PR, Poisson's ratio. Conversion factor: 1 psi = 6.894757 kPa.

Creep

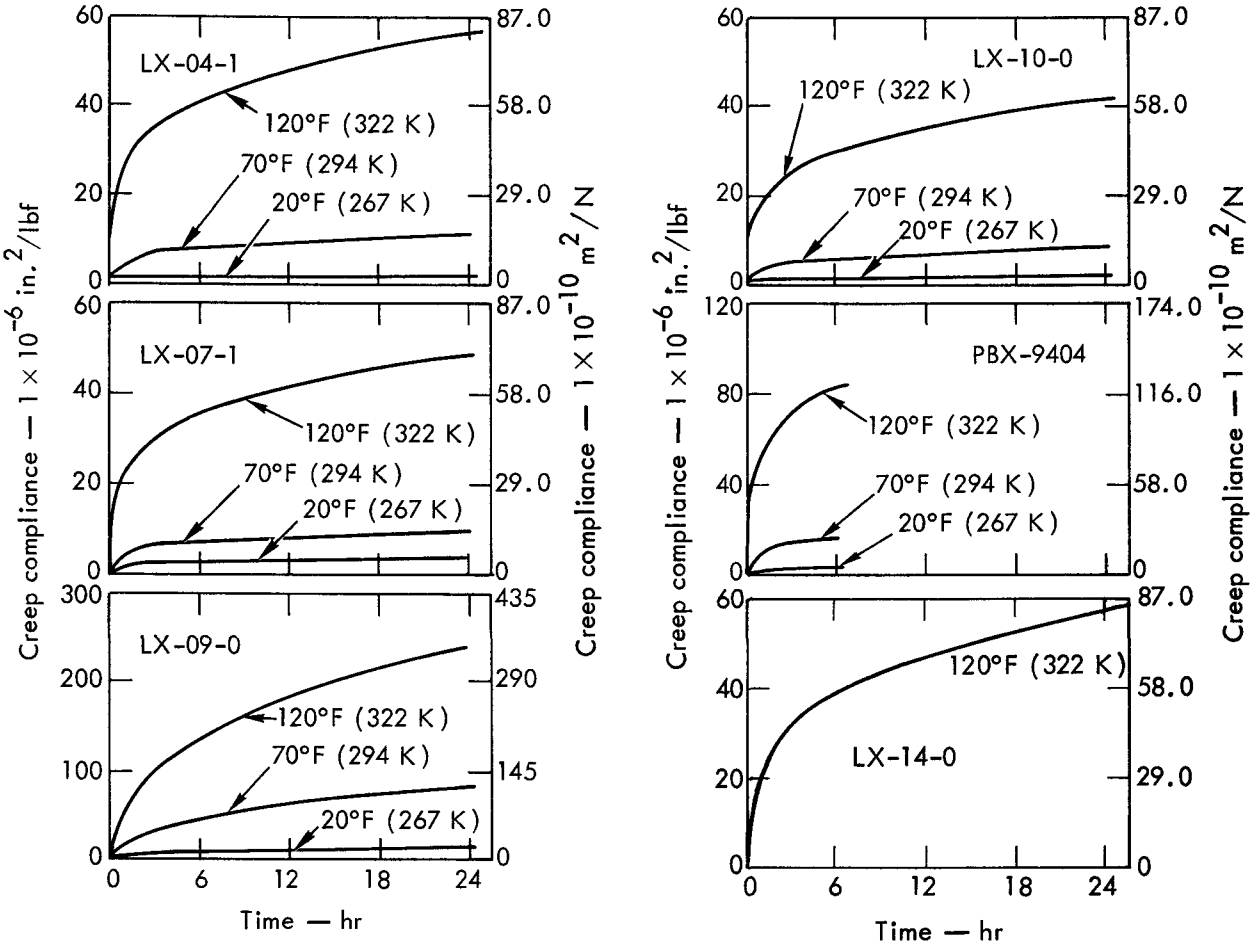


Fig. 7-4. Tension creep data for several explosives. Conversion factor: 1 $in.^2/lbf = 1.450377 \times 10^{-4}\ m^2/N$.

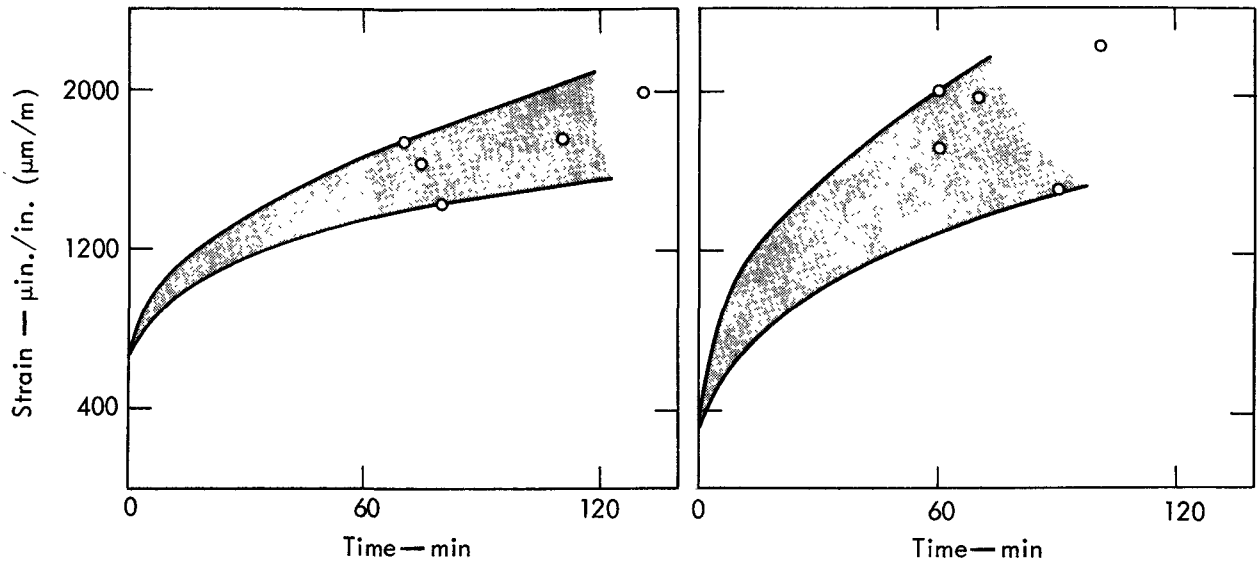


Fig. 7-5. Tension creep data for PBX-9501: left, at 100 psi (689 kPa), 70°F (294 K); right, at 50 psi (345 kPa), 120°F (322 K). The shaded area indicates the range; the points indicate rupture of the specimen.

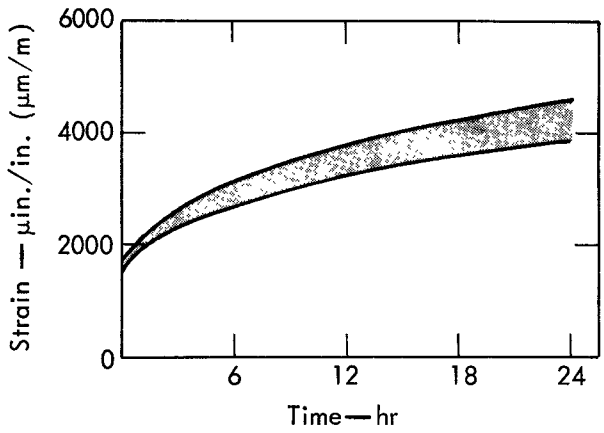


Fig. 7-6. Compression creep data for PBX-9501 at 100 psi (689 kPa), 120°F (322 K). The shading indicates the range.

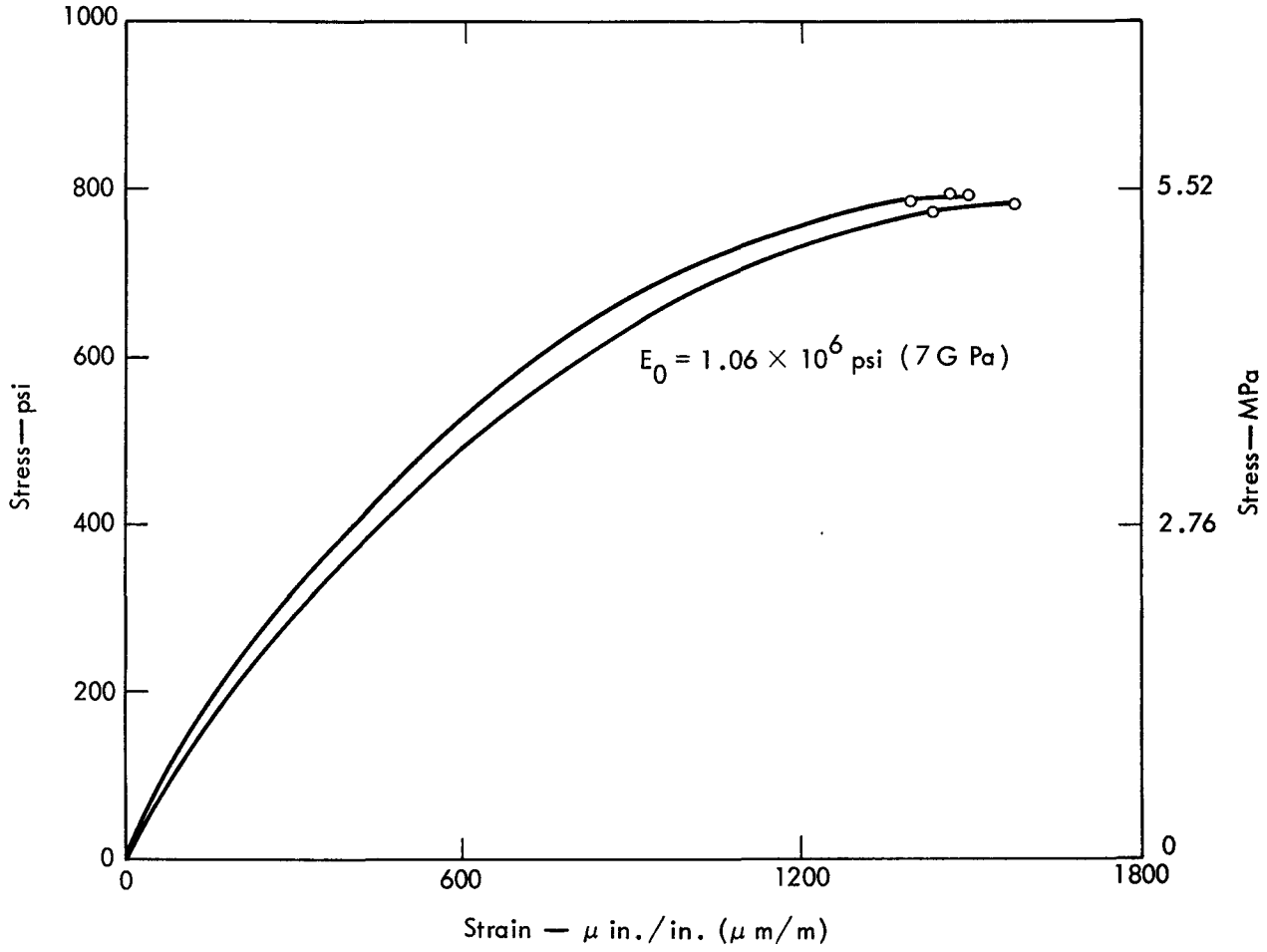


Fig. 7-7. Stress-strain data for PBX-9501. Crosshead velocity 0.005 in./min (7.62 mm/s) at -35°F (236 K). The points indicate rupture of the specimen.

Failure Envelope

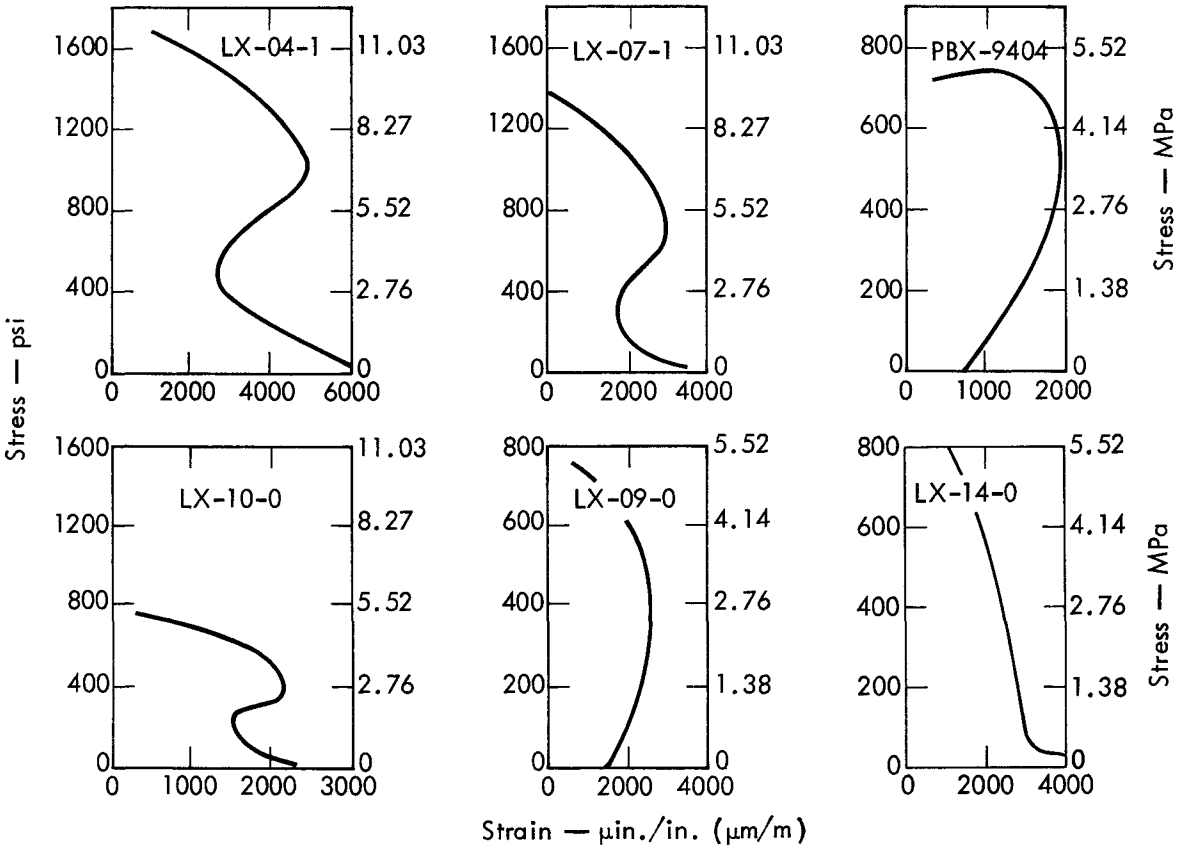
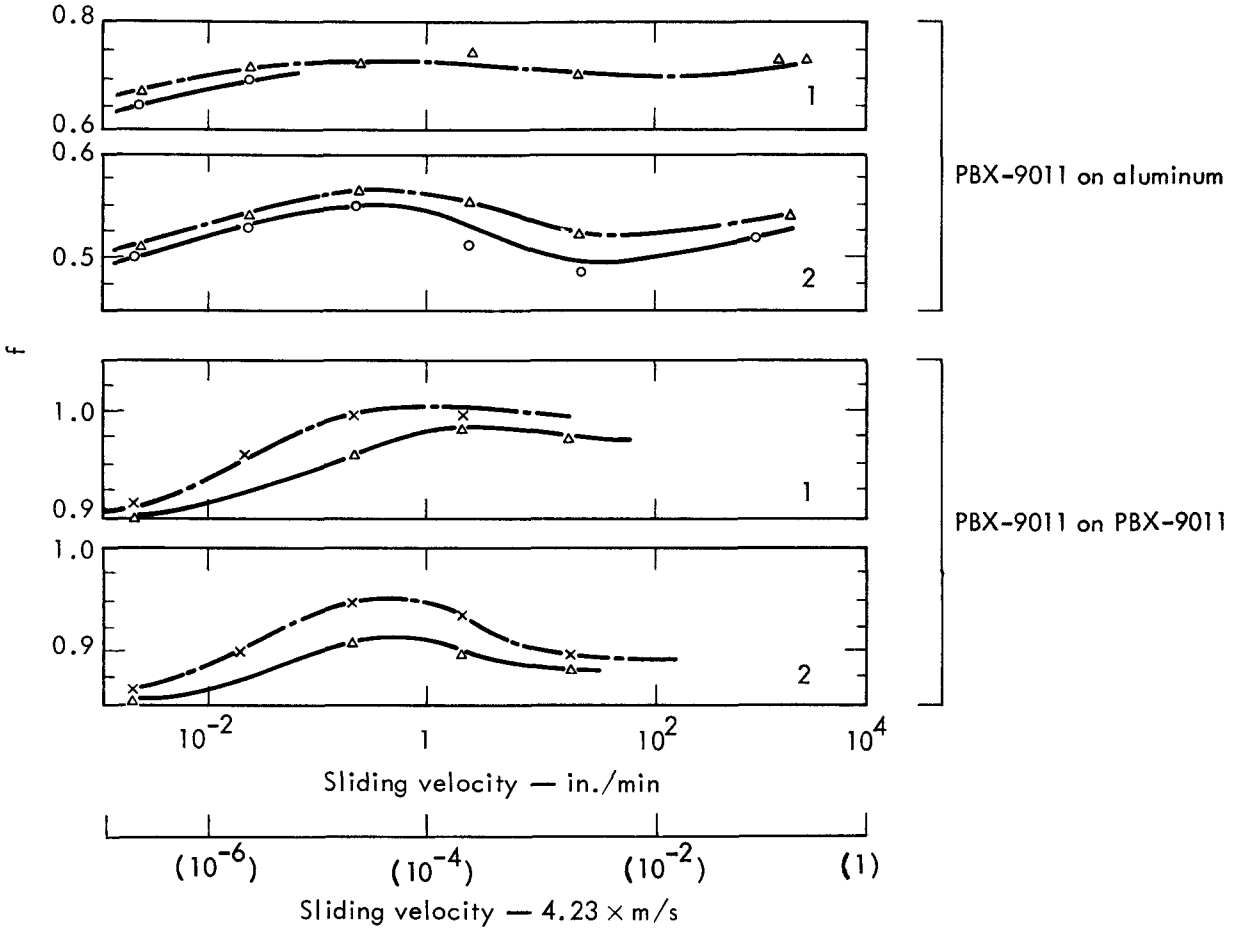


Fig. 7-8. Failure envelopes for several explosives. Conversion factor: 1 psi = 6.894757 kPa.

Friction

Coefficients of friction f were determined for several HEs sliding on themselves and on aluminum 6061-T6 as a function of sliding velocity ν, at different pressures (loads), temperatures, and surface finishes (Table 7-1 and Fig. 7-9). It was found that the Williams-Landel-Ferry (WLF)[5] shift equation could be used to correlate the effects of sliding velocity and temperature on f; thus, a curve could be calculated for some reduced temperature T_r (Fig. 7-10).



× 125 psi (0.86 MPa)

△ 250 psi (1.72 MPa)

○ 500 psi (3.45 MPa)

□ 1000 psi (6.89 MPa)

1 Surface finish 125

2 Surface finish 32

Fig. 7-9. Coefficient of friction f as a function of sliding velocity ν for several explosives.[6] Conversion factor: 1 in./min = 4.233×10^{-4} m/s.

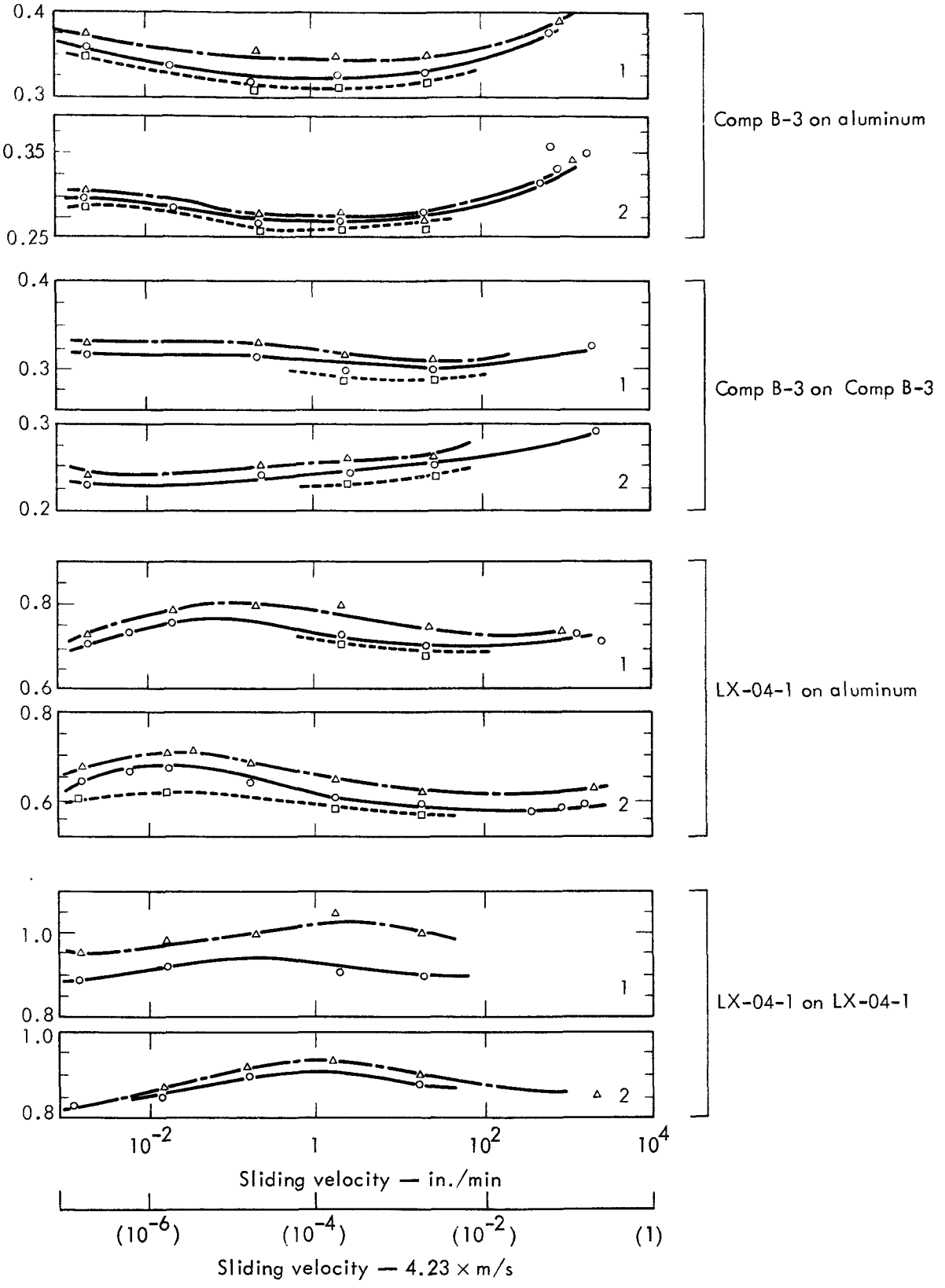


Fig. 7-9 (continued)

Table 7-1. Coefficients of friction f as functions of sliding velocity ν and pressure P at room temperature.[a,7]

Material[b]	$\nu = 10^{-2}$ in./min (4.23×10^{-6} m/s) P (psi (MPa))					$\nu = 10^{-1}$ in./min (4.23×10^{-5} m/s) P (psi (MPa))					$\nu = 10^{0}$ in./min (4.23×10^{-4} m/s) P (psi (MPa))				
	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)
Comp B-3/Al															
1		0.38	0.36		0.35		0.36	0.33		0.31		0.35	0.34		0.31
2		0.31	0.30		0.29		0.28	0.27		0.26		0.27	0.265		0.26
Comp B-3/Comp B-3															
1		0.33	0.32				0.33	0.32				0.32	0.31		0.30
2		0.24	0.23				0.25	0.24				0.26	0.24		0.23
LX-04/Al															
1		0.75	0.72				0.81	0.76				0.80	0.74	0.73	
2		0.70	0.67	0.62			0.69	0.67	0.62			0.65	0.72	0.57	
LX-04/LX-04															
1		0.95	0.90				0.98	0.93				1.3	0.94		
2		0.86	0.83				0.90	0.88				0.94	0.91		
PBX-9011/Al															
1		0.71	0.68				0.73					0.74			
2		0.58	0.52				0.61	0.59				0.62	0.59		
PBX-9011/PBX-9011															
1	0.94	0.92				0.98	0.95				1.1	0.98			
2	0.90	0.87				0.94	0.90				0.95	0.92			

Material[a]	$\nu = 10^{1}$ in./min (4.23×10^{-3} m/s) P (psi (MPa))					$\nu = 10^{2}$ in./min (4.23×10^{-2} m/s) P (psi (MPa))					$\nu = 10^{3}$ in./min (4.23×10^{-1} m/s) P (psi (MPa))				
	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)
Comp B-3/Al															
1		0.35	0.34		0.32		0.37	0.35		0.34		0.39	0.38		
2		0.28	0.27		0.27		0.30	0.30				0.35	0.34		
Comp B-3/Comp B-3															
1		0.31	0.30		0.28		0.31	0.30		0.29			0.33		
2		0.265	0.25		0.24			0.27					0.285		
LX-04/Al															
1		0.75	0.71	0.69			0.73	0.71	0.69			0.73	0.72		
2		0.63	0.59	0.56			0.61	0.56				0.61	0.58		
LX-04/LX-04															
1		1.1	0.91												
2		0.92	0.89				0.89					0.86			
PBX-9011/Al															
1		0.71					0.70					0.72			
2		0.57	0.51				0.57	0.50				0.54	0.52		
PBX-9011/PBX-9011															
1	1.0	0.98													
2	0.90	0.89				0.89									

[a] One in./min = 4.233×10^{-4} m/s.

[b] In this column, 1 is aluminum, surface finish 125, and 2 is aluminum, surface finish 32.

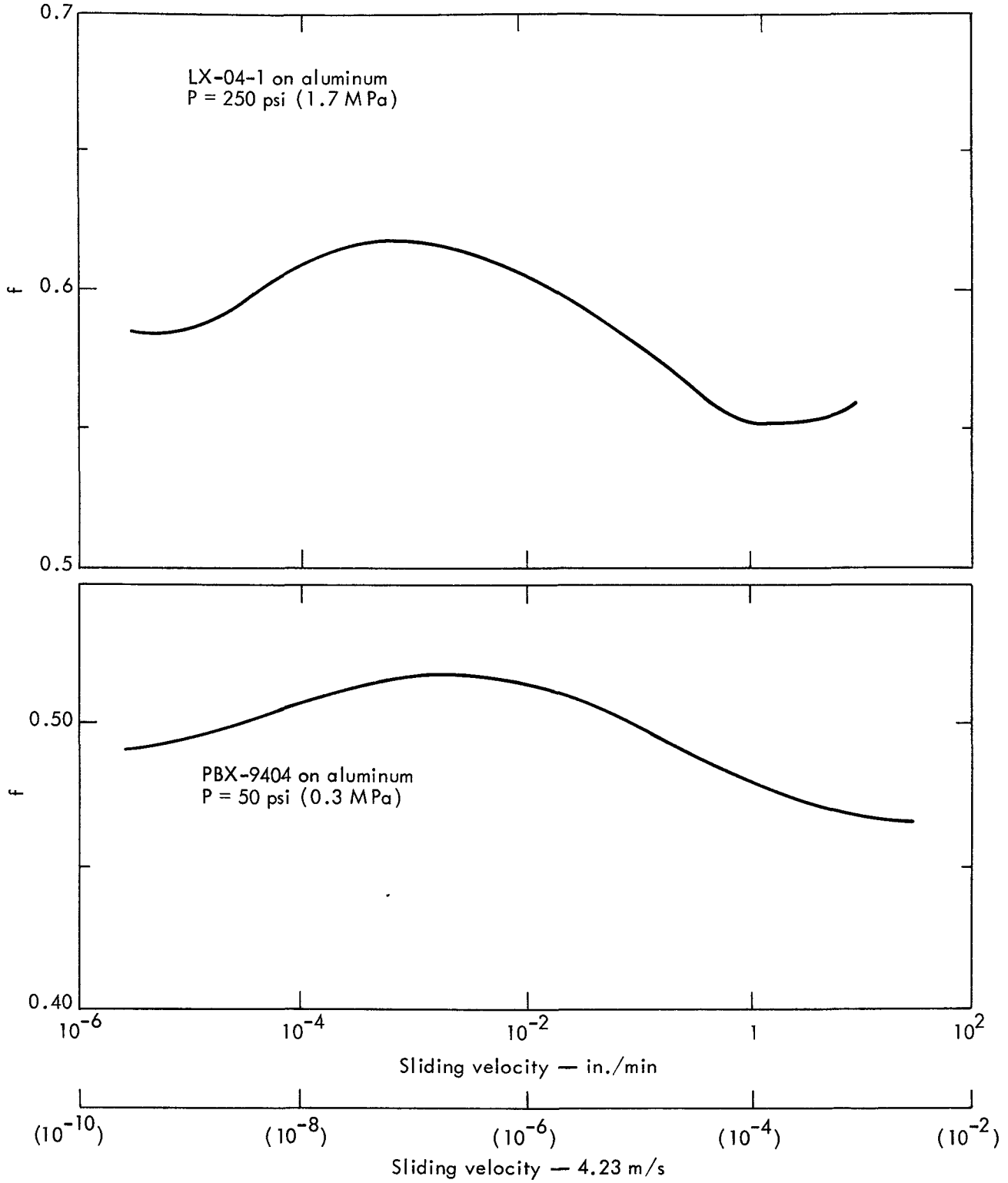


Fig. 7-10. Coefficients of friction f as a function of sliding velocity v for two explosives calculated for a reduced temperature T_r of 22°C (295 K).[5] Conversion factor: 1 in./min = 4.233×10^{-4} m/s.

Complex Shear

The complex shear modulus G, or rather two of its components, shear storage and shear loss, have been determined[8] for LX-04 at various frequencies (0.0004 to 1 Hz over the temperature range -15 to 125°F (247 to 325 K)). This material can be considered to be representative of the family of homogeneous, isotropic, linear viscoelastic and thermorheologically simple polymeric materials of which HEs are members.

Figure 7-11 shows the observed shear storage and shear loss moduli of LX-04 reduced to a temperature T_r of 22°C (295 K) by the WLF empirical equation.

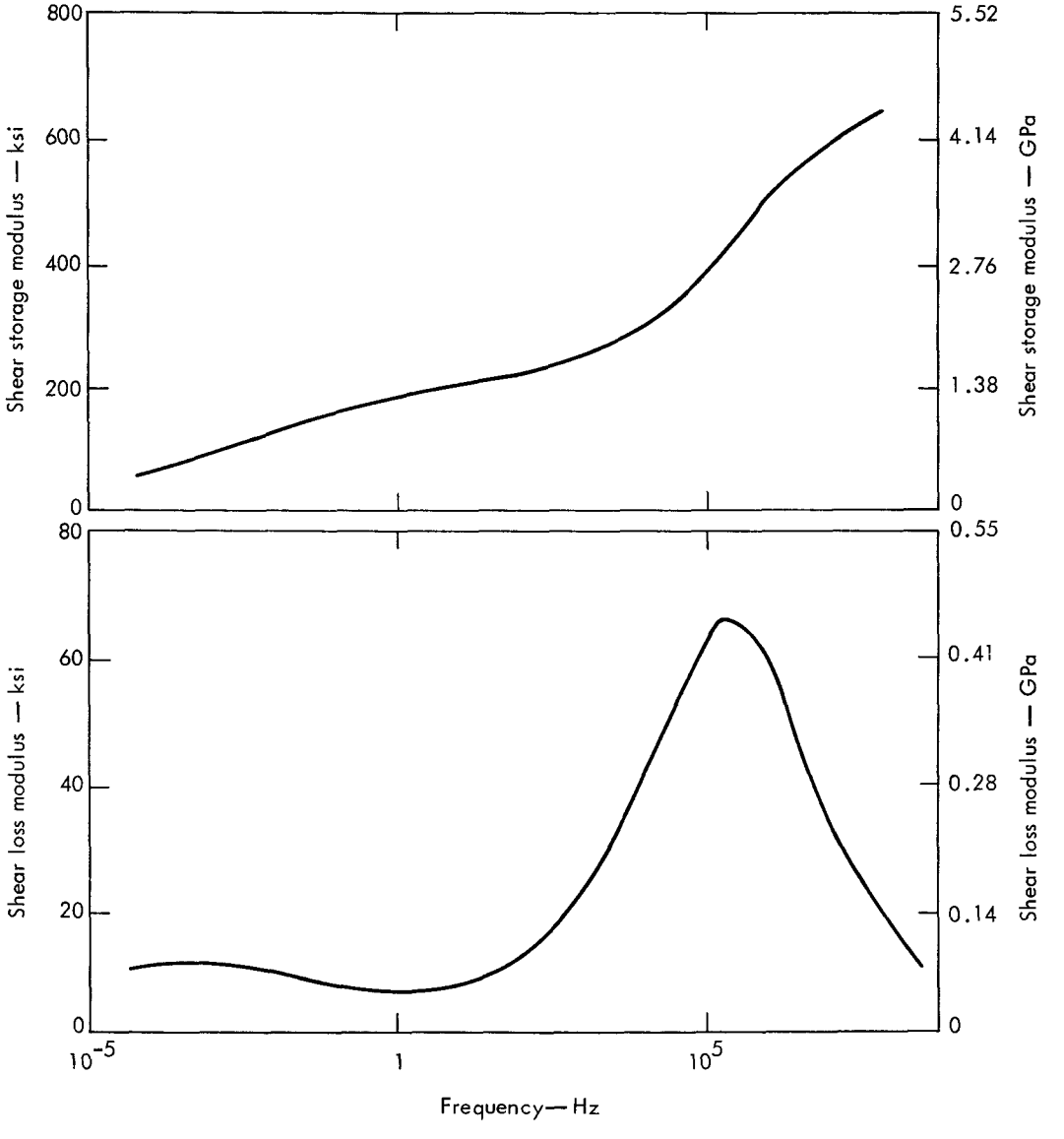


Fig. 7-11. Complex shear moduli of LX-04 at frequencies from 0.0004 to 1 Hz measured and calculated for T_r of 22°C (295 K) over the temperature range -15 to 125°F (247 to 325 K). Conversion factor: 1 psi = 6.894757 kPa.

Dynamic Mechanical Properties

Compressive Stress Strain and Tensile Strength

The Hopkinson split-bar technique was used to determine compressive stress-strain and ultimate tensile strength of a number of explosives and related materials at strain rates up to 5000 sec^{-1}. Hugoniot curves for the unreacted materials were obtained from a gun experiment with aluminum flyer plates.

Table 7-2 (from Ref. 2 and 6) gives dynamic ultimate tensile strength compared to static strength. Other dynamic mechanical properties obtained with the Hopkinson split-bar technique are shown in Fig. 7-12.[1] The figure also shows the ultrasonically determined modulus E_u, which provides an upper bound for modulus values.

Table 7-2. Dynamic and static tensile strengths.

Material	Strain rate (sec^{-1})	Ultimate stress (psi (MPa))	Type of fracture
LX-04-1	10^{-4}	340 (2.34)	Slightly ductile
	850	1500 (10.34)	Slightly ductile
	1100	1780 (12.27)	Slightly ductile
	1550	1750 (12.07)	Brittle
	3100	2100 (14.48)	Slightly ductile
LX-14-0	10^{-5}	450 (3.1)	Brittle
	10^{-4}	540 (3.7)	Brittle
	10^{-3}	580 (4.0)	Brittle
PBX-9011	10^{-4}	340 (2.34)	Slightly ductile
	1050	1300 (8.96)	Brittle
	1100	1450 (10.00)	Brittle
	1300	1400 (9.65)	Brittle
PBX-9404	10^{-4}	330 (2.28)	Slightly ductile
	950	1200 (8.27)	Brittle
	1070	1500 (10.34)	Slightly ductile
	1100	1340 (9.24)	Brittle
	1850	1510 (10.41)	Brittle
PETN	10^{-3}	160 (1.10)	Brittle
	10^{-2}	215 (1.48)	Brittle
	10^{-1}	215 (1.48)	Brittle
	1000	720 (4.96)	Brittle
	1120	700 (4.83)	Brittle
	1300	785 (5.41)	Brittle
	2600	840 (5.79)	Brittle

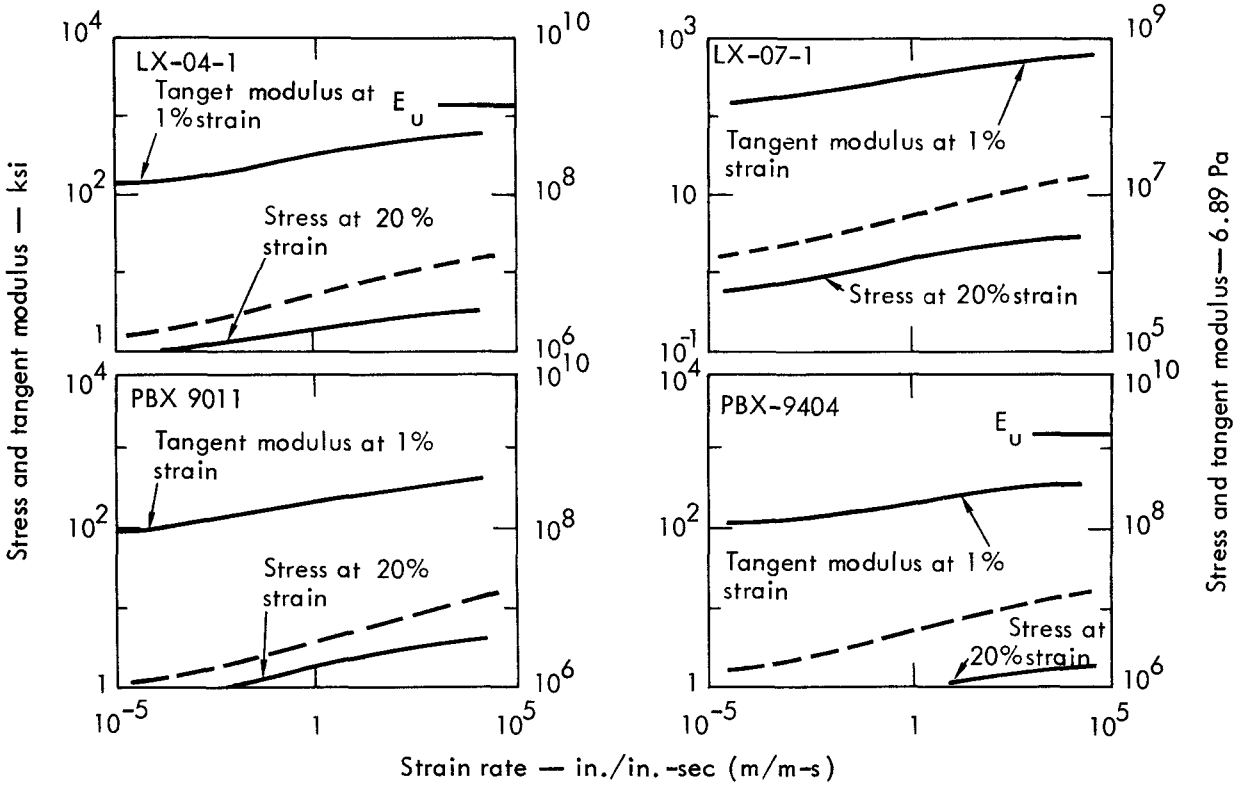


Fig. 7-12. Stress and tangent moduli of several explosives as a function of strain rate. The dashed line represents ultimate stress. The plots for LX-04-1 and PBX-9404 show the ultrasonically determined modulus E_u. Conversion factor: 1 psi = 6.894757 kPa.

Hugoniot Data

Narrow-pulse and sustained shock-loading effects obtained with the flyer-plate technique are shown in Fig. 7-13.[9] The transducer data were normalized to a plate-impact velocity of 0.3 mm/μsec (0.3 km/s).

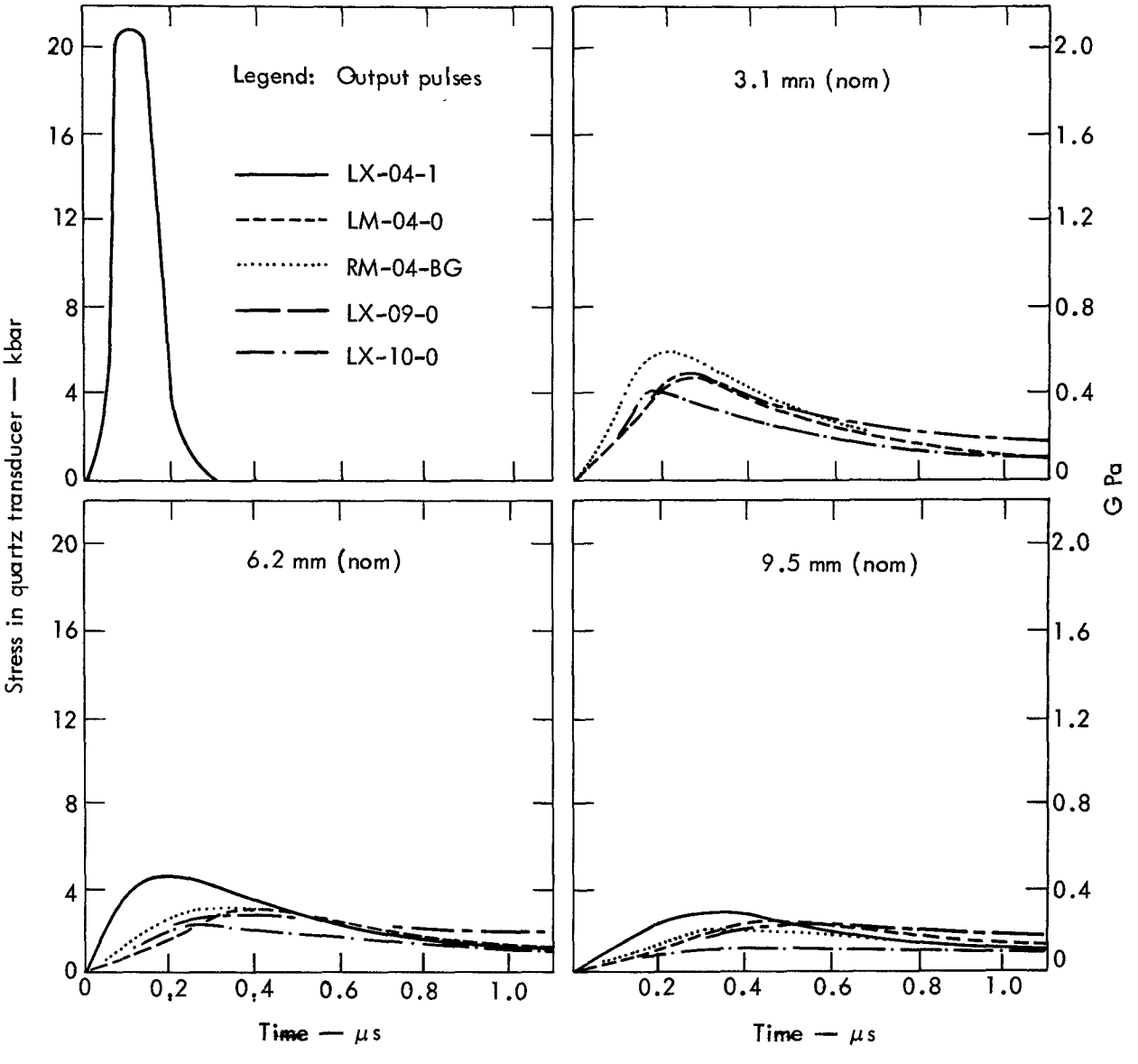


Fig. 7-13. Input and output pulses generated experimentally[9] at three depths in various materials by a 0.28-mm-thick (nominal) aluminum driver plate backed with foam. Conversion factor: 1 bar = 10^5 Pa.

The Hugoniot of unreacted HEs can also be expressed by a simple least squares relationship

$$U_s = A + BU_p,$$

where

U_s = shock velocity in km/s,
A, B = material constants,
U_p = particle velocity in km/s.

The data (at ambient temperature) have been compiled from various sources for the compositions listed in Table 3-1 to 3-3. The Grüneisen constant Γ is expressed as

$$\Gamma = \frac{\partial P}{\partial E} v,$$

where

P = pressure,
E = energy,
v = volume.

Least squares relationships for unreacted Hugoniots are given in Table 7-3.

Table 7-3. Least squares fits for Hugoniots of unreacted HEs.

Explosive	ρ_0 (g/cm^3 (Mg/m^3))	Equation	Range[a]	Γ	Ref.
Baratol	2.611	$U_s = 2.40 + 1.66\ U_p$ $U_s = 1.5 + 2.16\ U_p$	$c_0 \le U_s \le 3.66$ $3.66 \le U_s \le 4.0$		10
	2.63	$U_s = 2.79 + 1.25\ U_p$			11
Comp B	1.70	$U_s = 2.95 + 1.58\ U_p$			11
	1.710	$U_s = 1.20 + 2.81\ U_p$	$4.40 \le U_s \le 5.04$		12
Comp B (cast)	1.700	$U_s = 2.49 + 1.99\ U_p$	$3.57 \le U_s \le 5.02$		12
Comp B-3	1.70	$U_s = 3.03 + 1.73\ U_p$			11
	1.70	$U_s = 2.88 + 1.60\ U_p$	$4.24 \le U_s < 7.01$ $c_0 = 2.93$		12
	1.72	$U_s = 2.71 + 1.86\ U_p$	$3.42 \le U_s \le 4.45$		12
	1.723	$U_s = 1.23 + 2.81\ U_p$	$4.42 \le U_s \le 5.07$		12
Comp B-3 (cast)	1.680	$U_s = 2.710 + 1.860\ U_p$	$3.387 \le U_s \le 4.469$ $c_0 = 2.736$	0.947	12, 13
Cyclotol	1.729	$U_s = 2.02 + 2.36\ U_p$	$4.67 \le U_s \le 5.22$		12
DATB	1.780	$U_s = 2.449 + 1.892\ U_p$	$3.159 \le U_s \le 4.492$ $c_\ell = 2.660$	1.76	12, 13

Table 7-3. (continued)

Explosive	ρ_0 (g/cm^3 (Mg/m^3))	Equation	Range[a]	Γ	Ref.
H-6 (cast)	1.76	$U_s = 2.654 + 1.984\ U_p$	$U_s < 3.7$		14
H-6 (cast)	1.760	$U_s = 2.832 + 1.695\ U_p$	$2.832 \leq U_s \leq 4.535$; $c_0 = 2.759$		12, 13
HNS	1.38	$U_s = 0.61 + 2.77\ U_p$	$1.44 \leq U_s \leq 1.995$		15
	1.57	$U_s = 1.00 + 3.21\ U_p$	$1.00 \leq U_s \leq 3.18$; $c_0 = 1.00$		15
Kel-F	2.10	$U_s = 1.73 + 1.61\ U_p$	$2.65 \leq U_s \leq 3.78$		12
LX-04-1	1.860-1.863	$U_s = 2.36 + 2.43\ U_p$	$2.61 \leq U_s \leq 3.24$		12
LX-09-0	1.839	$U_s = 2.43 + 2.90\ U_p$			16
NM	1.13	$U_s = 2.00 + 1.38\ U_p$	$2.83 \leq U_s \leq 4.40$		12
	1.123-1.128	$U_s = 1.560 + 1.721\ U_p + 1.082\ (1.125-\rho_0)$	$2.918 \leq U_s \leq 4.639$		12
Octol	1.80	$U_s = 3.01 + 1.72\ U_p$			11
Octol (cast)	1.803	$U_s = 2.21 + 2.51\ U_p$	$3.24 \leq U_s \leq 4.97$		12
PBX-9011-06	1.790	$U_s = 2.225 + 2.644\ U_p$	$4.1 \leq U_s \leq 6.1$		10
PBX-9404-03	1.721	$U_s = 1.89 + 1.57\ U_p$	$2.4 \leq U_p \leq 3.7$		10
	1.840	$U_s = 2.494 + 2.09\ U_p$	$2.9 \leq U_s \leq 6.7$		10
	1.84	$U_s = 2.310 + 2.767\ U_p$	$U_s < 3.2$; $c_b = 2.310$		14
	1.84	$U_s = 2.45 + 2.48\ U_p$	$2.45 \leq U_s \leq 6.05$; $c_0 = 2.60$		15
PBX-9407	1.60	$U_s = 1.328 + 1.993\ U_p$	$2.11 \leq U_s \leq 3.18$		17
PBX-9501-01	1.844	$U_s = 2.683 + 1.906\ U_p$	$2.9 \leq U_s \leq 4.4$		10
Pentolite	1.67	$U_s = 2.83 + 1.91\ U_p$			11
	1.676	$U_s = 0.885 + 3.20\ U_p$	$4.52 \leq U_s \leq 5.25$		12
PETN	1.59	$U_s = 1.33 + 2.18\ U_p$	$1.40 \leq U_s \leq 2.14$; $c_0 = 2.45$		15
		$U_s = 0.64 + 4.19\ U_p$	$1.86 \leq U_s \leq 2.65$; $c_0 = 2.45$		15
	1.60	$U_s = 1.32 + 2.58\ U_p$	$1.89 \leq U_s \leq 2.56$	0.77	19

Table 7-3. (continued)

Explosive	ρ_0 (g/cm^3 (Mg/m^3))	Equation	Range[a]	Γ	Ref.
	1.72	$U_s = 2.326 + 2.342\ U_p$	$2.83 \le U_s \le 3.18$ $c_b = 2.326$		18
		$U_s = 1.83 + 3.45\ U_p$	$2.52 \le U_s \le 3.87$ $c_b = 2.24$	0.77	19
Polystyrene	1.05	$U_s = 2.40 + 1.637\ U_p$	$3.87 \le U_s \le 6.493$		12
RDX	1.64	$U_s = 1.93 + 0.666\ U_p$	$2.00 \le U_s \le 2.16$ $c_0 = 2.80$		15
		$U_s = 0.70 + 4.11\ U_p$	$2.14 \le U_s \le 2.63$ $c_0 = 2.80$		15
	1.80	$U_s = 2.87 + 1.61\ U_p$	$4.21 \le U_s \le 5.45$		10
TATB	1.847	$U_s = 2.340 + 2.316\ U_p$	$3.125 \le U_s \le 5.629$ $c_0 = 2.050$	1.60	11,12 13,16
	1.876	$U_s = 1.46 + 3.68\ U_p$	$c_0 \le U_s \le 3.23$		10
		$U_s = 2.037 + 2.497\ U_p$	$3.23 \le U_s \le 5.9$		
Tetryl	1.30	$U_s = 2.1620 + 1.4271\ U_p$	$2.58 \le U_s \le 4.16$ $c_\ell = 1.1$		20
	1.40	$U_s = 1.6111 + 1.9658\ U_p$	$2.20 \le U_s \le 4.07$ $c_\ell = 1.13$		20
	1.50	$U_s = 2.1674 + 1.6225\ U_p$	$2.63 \le U_s \le 4.17$ $c_\ell = 1.36$		20
	1.60	$U_s = 2.3621 + 1.5285\ U_p$	$2.86 \le U_s \le 4.25$ $c_\ell = 1.66$		20
	1.70	$U_s = 2.4763 + 1.4160\ U_p$	$3.08 \le U_s \le 4.17$ $c_\ell = 2.035$		20
TNT	1.582	$U_s = 2.52 + 1.69\ U_p$	$4.46 \le U_s \le 4.89$	0.737	12
	1.62	$U_s = 3.09 + 1.29\ U_p$	$4.17 \le U_s \le 5.22$		12
	1.643-1.648	$U_s = 2.372 + 2.16\ U_p$	$2.78 < U_s$ $c_0 = 2.30$ $2.345 \le U_s \le 3.375$		12
TNT (cast)	1.62	$U_s = 2.274 + 2.652\ U_p$ $U_s = 2.987 + 1.363\ U_p$	$U_s < 3.7$ $3.7 < U$ $c_\ell = 2.297$		14

Table 7-3. (continued)

Explosive	ρ_0 (g/cm^3 (Mg/m^3))	Equation	Range[a]	Γ	Ref.
	1.614	$U_s = 2.390 + 2.050\,U_p$	$3.034 < U_s < 5.414$; $c_0 = 2.572$	0.737	12, 13
	1.63	$U_s = 2.57 + 1.88\,U_p$	$c_\ell = 2.572$		11
TNT (liquid) (82°C)	1.472	$U_s = 2.14 + 1.57\,U_p$	$3.49 \leq U_s \leq 4.65$; $c_0 = 1.37$		12, 13
Tritonal (cast)	1.73	$U_s = 2.313 + 2.769\,U_p$	$U_s < 3.8$		14
XTX-8003	1.53	$U_s = 1.49 + 3.30\,U_p$	$2.38 \leq U_s \leq 4.06$	0.77	19

[a]Sound velocities through the sample are in km/s; c_0 = initial sound velocity, c_ℓ = longitudinal sound velocity, c_b = bulk sound velocity.

Sound Velocity

Longitudinal and transverse shear sound velocities were measured by Marsh of LASL in 1971[21] for materials with large acoustic attenuation. The arrival times of signals traveling through different thicknesses of stacked samples were measured and the sound velocities were determined by a differential technique, i.e., by measuring the transit times of the signals through the measured thicknesses of the samples.

The bulk sound velocities c_b were determined from the expression for isotropic materials:

$$c_b = \sqrt{c_\ell^2 - \frac{4}{3} c_s^2},$$

and are compiled in Table 7-4.[17,21,22]

Table 7-4. Sound velocities, c_ℓ, c_s, and c_b.

Explosive and preparation	ρ (Mg/m^3)	c_ℓ (km/s)	c_s (km/s)	c_b (km/s)
Baratol (cast)	2.538	2.95	1.48	2.40
Comp B-3 (cast)	1.726	3.12	1.71	2.42
Cyclotol (cast)	1.752	3.12	1.69	2.43
DATB (pressed)	1.78	2.99	1.55	2.40
Octol (cast)	1.80	3.14	1.66	2.49
PBX-9010-02	1.78	2.72	1.47	2.13
PBX-9011-04	1.77	2.89	1.38	2.41
PBX-9404	1.83	2.90	1.57	2.26
PBX-9407	1.78	3.04	1.70	2.32
TATB (pressed)	1.87	1.98	1.16	1.46
Tetryl (pressed)	1.68	2.27	1.24	1.76
TNT (pressed)	1.61	2.48	1.34	1.94
TNT (pressed)	1.632	2.58	1.35	2.08
TNT (molten)	1.47			2.1

References

1. K. G. Hoge, Appl. Polym. Symp. 5, 19-40 (1967).
2. D. Breithaupt, Lawrence Livermore Laboratory, personal communication (1974).
3. R. C. Murray, Lawrence Livermore Laboratory, personal communication (1970).
4. G. L. Goudreau, Lawrence Livermore Laboratory, personal communication (1970).
5. J. D. Ferry, Viscoelastic Properties of Polymers (J. Wiley and Sons, Inc., New York, 1970), 2nd ed.
6. K. G. Hoge, Explosivstoffe 18, 39-41 (1970).
7. K. G. Hoge, Frictional and Viscoelastic Properties of Highly Filled Polymers: Plastic-Bonded Explosives, Lawrence Livermore Laboratory, Rept. UCRL-70588 Rev. 1 (1968).
8. M. A. Hamstead, Complex Shear Modulus of a High Explosive, Lawrence Livermore Laboratory, Rept. UCRL-50357 (1967).
9. R. J. Wasley and R. H. Valentine, Shock-Pulse Attenuation and Hugoniot Studies of Three Explosives and Three Mock Explosives, Lawrence Livermore Laboratory, Rept. UCRL-50950 (1970).
10. B. G. Craig, Los Alamos Scientific Laboratory, personal communication (1974).
11. V. M. Boyle, R. L. Jameson, and M. Sultanoff, "Determination of Shock Hugoniots for Several Condensed Phase Explosives," in Proc. 4th Symp. (Intern.) on Detonation, U.S. Office of Naval Research, Washington, D.C., Rept. ACR-126 (1965) pp. 241-247.
12. M. Van Thiel, Compendium of Shock Wave Data, Vol. 2, Lawrence Livermore Laboratory, Livermore, California, Rept. UCRL-50108, Vol. 2 (1967).
13. N. L. Coleburn and T. P. Liddiard, Jr., J. Chem. Phys. 44, 1929-1936 (1966).
14. V. M. Boyle, W. G. Smothers, and L. H. Ervin, "The Shock Hugoniot of Unreacted Explosives"; in Proc. 5th Symp. (Intern.) on Detonation, U.S. Office of Naval Research, Washington, D.C., Rept. ACR-184 (1970) pp. 251-257.
15. J. Roth, "Shock Sensitivity and Shock Hugoniots of High-Density Granular Explosives," in Proc. 5th Symp. (Intern.) on Detonation, U.S. Office of Naval Research, Washington, D.C., Rept. ACR-184 (1970) pp. 219-230.
16. L. G. Green, Lawrence Livermore Laboratory, personal communication (1971).
17. J. E. Lindstrom, J. Appl. Phys. 37, 4873-4880 (1966).
18. J. Wackerle and J. O. Johnson, Pressure Measurements on the Shock-Induced Decomposition of High-Density PETN, Los Alamos Scientific Laboratory, Rept. LA-5131 (1973).
19. D. Stirpe, J. O. Johnson, and J. Wackerle, J. Appl. Phys. 41, 3884-3893 (1970).
20. J. E. Lindstrom, J. Appl. Phys. 41, 337-350 (1970).
21. S. Marsh, Los Alamos Scientific Laboratory, personal communication (1974).
22. J. B. Ramsey, Los Alamos Scientific Laboratory, personal communication (1974).

8. PERFORMANCE

This section contains tables of detonation velocities, detonation velocity equations, Chapman-Jouguet detonation pressures, cylinder-test measurements of explosive energies, equation-of-state parameters, and detonation energies.

Detonation Velocity

Table 8-1. Measured detonation velocities D characteristic of the materials at nominal composition and density ρ, under ambient conditions in large charges at LLL, unless otherwise indicated. (See also Table 8-2.)

Explosive	ρ (g/cm^3 (Mg/m^3))	D (mm/μsec (km/s))[a]	Ref.
Baratol	2.55	4.87	
Boracitol	1.55	4.86	
BTF	1.859	8.485	
Comp B, Grade A (pressed)	1.72	7.99	
Comp B-3 (cast)	1.62	7.70	
Comp C-4	1.59	8.04	
Cyclotol 75/25	1.76	8.30	
DATB	1.79	7.52	
DIPAM	1.76	7.40	1
EL-506A	1.48	7.2	
EL-506C	1.48	7.0	
H-6	1.72	7.5-7.7 (-65 to 77°F (219 to 298 K))	2
HMX	1.89	9.11	
HNAB II	1.77	7.6-7.7 (in 0.1-0.3 in. diam column)	3,4
HNS	1.70	7.00	1
LX-01	1.24	6.84	
LX-02	1.44	7.37	
LX-04	1.86	8.46	
LX-07-2	1.87	8.64	
LX-08	1.42	6.56	
LX-09	1.84	8.81	
LX-10-0	1.86	8.82	
LX-10-1	1.87	8.847	
LX-11	1.87	8.32	
LX-13	See XTX-8003		
LX-14	1.833	8.837	5
MEN-II	1.02	5.49	
NC (13.45% N)	1.20	7.30	
NG	1.60	7.70	
NM	1.13	6.32	6
NQ	1.55	7.65	
Octol	1.81	8.48	
PBX-9007	1.64	8.09	
PBX-9010	1.78	8.37	
PBX-9011	1.77	8.50	
PBX-9205	1.67	8.17	
PBX-9404	1.84	8.80	
PBX-9407	1.60	7.91	
PBX-9501	1.84	8.83	7
Pentolite 50/50	1.67	7.47	
PETN	1.76	8.26	
RDX	1.77	8.70	
TACOT	1.85	7.25	
TATB	1.88	7.76	
Tetryl	1.71	7.85	
TNM	1.6	6.4 (15 to 20°C (288 to 298 K))	8
TNT	1.64	6.93	
XTX-8003	≈1.53	7.30	

[a] One mm/μsec = 1 km/s.

Estimation

One method for estimating the detonation velocity and pressure of an organic C-H-N-O explosive from its chemical structure was devised by Kamlet and Jacobs of the U. S. Naval Ordnance Laboratory.[9] Detonation pressures P in kbars and detonation velocities D in km/s of C-H-N-O explosives at initial densities above 1.0 g/cm^3 can be calculated by means of the simple empirical equations

$$P = K\rho_0^2\phi$$

and

$$D = A\phi^{1/2}(1 + B\rho_0), \qquad \phi = NM^{1/2}Q^{1/2},$$

where

$K = 15.58$,
ρ_0 = initial density of HE (g/cm^3),
$A = 1.01$,
$B = 1.30$,
N = moles of gaseous detonation products per gram of HE (mol gas/g HE),
M = average molecular weight of detonation product gas (g gas/mol gas),
Q = chemical energy of the detonation reaction (cal/g).

Values of N, M, and Q can be estimated from the H_2O-CO_2 decomposition assumption. The other input parameters are the elemental composition, the ΔH_f in kcal/mol, and the loading density of the HE.

$$C_aH_bN_cO_d \rightarrow \frac{c}{2}N_2 + \frac{b}{2}H_2O + \left(\frac{d}{2} - \frac{b}{4}\right)CO_2 + \left(a - \frac{d}{2} + \frac{b}{4}\right)C.$$

Then,

$$N = \frac{2c + 2d + b}{48a + 4b + 56c + 64d},$$

$$M = \frac{56c + 88d - 8b}{2c + 2d + b},$$

$$Q = -\Delta H_0 = \frac{\Delta H_f(\text{detonation products}) - \Delta H_f(\text{HE})}{\text{formula weight}}$$

$$= \frac{28.9b + 47.0\left(d - \frac{b}{2}\right) + \Delta H_f(\text{HE})}{12a + b + 14c + 16d}.$$

Another simple empirical equation was demonstrated by Urizar at LASL in the late 1940s, and gives good agreement with measured detonation velocities of mixtures. The detonation velocity of a mixture or formulation can be estimated or predicted as the sum of the detonation or shock velocities of the components weighted by their

individual volume fractions. Table 8-2 gives values of characteristic velocities D_i for use in the equation

$$D = \sum (V_i D_i),$$

where D is the detonation velocity of the mixture of infinite diameter, V is the volume fraction, and subscript i refers to each of the i components including void space. Consult Table 8-1 for D of explosives not listed here.

Table 8-2. Characteristic velocities D_i.

Material	ρ (g/cm^3 (Mg/m^3))	D_i (mm/μsec (km/s))	Ref.
Polymers and plasticizers			
Adiprene L	1.15	5.69	10
AFNOL	1.48	6.35	11
Beeswax	0.96	5.46	10
BDNPF	1.55	6.50	10
BDNPF/BDNPA (50/50 wt% eutectic)	1.39	6.31	11
CEF	1.45	5.15	10
DNPA	1.47	6.10	11
EDNP	1.28	6.30	10
Estane 5740-X2	1.2	5.52	10
Exon-400 XR61	1.7	5.47	10
Exon-454 (85/15 wt% PVC/PVA)	1.35	4.90	11
FEFO (as constituent to ~35%)	1.60	7.20	11
Fluoronitroso rubber	1.92	6.09	11
Halowax 1014	1.78	4.22	10
Kel-F wax		5.62	10
Kel-F elastomer	1.85	5.38	10
Kel-F 800/827	2.00	5.83[a]	10
Kel-F 800	2.02	5.50	11
Neoprene CNA	1.23	5.02	10
NC	1.5	6.70	10
Paracril BJ (Buna-N nitrile rubber)	0.97	5.39	10
Polyethylene	0.93	5.55	11
Polystyrene	1.05	5.28	10
Saran F-242		5.55	10
Silastic 160		5.72	10
Sylgard 182	1.05	5.10	11
Teflon	2.15	5.33	10
Viton A	1.82	5.39	10,11

Table 8-2 (continued)

Material	ρ (g/cm^3 (Mg/m^3))	D_i (mm/μsec (km/s))	Ref.
Inorganic additives			
Air or void		1.5	10
Al	2.70	6.85	11
$Ba(NO_3)_2$	3.24	3.80	10
$KClO_4$	2.52	5.47	11
$LiClO_4$	2.43	6.32	11
LiF	2.64	6.07	11
Mg	1.74	7.2	11
Mg/Al alloy (61.5/38.5 wt%)	2.02	6.9	11
NH_4ClO_4	1.95	6.25	11
SiO_2 (Cab-O-Sil)	2.2	4.0	11
Pure explosives at TMD			
DATB	1.84	7.52	10
FEFO (invalid when < 35% present)	1.61	7.50	11
HMX	1.90	9.15	11
NQ	1.72	8.74	10
PETN	1.77	8.28	11
RDX	1.81	8.80	10
TATB	1.94	8.00	10
TNT	1.65	6.97	10

[a]One shot only.

Equations

To calculate detonation velocities at conditions other than those specified in Table 8-1, the equations in Table 8-3 were developed to take into account composition and density of the explosive, charge diameter, and temperature.

Table 8-3. Detonation velocity equations. Symbols and units are: D = detonation velocity in mm/μsec (km/s), ρ = density in g/cm^3 (kg/m^3), R = charge radius in cm (m), W = composition in wt%, V = composition in vol%, T = temperature in °C (K). Values or equations in parentheses are in SI units.

Explosive	Equation		Condition	Ref.
Baratol	$D = 4.96 - (0.454/R)$	$(4.96 - [(4.54 \times 10^{-3})/R])$	27% TNT, ρ~2.60, 2.5 < R < 10	12
Boracitol	$D = 5.15 - (6.25/R)$	$(5.15 - [(62.5 \times 10^{-3})/R])$	R > 5 (0.05)	12
BTF	$D = 4.265 + 2.27\rho$	$(4.265 + (2.27 \times 10^{-3}\rho E))$		11
Comp B, Grade A	$D = 7.99 - [(75.6 \times 10^{-3})/R]$ $\Delta D/\Delta T = -0.5 \times 10^{-3}$	$(7.99 - [(0.756 \times 10^{-3})/R])$	ρ = 1.715	12
Cyclotol	$D = 8.298 - [(57.7 \times 10^{-3})/R]$	$(8.298 - [(0.577 \times 10^{-3})/R])$	77% RDX, ρ = 1.755	12
DATB	$D = 7.52 - [(52.76 \times 10^{-3})/R]$ $D = 2.495 + 2.834\rho$	$(7.52 - [(0.528 \times 10^{-3})/R])$ $(2.495 + (2.834 \times 10^{-3}\rho))$	ρ = 1.788	13
LX-01-0	$\Delta D/\Delta T = -3.8 \times 10^{-3}$			
LX-02	$D = 7.44 - [(4.31 \times 10^{-3})/R]$	$(7.44 - [(43.1 \times 10^{-6})/R])$	Brass confinement; varies with confinement.	
LX-04-1	$D_\infty = 1.733 + 3.62\rho$ $D = 8.46 - [(24.015 \times 10^{-3})/R]$ $\Delta D/\Delta T = -1.55 \times 10^{-3}$ $\Delta D/\Delta W = -38 \times 10^{-3}$ (W = wt% Viton)	$(1.733 + (3.62 \times 10^{-3}\rho))$ $(8.46 - [(0.24 \times 10^{-3})/R])$	ρ = 1.86 -54 to 74°C (219-347 K)	
LX-07	$\Delta D/\Delta T = -1.55 \times 10^{-3}$ $\Delta D/\Delta W = -35 \times 10^{-3}$ (W = wt% HMX)		-54 to 74°C (219-347 K)	
LX-08	$\Delta D/\Delta T = -3.56 \times 10^{-3}$		-36 to 23°C (237-296 K)	
LX-09	$\Delta D/\Delta T = -3.31 \times 10^{-3}$			14
LX-13	See XTX-8003			
NM	$\Delta D/\Delta T = -3.7 \times 10^{-3}$ $\Delta D/\Delta P = 0.197 \times 10^{-3}$ mm/μsec-atm (19.96 km/s-Pa)		4°C (277 K), infinite diam	15
NQ	$D = 1.44 + 4.015\rho$	$(1.44 + (4.015 \times 10^{-3})\rho)$	$0.4 \le \rho \le 1.63$	13
Octol	$D = 8.48 - [(64.97 \times 10^{-3})/R]$	$(8.48 - [(0.65 \times 10^{-3})/R])$	77% HMX, ρ = 1.814	12
PBX-9010	$D = 2.843 + 3.1\rho$ $D = 8.371 - [(10.16 \times 10^{-3})/R]$	$(2.843 + (3.1 \times 10^{-3}\rho))$ $(8.371 - [(0.1016 \times 10^{-3})/R])$	ρ = 1.781	11
PBX-9205	$D = 2.41 + 3.44\rho$ $D = 4.995 + (36.54 \times 10^{-3}V)$ (V = vol% RDX)	$(2.41 + (3.44 \times 10^{-3}\rho))$	ρ = 97.5% TMD	
PBX-9404	$D = 8.8 - [(24.12 \times 10^{-3})/R]$ $D = 2.176 + 3.6\rho$ $\Delta D/\Delta T = -1.165 \times 10^{-3}$	$(8.8 - [(0.24 \times 10^{-3})/R])$ $(2.176 + (3.6 \times 10^{-3}\rho))$	-54 to 74°C (219-347 K)	
Pentolite	$\Delta D/\Delta T = -0.4 \times 10^{-3}$			
PETN	$D = 2.14 + 2.84\rho$ $D = 3.19 + 3.7(\rho - 0.37)$ $D = 7.92 + 3.05(\rho - 1.65)$	$(2.14 + (2.84 \times 10^{-3}\rho))$	$\rho \le 0.37$ $0.37 \le \rho \le 1.65$ $\rho \ge 1.65$	16
RDX	$D = 2.56 + 3.47\rho$	$(2.56 + (3.47 \times 10^{-3}\rho))$	$\rho > 1.0$	17
TATB	$D = 0.343 + 3.94\rho$ $D = 7.79 - [(16.8 \times 10^{-3})/R]$	$(0.343 + (3.94 \times 10^{-3}\rho))$ $(7.79 - [(0.168 \times 10^{-3})/R])$	$\rho > 1.2$ ρ = 1.876	12
TNT	$D_\infty = 1.873 + 3.187\rho$ $D_\infty = 6.763 + 3.187(\rho - 1.534) - 25.1(\rho - 1.534)^2 + 115.1(\rho - 1.534)^3$	$(1.873 + (3.187 \times 10^{-3}\rho))$	$0.9 < \rho < 1.534$ $1.534 < \rho < 1.636$	18
XTX-8003	$D = 7.26 - 3.02 \times 10^{-3}/R$ $D = 3.68 + (44.8 \times 10^{-3}W)$ (W = wt% PETN) $\Delta D/\Delta T = -2.34 \times 10^{-3}$	$(7.26 - [(30.2 \times 10^{-6})/R])$	$\rho \approx 1.53$ -54 to 74°C (219-347 K)	14

Chapman-Jouguet Detonation Pressure

In idealized detonation theory, a detonation front consists of several regions: (1) The leading surface is a shock front, chemically unreactive, with a discontinuous high pressure. (2) Following the shock front is the reaction zone where chemical reactions take place and release the bulk of the detonation energy; its thickness is estimated to be of the order of 10^{-1} mm for some pure explosives, but may vary by several powers of 10 depending on the HE. (3) The surface at the rear of the reaction zone is called the Chapman-Jouguet (C-J) plane. Complete thermodynamic equilibrium is assumed to exist at the C-J plane, and the detonation products are said to be at the C-J state. Detonation pressure normally refers to the pressure in the C-J state; it is somewhat lower than the pressure at the shock front.

Experimentally, C-J pressures (Table 8-4) are measured by various indirect hydrodynamic methods. These measurements may span a range of 10-20%, and their exact interpretation is uncertain. Calculated C-J pressures (Table 8-4) are obtained with the RUBY hydrodynamic-thermodynamic computer code, which combines the Rankine-Hugoniot conservation equations, the C-J condition, the density and enthalpy of formation ΔH_f of the explosive, the laws of chemical thermodynamic equilibrium, and the Brinkley-Kistiakowsky-Wilson (BKW) equation of state for the gaseous products. The code parameters are normalized with measured detonation velocities and C-J pressures of several explosives.

Table 8-4. Chapman-Jouguet detonation pressures P_{CJ}.

Explosive	ρ (g/cm^3 (Mg/m^3))	P_{CJ} (kbar (10^{-1} GPa))[a]	
		Measured	Calculated, RUBY code
Baratol	2.61	140	---
BTF	1.882	---	294
Comp B, Grade A	1.717	295[b]	---
Comp B-3	1.715	287	286
Comp C-4	1.59	---	257
Cyclotol (77/23)	1.752	316	---
DATB	1.78	259	250
HMX	1.90	---	387
LX-01	1.31	1.56	177
LX-04	1.865	350	330
LX-07-2	1.865	---	346
LX-09-0	1.837	377	373
LX-10	1.860	375	360
LX-11	1.87	---	310
LX-13	See XTX-8003		
LX-14	1.833	370	---
MEN-II	1.017	---	113
NC (12.0% N)	1.58	---	200
NC (13.35% N)	1.58	---	210
NG	1.60	253	251
NM	1.135	130	144
Octol (77.6/22.4)	1.821	342	---
PBX-9007	1.60	265	---
PBX-9010	1.783	328 ± 5	---
PBX-9011	1.767	324 ± 5	298
PBX-9205	1.69	---	288
PBX-9404	1.840	375	354
PBX-9407	1.60	287	300
Pentolite (50/50)	1.66	---	280
PETN	1.77	340	326
	1.67	300	280
	0.99	87	100
RDX	1.767	338	348
TACOT	1.61	---	181
TATB	1.88	---	291
Tetryl	1.71	---	260
TNM	1.65	---	144
TNT	1.630	190	207
XTX-8003	1.546	170	210

[a] One GPa = 10 kbar.

[b] Pressure can be corrected for small changes in %RDX and density by the formula $P = 295 + 1.57\ (\%RDX - 64) + 678.5\ [(\rho_0 - 1.717)/\rho_0]$.

Cylinder Test Measurements of Explosive Energy

The cylinder test gives a measure of the hydrodynamic performance of an explosive. The test geometry is based on a constant volume of HE. The test system consists of an explosive charge 1 in. (25.4 mm) in diameter and 12 in. (0.31 m) long in a tightly fitting copper tube with a wall 0.1022 in. (2.6 mm) thick. The charge is initiated at one end. The radial motion of the cylinder wall is measured at about 8 in. (0.2 m) from the initiated end with a streak camera technique. Detailed radius-time data are available from the Organic Materials Division.

The kinetic energy imparted to the copper wall in a fixed geometry leads to a simple way of expressing the performance of the explosive. Two extreme geometric arrangements have been considered for the transfer of explosive energy to adjacent metal in this range of mass ratio of explosive to metal: (1) detonation normal or head-on to the metal, and (2) detonation tangential or sideways to the metal. The effective explosive energy is frequently different for the two cases, even on a relative basis, because of the effects of the equations of state of the detonation products. The cylinder test provides a measure of the relative effective explosive energy for both head-on and tangential detonation. The radial wall velocity at 5-6 mm wall displacement, expressed as volume ratio ($V = V/V_0 \simeq 2$) is indicative of explosive energy in head-on geometry. The wall velocity at 19 mm displacement, $V/V_0 \approx 7$, is indicative of performance in tangential geometry.

Table 8-5 lists the specific wall kinetic energies at 6 mm and 19 mm wall displacement; these are characteristic of head-on and tangential detonation, respectively. Terminal wall velocities at breakup are about 7-10% higher. Approximately 50% of the detonation energy is transferred to the cylinder wall.

Table 8-5. Cylinder-test measurements of explosive energy.[11] Specific kinetic energy E_{cyl} delivered to the copper cylinder wall in geometries characterized by head-on (6 mm displacement) and tangential (19 mm displacement).

Explosive	ρ (g/cm^3 (Mg/m^3))	$E_{cyl}\left(\frac{(mm/\mu sec)^2}{2}\ (MJ/kg)\right)$ Head-on 6 mm	Tangential 19 mm
BTF	1.859	1.305	1.680
Comp B, Grade A	1.717	1.035	1.330
Cyclotol 77/23	1.754	1.140	1.445
HMX	1.894	1.410	1.745
LX-04	1.865	1.170	1.470
LX-07-1	1.857	1.250	1.575
LX-09-0	1.836	1.320	1.675
LX-10	1.862	1.315	1.670
LX-11	1.876	1.105	1.360
LX-13	See XTX-8003		
NM	1.14 (11-15°C) (284-288 K)	0.560	0.745
Octol 78/22	1.813	1.215	1.535
PBX-9010	1.788	1.160	1.470
PBX-9011	1.777	1.120	1.415
PBX-9404	1.843	1.295	1.620
PBX-9501[6]	1.843	1.288	1.656
Pentolite 50/50	1.696	0.960	1.260
PETN	1.765	1.255	1.575
TNT	1.630	0.735	0.975
XTX-8003	1.554	0.710	0.950

Equation of State

The Jones-Wilkins-Lee (JWL) equation of state has been used to describe accurately the pressure-volume-energy behavior of the detonation products of explosives in applications of metal acceleration. All values are valid only for large charges.[19,20] The equation for pressure P is

$$P = A\left(1 - \frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E}{V},$$

and that for P_s, pressure as a function of volume at constant entropy (i.e., the isentrope), is

$$P_s = Ae^{-R_1 V} + Be^{-R_2 V} + CV^{-(\omega+1)},$$

where A, B, and C are linear coefficients (in Mbar (GPa)); R_1, R_2, and ω are nonlinear coefficients; $V = V/V_0$ (volume of detonation products/volume of undetonated HE); P and P_s are in Mbar (GPa), and E, the detonation energy per unit volume is in (Mbar-cm^3)/cm^3 ((GPa-m^3)/m^3).

Some explosives have been subjected to a rigorous comparison in which coefficients are determined by matching the equation with experimental C-J conditions, calorimetric data, and expansion behavior—usually cylinder-test data. These explosives are listed in Table 8-6 without additional notation. It has proved very useful to estimate coefficients for which only limited data are available; for these HEs the estimated parameters are listed as noted. The best estimates are for those explosives for which cylinder-test data are available. In many instances, P_{CJ} is estimated by assuming that $2.7 < \Gamma < 2.8$, where Γ is the adiabatic coefficient of expansion. Where data were extremely limited, estimates were made from RUBY code calculations for P_{CJ}, D, and E_0; R_1, R_2, and ω were estimated.

Table 8-6. Equation-of-state parameters.[a]

Explosive[b]	Composition (wt%)	C-J parameters[c] ρ_0 (g/cm^3) (Mg/m^3)	P (Mbar) (100 GPa)	D (cm/μsec) (10^{-1} km/s)	E_0 (Mbar-cm^3/cm^3) (100 GPa-m^3/m^3)	Γ	Equation-of-state parameters A (Mbar (100 GPa))	B (Mbar (100 GPa))	C (Mbar (100 GPa))	R_1	R_2	ω
BTF	Benzotrifuroxan	1.859	0.360*	0.848	0.1150	2.717	8.407	0.14960	0.01368	4.60	1.20	0.30
Comp B, Grade A	RDX/TNT 64/36	1.717	0.295	0.798	0.0850	2.706	5.242	0.07678	0.01082	4.20	1.10	0.34
Cyclotol	RDX/TNT 77/23	1.754	0.320	0.825	0.0920*	2.731	6.034	0.09924	0.01075	4.30	1.10	0.35
DIPAM**	Diamino-hexanitro biphenyl	1.550	0.180*	0.670	0.0620*	2.842	4.254	0.08007	0.01175	4.70	1.30	0.39
EL-506A**	PETN/CH_2 85/15	1.480	0.205*	0.720	0.0700*	2.752	3.738	0.03647	0.01138	4.20	1.10	0.30
EL-506C**	PETN/NC/CH_2 63/8/29	1.480	0.195*	0.700	0.0620*	2.719	3.490	0.04524	0.00854	4.10	1.20	0.30
HMX	Tetranitrotetrazacyclooctane	1.891	0.420*	0.911	0.1050	2.740	7.783	0.07071	0.00643	4.20	1.00	0.30
HNS**	Hexanitrostilbene	1.540	0.175*	0.660	0.0600*	2.885	4.469	0.08358	0.01010	4.80	1.30	0.39
LX-01**	TNM/NM/INP 33.3/52/14.7	1.230	0.155	0.684	0.0610*	2.711	3.110	0.04761	0.01039	4.50	1.00	0.35
LX-04-1	HMX/Viton 85/15	1.865	0.340	0.847	0.0950	2.936	8.498	0.15277	0.01159	4.65	1.30	0.35
LX-07	HMX/Viton 90/10	1.865	0.355	0.864	0.1000*	2.921	8.710	0.13896	0.00891	4.60	1.15	0.30
LX-09-0	HMX/DNPA/FEFO 93/4.6/2.4	1.838	0.373	0.884	0.1050*	2.851	8.684	0.18711	0.00729	4.60	1.25	0.25
LX-10	HMX/Viton 95/5	1.860	0.375	0.882	0.1040*	2.861	8.802	0.17437	0.00809	4.60	1.20	0.30
LX-11	HMX/Viton 80/20	1.875	0.330	0.832	0.0900*	2.930	7.791	0.10668	0.00885	4.50	1.15	0.30
LX-13	See XTX-8003											
NM	Nitromethane	1.128	0.125	0.628	0.0510	2.538	2.092	0.05689	0.00770	4.40	1.20	0.30
Octol	HMX/TNT 78/22	1.821	0.342	0.848	0.0960*	2.830	7.486	0.13380	0.01167	4.50	1.20	0.38
PBX-9010	RDX/KEL F 90/10	1.787	0.340	0.839	0.0900	2.700	5.814	0.06801	0.00234	4.10	1.00	0.35
PBX-9011	HMX/Estane 90/10	1.777	0.340	0.850	0.0890*	2.776	6.347	0.07998	0.00727	4.20	1.00	0.30
PBX-9404-3	HMX/NC/CEF 94/3/3	1.840	0.370	0.880	0.1020	2.850	8.545	0.20493	0.00754	4.60	1.35	0.25
PBX-9407	RDX/EXON 94/6	1.600	0.265*	0.791	0.0860*	2.513	5.73187	0.146390	0.01200	4.60	1.40	0.32
Pentolite	TNT/PETN 50/50	1.670	0.250*	0.747	0.0800	2.727	4.911	0.09061	0.00876	4.40	1.10	0.30
PETN	Pentaerythritol tetranitrate	1.770	0.335	0.830	0.1010	2.640	6.170	0.16926	0.00699	4.40	1.20	0.25
		1.500	0.220	0.745	0.0856*	2.788	6.253	0.23290	0.01152	5.25	1.60	0.28
		1.260	0.140	0.654	0.0719*	2.831	5.731	0.20160	0.01267	6.00	1.80	0.28
PETN**		0.880	0.062	0.517	0.0502*	2.668	3.486	0.11288	0.00941	7.00	2.00	0.24
Tetryl**	Trinitrophenylmethylnitramine	1.730	0.285	0.791	0.0820	2.798	5.868	0.10671	0.00774	4.40	1.20	0.28
TNT	Trinitrotoluene	1.630	0.210	0.693	0.0600	2.727	3.738	0.03747	0.00734	4.15	0.90	0.35
XTX-8003	PETN/Sylgard 80/20	1.540	0.170	0.735	0.0660*	3.894	27.140	0.17930	0.01202	7.00	1.60	0.35

[a] One Mbar = 100 GPa.

[b] Two asterisks indicate that cylinder data are not available.

[c] Values followed by one asterisk are estimated quantities.

Detonation Energy

Detonation energies[21] (as measured by metal acceleration in the cylinder test) of formulations containing mostly HMX can be correlated with the volume fraction of additives by a simple linear relationship

$$E = E_{HMX}\left(1 - \sum S_i V_i\right), \tag{8-1}$$

where

E = detonation energy per unit volume of a formulation at its loaded density,

E_{HMX} = detonation energy per unit volume of pure HMX at its theoretical maximum density (TMD) of 1.90 g/cm^3 (Mg/m^3). The reference value is (wall velocity)^2 at 19 mm displacement in the cylinder test corrected to TMD. The corrected wall velocity is 1.872 mm/μsec (km/s).

S_i = characteristic energy decrement for each diluent,

V_i = volume fraction of each additive.

The energy decrement for a fixed combination of two or more ingredients is readily computed as

$$S_b = \frac{\sum S_i V_i}{\sum V_i} \quad \text{and} \quad V_b = \sum V_i, \tag{8-2}$$

where the subscript b denotes the fixed combination. The quantity $S_b V_b$ for the combination becomes one of the terms in Eq. 8-1. An $S_i V_i$ term for air or void takes account of porosity in the actual explosive. A convenient form of Eq. 8-1 gives relative energy as a percentage of HMX energy, $E_{Rel\%}$, and as a function of the volume percent, $V_{i\%}$, of additives:

$$E_{Rel\%} = \frac{100E}{E_{HMX}} = 100 - \sum S_i V_{i\%}. \tag{8-3}$$

The characteristic S_i can be recognized as a percent energy degradation from pure HMX for each volume percent of the additive. The S_i values for a number of additives are given in Table 8-7. Neither the applicable range of composition nor the exact linearity of Eq. 8-1 has been tested, but all formulations contained at least 70 wt% HMX.

Table 8-7. Characteristic energy decrement S_i from pure HMX for additives to HMX.

Additive[a]	S_i ($E_{Rel\%}/V_i$)	Additive[a]	S_i ($E_{Rel\%}/V_i$)
AFNOL	0.75	FEFO	0.3
Air	1.3	Graphite	1.3
BEAF	0.75	*HNS	0.5
BDNPA	0.75	Kel F	1.0
BDNPF	0.75	NC	0.75
CAB	1.3	*NG	0.3
CEF	1.3	Nitrosorubber	0.75
*DATB	0.5	*NONA	0.5
DFTNB	0.25	Polyethylene	1.3
*DIPAM	0.5	Sylgard	1.3
BDNPA/BDNPF 50/50	0.75	*TACOT	0.5
DNPA	0.75	*TATB	0.5
DNPN	0.75	Teflon	1.0
EDNP	0.75	TNT	0.5
Estane	1.3	Viton	1.0
EXON (polyvinyl chloride/ polyvinyl alcohol 85/15	1.0	Void	1.3
		Wax	1.3

[a]An asterisk denotes materials not actually tested; values estimated with RUBY code.

References

1. E. E. Kilmer, J. Spacecr. Rockets 5, 1216-1219 (1968).
2. U.S. Material Command, Engineering Design Handbook, Explosives Series, Properties of Explosives of Military Interest, Army Material Command, Rept. AMCP-706-177 (1967).
3. E. E. Kilmer, Naval Ordnance Laboratory, White Oak, Md., personal communication (1966).
4. A. C. Schwartz, Application of Hexanitrostilbene (HNS) in Explosive Components, Sandia Laboratories, Albuquerque, N. Mex., Rept. SC-RR-710673 (1972).
5. J. R. Humphrey, Lawrence Livermore Laboratory, personal communication (1974).
6. A. W. Campbell, M. E. Malin, T. J. Boyd, and J. A. Hull, Rev. Sci. Instrum. 27, 567-574 (1956).
7. T. M. Benziger, X-0242: A High-Energy Plastic-Bonded Explosive, Los Alamos Scientific Laboratory, N. Mex., Rept. LA-4872 (1972).
8. A. N. Dremin, Combust. Explos. Shock Waves 2 (4), 45-51 (1966).
9. M. J. Kamlet and S. J. Jacobs, J. Chem. Phys. 48, 23-35 (1968).
10. J. B. Panowski, Los Alamos Scientific Laboratory, N. Mex., personal communication (1974).
11. H. C. Hornig, Lawrence Livermore Laboratory, personal communication (1972).
12. A. Popolato, Los Alamos Scientific Laboratory, N. Mex., personal communication (1957).
13. D. Price and A. R. Clairmont, Jr., "Explosive Behavior of Nitroguanidine," in Symp. (Intern.) on Combustion, 12th, Combustion Institute, Pittsburgh (1969).
14. M. Finger, Lawrence Livermore Laboratory, personal communication (1971).
15. A. W. Campbell, M. E. Malin, and T. E. Holland, J. Appl. Phys. 27, 963 (1965).
16. H. C. Hornig, E. L. Lee, M. Finger, and K. E. Kurrle, "Equation of State of Detonation Products," in Proc. 5th Symp. (Intern.) on Detonation, U.S. Office of Naval Research, Washington, D.C., Rept. ACR-184 (1970), pp. 503-512.
17. E. L. Lee, Lawrence Livermore Laboratory, personal communication (1971).
18. M. J. Urizar, E. James, Jr., and L. C. Smith, Phys. Fluids 4, 262-274 (1961).
19. E. L. Lee and M. Finger, Lawrence Livermore Laboratory, personal communication (1972).
20. E. L. Lee, H. C. Hornig, and J. W. Kury, Adiabatic Expansion of High Explosive Detonation Products, Lawrence Livermore Laboratory, Rept. UCRL-50422 (1968).
21. J. W. Kury, H. C. Hornig, E. L. Lee, J. L. McDonnel, D. L. Ornellas, M. Finger, F. M. Strange, and M. L. Wilkins, "Metal Acceleration by Chemical Explosives," in Proc. 4th Symp. (Intern.) on Detonation, U.S. Office of Naval Research, Washington, D.C., Rept. ACR-126 (1965), pp. 3-13.

9. SENSITIVITY AND INITIATION

Several tests have been designed to evaluate the sensitivity of HEs to different kinds of impact under varying conditions. This aspect of the characterization of explosives is treated here in some detail in descriptions of drop-weight impact, Susan, skid, and gap tests. The sensitivity of liquid explosives can be assessed through determination of their low-velocity detonation (LVD) and high-velocity detonation (HVD) characteristics as established by a gap test. Some critical energies for shock initiation are given.

Drop-Weight Test

The drop-weight machine, or drop hammer, offers one means of evaluating impact sensitivity. In the test, a 2.5- or 5-kg weight is dropped from a preset height onto a small (~35-mg) sample of explosive. A series of drops is made from different heights, and explosion or nonexplosion is recorded. The criterion for "explosion" is an arbitrarily set level of sound produced by the explosive on impact. The result of the test is summarized as H_{50}, the height in cm (m) at which the probability of explosion is 50%.

Values in Table 9-1 were determined on a machine patterned after the one designed at the Explosives Division, Atomic Weapons Research Establishments (AWRE) at the time of World War II. Because of the extremely complicated process involved in initiation by impact, these drop-hammer data serve only as approximate indications of sensitivity. The H_{50} values are quite dependent on the anvil surface. Two surfaces are usually used: sandpaper (type 12 tooling) and roughened steel (type 12B tooling).

In general, values below 25 cm (0.25 m) usually indicate relative sensitivity to impact. Values of 25 to 70 cm (0.25 to 0.70 m) indicate a material of moderate sensitivity that possibly can be handled in accordance with standard procedures. Values above 70 cm (0.70 m) usually indicate relative insensitivity to impact.

The indications of sensitivity given by the drop-hammer test are always verified by large-scale testing (see the succeeding tests in this section) for any material to be handled in large quantities.

Table 9-1. Sensitivities of explosives as indicated by the drop-weight impact test.

Explosive	H_{50} (cm (10^{-2} m))		
	5-kg weight		2.5-kg weight
	Type 12 tooling	Type 12B tooling	Type 12B tooling
Baratol	95	--	--
Boracitol	>177	--	--
BTF	11	--	--
Comp B, Grade A	45	--	--
Comp B-3	29	65	--
Cyclotol 75/25	33	--	--
DATB	>177	>177	--
DIPAM[1]	95	--	--
DNPA	>177	--	--
EL-506A	59	--	--
EL-506C	54	--	--
FEFO	28	--	--
H-6	60	--	--
HMX	33	40	--
LX-02-1	80	--	--
LX-04-1	41	55	--
LX-07-2	38	--	--
LX-09-0	32	--	--
LX-10-0	35	--	40
LX-11-0	59	--	--
LX-13	See XTX-8002		
LX-14-0			51
NQ	>177	--	--
Octol	41	--	--
PBX-9007	35	28	--
PBX-9010	30	45	--
PBX-9011	44	98	--
PBX-9205	42	36	--
PBX-9404	34	35	40
PBX-9407	33	30	--
PBX-9501[2]	44	80	--
Pentolite 50/50	~35	--	--
PETN	11	--	--
RDX	28	--	--
TATB	>100	--	--
Tetryl	28	--	--
TNT	80	>177	--
XTX-8003 (uncured)	25	--	--
(cured)	21	--	--

Susan Test

The Susan Sensitivity Test[2] is a projectile impact test with the projectile shown in Fig. 9-1. The weight of explosive in the projectile head is about 1 lb (0.45 kg). The

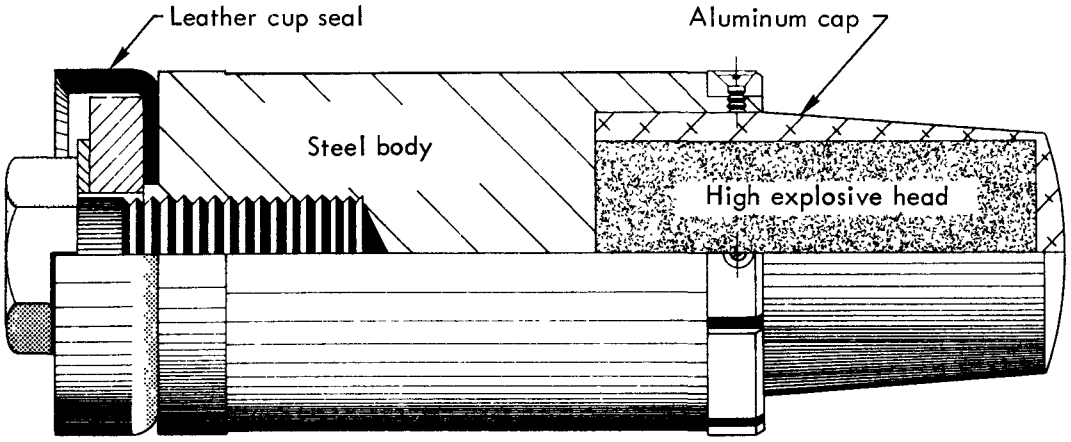


Fig. 9-1. The Susan projectile. Scaled drawing; the high explosive head is 4 in. long by 2 in. in diameter (0.102 m × 0.051 m).

target is armor-plate steel. The results of the tests are expressed in terms of a "sensitivity" curve in which the relative "point-source detonation energy" released by the explosive as a result of the impact is plotted against the velocity of the projectile. The relative point-source detonation energy can be derived from a transit-time measurement of the air shock from the point of impact to a pressure gauge 10 ft (3.1 m) away. The results determined in this manner are somewhat subjective, particularly when the reaction level shows a large but relatively slow increase with time. The preferred way to get at the "point-source detonation energy" at present is to relate it to the overpressure measured 10 ft (3.1 m) from the impact. This results in much more reproducible data and is not subject to many of the errors of the transit-time measurements.

On the figures in this section the energy scale has been set to range from zero for no chemical reaction to approximately 100 for the most violent detonation-like reactions (all explosive consumed) for the most energetic explosives. Less violent burning reactions that appear to consume all of the explosive can give values on the scale as low as 40; the energy equivalent of TNT fully reacted as a point source, would register at 70 on the scale. For each explosive considered, comments are made on the details of the impact process that seem to bear on the impact safety of an explosive. Remarks about probabilities of large reactions are relevant to unconfined charges in the 25-lb (11.3-kg) class. Smaller unconfined charges show a trend of decreasing reaction level as the charge size gets smaller.

References to the "pinch" stage of the impact refer to the terminal stage when the nose cap has been completely split open longitudinally and peeled back to the steel projectile body, which is rapidly being brought to a halt.

Comp B-3

Comp B-3 (RDX/TNT 60/40) behaves reasonably well in the standard Susan test (Fig. 9-2). Ignition is observed only after extensive splitting and deformation of the projectile nosecap, more or less at the beginning of the "pinch" stage of impact. This results in a threshold velocity of about 180 ft/sec (55 m/sec). The reaction level is quite dependent on impact velocity; it never rises to its full potential even at an impact velocity of 1500 ft/sec (457 m/sec). Any reaction enhancement is seen quite soon after initial ignition. Comp B-3 should be considered as generally rather difficult to ignite by mechanical means and as having a low probability for violent reaction once ignited, provided the relative confinement is rather low. It has given substantially larger reactions in the Mod-IA projectile than in the standard Mod I; the important difference between the two projectiles appears to be the exceptionally straight flight of the Mod-IA, which results in higher pressures on the explosive and more effective confinement. Comp B-3 has been observed to detonate in impact geometries where there was good inertial confinement at the time of ignition, and where it has been subjected to mechanical work by the impact.

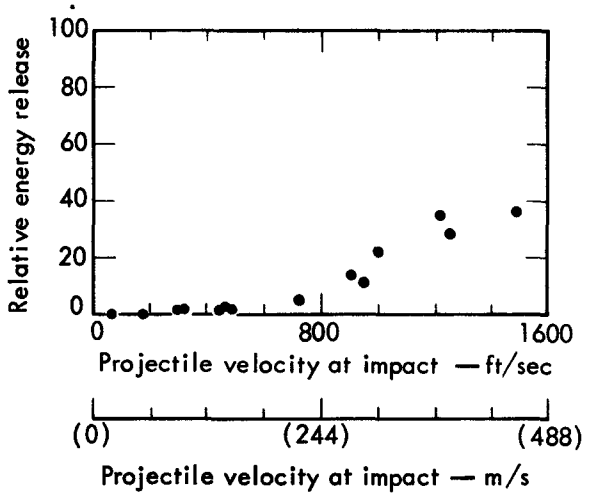


Fig. 9-2. Susan test: Comp B-3. Conversion factor: 1 ft/sec = 3.048 × 10^{-1} m/s.

Cyclotol 75/25

Cyclotol 75/25 (RDX/TNT 75/25) has both good and bad properties as measured by the Susan test (Fig. 9-3). The threshold velocity for reaction is probably about 180 ft/sec (55 m/sec), which is rather typical of the TNT-bonded cast explosives and higher than most plastic-bonded explosives. On the other hand, reaction levels generally are moderately high at relatively low velocity and on occasion are considerably higher. Cyclotol 75/25 should be considered as generally rather difficult to ignite by mechanical means but capable of a large reaction once ignited. Note should be taken of the very low drop height for ignition in the 14-deg (0.24-rad) skid test (Table 9-2).

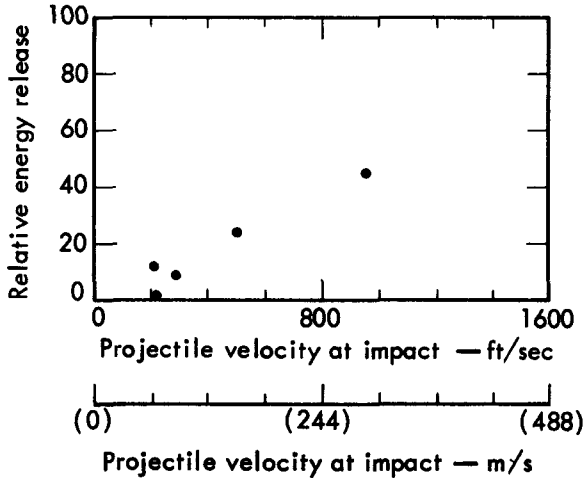


Fig. 9-3. Susan test: Cyclotol 75/25. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

LX-02-1

LX-02-1 (PETN/butyl rubber/acetyltributyl citrate/Cab-O-Sil 73.5/17.6/6.9/2.0) appears more difficult to ignite in the Susan test than XTX-8003, but the exact threshold value is poorly defined due to the very small reactions observed and the limited number of tests (Fig. 9-4). Even at 505 ft/sec (154 m/s), the reaction level was very low. The very limited data indicate that LX-02-1 has a very small probability of building to a violent reaction from an accidental ignition where there is relatively little or no confinement.

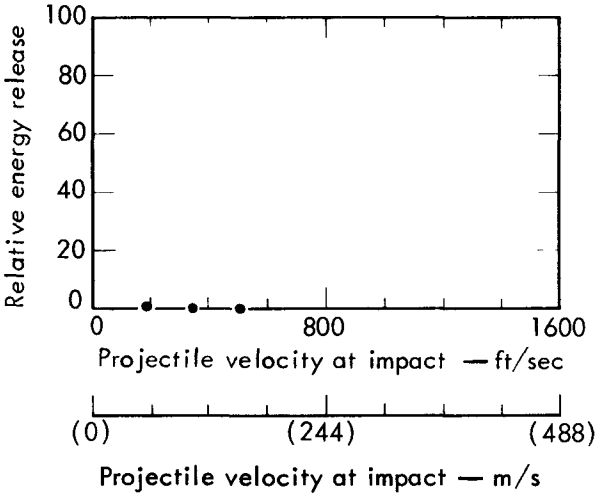


Fig. 9-4. Susan test: LX-02-1. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

LX-04-1

LX-04-1 (HMX/Viton 85/15) is moderately easy to ignite in the Susan test (Fig. 9-5), requiring an impact velocity of 140 to 150 ft/sec (43 to 46 m/s). At impact velocities higher than threshold, the nosecap deforms about an inch before ignition is observed. Reaction levels are dependent on impact velocity, rising very slowly to three or four energy units from threshold out to about 350 ft/sec (107 m/s) and then rising more rapidly as impact velocity increases to 40 or 50 energy units at 1000 ft/sec (305 m/s). Thus, while LX-04-1 is moderately easy to ignite from mechanical impact, it has a low probability of building to a violent reaction or detonation from a minor ignition where there is little or no confinement. Note that LX-04-1 frequently has been observed to detonate high-order in other impact test geometries where the effective confinement was rather good and the explosive was well pulverized to give a large surface area at the time of ignition.

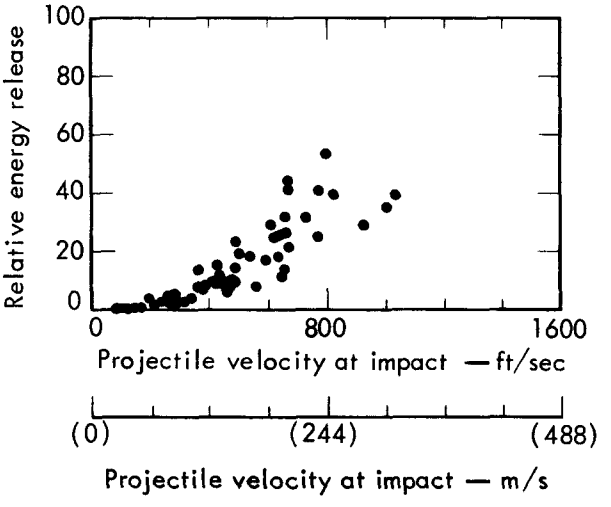


Fig. 9-5. Susan test: LX-04-1. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

LX-07-2

LX-07-2 (HMX/Viton 90/10) is intermediate in sensitivity between PBX-9404 and LX-04-1. The threshold for reaction is about 125 ft/sec (38 m/s), and the reaction level, while dependent upon impact velocity, becomes large at a rather low velocity (Fig. 9-6). Small changes in manufacturing variables can affect the extent of reaction in the Susan test. The LX-07-2 initially tested was a handmade batch that gave appreciably larger reactions than previously tested LX-07-type explosives. Figure 9-6 also shows the results for RX-07-BA, manufactured at the Holston Army Ammunition Plant, which meets the LX-07-2 specifications and, based on the results of three shots, appears to be more like the previous LX-07-type explosives. Thus, LX-07-2 has a low threshold for reaction but only a moderate rate of buildup to violent reaction. It appears that accidental mechanical ignition of LX-07-2 would have a moderate probability of building to violent deflagration or detonation where the relative confinement was rather low.

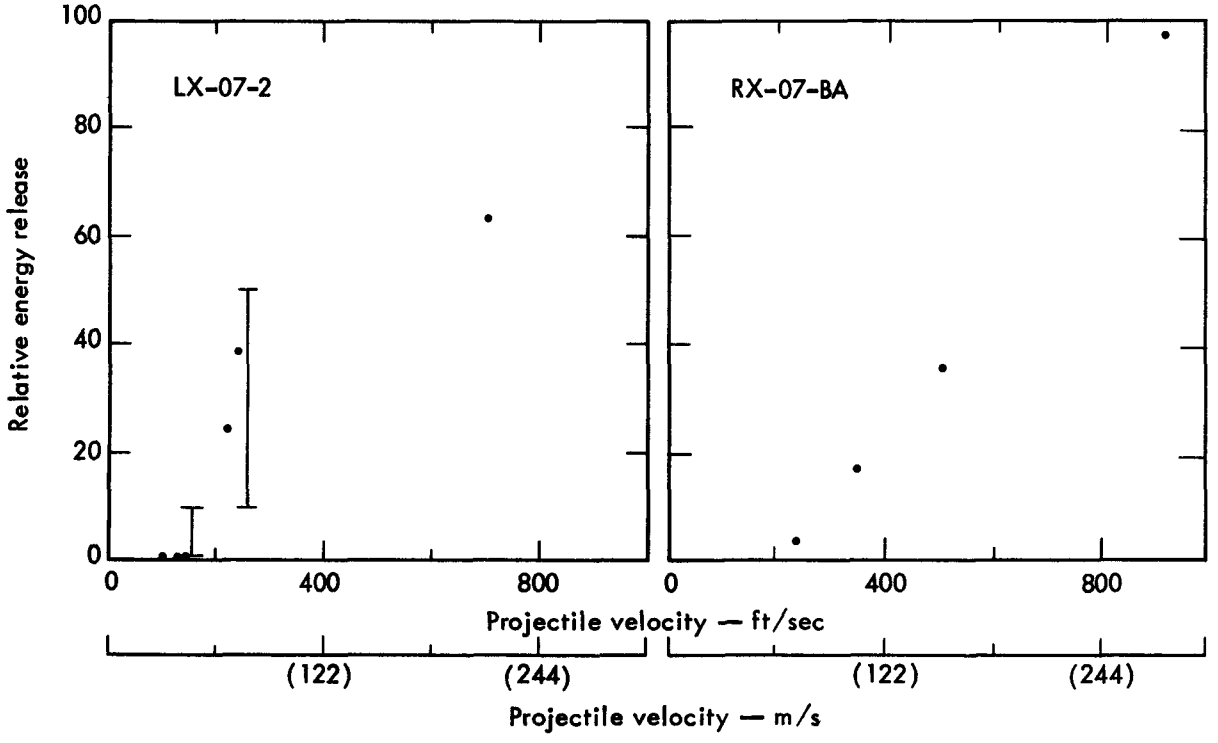


Fig. 9-6. Susan test: LX-07-2 and RX-07-BA. Conversion factor: 1 ft/sec = 3.048 $\times 10^{-1}$ m/s.

LX-09-0

LX-09-0 (HMX/pDNPA/FEFO 93/4.6/2.4) displays some very undesirable properties in the Susan test (Fig. 9-7); it is very similar to PBX-9404 in many respects. Ignition is seen after about 0.5-in. (13-mm) deformation of the projectile nosecap, which is consistent with the very low threshold velocity of 110 ft/sec (34 m/s). As with PBX-9404, "pinch"-stage enhancement of the reaction is observed only at impact velocities greater than about 200 ft/sec (51 m/s). At lower-impact velocities, reactions build to violent levels with sufficient rapidity that no "pinch" stage enhancement is observed. The reaction levels observed are generally quite high and independent of impact velocity. Thus, LX-09-0 exhibits both low-threshold velocity for reaction and rapid buildup to violent reaction. Any accidental mechanical ignition has a large probability of building to a violent deflagration or detonation.

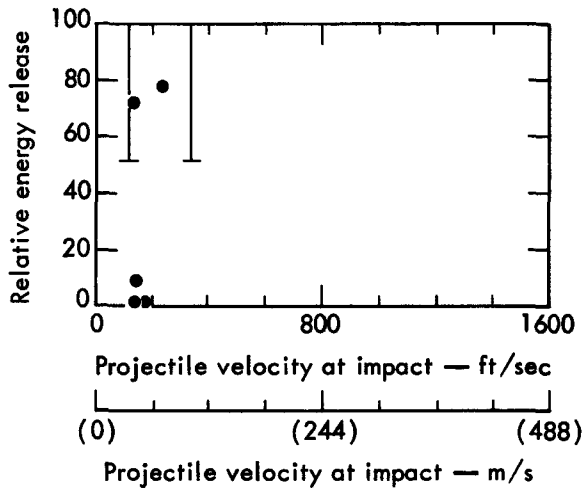


Fig. 9-7. Susan test: LX-09-0. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

LX-10-0

LX-10-0 (HMX/Viton 95/5) displays some very undesirable properties in the Susan Test (Fig. 9-8). Ignition is observed after about 0.6-in. (15 mm) of projectile nosecap deformation, which is consistent with the low threshold velocity of about 120 ft/sec (37 m/s). The reaction levels observed are generally quite high and independent of impact velocity. The reaction buildup is sufficiently rapid that no "pinch" stage enhancement of the reaction is observed. LX-10-0 exhibits both a low threshold for reaction and an extremely rapid buildup to violent reaction. Any accidental mechanical ignition of LX-10-0 has a very large probability of building to violent deflagration or detonation.

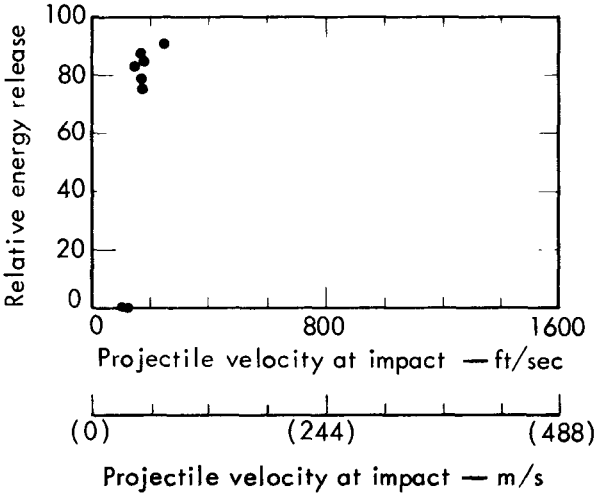


Fig. 9-8. Susan test: LX-10-0. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

LX-11-0

LX-11-0 (HMX/Viton 80/20) is among the least reactive of the PBXs tested in the Susan test (Fig. 9-9). The threshold for reaction is probably about 170 ft/sec (52.8 m/s), judging from the nosecap deformation of 1.8 to 1.9 in. (46 to 49 mm) at the time ignitions were observed for the higher velocity shots. Most TNT-containing cast explosives require even more deformation for ignition; however, the reaction level is quite dependent on impact velocity and is generally lower than that observed for LX-04-1, although not as low as that observed for Comp B-3. The rather high value of 44 energy units at 612 ft/sec (187 m/s) is considered atypical and possibly due to axisymmetric impact. Reaction enhancement is observed at the "pinch" stage of the impact. LX-11-0 should be considered as moderately difficult to ignite by mechanical means and as having very low probability of building to violent reaction from a minor ignition where there is relatively little confinement.

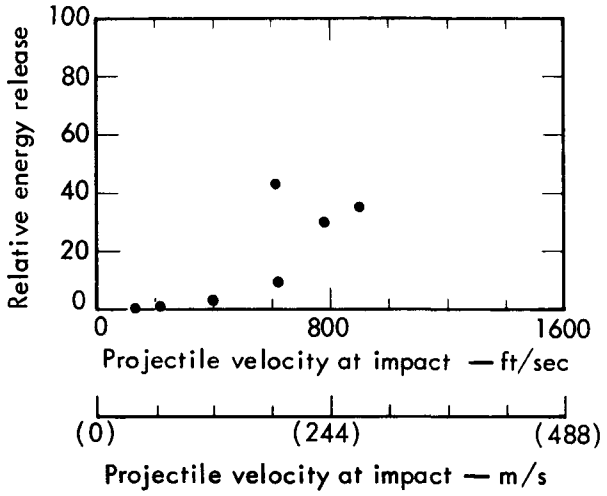


Fig. 9-9. Susan test: LX-11-0. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

LX-14-0

LX-14-0 (HMX/Estane 95.5/4.5) is moderately easy to ignite in the Susan test, requiring an impact velocity of about 48 m/s.(Fig. 9-10). This is slightly higher than that required for LX-04-1. Nosecap deformation is generally greater than 25 mm before ignition is observed. Reaction levels tend to be somewhat large and erratic once the threshold velocity is exceeded, somewhat like those of LX-07-2. In support of this tendency skid test results on LX-14 are intermediate in reaction level between LX-04-1 and LX-07-2. It appears that accidental mechanical ignition of LX-14-0 would have a moderately low probability of building to a violent reaction or detonation where there was little or no confinement.

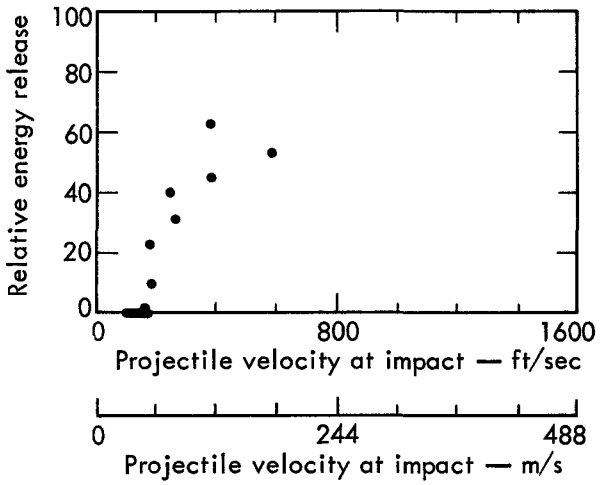


Fig. 9-10. Susan test: LX-14-0. Conversion factor = 1 ft/sec = 3.048×10^{-1} m/s.

Octol 75/25

Octol 75/25 (HMX/TNT 75/25) has both good and bad properties as measured by the Susan test (Fig. 9-11). The threshold velocity for reaction is probably about 180 ft/sec (55 m/s), which is rather typical of the TNT-bonded cast explosives and higher than most plastic-bonded explosives. On the other hand, reaction levels become moderately high, generally at relatively low velocity. The variability of results is less than that observed with Cyclotol 75/25. Octol 75/25 should be considered as rather difficult to ignite accidentally by mechanical means but capable of a large reaction once ignited under certain conditions.

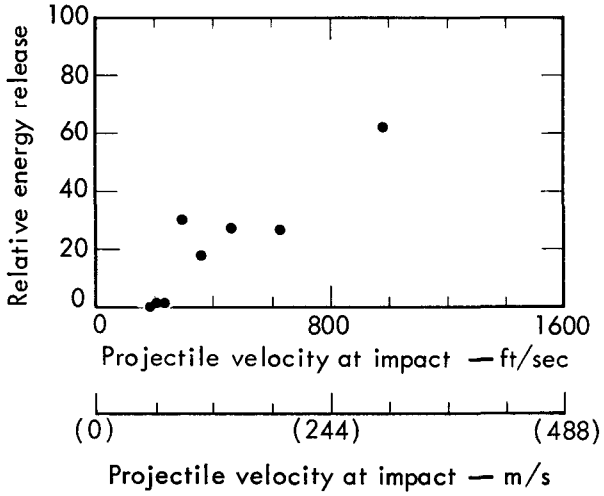


Fig. 9-11. Susan test: Octol 75/25. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

PBX-9010

PBX-9010 (RDX/Kel F 90/10) displays some very undesirable properties in the Susan test (Fig. 9-12). Ignition is observed after about 0.5-in. (13 mm) of projectile nosecap deformation, which would make the threshold velocity for reaction about 110 ft/sec (34 m/s). The reaction levels observed are high and independent of impact geometry. The observed energy release is not as high as that often seen with the more energetic explosives PBX-9404, LX-09-0, and LX-10-0, but intrinsic energy content does not completely explain the difference; geometric factors at the time of maximum reaction are thought to also contribute to the observed results. The reaction buildup is sufficiently rapid that no "pinch" stage enhancement of the reaction is observed. PBX-9010 exhibits both a low threshold for reaction and sufficient reactivity to indicate a very large probability of violent reaction or detonation from any accidental mechanical ignition.

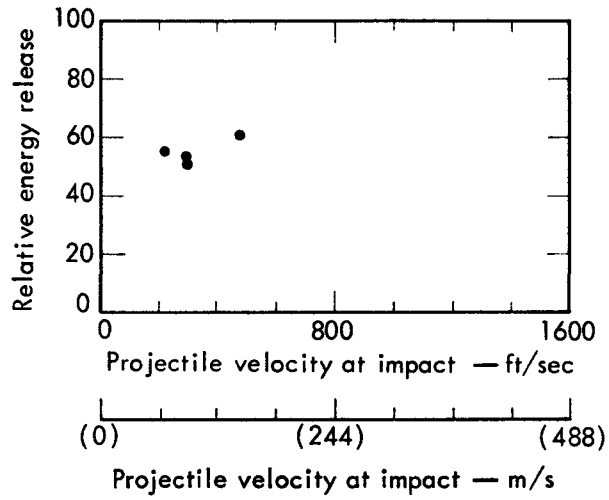


Fig. 9-12. Susan test; PBX-9010. Conversion factor: 1 ft/sec = 3.048 × 10^{-1} m/s.

PBX-9011

PBX-9011 (HMX/estane 90/10) is among the least reactive of the PBXs tested in the Susan test (Fig. 9-13). The threshold for reaction is probably about 165 ft/sec (50 m/s), judging from the nosecap deformation of about 1.7-in. (43 mm) at the time of observed ignition for the higher-velocity shots. The reaction level is quite dependent on the impact velocity; it is generally somewhat lower than that observed for LX-04-1 but not as low as for Comp B-3. Reaction enhancement is observed only at the "pinch" stage of the impact. PBX-9011 should be considered as moderately difficult to ignite by mechanical impact and as having very low probability of building to violent reaction from a minor ignition where there is relatively little confinement. PBX-9011 has given only mild reactions in other impact geometries that often give detonations with explosives such as LX-04-1.

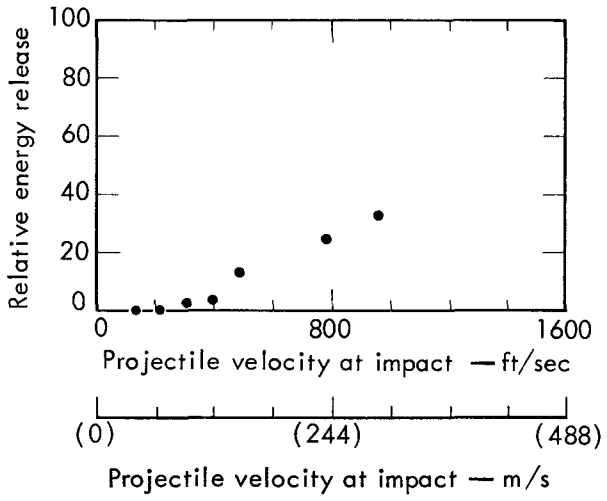


Fig. 9-13. Susan test: PBX-9011. Conversion factor: 1 ft/sec = 3.048 × 10^{-1} m/s.

PBX-9205

PBX-9205 (RDX/polystyrene/di-2-ethylhexylphthalate 92/6/2) is similar to LX-07-2 in some of its properties (Fig. 9-14). The threshold velocity for reaction is probably about 120 ft/sec (37 m/s), judging from the nosecap crush-up at the time of observed ignition with higher-velocity impacts. As with LX-07-2, the response is dependent on impact velocity and is intermediate between that of PBX-9404 and LX-04-1. Thus, PBX-9205 has a low threshold for reaction but only a moderate rate of buildup to violent reaction. It appears that accidental mechanical ignition of PBX-9205 would have a moderate probability of building to violent deflagration or detonation.

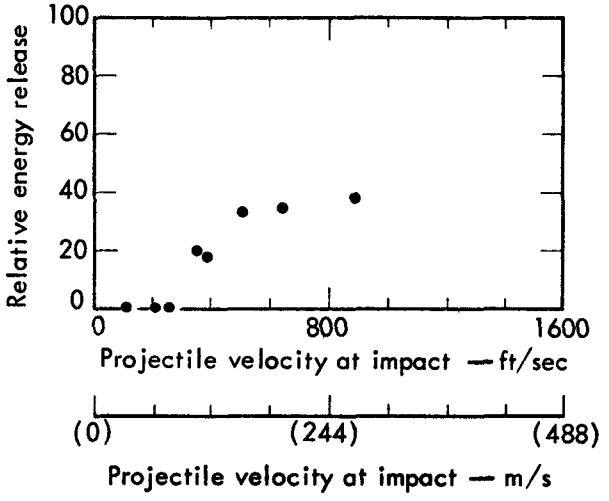


Fig. 9-14. Susan test: PBX-9205. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

PBX-9404-03

PBX-9404 (HMX/NC/tris-β-chloroethyl phosphate 94/3/3) displays some very undesirable properties in the Susan test (Fig. 9-15). Ignition is seen after only about 0.35-in. (8.9 mm) of deformation of the projectile nosecap, which is consistent with the very low threshold velocity of 105 ft/sec (32 m/s). The reaction levels are generally quite high for impacts in the range of 105 to 200 ft/sec (32 to 61 m/s). These reactions build to violent levels with sufficient rapidity that no "pinch" stage enhancement of the reaction is observed. At higher impact velocities, the reaction level seems to depend somewhat on impact velocity, but it is always at least moderately high. "Pinch" stage enhancement of the reaction at these higher-impact velocities is very noticeable. PBX-9404 exhibits both a very low threshold velocity for reaction and rapid buildup to violent reaction. Any mechanical ignition of PBX-9404 has a very large probability of building to violent deflagration or detonation.

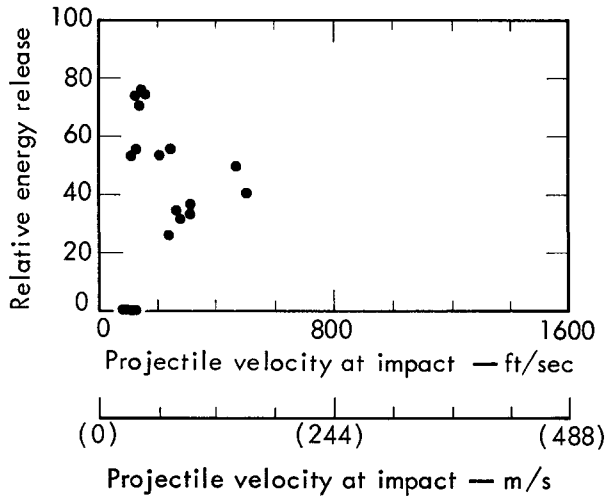


Fig. 9-15. Susan test: PBX-9404. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

PBX-9501

PBX-9501 (HMX/estane/DNPAF 95/2.5/2.5) is a high-energy explosive with low impact sensitivity for an explosive of its power (Fig. 9-16). The threshold velocity for reaction is about 200 ft/sec (61 m/s), which is higher than that for most PBXs and about equal to that for many TNT-based explosives. Reactions start after about 2.52 in. (6.4 cm) of projectile deformation, which is consistent with the observed threshold velocity. Once threshold velocity is exceeded, reactions become violent over a rather narrow velocity range. Small reactions do not automatically grow to large reactions as they do in many other high-energy PBXs. Skid-test ignitions, for example, give very low reactions.

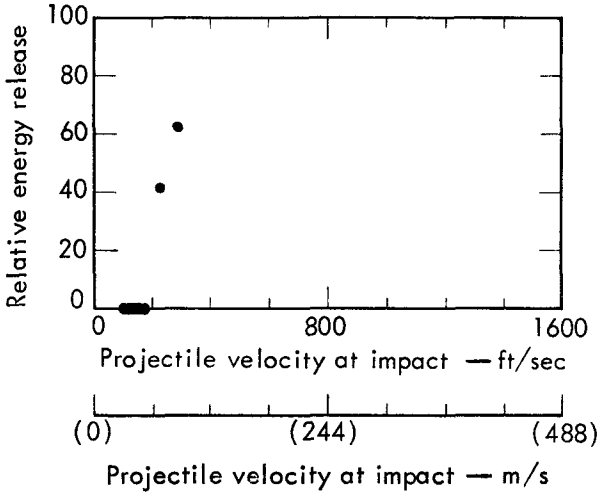


Fig. 9-16. Susan test: PBX-9501. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

TNT

TNT shows no undesirable properties by the Susan test (Fig. 9-17). Minor ignitions are seen down to about 235 ft/sec (72 m/s) impact velocity but only after extensive splitting of the projectile nosecap and abrupt halt of the projectile at the final or "pinch" stage of impact. No violent reactions are observed even at impact velocities above 1200 ft/sec (366 m/s). Further, the TNT response is independent of whether it is cast or is a high- or medium-density pressing. TNT should be considered very difficult to ignite accidentally by mechanical means; any reaction from such an ignition should be regarded as having an extremely low probability of building to violent levels where there is relatively little confinement.

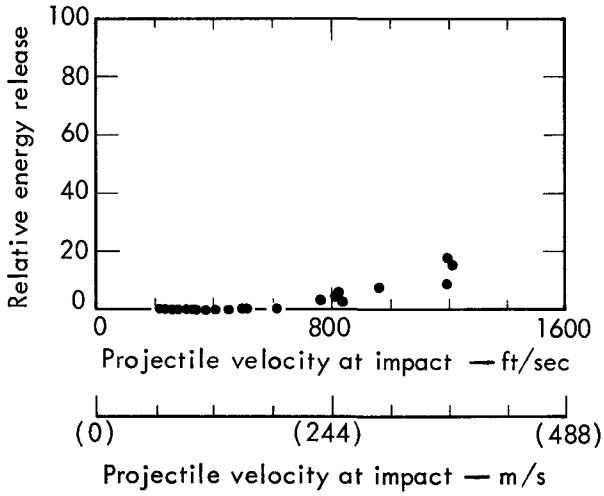


Fig. 9-17. Susan test: TNT. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

XTX-8003

XTX-8003 (PETN/silicone rubber 80/20) is moderately difficult to ignite in the Susan test (Fig. 9-18), requiring an impact velocity of about 160 ft/sec (49 m/s), judging from the 1.4-in. (36 mm) of projectile nosecap deformation at the time of observed ignition. Reaction levels ranged from quite low to moderately low over the velocity range tested. While the number of tests is limited, it appears that XTX-8003 has a very small probability of building to violent reaction from an accidental ignition where there is relatively little or no confinement.

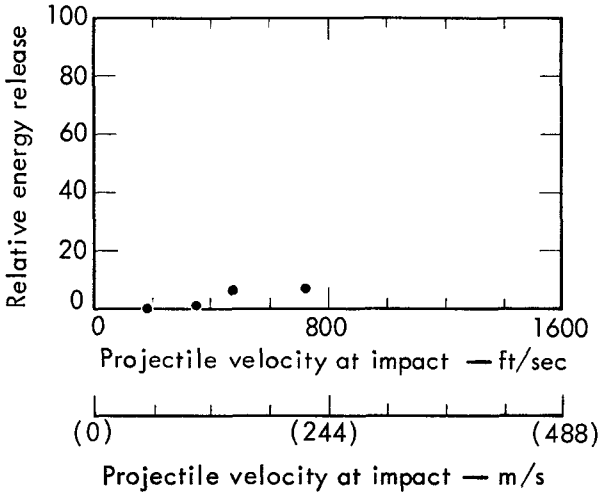


Fig. 9-18. Susan test: XTX-8003. Conversion factor: 1 ft/sec = 3.048×10^{-1} m/s.

Skid Test

Results from a sliding impact sensitivity test (skid test) with large hemispherical billets of HE have proved valuable for evaluating the plant-handling safety of HEs.[4,5] The test was developed at AWRE in England.

In the LLL-Pantex version of this test, the explosive billet, supported on a pendulum device, is allowed to swing down from a preset height and strike at an angle on a sand-coated steel target plate. Impact angles employed are 14 deg (0.24 rad) and 45 deg (0.79 rad) (defined as the angle between the line of billet travel and the horizontal target surface; the heights vary). The spherical surface of the billet serves to concentrate the force of the impact in a small area; the pendulum arrangement gives the impact both a sliding or skidding component as well as a vertical one. The results of the test (Table 9-2) are expressed in terms of the type of chemical event produced by the impact as a function of impact angle and vertical drop. Chemical events are defined as follows:

0 No reaction; charge retains integrity.

1 Burn or scorch marks on HE or target; charge retains integrity.

2 Puff of smoke, but no flame or light visible in high-speed photography. Charge may retain integrity or may be broken into large pieces.

3 Mild low-order reaction with flame or light; charge broken up and scattered.

4 Medium low-order reaction with flame or light; major part of HE consumed.

5 Violent deflagration; virtually all HE consumed.

6 Detonation.

The sliding-impact test results are significant indications of plant-handling safety because the drop heights and impact angles used in the test are quite within the limits one might find for the accidental drop of an explosive billet. The test is used not only to evaluate the relative sensitivity of different explosives, using the sand-coated target as a reference surface (Table 9-2), but also to evaluate typical plant floor coverings, using PBX-9010 as a reference explosive (Table 9-3 and 9-4).

Table 9-2. Standard LLL-Pantex skid test with hemispheres of explosive 11 in. (0.28 m) in diameter and weighing 23 lb (10.4 kg).[a]

Explosive	Impact angle (deg)	Impact angle (rad)	Vertical drop (ft)	Vertical drop (m)	Chemical event
Comp B-3	14	(0.24)	3.5	(1.07)	0
	14	(0.24)	5.0	(1.52)	1, 0, 4
	14	(0.24)	7.1	(2.16)	2
	45	(0.79)	28.0	(8.53)	0
Cyclotol 75/25	14	(0.24)	0.62	(0.19)	0
	14	(0.24)	0.88	(0.27)	4
	14	(0.24)	1.75	(0.53)	3
	45	(0.79)	7.1	(2.16)	0
	45	(0.79)	14.0	(4.27)	0
	45	(0.79)	28.0	(8.53)	0
LX-04-1	14	(0.24)	1.75	(0.53)	0
	14	(0.24)	2.5	(0.76)	2
	14	(0.24)	14.1	(4.30)	2, 1
	45	(0.79)	3.5	(1.07)	0, 0
	45	(0.79)	5.0	(1.52)	3, 0
	45	(0.79)	7.1	(2.16)	1, 0
	45	(0.79)	10.0	(3.05)	2
	45	(0.79)	14.1	(4.30)	3
LX-07-1	14	(0.24)	0.88	(0.27)	0, 0, 0, 0
	14	(0.24)	1.25	(0.38)	0, 0, 0
	14	(0.24)	1.75	(0.53)	0, 0, 0
	14	(0.24)	2.5	(0.76)	6, 4, 3
	45	(0.79)	2.5	(0.76)	0, 0
	45	(0.79)	3.5	(1.07)	0, 0, 0, 0, 0
	45	(0.79)	5.0	(1.52)	0, 0, 0
	45	(0.79)	7.1	(2.16)	5, 0, 0, 0, 0, 0, 0
LX-09-0	14	(0.24)	0.88	(0.27)	0, 0, 0, 0
	14	(0.24)	1.25	(0.38)	6, 0, 0
	45	(0.79)	3.5	(1.07)	0, 0, 0
	45	(0.79)	5.0	(1.52)	6, 0, 0, 0
	45	(0.79)	7.1	(2.16)	0
LX-10-0	14	(0.24)	0.88	(0.27)	0, 0, 0, 0, 0 0, 0, 0, 0
	45	(0.79)	2.5	(0.76)	0, 0, 0
	45	(0.79)	3.5	(1.07)	6, 6, 0, 0, 0 0, 0, 0, 0, 0 0, 0, 0, 0, 0
Octol 75/25	14	(0.24)	2.5	(0.76)	0, 0
	14	(0.24)	3.5	(1.07)	6, 6
PBX-9010	14	(0.24)	0.88	(0.27)	0
	14	(0.24)	1.25	(0.38)	6, 0, 0, 0
	14	(0.24)	1.5	(0.46)	0
	14	(0.24)	1.75	(0.53)	0, 0
PBX-9011	14	(0.24)	7.1	(2.16)	0
	14	(0.24)	10.0	(3.05)	0
	14	(0.24)	20.0	(6.10)	2
	45	(0.79)	14.1	(4.30)	0
	45	(0.79)	20.0	(6.10)	0
PBX-9205	14	(0.24)	0.88	(0.27)	0
	14	(0.24)	1.25	(0.38)	2
	14	(0.24)	1.75	(0.53)	3
	45	(0.79)	1.25	(0.38)	0
	45	(0.79)	1.75	(0.53)	0
	45	(0.79)	2.5	(0.76)	4
PBX-9404	14	(0.24)	0.88	(0.27)	0, 0, 0, 0
	14	(0.24)	1.25	(0.38)	6, 6, 6, 0
	14	(0.24)	1.75	(0.53)	6, 6
	45	(0.79)	1.75	(0.53)	0, 0, 0, 0, 0, 0
	45	(0.79)	2.5	(0.76)	0, 0, 0
	45	(0.79)	3.5	(1.07)	6, 0, 0, 0, 0, 0, 0, 0
	45	(0.79)	5.0	(1.52)	6, 6, 6, 6, 0, 0, 0, 0, 0
	45	(0.79)	7.1	(2.16)	6, 6
PBX-9501	14	(0.24)	1.25	(0.38)	0, 0, 0
	14	(0.24)	5.0	(1.52)	0
	14	(0.24)	10.0	(3.05)	3
	45	(0.79)	5.0	(1.52)	0, 0, 0
	45	(0.79)	10.0	(3.05)	0, 0, 0

[a]One in. = 2.540×10^{-2} m; 1 lb = 4.535924×10^{-1} kg; 1 ft = 3.048×10^{-1} m; 1 deg = 1.745329×10^{-2} rad.

Table 9-3. Nonstandard skid tests of interest. Target: standard sand-coated steel (1/4-in. (6.375-mm)) bonded to concrete.[a]

Explosive		Weight (lb)	Weight (kg)	Impact angle (deg)	Impact angle (rad)	Vertical drop (ft)	Vertical drop (m)	Chemical event
Comp B		50	(22.7)	14	(0.24)	5.0	(1.52)	4
LX-04-0	-57°F (224 K)	23	(10.4)	45	(0.79)	3.5	(1.07)	2
	60°F (290 K)	23	(10.4)	14	(0.24)	1.25	(0.38)	0
		23	(10.4)	14	(0.24)	1.75	(0.53)	2
		23	(10.4)	45	(0.79)	3.5	(1.07)	0
		23	(10.4)	45	(0.79)	5.0	(1.52)	3
	235°F (385 K)	23	(10.4)	14	(0.24)	5.0	(1.52)	0
		23	(10.4)	45	(0.79)	14.1	(4.30)	0
		50	(22.7)	45	(0.79)	7.1	(2.16)	0
LX-04-1		298	(135.2)	45	(0.79)	0.88	(0.27)	0
		298	(135.2)	45	(0.79)	1.25	(0.38)	0
		298	(135.2)	45	(0.79)	1.75	(0.53)	5
LX-09-0	Aged 11 months;	28	(12.7)	14	(0.24)	0.88	(0.27)	0
	70°C (343 K)	28	(12.7)	45	(0.79)	2.5	(0.76)	0
		28	(12.7)	45	(0.79)	3.5	(1.07)	6, 0
	Control for aged sample	28	(12.7)	14	(0.24)	0.88	(0.27)	6
		28	(12.7)	45	(0.79)	2.5	(0.76)	0
		28	(12.7)	45	(0.79)	3.5	(1.07)	0, 0
LX-10-0	Made with Fluorel	23	(10.4)	14	(0.24)	0.88	(0.27)	0, 0, 0
		23	(10.4)	45	(0.79)	3.5	(1.07)	0, 0, 0
	With 48 lb (21.8 kg) of	69	(31.3)	14	(0.24)	0.44	(0.13)	0
	steel plate on HE equator	70	(31.8)	14	(0.24)	0.66	(0.20)	6
LX-14-0		291	(132)	45	(0.79)	0.88	(0.27)	0
		292	(132.4)	45	(0.79)	1.25	(0.38)	0
		291	(132)	45	(0.79)	1.50	(0.46)	0
		290	(131.6)	45	(0.79)	1.75	(0.53)	0
		290	(131.6)	45	(0.79)	2.5	(0.76)	0
		290	(131.6)	45	(0.79)	5.0	(1.52)	6
PBX-9404		296	(134.3)	14	(0.24)	0.25	(0.08)	0
		292	(132.4)	14	(0.24)	0.33	(0.10)	6
		296	(134.3)	14	(0.24)	0.48	(0.15)	6
		296	(134.3)	45	(0.79)	0.33	(0.10)	0
		298	(135.2)	45	(0.79)	0.44	(0.13)	0
		293	(132.9)	45	(0.79)	0.60	(0.18)	0
		291	(132.0)	45	(0.79)	0.63	(0.19)	0
		297	(134.7)	45	(0.79)	1.23	(0.38)	0
		295	(133.8)	45	(0.79)	1.83	(0.56)	0
		296	(134.3)	45	(0.79)	2.5	(0.76)	0
PBX-9501	-34°C (239 K)	23	(10.4)	14	(0.24)	0.62	(0.19)	6
	16°C (289 K)	23	(10.4)	14	(0.24)	0.88	(0.27)	0, 0, 0, 0, 0
	16°C (289 K)	23	(10.4)	14	(0.24)	1.25	(0.38)	6, 6, 0
	-34°C (239 K)	23	(10.4)	45	(0.79)	0.88	(0.27)	0[b]
	-34°C (239 K)	23	(10.4)	45	(0.79)	1.25	(0.38)	0[b]
	-34°C (239 K)	23	(10.4)	45	(0.79)	1.75	(0.53)	0[b]
	-34°C (239 K)	23	(10.4)	45	(0.79)	2.5	(0.76)	0[b]
	-34°C (239 K)	23	(10.4)	45	(0.79)	3.5	(1.07)	0[b]
	-34°C (239 K)	23	(10.4)	45	(0.79)	5.0	(1.52)	6
	16°C (289 K)	23	(10.4)	45	(0.79)	2.5	(0.76)	0, 0, 0
	16°C (289 K)	23	(10.4)	45	(0.79)	3.5	(1.07)	6, 6, 0, 0, 0
	16°C (289 K)	23	(10.4)	45	(0.79)			0, 0, 0, 0, 0
	16°C (289 K)	23	(10.4)	45	(0.79)			0, 0, 0, 0, 0
	16°C (289 K)	23	(10.4)	45	(0.79)			0, 0, 0
	71°C (344 K)	23	(10.4)	45	(0.79)	2.5	(0.76)	0
	71°C (344 K)	23	(10.4)	45	(0.79)	3.5	(1.07)	0
	71°C (344 K)	23	(10.4)	45	(0.79)	5.0	(1.52)	0
	71°C (344 K)	23	(10.4)	45	(0.79)	7.1	(2.16)	0

[a] One in. = 2.540×10^{-2} m; 1 lb = 4.535924×10^{-1} kg; 1 ft = 3.048×10^{-1} m; 1 deg = 1.745329×10^{-2} rad.

[b] Acrid or burnt odor noticed after test.

Table 9-4. Evaluation of plant floorings by LLL-Pantex test with 50-lb (22.7-kg) hemispheres of PBX-9010 and, except where otherwise noted, 45 deg (0.79 rad) impact angle.[a]

Floor Material	Thickness (in.)	Thickness (mm)	Vertical drop (ft)	Vertical drop (m)	Chemical event
Corrugated rubber floor covering					
Against grain			10	(3.05)	0, 0
With grain			10	(3.05)	0
			20	(6.10)	0
Linoleum	1/8	(3.18)	7.1	(2.16)	0
			10.0	(3.05)	0
			14.1	(4.30)	0
			20.0	(6.10)	0
Poly-Con[b]			2.5	(0.76)	0
			3.5	(1.07)	0
			5.0	(1.52)	0
			7.1	(2.16)	6
14 deg (0.24 rad) impact angle			1.25	(0.38)	0
			1.75	(0.53)	0
			2.5	(0.76)	0
			3.5	(1.07)	0
			5.0	(1.52)	6
Polyurethane (Adiprene L-100)	5/64	(1.98)	7.1	(2.16)	0
			14.1	(4.30)	0
			24.0	(7.32)	0
Sanded steel			1.75	(0.53)	0
			2.5	(0.76)	6, 6
Torginal (Torga-Deck)	1/16	(1.59)	14.0	(4.27)	0
			20.0	(6.10)	6
	3/16 to 1/4	(4.76 to 6.35)	20.0	(6.10)	0
			28.0	(8.53)	1
Urapol floor covering	3/32	(2.38)	10	(3.05)	0
			14.1	(4.30)	0
			20	(6.10)	0
	1/8	(3.18)	10	(3.05)	0
			14.1	(4.30)	0
			20	(6.10)	0
14 deg (0.24 rad) impact angle			20.0	(6.10)	0
Vinyl			5.0	(1.52)	0, 0
			7.1	(2.16)	6, 6

[a]One in. = 2.540×10^{-2} m; 1 lb = 4.535924×10^{-1} kg; 1 ft = 3.048×10^{-1} m; 1 deg = 1.745329×10^{-2} rad.

[b]A poured polyurethane floor covering.

Gap Test

The gap test gives a measure of the shock sensitivity of an explosive. The values are obtained by measuring the thickness of inert spacer material (expressed in "cards" or inches) that will just produce 50% probability of detonation when placed between the test explosive and a standard detonating charge. In general, the larger the spacer gap the more shock-sensitive is the HE. The numbers, however, depend on test size and geometry as well as on the particular lot, its method of preparation, and density or percent voids. They are, therefore, only approximate indications of relative shock sensitivity. Two tests were developed at LASL for different amounts of solid HE; they are identified as the large-scale and the small-scale gap tests.[6]

In the small-scale gap test the acceptors (samples) are pellets 1/2 in. (12.7 mm) in diameter and 1-1/2 in. (38.1 mm) long; the spacers (constituting the gap) are brass shims in 0.1 in. (2.54 mm) increments. The donors are modified SE-1 detonators with PBX-9407 pellets 0.300 in. (7.62 mm) in diameter and 0.207 in. (5.26 mm) long. Detonation of the acceptor charge is ascertained by the dent produced in a 6-in. (152 mm) square, 2-in. (102-mm) thick witness plate. The values in Table 9-5 were obtained at LASL and at Pantex.

Results from the large-scale gap test at LASL are given in Table 9-6. This test differs from the small-scale test in the following respects:

1. The acceptors are pellets 1-5/8 in. (41.3 mm) in diameter and 4 in. (102 mm) long.
2. The donors are 1-5/8 in. (41.3 mm) diameter by 4 in. (102 mm) long PBX-9205 pellets.
3. The spacers are 1-5/8 in. (41.3 mm) diameter disks of 2020-T4 Dural (aluminum).

Table 9-5. Small-scale gap-test sensitivities of various explosives.[a]

Explosive	Preparation	ρ (g/cm^3 (Mg/m^3))	Percent voids (%)	Expected gap range (mils)	Expected gap range (mm)
Baratol	Cast	2.565	2.6	Failed at 0	
Comp B, Grade A	Cast	1.710	1.1	16-26	(0.41-0.66)
Comp B-3	Cast	1.721	1.8	44-54	(1.1-1.4)
Cyclotol 75/25	Cast	1.753	1.1	10-16	(0.25-0.41)
DATB	Hot-pressed	1.801	2.1	11-17	(0.28-0.43)
LX-04-1 (pre-6/65)	Hot-pressed	1.865	1.3	60-80	(1.5-2.0)
(post-6/65)	Hot-pressed	1.865	1.3	40-60	(1.0-1.5)
LX-07-1	Hot-pressed	1.857	1.8	70-90	(1.8-2.3)
LX-07-2	Hot-pressed	1.859	1.3	70-90	(1.8-2.3)
LX-09-0	Hot-pressed	1.835	1.3	75-105	(1.9-2.7)
LX-10-0	Hot-pressed	1.872	1.7	80-100	(2.0-2.5)
LX-11-0	Hot-pressed	1.867	0.3	45-65	(1.1-1.7)
LX-13	See XTX-8003				
LX-14	Hot-pressed	1.833	0.9	60-80	(1.5-2.0)
NM (modified test)[b]				7-17	(0.18-0.43)
(modified test)[c]				2-8	(0.05-0.20)
Octol 75/25	Cast	1.810	1.1	22-28	(0.56-0.71)
PBX-9007 (0.8% graphite)	Hot-pressed	1.665	1.8	45-55	(1.1-1.4)
PBX-9010-02	Hot-pressed	1.783	1.7	75-95	(1.9-2.4)
PBX-9011-03	Hot-pressed	1.783	0.7	55-70	(1.4-1.8)
PBX-9205	Hot-pressed	1.682	1.6	25-35	(0.64-0.89)
PBX-9404-03	Hot-pressed	1.850	0.9	85-105	(2.2-2.7)
PBX-9407	Hot-pressed	1.600	11.3	180-210	(4.6-5.3)
	Hot-pressed	1.770	1.8	90-120	(2.3-3.1)
PBX-9501	Hot-pressed	1.843	0.6	50-70	(1.3-1.8)
Pentolite 50/50	Hot-pressed	1.676	2.0	105-140	(2.7-3.6)
	Cast	1.700	0.6	30-38	(0.76-0.97)
PETN	Hot-pressed	1.757	0.8	190-220	(4.8-5.6)
RDX	Hot-pressed	1.735	4.1	190-220	(4.8-5.6)
TATB	Hot-pressed	1.872	2.5	2-8	(0.05-0.2)
Tetryl	Hot-pressed	1.684	2.7	135-165	(3.4-4.2)
TNT	Hot-pressed	1.624	1.8	8-16	(0.20-0.41)
XTX-8003	Uncured	1.53	1.7	160-190	(4.1-4.8)
	Cured	1.53	1.7	130-160	(3.3-4.1)

[a] One mil = 2.540×10^{-2} mm.

[b] In brass sleeve 0.200 in. (5.008 mm) i.d. by 0.147 in. (3.74 mm) thick.

[c] In brass sleeve 0.400 in. (10.2 mm) i.d. by 0.43 in. (10.9 mm) thick.

Table 9-6. Large-scale gap test sensitivities.

Explosive	Preparation	ρ (g/cm^3 (Mg/m^3))	Percent voids (%)	Expected gap range (in.)	(mm)
Comp B-3		1.727	1.4	1.982	(50.3)
Cyclotol		1.734	2.2	1.801	(45.7)
		1.756	0.8	1.646	(41.8)
DATB		0.81	56.0	1.940	(49.3)
		1.705	7.3	1.786	(45.4)
		1.757	2.9	1.699	(43.2)
		1.786	0.6	1.641	(41.7)
HMX		1.07	43.7	2.783	(70.7)
Octol (large HMX)		1.815	1.4	1.863	(47.3)
(regular HMX)		1.822	0.7	1.947	(49.5)
PBX-9010-01		0.81	55.3	2.654	(67.4)
		1.786	1.5	2.090	(53.1)
PBX-9010-02		0.85	53.1	2.617	(66.5)
		1.781	1.8	2.107	(53.5)
PBX-9404-03	(ground, bulk density)	0.920	50.3	2.694	(68.4)
	(ground)	1.230	33.5	2.526	(64.2)
	(ground)	1.400	24.3	2.483	(63.1)
	(ground)	1.585	14.3	2.471	(62.8)
	(ground)	1.679	9.2	2.423	(61.6)
	(ground)	1.755	5.1	2.410	(61.2)
	(slurry)	1.825	1.4	2.223	(56.5)
	(bimodal)	1.841	0.5	2.268	(57.6)
PBX-9407		0.60	66.7	2.455	(62.4)
		1.773	1.7	2.120	(53.9)
Pentolite		1.635	4.4	2.703	(68.7)
		1.702	0.8	2.549	(64.8)
PETN	(raw)	0.81	54.2	2.732	(69.4)
RDX		1.09	39.8	2.764	(70.2)
	(raw)	1.750	3.3	2.434	(61.8)
Tetryl		0.85	50.9	2.725	(69.2)
		1.666	3.7	2.386	(60.0)
TNT	(granular)	0.73	55.9	2.368	(60.2)
	(flake)	0.87	47.4	1.460	(37.1)
		1.615	2.4	1.114	(28.3)
	(granluar)	1.626	1.7	1.944	(49.4)
Tritonal		1.792	~1.0	0.870	(22.1)

The values in Table 9-7 were obtained at Stanford Research Institute with a gap test for liquid explosives.[6] The acceptors are steel tubes of 1/2 in. (12.7 mm) i.d. × 0.1 in. (2.54 mm) thick × 4 in. (101.6 mm) long. The spacers are cellulose acetate disks ("cards") 10 mils (0.25 mm) thick and 1-5/8 in. (41.4 mm) in diameter, used here as a unit of measurement. The donors are two tetryl pellets 1-5/8 in. (41.4 mm) in diameter and 1/2 in. (12.7 mm) long, each weighing ~50 g. Detonation is detected on a witness plate 1/16 in. (1.6 mm) thick for LVD and 3/8 in. (9.6 mm) thick for HVD.

Table 9-7. Gap test sensitivities of liquid explosives.[7]

Explosive	LVD gap (cards)	LVD gap (mm)	HVD gap (cards)	HVD gap (mm)	HVD velocity (km/s)
FEFO	1500-1800	(381-457)	77	(19.6)	7.2
NG/EGDN 50/50	11,000	(2790)	180	(45.7)	7.61
NM	-[a]	-	20-44	(5.1-10.2)	6.3
NM/TNM 50/50	354-394	(90-100)	40	(10)	7.4

[a]None in this geometry.

Shock Initiation

Critical Energy

Data from a number of sources show that there is a rather strict boundary between shock initiation and noninitiation of an explosive as a function of the energy fluence of the shock wave. Each explosive studied has a specific critical energy fluence value. Critical energy as a function of pressure and time has not been explored widely, but the data to date indicate that the critical energy fluence for initiation is probably reasonably constant over the initiation pressure ranges of interest. A critical energy equation has been derived from the conservation and Hugoniot relationships. The equation is

$$E_c = \frac{tP^2}{\rho U_s} ,$$

where E_c is the critical energy in cal/cm^2 (J/m^2), t is the pulse-width of the incident shock in μs, P is the shock pressure in kbar (GPa), ρ is the density of the explosive in g/cm^3 (Mg/m^3), and U_s is the shock velocity in cm/μs (km/s) in the explosive at pressure P. Table 9-8 gives the E_c values for several HEs.

Table 9-8. Critical energies.[a]

Explosive	ρ (g/cm^3 (Mg/m^3))	E_c (cal/cm^2 (kJ/m^3))	Ref.
Comp B	1.715	35(~1500)[b]	8
Comp B-3	1.727	~29(1250)	8
HNS-I	1.555	<34(<1422)	9
LX-04	1.865	26(1090)	8
LX-09	1.84	23(962)	10
NM	1.13	404.7(17,000)	8
PBX-9404	1.84	15(630)	8
	1.842	15(644)	11
PETN	≈1.0	~2(~84)	8
	1.0	2.7(120)	8
	≈1.6	~4(~167)	8
TATB	1.93	226(9500)	8
Tetryl	1.655	10(420)	12
TNT (cast)	1.6	100(~4200)	13
(pressed)	1.645	34(1420)	8

[a] One $cal/cm^2 = 4.184 \times 10^{-4}$ J/m^2.

[b] The asterisks indicate that the values were estimated from data other than critical energy determinations and should be considered as tentative.

Initial Shock Pressure

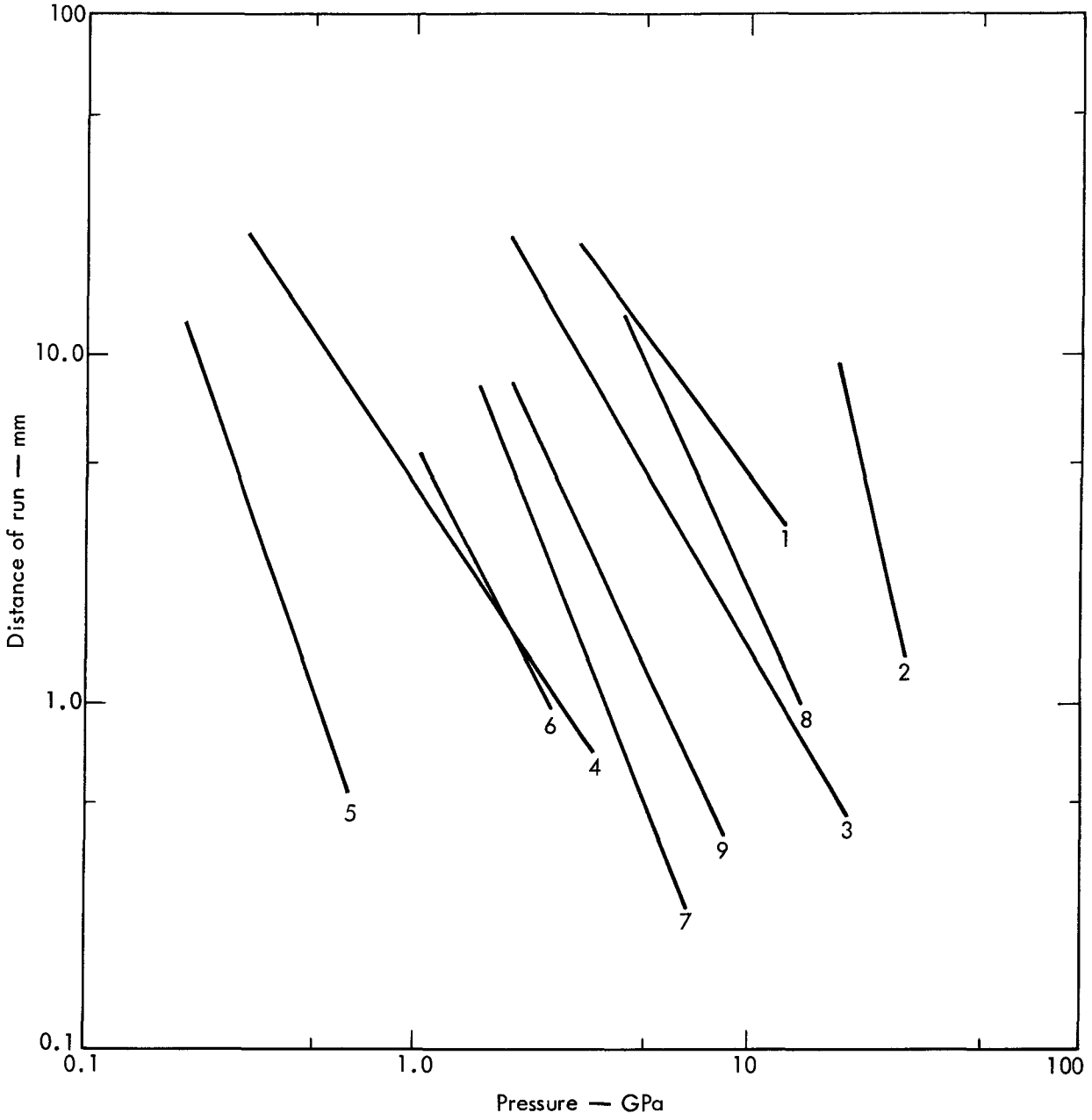
Shock initiation experiments, such as wedge tests, provide records of initial shock pressure-distance histories characteristic to each HE. The log P-log x equations in Table 9-9 represent least squares fits in the pressure ranges indicated. The $P\text{-}x^{-1}$ equations in the table represent least square fits for runs (x) of less than 25 mm. Some of the fits are shown graphically in Fig. 9-19.

Table 9-9. Least squares fits for shock initiation data.

Explosive	ρ (Mg/m^3)	Equation	Range	Ref.
Baratol	2.611	$\log P = 1.2352 - 0.3383 \log x$	$6.8 \le P \le 12$	14
		$P = 5.44 + 22.47\ x^{-1}$	$6.8 \le P \le 12$	14
PBX-9011-06	1.790	$\log P = 1.1835 - 0.6570 \log x$	$4.8 \le P \le 16$	14
		$P = 2.59 + 13.55\ x$	$4.8 \le P \le 16$	14
PBX-9404	1.840	$\log P = 1.1192 - 0.6696 \log x$	$2 \le P \le 25$	14
		$P = 2.17 + 9.88\ x^{-1}$	$3 \le P \le 25$	14
	1.721	$\log P = 0.9597 - 0.7148 \log x$	$1.2 \le P \le 6.3$	14
		$P = 1.09 + 8.71\ x^{-1}$	$2.0 \le P \le 6.3$	14
PBX-9501-01	1.833	$\log P = 1.0999 - 0.5878 \log x$	$2.5 \le P \le 6.9$	14
	1.844	$\log P = 1.1029 - 0.5064 \log x$	$2.5 \le P \le 7.2$	14
PETN	1.72	$\log P = 0.6526 - 0.5959 \log x$	$2.0 \le P \le 4.2$	15
	1.60	$\log P = 0.3872 - 0.5038 \log x$	$1.2 \le P \le 2.0$	15
	1.0	$\log P = 0.3855 - 0.2916 \log x$	$0.2 \le P \le 0.5$	16
TATB	1.876	$\log P = 1.4170 - 0.4030 \log x$	$11 \le P \le 16$	14
		$P = 8.24 + 26.01\ x^{-1}$	$11 \le P \le 16$	14
XTX-8003	1.53	$\log P = 0.7957 - 0.463 \log x$	$3.0 \le P \le 5.0$	16

[a] x = distance of run to transition to high order in mm

[b] P = initial shock pressure in GPa.



Curve No.	Explosive	ρ(Mg/m^3)	Ref.
1	Comp B	1.72	17
2	NQ	1.69	17
3	PBX-9404	1.83	17
4	PBX-9407	1.60	18
5	PETN	1.0	17
6	PETN	1.60	16
7	PETN	1.72	16
8	TNT	1.63	17
9	XTX-8003	1.53	16

Fig. 9-19. Log-Log plots of distance of run to detonation vs initial shock pressure of various explosives.

References

1. E. E. Kilmer, J. Spacecr. Rockets 5, 1216-1219 (1968).
2. T. M. Benziger, X-0242, A High-Energy Plastic-Bonded Explosive, Los Alamos Scientific Laboratory, N. M., Rept. LA-4872-MS (1972).
3. L. G. Green and A. M. Weston, Data Analysis of the Reaction Behavior of Explosive Materials Subjected to Susan Test Impacts, Lawrence Livermore Laboratory, Rept. UCRL-13480 (1970).
4. L. G. Green, A. M. Weston, and J. H. van Velkinburg, Mechanical Behavior of Plastic-Bonded Explosives Vertically Dropped on a Smooth, Rigid, Steel Target Surface, Lawrence Livermore Laboratory, Rept. UCRL-51022 (1971).
5. L. G. Green, A. M. Weston, and J. H. van Velkinburg, Mechanical and Functional Behavior of Skid Test Hemispherical Billets, Lawrence Livermore Laboratory, Rept. UCRL-51085 (1971).
6. M. J. Urizar and L. C. Smith, Los Alamos Scientific Laboratory, N.M., personal communication (1970).
7. R. W. Woolfolk, Stanford Research Institute, Menlo Park, Calif., personal communication (1970).
8. F. W. Walker, Lawrence Livermore Laboratory, to be published (1974).
9. D. Price, U.S. Naval Ordnance Laboratory, White Oak, Md., personal communication (1967)
10. L. G. Green, Lawrence Livermore Laboratory, personal communication (1972).
11. L. G. Green, E. J. Nidick, Jr., and F. E. Walker, Critical Shock Initiation of PBX-9404, A New Approach, Lawrence Livermore Laboratory, Rept. UCRL-51522 (1974).
12. L. G. Green, E. J. Nidick, Jr., and F. E. Walker, Critical Energy for Shock Initiation of Tetryl and A-5, Lawrence Livermore Laboratory, Rept. UCID-16469 (1974).
13. M. L. Schimmel, QUEST-Quantitative Understanding of Explosive Stimulus Transfer, Summary Report - Tasks 1 thru 6. McDonnell Aircraft Co., St. Louis, Mo., Rept. MDC-A-1021 (1971).
14. B. G. Craig, Los Alamos Scientific Laboratory, N.M., personal communication (1974).
15. J. Wackerle and J. O. Johnson, Pressure Measurements on the Shock-Induced Decomposition of High-Density PETN, Los Alamos Scientific Laboratory, N.M., Rept. LA-5131 (1973).
16. D. Stirpe, J. O. Johnson, and J. Wackerle, J. Appl. Phys. 41, 3884-3893 (1970).
17. J. B. Ramsey and A. Popolato, "Analysis of Shock Wave and Initiation Data for Solid Explosives," in Proc. 4th Symp. (Intern.) on Detonation, U.S. Office of Naval Research, Washington, D.C., Rept. ACR-126 (1965), pp. 233-238.
18. I. E. Lindstrom, J. Appl. Phys. 37, 4873-3880 (1966).

10. ELECTRICAL PROPERTIES

Like other polymeric materials, the secondary HEs discussed here are good electrical insulators. They are not considered to be sensitive to accidental initiation from electric sparks.

Dielectric Constant

The dielectric constant ϵ, also called relative permittivity, is density-dependent; it is defined as the ratio of the capacitance of a condenser filled with the sample material to the capacitance of the condenser with a vacuum between its plates. The dielectric constants of several explosives are given in Table 10-1. An empirical, logarithmic relationship has been established for two-component HEs composed of the same materials in different proportions.[1] Figure 10-1 illustrates this mixing rule for TNT/RDX compositions. The relationship is expressed as

$$\log k_t = \theta_1 \log K_1 = \theta_2 \log k_2,$$

where

k_t = relative permittivity of the mixture,
k_1, k_2 = relative permittivities of components, and
θ_1, θ_2 = volume ratios of components.

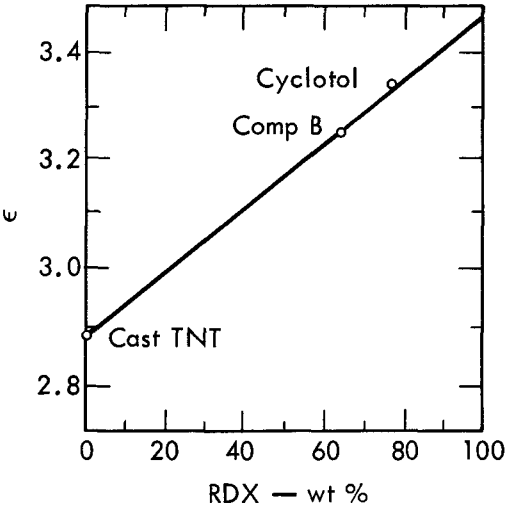


Fig. 10-1. Logarithmic mixing rule applied to TNT-RDX mixtures.[1]

Table 10-1. Dielectric constants, ϵ.

	ρ																				
	0.9	1.0	1.05	1.12	1.4	1.5	1.53	1.6	1.7	1.72	1.73	1.75	1.76	1.81	1.82	1.84	1.86	1.87	1.90	2.02	2.59
										Reference											
Material	2	2	3,4	3	2	2	1	1,2	2,5	1	6	6	1,7	1	8	6	6	8	8	9	1
Baratol	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4.12[d]
Boracitol	–	–	–	–	–	–	2.84[d]	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Comp B	–	–	–	–	–	–	–	–	–	3.25[d]	–	–	–	–	–	–	–	–	–	–	–
Comp B-3[a] (pressed)	–	–	–	–	–	–	–	–	–	–	3.41[f]	–	–	–	–	–	–	–	–	–	–
Cyclotol	–	–	–	–	–	–	–	–	–	–	–	–	3.38[d]	–	–	–	–	–	–	–	–
Exon 461	–	–	–	–	–	–	–	–	2.82[c]	–	–	–	–	–	–	–	–	–	–	–	–
HMX-I(β)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.087[e]	–	–
HMX-II(α)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4.671[e]	–	–	–
HMX-III(γ)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.867[e]	–	–	–	–	–	–
Kel-F	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.00[c]	–
LX-04-1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.44[f]	–	–	–	–
Octol	–	–	–	–	–	–	–	–	–	–	–	–	–	3.20[e]	–	–	–	–	–	–	–
PBX-9404 (pressed)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.52[f]	–	–	–	–	–
PETN	2.102[b]	2.310[b]	–	–	2.447[b]	2.577[b]	–	2.727[b]	2.897[b]	–	–	–	–	–	–	–	–	–	–	–	–
PETN (detonator grade)	–	–	–	–	–	–	–	–	–	–	–	2.95[f]	3.5[c]	–	–	–	–	–	–	–	–
Polystyrene	–	–	2.49-2.55[c]	– 2.61[c]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sylgard	–	–	2.77[d]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tetryl	2.059[b]	2.163[b]	–	–	2.728[b]	2.905[b]	–	3.097[b]	3.304[b]	–	–	–	–	–	–	–	–	–	–	–	–
TNT	2.048[b]	2.131[b]	–	–	2.629[b]	2.795[b]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
TNT (cast)	–	–	–	–	–	–	–	2.88[e]	–	–	–	–	–	–	–	–	–	–	–	–	–

[a] Comp B-3; TNT/RDX 37.8/62.2.

[b] Measured at 35 GHz.

[c] Measured at 1 kHz.

[d] Measured at 3 GHz.

[e] Measured at 5 MHz.

[f] Measured at 25 GHz.

References

1. B. Hayes, Los Alamos Scientific Laboratory, N. M., personal communication (1956).
2. G. F. Cawsey, J. L. Farrands, and S. Thomas, Proc. Roy. Soc. (London) 248A, 499-521 (1958).
3. J. Brandrup and E. H. Immergut, eds., Polymer Handbook, Interscience, N. Y. (1966).
4. Dow Corning, Hemlock, Mich., Information About Electronic Materials, Bulletin 07-123 (May 1964).
5. Firestone Plastics Company, Exon, Sales Service Bulletin No. 20 (1956).
6. K. Ernst, Lawrence Livermore Laboratory, personal communication (1972).
7. M. Fulk, Lawrence Livermore Laboratory, personal communication (1972).
8. M. Bedard, H. Huber, J. L. Myers, and G. F. Wright, Can. J. Chem. 40, 2278-2299 (1962).
9. Minnesota Mining and Manufacturing Co., St. Paul, Minn., Kel-F Elastomer – Properties and Applications, Service Bulletin (no date).

11. TOXICITY

Toxic symptoms can result from exposure to some HEs and components by inhalation of the dust or vapor, by ingestion, or by contact with the skin. Most explosives are not highly toxic, but careless handling could result in systemic poisoning, usually affecting the bone marrow (blood-cell-producing system) and the liver.

The following general precautions (LLL standard operating procedures) should be observed on all HEs:

1. The material should be handled only in a well-ventilated area.
2. Skin contact should be avoided. Explosives can be absorbed through the skin, or they may cause skin rash (the most common symptom among explosives handlers). Daily baths and clean clothing are recommended for persons engaged in HE processing.

Toxicities, where known, are listed in Table 11-1.

Table 11-1. Health hazards of explosives.

Explosive	Toxicity
BDNPA/BDNPF	None[1]
Cab-O-Sil	Low[2]
Comp C-4	Moderate[3]
DIPAM	Moderate[4]
DOP	Low[5]
Estane	None[6]
Exon 461	Slight[7]
FEFO	High[8]
HNAB	Slight[9]
HNS	Slight[9]
NC	None[4]
NG	Very high[4]
NM	Moderate[4]
NQ	Slight[4]
PETN	High[4]
RDX	Slight[10]
TEF	Moderate when ingested[11]
Tetryl	High[4]
TNM	Very high[4]
TNT	Moderate[4]

References

1. M. Finger, Properties of Bis(2,2-dinitropropyl)acetal and Bis(2,2-dinitropropyl)formal, Eutectic Mixture, Lawrence Livermore Laboratory, Rept. UCID-16088 (1972).
2. H. G. Hammond, Lawrence Livermore Laboratory, personal communication (1974).
3. A. J. Hollander, Mil. Med. 134, 1529-1530 (1969).
4. N. I. Sax, Dangerous Properties of Industrial Materials (Reinhold, New York, 1968).
5. M. Radeva and S. Dinoeva, Khig. Zdraveopazvane, 9(5), 510-16 (1966). (Cited in Chem. Abstr. 66, Abstr. 103632 (1967).
6. B. F. Goodrich Company, Cleveland, Ohio, Estane Polyurethane Solution Systems, TSR 64-18 (1964).
7. Firestone Plastics Co., Pottstown, Pa., Sales Service Bulletin No. 20 (nd).
8. B. J. Mechalas and P. H. Allen, Toxicology Screening of FEFO, Lawrence Livermore Laboratory, Rept. UCRL-13372 (1968).
9. A. C. Schwarz, Applications of Hexanitrostilbene (HNS) in Explosive Components, Sandia Laboratories, Albuquerque, N. Mex., Rept. SC-RR-710673 (1972).
10. A. S. Kaplan, C. F. Berghout, and A. Peczenik, Arch. Environ. Health 10, 877-883 (1965).
11. Celanese Corporation, Chemical Division, New York, N.Y., Celluflex CEF, Products Bulletin N-46-2 (1955).

II. Mock Explosives

12. INTRODUCTION

It is often convenient for test purposes to have materials that duplicate compositional, mechanical, or other properties of an HE but lacks its hazards. A series of mock materials has been formulated for these purposes. Characteristics and properties of these mocks are summarized in this section according to the same scheme used for HEs in the preceding sections.

A mock HE is a nonexplosive equivalent of a particular explosive formulation. The approved all-purpose mock for LX-04-1 might naturally be called LM-04-1. However, mocks do not always (in fact, they seldom do) pair in one-to-one relation with the corresponding HE. For PBX-9404, for example, there are three separate mocks: a compositional mock, a physical-property mock, and a thermal mock. For this and other reasons too involved to detail here, no attempt is made to achieve correspondence beyond the class designation. Thus, there may be an LM-04-5 that mocks the thermal-expansion characteristics of LX-04-2, or an RM-06-H that mocks the density of RX-06-AA, etc.

Selection of the best mock HE for a specific purpose involves the following steps:

- Selection of the properties to be mocked. Some examples:
    1. Atomic composition
    2. Density
    3. Thermal properties
        - Coefficient of thermal expansion
        - Heat transfer properties (Table 15-1 shows how to select the properties for a specific boundary condition)
    4. Mechanical properties
        - Elastic behavior
        - Viscoelastic behavior
        - Failure behavior
- Comparison with the HE of interest over the appropriate temperature range, either by direct comparison of properties or by comparison of results from analytical calculations.

13. NAMES AND FORMULATIONS

Table 13-1. Formulations of mock explosives.

Mock	Explosive properties mocked	Composition[a] (wt%)		Molecular formula[b]
90010	PBX-9404: mechanical properties	Pentaerythritol	48.0	$C_{1.89}H_{4.44}N_{0.38}O_{2.62}Ba_{0.18}Cl_{0.03}P_{0.01}$
		$Ba(NO_3)_2$	46.0	
		NC	2.8	
		CEF	3.2	
90503	PBX-9404 and LX-10: atomic composition	Cyanuric acid	60	$C_{2.32}H_{3.18}N_{2.96}O_{1.60}Cl_{0.04}P_{0.01}$
		Melamine	32	
		NC	4	
		CEF	4	
LM-04-0	LX-04: atomic composition[c]	Cyanuric acid	59.7	$C_{2.34}H_{2.66}N_{2.51}O_{1.39}F_{0.63}$
		Melamine	23.5	
		Viton A	16.8	
RM-04-BG	LX-04: mechanical properties — static and dynamic	Cyanuric acid	70.5	$C_{2.02}H_{1.86}N_{1.75}O_{1.97}F_{0.54}Ba_{0.06}$
		$Ba(NO_3)_2$	14.5	
		Viton A	15	

[a] Approximately 0.05% of a red pigment is also added to these formulations.

[b] Molecular weights of these mixtures are arbitrarily taken as 100.

[c] Although designed as an atomic-composition mock, LM-04-0 can also be used as an approximate mock of the mechanical properties of LX-04-1 at ambient conditions.

14. PHYSICAL PROPERTIES

Table 14-1. Physical states and densities.[1]

Mock HE	Physical state	TMD, ρ (g/cm^3 (Mg/m^3))	Nominal density, ρ (g/cm^3 (Mg/m^3))
90010	Solid	1.89	1.88
90503	Solid	1.68	1.57
LM-04-0	Solid	1.727	1.70
RM-04-BG	Solid	1.914	1.87

Mock HE 90010 has been widely used for many years, both at LLL and at LASL, where it was originally formulated. However, it could be considered a very low-grade propellant, since it contains a fair amount of $BaNO_3$. It burns in air with a sooty flame. Decomposition at 250°C (523 K) results in about 117 ml of gas evolved per gram of material. RUBY calculations were made for approximations of volume burn. The identity of the solid products of combustion is not clear; they could be either $BaCO_3$ or BaO. If we assume that the more energetic $BaCO_3$ is a product, the calculated energy equivalent is about one-third that for TNT. Many differential thermal analyses have been made; they all show a characteristic exotherm. Mock HE 90010 is difficult to ignite and will not propagate a detonation, but it is definitely an exothermic material. It is strongly recommended that 90010 no longer be used in experiments involving fissile materials.[2]

RM-04-BG contains relatively much less $BaNO_3$. Its RUBY calculations for volume burn indicate that the greater heat input would be required to decompose it than would be obtained from the final oxidation; nevertheless it does show a small exotherm at 400°C (673 K). Clearly it presents less of a potential hazard than mock 90010, but it also should not be used for experiments with fissile materials.[2]

References

1. R. C. Murray, Lawrence Livermore Laboratory, personal communication (1972).
2. E. James, Jr., Lawrence Livermore Laboratory, personal communication (1973).

15. THERMAL PROPERTIES

This section contains information on the selection of heat transfer properties, thermal conductivities k, coefficients of thermal expansion CTE, glass transition points T_g, and specific heats C_p.

Table 15-1 shows how to select the appropriate heat-transfer properties to be mocked. This table is based on mocking the temperature under specific conditions. In steady-state problems with insulated or prescribed-temperature boundary conditions, thermal properties have no significance and any material could be used.

Table 15-1. Criteria for selection of heat-transfer properties to be mocked.

Boundary conditions	Transient problems[a]	Steady-state problems[a]
No heat generation		
Insulated	α	-
Prescribed temperature	α	-
Prescribed heat flux	α, k	k
Convection	α, k	k
Heat generation		
Insulated	α, k	k
Prescribed temperature	α, k	k
Prescribed heat flux	α, k	k
Convection	α, k	k

[a]Here k = thermal conductivity, $\alpha = k/\rho C_p$ = thermal diffusivity.

Thermal Conductivity and Specific Heat

Specific heats were determined by an ice calorimetry technique. Data are given in Table 15-2 and Figs. 15-1 and 15-2.

Table 15-2. Thermal conductivities k and specific heats C_p.

	k (Ref. 1)			C_p (Ref. 2)	
Mock HE	(BTU/hr-ft-°F)	(10^{-4} cal/sec-°C)	(W/m-K)[a]	BTU/lb-°F or cal/g-°C	(kJ/kg-K)[b]
90010	0.31	(12.8)	(0.54)	0.23	(0.96)
90503	0.36	(14.9)	(0.62)	0.29	(1.21)
LM-04-0	0.59	(24.3)	(1.02)	0.28	(1.17)
RM-04-BG	0.66	(27.2)	(1.14)	0.24	(1.004)

[a]One cal/cm-sec-°C = 4.184 × 10^2 W/m-K; 1 BTU/hr-ft-°F = 0.004135 cal/cm-sec-°C = 1.729577 W/m-K.

[b]One BTU/lb-°F = 1 cal/g-°C = 4.184 kJ/kg-K.

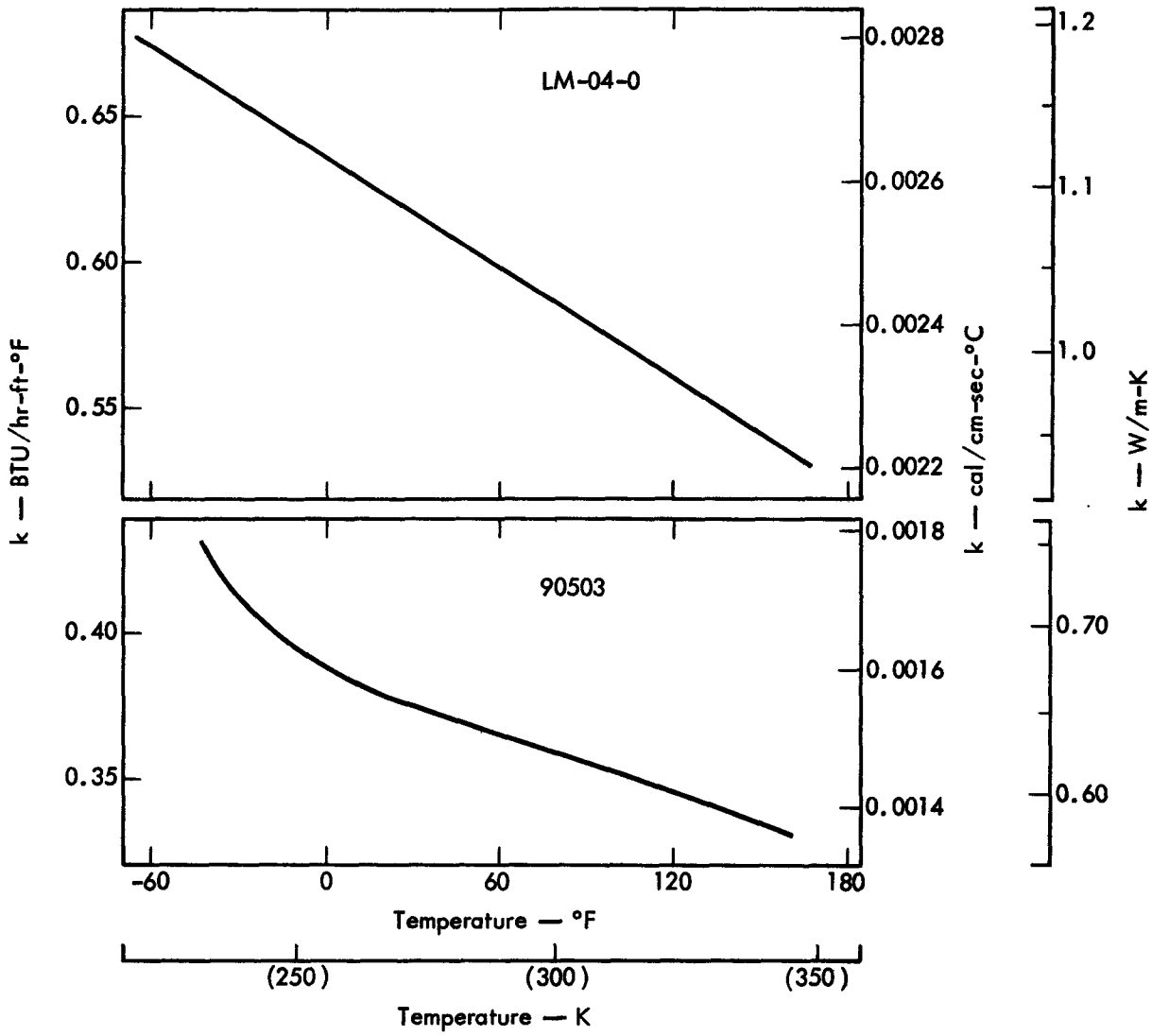


Fig. 15-1. Thermal conductivity k as a function of temperature. Conversion factors: 1 BTU/hr-ft-°F = 1.729577 W/m-K; 1 cal/sec-cm-°C = 4.184×10^2 W/m-K.

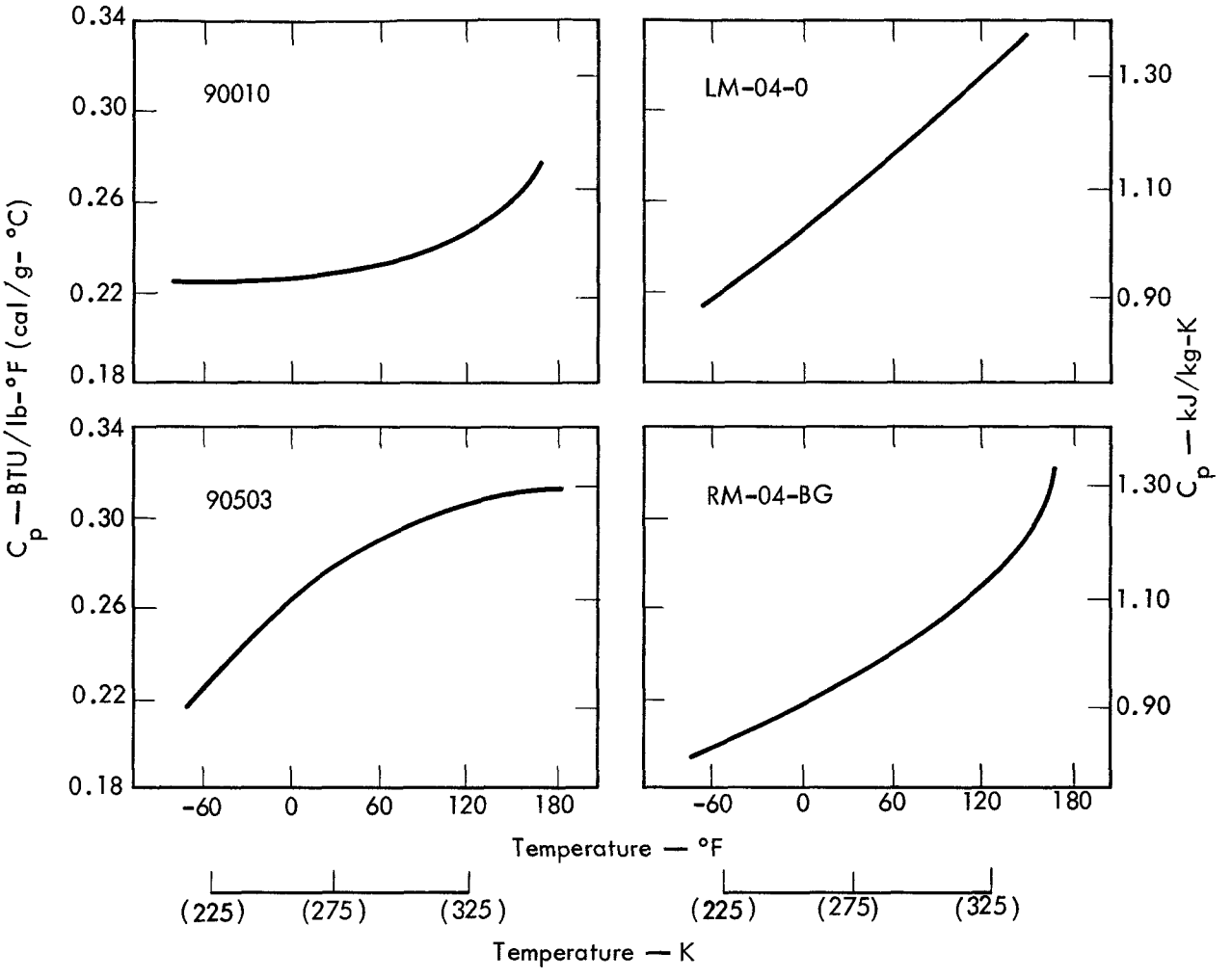


Fig. 15-2. Specific heat C_p as a function of temperature. Conversion factor: 1 BTU/lb-°F = 1 cal/g-°C = 4.184 kJ/kg-K.

Thermal Expansion

Early CTE data for cyanuric-acid-type mock HEs were affected by surface chalking and growth; this is now prevented by a parylene coating. CTE data are given in Table 15-3.

Table 15-3. Coefficients of thermal expansion CTE[a, 3] and glass transition temperatures Tg.

	Linear CTE (α)				Cubic CTF (β)			
			Temperature			Temperature	T_g	Pressed density ρ
Mock HE	(10^{-6} in./in.-°F)	(10^{-6} cm/cm-°C (μm/m-K))	(°F)	(K)	(10^{-6} cm cm-°C (μm m-K))	(°C (K))	(°F (K))	(g/cm^3 (Mg/m^3))
90010	15 5	(27.9)	-65 to -30	(219-239)			-18 (245)	1.880-1 882
	23 3	(41.9)	-10 to 165	(250-347)				
90503	20.8	(37.4)	-65 to -10	(219-250)			-18 (245)	1.574-1.589
	29.5	(53.1)	10 to 165	(261-347)				
LM-04-0	21.5	(38 7)	-65 to -24	(219-243)			-18 (245)	1 705-1.715
	43.9	(79 0)	10 to 165	(261-347)				
RM-04-BG	19.2	(34.6)	-65 to -20	(219-244)	199 4 meas.[4]	-30 to 70	-18 (245)	1.80
	37.5	(67.5)	0 to 165	(255-347)	198 calc	(243-343)		

[a]One in./in.-°F - 1.8 cm/cm-°C - 1.8 m/m-K.

References

1. R. C. Murray, Lawrence Livermore Laboratory, personal communication (1972).
2. T. Hoheisel, Lawrence Livermore Laboratory, personal communication (1969).
3. R. C. Murray, Lawrence Livermore Laboratory, personal communication (1968).
4. M. Finger, Lawrence Livermore Laboratory, personal communication (1965).

16. MECHANICAL PROPERTIES

The data presented here[1] are for each mock HE without comparison with the corresponding live HE. A mechanical mock can best be selected by selecting the appropriate mechanical property to be mocked and then making a comparison with the available data for the HE.

Figure 16-1 shows the stress-strain relationship in compression for RM-04-BG.

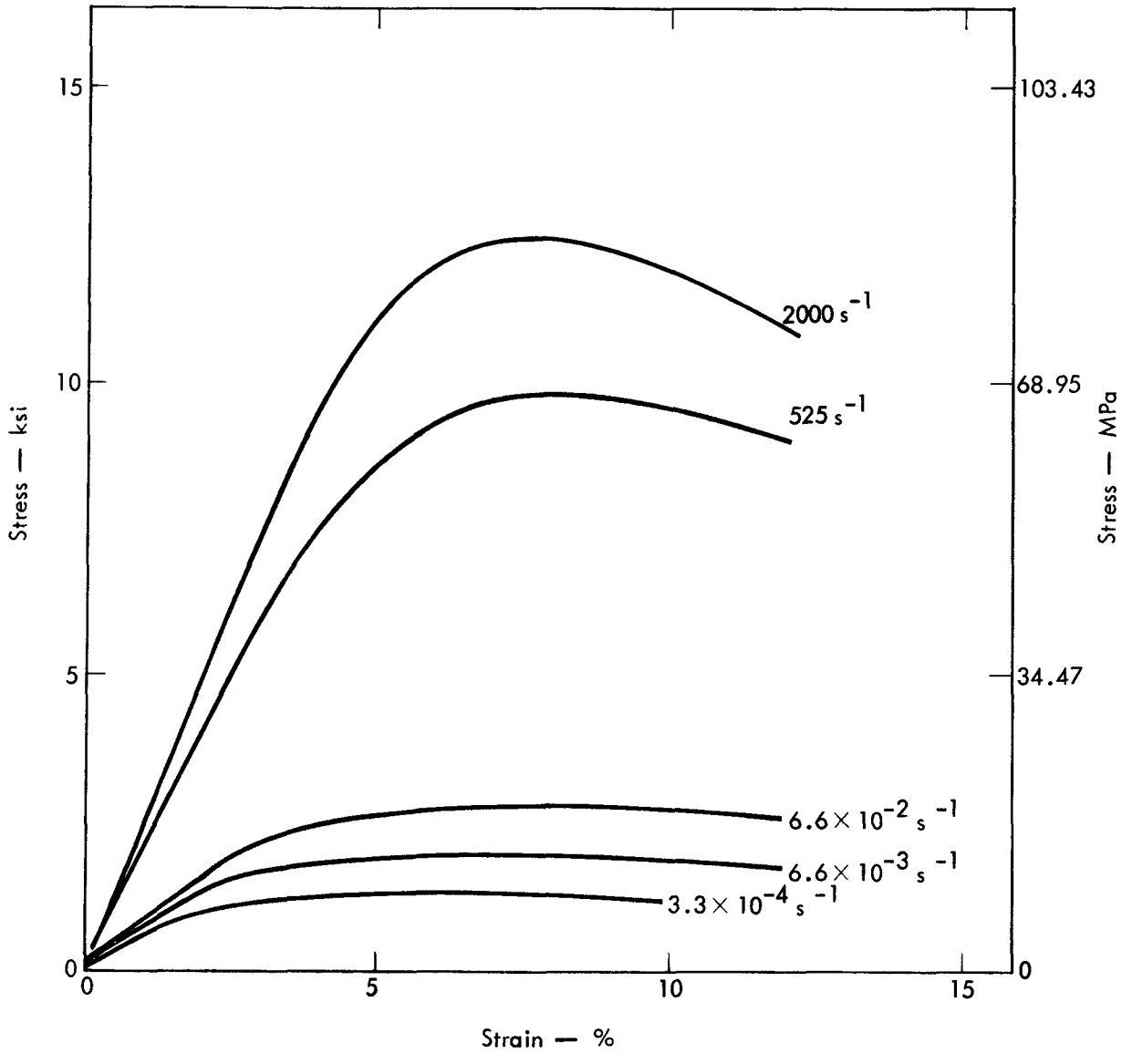


Fig. 16-1. Compressive stress strain curves for RM-04-BG at various strain rates.[2]

Static Mechanical Properties

Included here are data on initial modulus E_0, tension creep, failure envelope, and coefficient of friction f.[3]

Initial Modulus

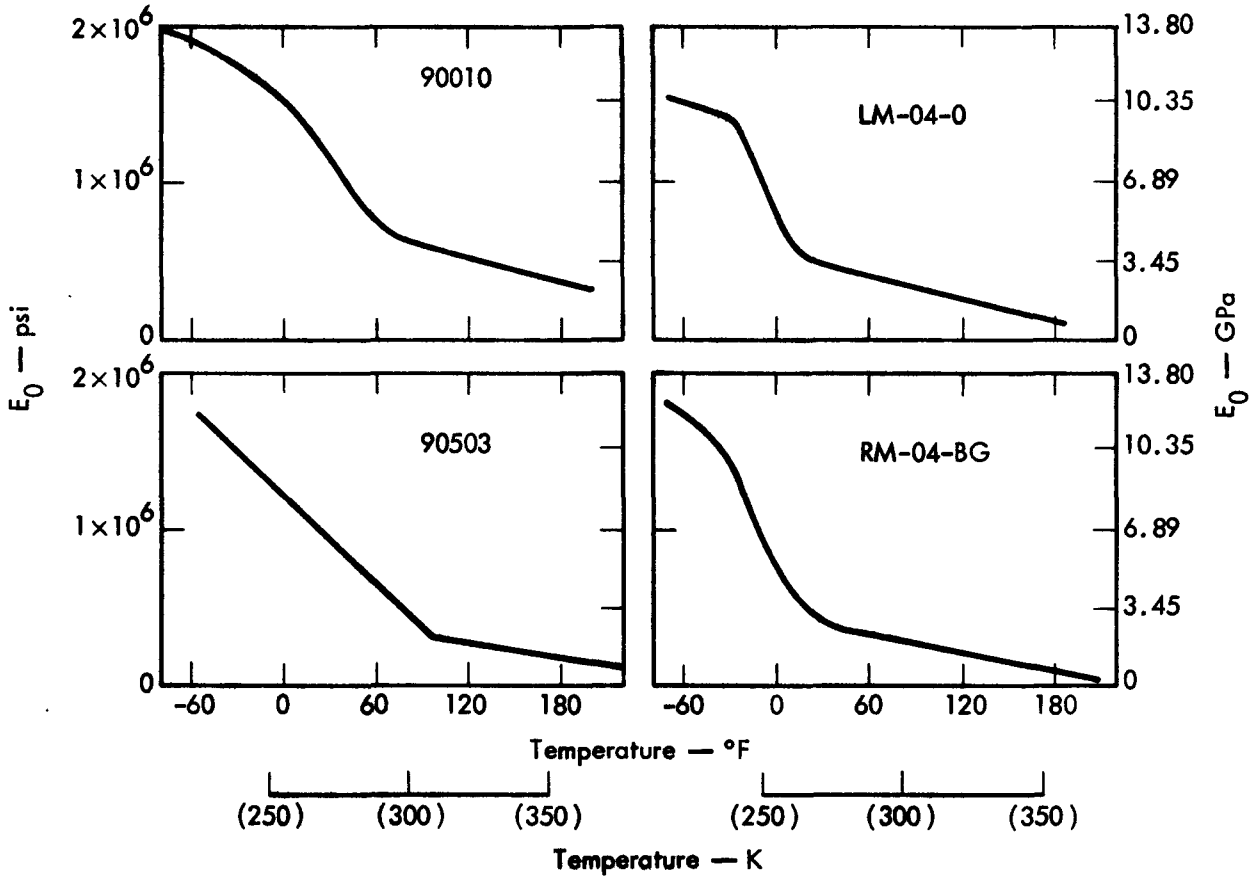


Fig. 16-2. Initial longitudinal modulus E_0 vs temperature. Conversion factor: 1 psi = 6.894757 kPa.

Tension Creep

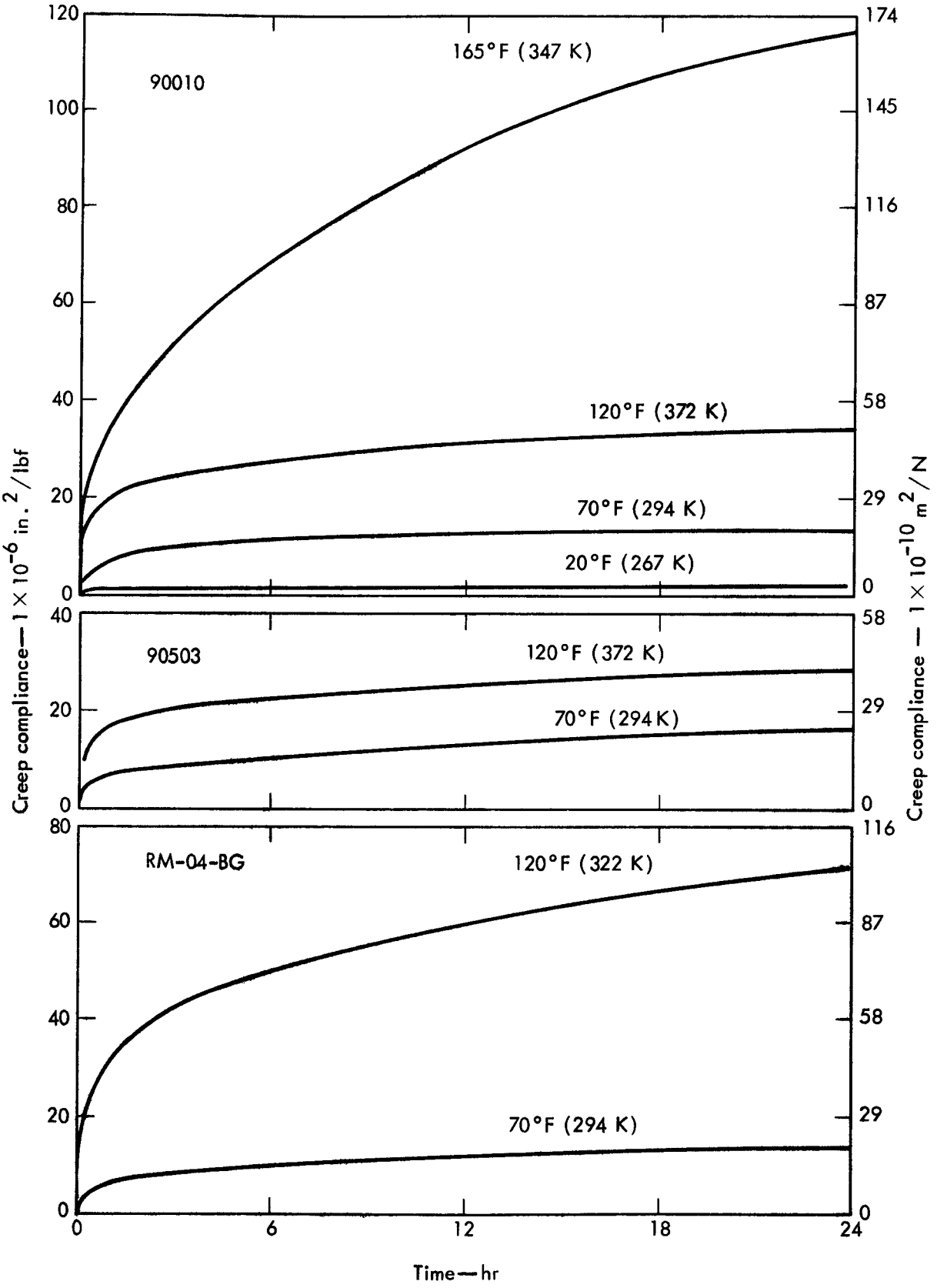


Fig. 16-3. Tension creep data. Conversion factor: 1 $in.^2/lbf$ = 1.450377 × 10^{-4} m^2/N.

Failure Envelope

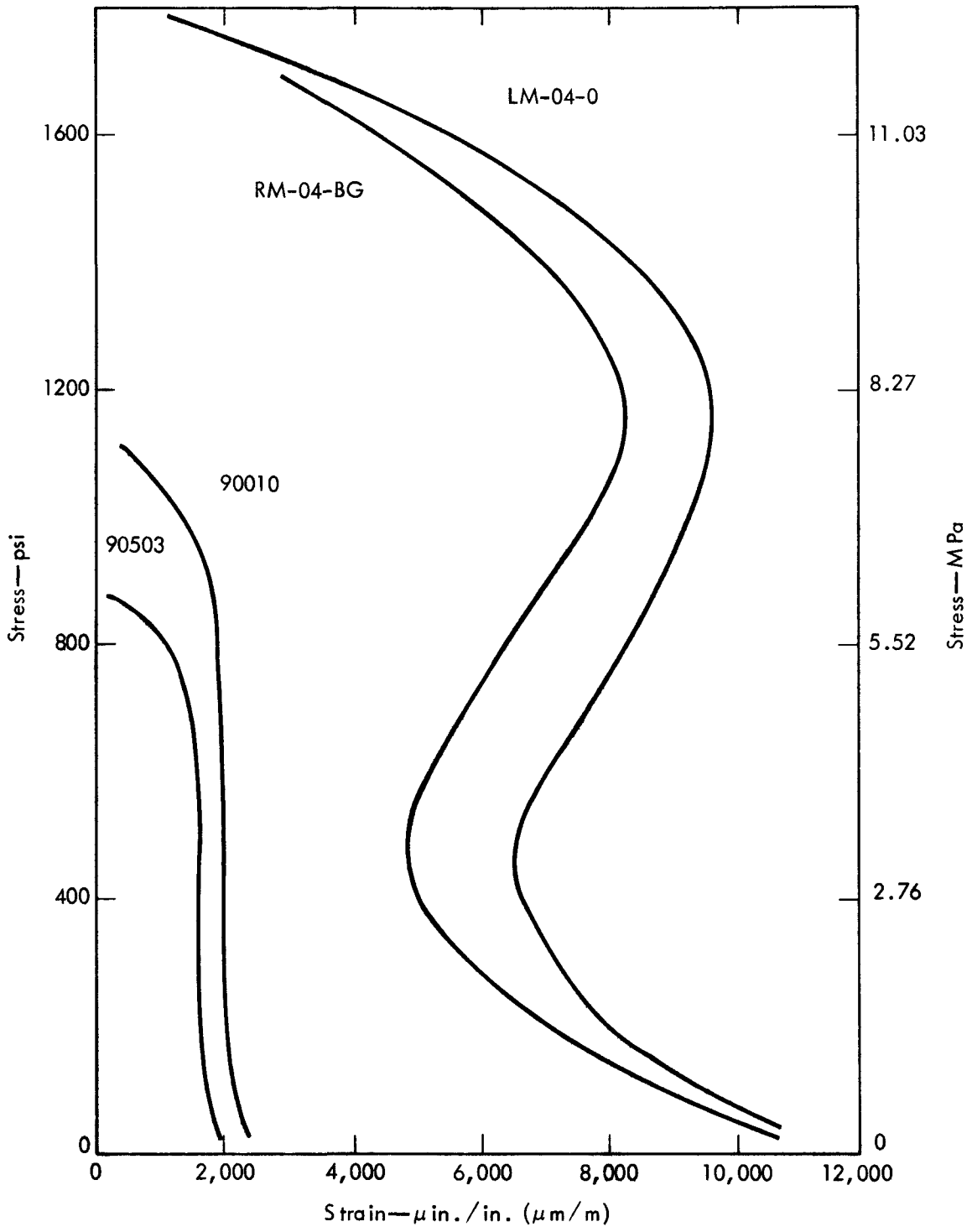


Fig. 16-4. Failure envelopes. Conversion factor: 1 psi = 6.894757 kPa.

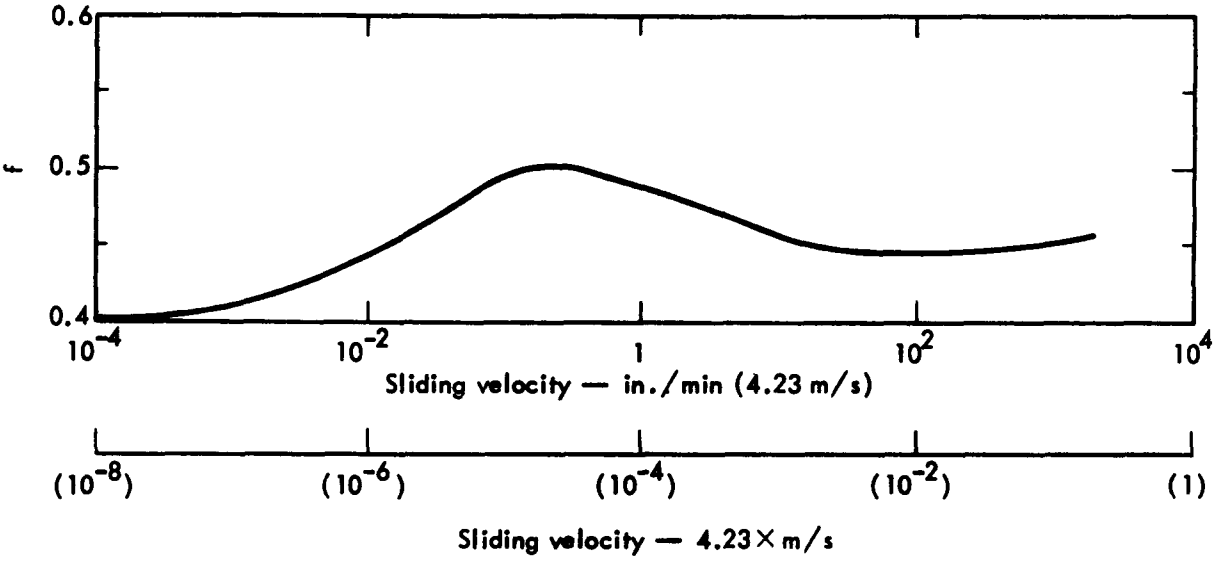


Fig. 16-5. Coefficient of friction f as a function of sliding velocity ν. Conversion factor: 1 in./min = 4.23 × 10^{-4} m/s.

Dynamic Mechanical Properties

Compressive Stress-Strain

The Hopkinson split-bar technique was used to determine the compressive stress-strain properties of mock HE and Viton.[4] The results are shown in Fig. 16-6.

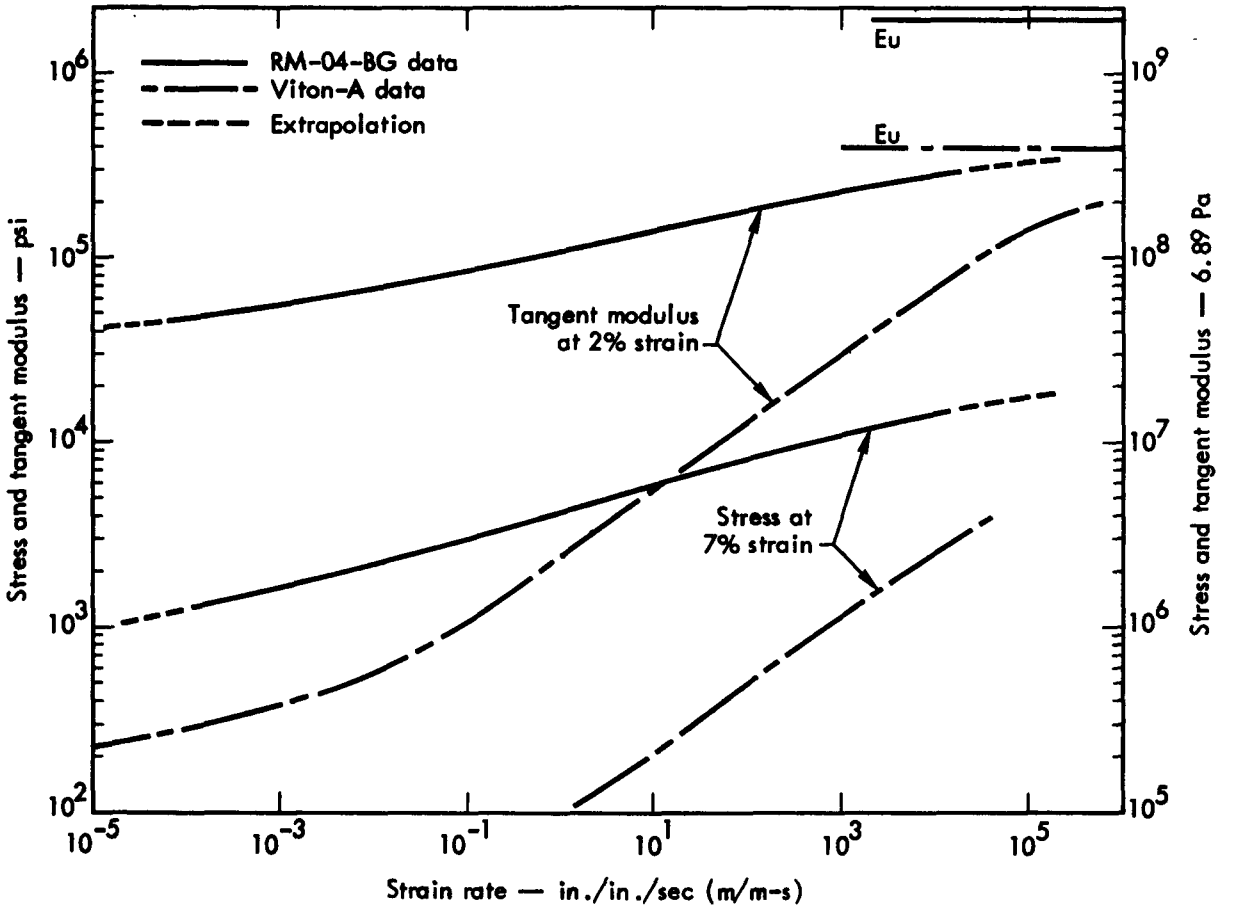


Fig. 16-6. Stress and tangent moduli for RM-04-BG and Viton as a function of strain rate.[2] Also shown is the ultrasonically determined modulus E_u. Conversion factor: 1 psi = 6.894757 kPa.

Hugoniot Data

The Hugoniots of unreacted mock HEs were determined from Marsh's measured sound velocities[5] (Tables 7-4 and 16-1), and are summarized in Table 16-2.

Table 16-1. Sound velocities.

Mock	ρ (Mg/m^3)	c_ℓ (km/s)	c_s (km/s)	c_b (km/s)
90010	1.84	3.22	1.56	2.67
90503	1.61	2.70	1.48	2.09

Table 16-2. Least squares fits for Hugoniots of unreacted mock HEs.

Mock	ρ (Mg/m^3)	Equation	Range
90010	1.84	$U_s = 2.70 + 1.62\ U_p$	
90503	1.61	$U_s = 2.67 + 1.57\ U_p$	$U_s < 6.28$
		$U_s = 3.39 + 1.25\ U_p$	$U_s > 6.27$

The flyer-plate data for mock HEs are shown in Fig. 16-7; compare with Figs.7-13 through 7-15. See also the section on Dynamic Mechanical Properties of HEs (p. 7-15).

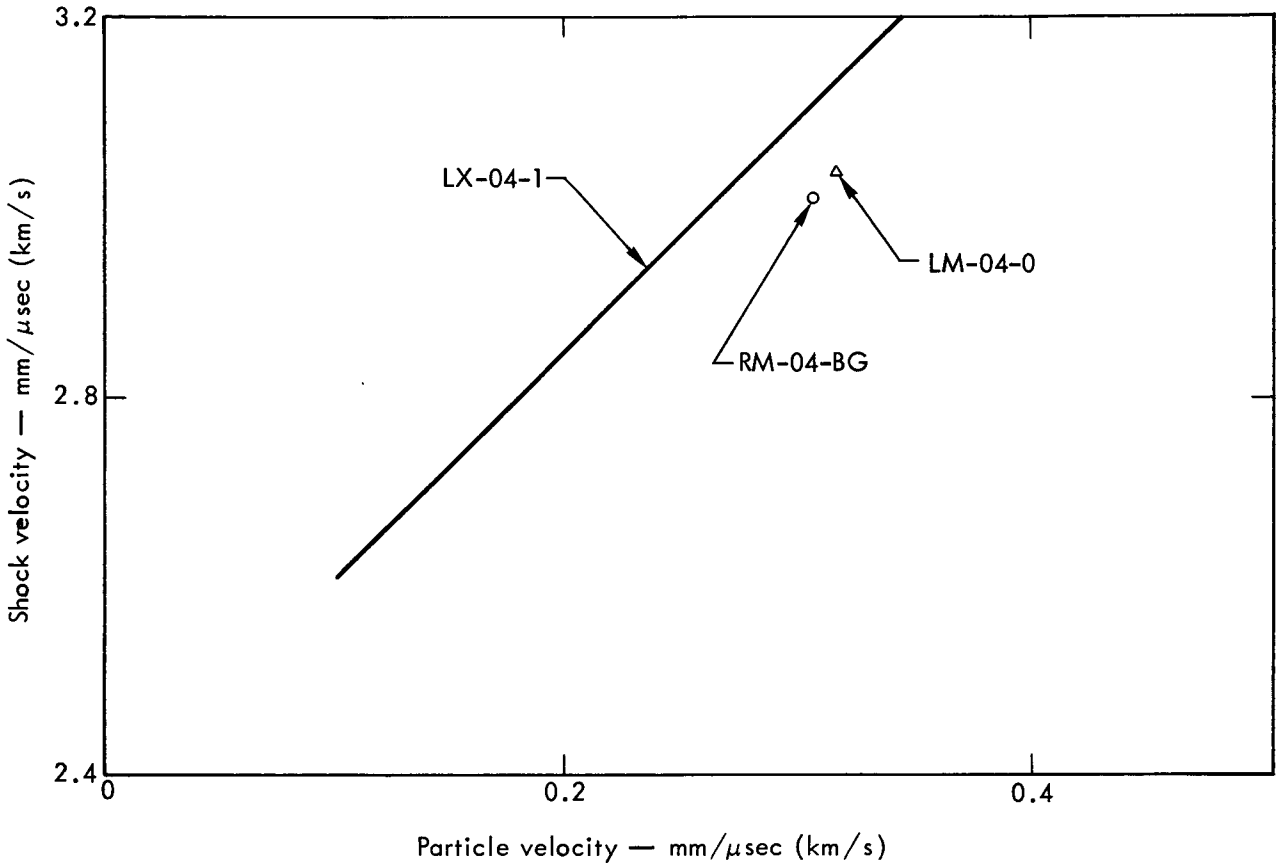


Fig. 16-7. Hugoniot data for LM-04-0 and RM-04-BG, compared with LX-04-1.[6]

References

1. R. C. Murray, Lawrence Livermore Laboratory, personal communication (1970).
2. K. G. Hoge, Applied Polymer Symposia 5, 19-40 (1967).
3. K. G. Hoge, "Friction and Viscoelastic Properties of Highly Filled Polymers: Plastic-Bonded Explosives," in Developments in Theoretical and Applied Mechanics, Vol. 4 (Pergamon Press, Oxford, 1970), pp. 371-392.
4. K. G. Hoge, Explosivstoffe 18, 39-41 (1970).
5. S. Marsh, Los Alamos Scientific Laboratory, N. M., personal communication (1974).
6. R. J. Wasley and R. H. Valentine, Shock-Pulse Attenuation and Hugoniot Studies of Three Explosives and Three Mock Explosives, Lawrence Livermore Laboratory, Rept. UCRL-50950 (1970).

III. Code Designations

This section defines and describes the codes now in use at LLL and LASL for designating explosive materials. Three categories of explosives are covered. LLL formulations in production, LLL research formulations and LASL PBX designations. The code for each type is distinctive and easily recognized.

LLL CODE DESIGNATIONS

Formulations in Production (LX Code)

A specific code designation in this category is assigned to an explosive when the state of development of its formulation has reached the point where

(1) a set of reasonable manufacturing specifications can be written for the developed formulation,

(2) the evaluation of the material's chemical, physical, explosive properties and sensitivity is essentially complete,

(3) the material has a definite application.

This code consists of the two letters LX followed by a dash, two digits, a second dash, and finally a single digit. The first pair of digits is merely an arbitrary serial number assigned in sequence. The last digit denotes a subclass in the series. Thus we have LX-01-0, LX-02-1, ..., LX-05-0, etc. The last digit provides for the small changes in manufacturing specifications that inevitably occur. For example, when LX-04-0 has undergone a revision of explosive particle size, new lots, manufactured under the revised specification, are identified as LX-04-1.

LX-01—A liquid material, characterized by a wide liquid range (-65° to +165°F (219-347 K)), moderate energy release, and good stability and sensitivity properties. CAUTION: The TNM component is moderately volatile and highly toxic.

LX-02—A material of puttylike texture characterized by ability to propagate in very small diameters. LX-02 is derived from a series of DuPont formulations, the EL-506 series. Its immediate predecessor in development, called EL-506 L-3, represented one of several LLL modifications to DuPont's EL-506D. EL-506 L-3 became LX-02-0, and differed from the composition above by the inclusion of a few tenths of a percent of a red dye (DuPont Oil Red). Later, the dye was omitted because it tends to migrate out of the explosive under certain conditions.

LX-04 — A solid explosive characterized by excellent mechanical and compatibility properties, an energy release about 9% less than LX-09, and sensitivity properties much superior to LX-09.

LX-07-2 — A modification of LX-04 with a higher energy release (5% less than LX-09-0) obtained at the expense of some degradation in the mechanical properties (less elongation, etc.) and in sensitivity.

LX-08 — An extrudable, curable explosive developed for use in Dautriche timing tests.

LX-09 — Similar to the LASL explosive PBX-9404, but with significantly improved thermal stability and slightly poorer physical properties.

LX-10 — In the same energy class as LX-09 and PBX-9404, but utilizing HMX and Viton A like LX-04, and having excellent thermal characteristics. It also exhibits high creep resistance but may be somewhat more sensitive than the others.

LX-11 — Like LX-04 but intentionally degraded in energy by adding an additional 5% binder.

LX-13 — A variant of the LASL explosive XTX-8003.

A master log kept in the office of the Organic Materials Division contains the current listing of LX number assignments. The listing includes a detailed description of each LX explosive.

Research Explosives (RX Code)

A great variety of explosive formulations that never enter "production" are generated as the result of various research and development programs. These materials are designated "research" explosives and identified by a code patterned after the LX code. The code is applied to all materials that are formulated in large amounts or that are handled by large numbers of people outside the Organic Materials Division (either in- or outside the Laboratory).

The RX-code consists of the letters RX followed by a dash, two digits, another dash, and finally two capital alphabetic characters. Thus we might have RX-01-AA, RX-13-XD, etc. The two digits, assigned arbitrarily in sequence, define a general class of formulation. Thus, RX-01 refers to nitromethane liquid formulations, RX-02 to PETN extrudable formulations, etc. The two final letters in the code, also assigned arbitrarily in sequence (AA, AB, etc.) refer to a specific formulation within that general class.

RX-01—A series of liquid materials containing nitromethane.

RX-02—A series of extrudable materials containing PETN.

RX-03—A series of solid, plastic-bonded materials containing DATB or TATB.

RX-04—A series of solid, plastic-bonded materials composed of HMX and fluorocarbon elastomer. A specific example is RX-04-AB (HMX/Viton A 85/15); the HMX is defined as Holston's Class A. This material is for research purposes only, it is very much more sensitive than LX-04 with the identical chemical composition.

RX-05—A series of solid, plastic-bonded materials based on HMX and polystyrene.

RX-06—A series of extrudable materials based on HMX/4, 4-dinitropentanoic acid ester formulations.

RX-07—A Series: A series of cyclotols (RDX/TNT) containing various additives.
B Series: A series of LX-07-type explosives.

RX-08—A series of research explosives based on formulations of HMX, energetic liquids, and polymers. They are primarily for use in polymerization/pressure-casting experiments.

RX-09—A series of research explosives based on formulations of HMX and energetic binders. The binders are primarily based on plasticized poly(2, 2-dinitropropylacrylate). These explosives are intended to be high-energy formulations replacing PBX-9404.

RX-10—A series of rigid plastic-bonded explosives containing RDX and a fluorocarbon binder. They are primarily designed as insensitive replacements of PBX-9010.

RX-11—A series of rigid plastic-bonded explosives containing HMX and a light metal perchlorate.

RX-12—A series of inert metal-loaded formulation of HMX/Viton.

RX-13—Potentially explosive materials compounded to produce color changes from the heat produced upon impact.

RX-14—A series of HMX/polyethylene formulations. These explosives possess a very high degree of insensitivity, even though they are formulated with relatively low volume percentages of binder.

RX-15—PETN- or BTF-based rigid PBXs for booster applications.

RX-16—HMX/silicone formulations made in paste or putty form using a spray-on catalyst.

RX-17—A series of HMX-based rigid explosives using various binders and energetic plasticizers.

RX-18—A series of paste explosives containing HMX and a perchlorate. The carrier fluid is energetic, for example, EDNP or FEFO.

RX-19—An extrudable explosive consisting of class-E HMX and water with a reinforcing agent, such as milled glass fibers, and a wetting agent.

RX-20—A series of research explosives based on HMX and an energetic binder (NFPA-TVOPA). These are primarily formulations to replace PBX-9404.

RX-21—A series of research explosives based on HMX, a perchlorate, and energetic binders.

RX-22—A series of research explosives for exploring advanced energy concepts.

RX-23—A series of liquid explosives based on hydrazine.

RX-24—A series of research explosives containing HMX, PVC/PVA, and graphite.

RX-25—A series of research explosives based on HMX, a light metal, a perchlorate, and a binder.

RX-26—A series of high-temperature composite explosives based on TATB.

RX-27—A series of high-temperature explosives based on TACOT.

RX-28—A series of conventional high-temperature plastic-bonded explosives.

RX-29—A series of explosives consisting of separate components which are non-detonable until mixed.

RX-30—A series of research explosives based on gelled nitromethane and various perchlorates.

A master log kept in the office of the Organic Materials Division (Bldg. 222) lists and describes in detail each RX explosive. No correlation exists between RX and LX code number sequences.

LASL CODE DESIGNATIONS

The Los Alamos Scientific Laboratory has a number code for designating PBX materials that reach the stage of pilot or full-scale production. The code consists of four digits, a dash, and two more digits (for example, 9010-02). The first two digits give the weight percentage of the major explosive ingredient in the formulation. The next two digits represent an arbitrary serial number, assigned in sequence as materials are developed. The digits following the dash represent a second arbitrarily assigned serial number to designate different modifications of a given formulation. Thus, PBX-9010-02 is a material that contains 90 weight percent of the major explosive ingredient, is the tenth 90% material to be developed, and is the second modification of that particular composition.

The last two digits are often deleted in references to LASL materials. Thus, production PBX-9404 should, strictly speaking, be designated PBX-9404-03. The -03 designates a product manufactured in Holston equipment from HMX with a particular particle-size distribution.

LASL research explosives carry the designation X followed by a four-digit number.

IV. Data Sheets: Collected Properties of Explosives and Energetic Materials

This section contains the assembled data sheets of properties of individual explosives and related materials of continuing interest to this Laboratory. For details, conversion factors, and references, please refer to Section I.

The symbols and units used in these data sheets are listed below for your convenience.

Property	Symbol	Unit
Boiling point	b.p.	°C (K)
Chapman-Jouguet pressure	P_{CJ}	kbar (GPa)
Coefficient of thermal expansion—linear	α	m/m-K
cubical	β	m/m-K
Creep compliance	—	m^2/N
Crystal data	—	Å
Density	ρ	g/cm^3
Detonation velocity	D	mm/μsec (km/s)
Dielectric constant	ϵ	—
Drop weight sensitivity	H_{50}	cm (10^{-2} m)
Energy—cylinder test	E_{cyl}	$(mm/\mu sec)^2/2$ (MJ/kg)
Gap test (1/2 in.)	Gap	mil (mm)
Glass transition point	T_g	°F (K)
Heat of detonation	ΔH_{det}	kcal/g (kJ/kg)
Heat of formation	ΔH_f	kcal/mol (kJ/mol)
Initial modulus	E_o	GPa
Melting point	m.p.	°C (K)
Molecular refraction	R	—
Molecular weight	MW	—
Refractive index	n	—
Skid test	Skid	ft (m)
Solubility	sol.	—
Specific heat	C_p	cal/g-°C (kJ/kg-K)
Thermal conductivity	k	cal/sec-cm-°C (W/m-K)
		BTU/hr-ft-°F (W/m-K)
Vapor pressure	v.p.	mm Hg (Pa)

MATERIAL: BIS(2,2-DINITROPROPYL)ACETAL/ BIS(2,2-DINITROPROPYL)FORMAL (Plasticizer)	DESIGNATION: **BDNPA/BDNPF** SUPPLIER: —

2. STRUCTURAL FORMULATION

	wt%
BDNPA	50
BDNPF	50

4. PHYSICAL PROPERTIES

Physical state: liquid
Color: straw
At. comp.:
MW: 100
Density (g/cm^3): TMD:
Nominal: 1.383-1.397 at 25°C (298 K)
m.p. (°C (K)):
b.p. (°C (K)): ~150 at 0.01 mm Hg (~428 at 1.33 Pa)
v.p. (mm Hg (Pa)):
Brittle point (°C (K)):
f.p. (°C (K)): <-5 (<268)

Crystal data:
R:
n: 1.462-1.464 at 25°C (298 K)
Shore hardness:

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)):
-46.38 kcal/100 g (-194.1 kJ/0.1 kg)
Solubility (s-sol., sl-sl. sol., i-insol.):
s – benzene, toluene
i – water

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):
Elongation (%):

6. THERMAL PROPERTIES

k:
CTE:
T_g (°F (K)):
C_p (cal/g-°C (kJ/kg-K)):

10. ELECTRICAL PROPERTIES

ϵ: (ρ =

11. TOXICITY

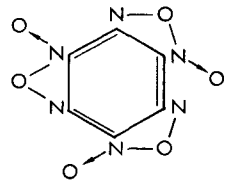
None.

NOTES

EXPLOSIVE: BENZOTRIS-[1,2,5]OXADIAZOLE-[1,4,7]TRIOXIDE

DESIGNATION: **BTF**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: buff

At. comp.: $C_6N_6O_6$

MW: 252.1

Density (g/cm^3): TMD: 1.901

Nominal: 1.87

m.p. (°C (K)): 198-200 (471-473)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: orthorhombic ($Pna2_1$)

a = 9.92

b = 19.52

c = 6.52

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.69 (7.07)	1.69 (7.07)
Exp:	1.41 (5.90)	1.41 (5.90)

ΔH_f (kcal/mol (kJ/mol)): +144.5 (+605)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—acetone, benzene, DMFA, DMSO, ethanol, ethyl acetate, ethyl ether, pyridine

i—carbon tetrachloride, water

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.24-0.40
0.05 (purified)

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.485 (ρ= 1.859)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.882)

Meas.: —

Calc.: 294

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ = 1.859)

6 mm: 1.305

19 mm: 1.680

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
11	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ: —

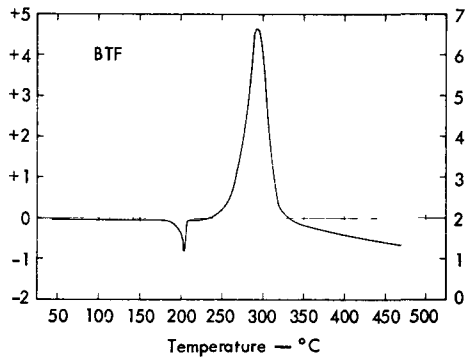
11. TOXICITY

—

BTF BENZOTRIS-[1,2,5] OXADIAZOLE-[1,4,7] TRIOXIDE

7. MECHANICAL PROPERTIES

Initial modulus



Creep

Failure envelope

NOTES

MATERIAL: AMORPHOUS SILICON OXIDE (Gelling agent)	DESIGNATION: **Cab-O-Sil M-5** SUPPLIER: Cabot Corp.

2. STRUCTURAL FORMULATION

O — Si — O

4. PHYSICAL PROPERTIES

Physical state: solid (fluffy powder) Color: white At. comp.: SiO_2 MW: 60.09 Density (g/cm^3): TMD: 2.3 Nominal: 2.2 m.p. (°C (K)): b.p. (°C (K)): v.p. (mm Hg (Pa)): Brittle point (°C (K)): f.p. (°C (K)):	Crystal data: amorphous R: n: 1.46 Shore hardness:

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)): -215.94 (-903.5)

Solubility (s-sol., sl-sl. sol., i-insol.):

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%):

6. THERMAL PROPERTIES

k:

CTE:

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

10. ELECTRICAL PROPERTIES

ϵ: (ρ =

11. TOXICITY

Low.

NOTES

Cab-O-Sil M-5

EXPLOSIVE: COMP B, GRADE A

DESIGNATION: **Comp B**

2. STRUCTURE OR FORMULATION

	wt%
RDX	63
TNT	36
Wax	1

4. PHYSICAL PROPERTIES

Physical state: solid

Color: —

At. comp.: $C_{2.03}H_{2.64}N_{2.18}O_{2.67}$

MW: 100

Density (g/cm^3): TMD: 1.74

Nominal: 1.71

m.p. (°C (K)): ~80 (~353)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.54 (6.44)	1.40 (5.86)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +1.0 (+5.78)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: 6.27 × 10^{-4} cal/sec-cm-°C (0.262 W/m-K)

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.051

1 g for 48 hr: 0.05-0.16

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.99 (ρ= 1.72)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.717)

Meas.: 295

Calc.: —

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.717)

6 mm: 1.035

19 mm: 1.330

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	45	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ= 1.710)
16-26 (0.41-0.66)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

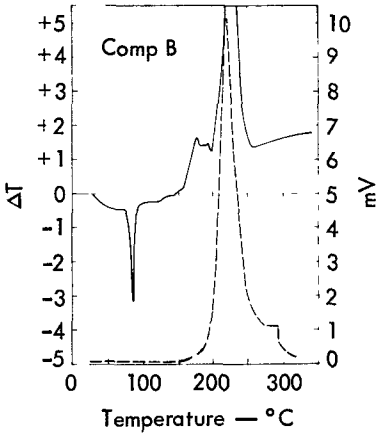
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



EXPLOSIVE: CYCLOTOL 75/25

DESIGNATION: **Cyclotol 75/25**

2. STRUCTURE OR FORMULATION

	wt%
RDX	75
TNT	25

4. PHYSICAL PROPERTIES

Physical state: solid

Color: —

At. comp.: $C_{1.78}H_{2.58}N_{2.36}O_{2.69}$

MW: 100

Density (g/cm^3): TMD: 1.77

Nominal: 1.75-1.76

m.p. (°C (K)): 79-80 (352-353)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 0.1 at 100°C (13.33 at 373 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

Δ H_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.57 (6.57)	1.44 (6.03)
Exp:	—	—

Δ H_f (kcal/mol (kJ/mol)): +3.01 (+13.8)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.014-0.04

1 g for 48 hr: 0.25-0.94

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.30 (ρ = 1.76)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.752)

Meas.: 316

Calc.: —

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.754)

6 mm: 1.140

19 mm: 1.445

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
33	—

Susan test: Threshold velocity ~ 180 ft/sec (~ 55 m/s); generally difficult to ignite but capable of large reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	0.88 (0.27)	4
45 (0.79)	28.0 (8.53)	0

Gap test (mils (mm)):
Small scale: 10-16 (0.25-0.41) (ρ = 1.753)
Large scale: 1.646 (41.8) (ρ = 1.756)

10. ELECTRICAL PROPERTIES:

ϵ: 3.38 (ρ = 1.75)

11. TOXICITY

—

Cyclotol 75/25

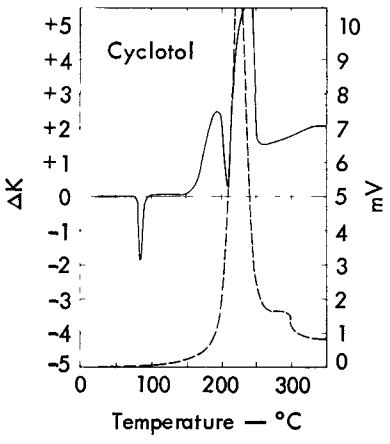
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

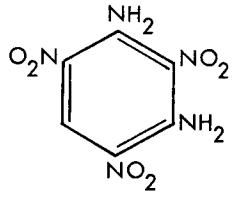


DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: 1,3-DIAMINO-2,4,6-TRINITROBENZENE

DESIGNATION: **DATB**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_6H_5N_5O_6$

MW: 243.1

Density (g/cm^3): TMD: 1.837

Nominal: 1.79

m.p. (°C (K)): 286 (559)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: (Pc2)

a = 7.30

b = 5.20

c = 11.63

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.26 (5.27)	1.15 (4.81)
Exp:	0.98 (4.10)	0.91 (3.81)

ΔH_f (kcal/mol (kJ/mol)): -29.23 (-122)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—DMFA, DMSO

i—acetone, benzene, carbon disulfide, carbon tetrachloride, ethanol, water

6. THERMAL PROPERTIES

k: 6.00×10^{-4} cal/sec-m-°C (0.251 W/m-K)

CTE: α = 32-46 μm/m-K at 253 K

α = 52-66 μm/m-K at 358 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: < 0.03

1 g for 48 hr: < 0.03

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.52 (ρ= 1.79)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.78)

Meas.: 259

Calc.: 250

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
> 177	> 177

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

Small scale: 11-17 (0.28-0.43) (ρ = 1.801)

Large scale: 1.641 (41.7) (ρ = 1.786)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

DATB 1,3-DIAMINO-2, 4, 6-TRINITROBENZENE

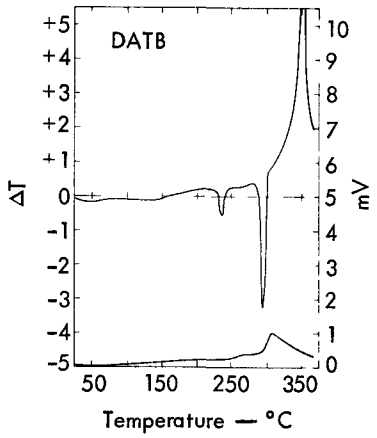
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

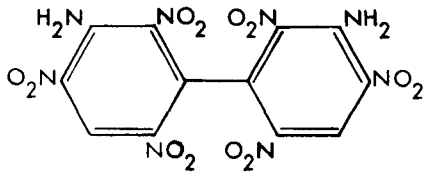


DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: 3,3-DIAMINO-2, 2', 4,4',6,6'-HEXANITROBIPHENYL

DESIGNATION: **DIPAM**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: —

At. comp.: $C_{12}H_6N_8O_{12}$

MW: 454.1

Density (g/cm^3): TMD: 1.79

Nominal: —

m.p. (°C (K)): 304 (577)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.35 (5.65)	1.27 (5.31)
Exp:	—	—

ΔH_f (kcal/mol (kj/mol)): -20.1 (-84.1)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.40 (ρ= 1.76)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	95	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

Moderate.

DIPAM 3,3-DIAMINO-2,2',4,4',6,6'-HEXANITROBIPHENYL

7. MECHANICAL PROPERTIES

Initial modulus

Creep

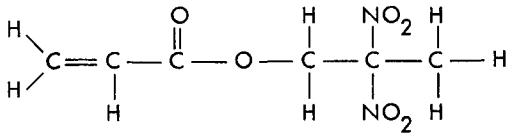
Failure envelope

NOTES

EXPLOSIVE: 2,2-DINITROPROPYL ACRYLATE

DESIGNATION: **DNPA**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: off-white

At. comp.: $C_6H_8N_2O_6$

MW: 204.1

Density (g/cm^3): TMD: 1.47

Nominal: —

m.p. (°C (K)): —

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.06 (4.44)	0.85 (3.57)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -110 (-460)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—acetone

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.04-0.06

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): — (ρ=)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
>177	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

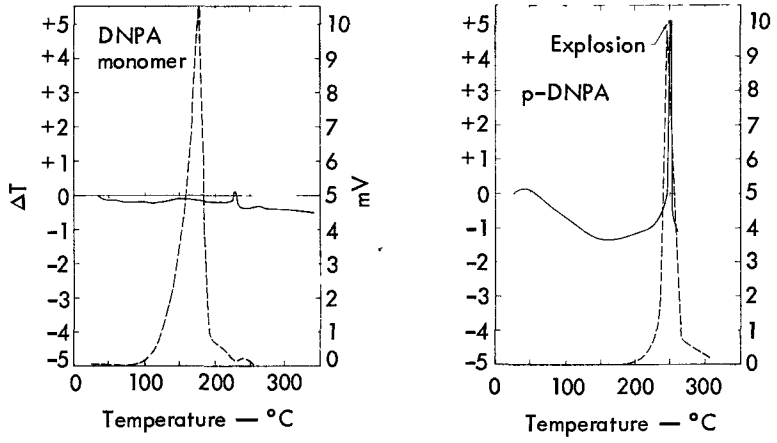
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



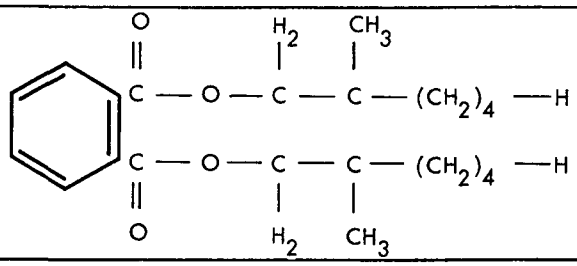
DTA (-) and pyrolysis (---) curves.

MATERIAL: DI-2-ETHYLHEXYL PHTHALATE
(Plasticizer)

DESIGNATION: **DOP**

SUPPLIER:

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_{24}H_{38}O_4$

MW: 390.57

Density (g/cm^3): TMD: 0.9861

Nominal: ——

m.p. (°C (K)):

b.p. (°C (K)): 222-230 (495-503)

v.p. (mm Hg (Pa)): <0.06 at 150°C (<8.0 at 423 K)

Brittle point (°C (K)):

f.p. (°C (K)): -55 (218)

Crystal data:

R:

n: 1.485 at 25°C (298 K)

Shore hardness:

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)): -268.2 (-1 122)

Solubility (s-sol., sl-sl. sol., i-insol.):

s – gasoline, mineral oil

i – glycerine, water

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%):

6. THERMAL PROPERTIES

k:

CTE: 74 μm/m at 10-40°C (283-313 K)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

~0.57 at 50-150°C (~2.385 at 323-423 K)

10. ELECTRICAL PROPERTIES

ϵ: (ρ =

11. TOXICITY

None.

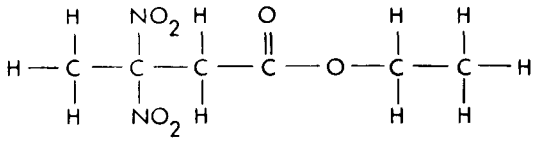
NOTES

DOP

EXPLOSIVE: ETHYL 4,4-DINITROPENTANOATE

DESIGNATION: **EDNP**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: yellow

At. comp.: $C_7H_{12}N_2O_6$

MW: 220.2

Density (g/cm^3): TMD: 1.28

Nominal: —

m.p. (°C (K)): -6 (268)

b.p. (°C (K)): 83 at 0.05 mm (356 at 6.7 Pa)

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.23 (5.15)	0.94 (3.93)
Exp:	—	—

ΔH_f (kcal/mol (kj/mol)): -140 (-586)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—acetone, carbon tetrachloride, chloroform, DMFA, DMSO, ethanol, ethyl acetate, ethyl ether, pyridine

i—water

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): — (ρ=)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

7. MECHANICAL PROPERTIES

Initial modulus

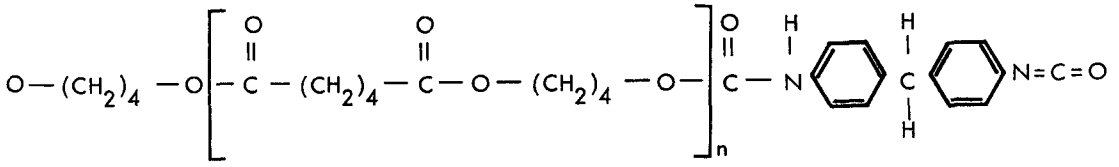
Creep

Failure envelope

NOTES

MATERIAL: POLYURETHANE SOLUTION SYSTEM (Binder)	DESIGNATION: **Estane 5702-F1** SUPPLIER: B. F. Goodrich

2. STRUCTURAL FORMULATION



n = 5-10

4. PHYSICAL PROPERTIES

Physical state: rubbery solid
Color: light amber
At. comp.: $(C_{5.137}H_{7.500}N_{0.187}O_{1.758})_n$
MW: 100
Density (g/cm^3): TMD:
Nominal: 1.18
m.p. (°C (K)):
b.p. (°C (K)):
v.p. (mm Hg (Pa)):
Brittle point (°C (K)):
f.p. (°C (K)):

Crystal data:

R:
n:
Shore hardness: A 70

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)): -95 (-397)

Solubility (s-sol., sl-sl. sol., i-insol.):
s – acetone, dichloroethane, DMFA, DMSO, MEK, MIBK, THF

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%):

6. THERMAL PROPERTIES

k:
CTE:

T_g (°F (K)): -31 (242)

C_p (cal/g-°C (kJ/kg-K)):

10. ELECTRICAL PROPERTIES

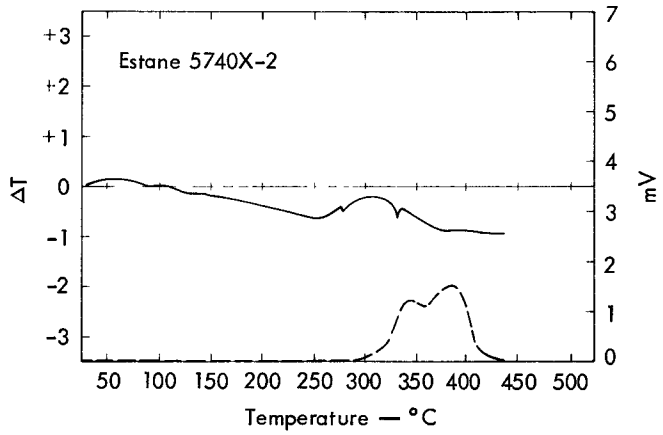
ϵ: (ρ =

11. TOXICITY

None.

NOTES

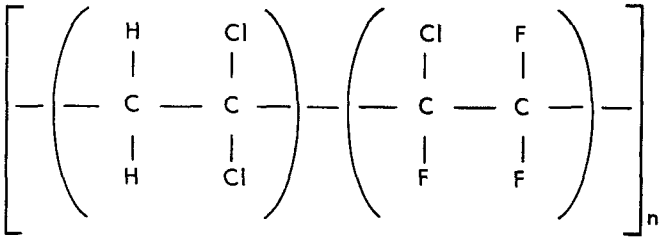
Estane 5702-F1



DTA (-) and pyrolysis (---) curves.

MATERIAL: TRIFLUOROCHLOROETHYLENE/ VINYLIDINE CHLORIDE COPOLYMER (Binder)	DESIGNATION : **Exon 461** SUPPLIER : Firestone Plastics Co.

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

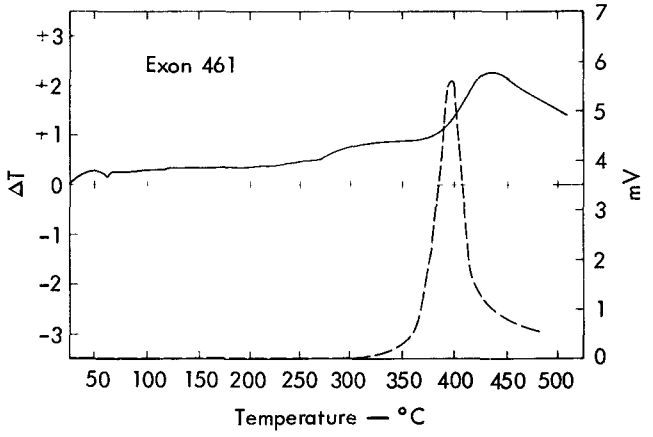
Physical state : solid Color : white At. comp. : $(C_4H_2Cl_3F_3)_n$ MW : $(213.43)_n$ Density (g/cm^3) : TMD : Nominal : 1.70 m.p. (°C (K)) : b.p. (°C (K)) : v.p. (mm Hg (Pa)) : Brittle point (°C (K)) : f.p. (°C (K)) :	Crystal data : R : n : Shore hardness :

5. CHEMICAL PROPERTIES	7. MECHANICAL PROPERTIES
ΔH_f (kcal/mol (kJ/mol)) : Solubility (s-sol., sl-sl. sol., i-insol.) : s – gasoline, MEK, toluene, xylene	Tensile strength (psi (kPa)): Elongation (%) :

6. THERMAL PROPERTIES	10. ELECTRICAL PROPERTIES
k : CTE :	ϵ : 2.82 (ρ = 1.7)
	11. TOXICITY
T_g (°F (K)) : C_p (cal/g-°C (kJ/kg-K)) :	Slight.

NOTES

Exon 461

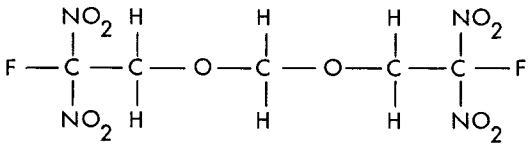


DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: BIS(2-FLUORO-2,2-DINITROETHYL) FORMAL

DESIGNATION: **FEFO**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: straw

At. comp.: $C_5H_6N_4O_{10}F_2$

MW: 320.1

Density (g/cm^3): TMD: 1.607

Nominal: —

m.p. (°C (K)): 11.3-12.9 (284-286)

b.p. (°C (K)): 120-124 at 10.3 mm (393-397 at 40 Pa)

v.p. (mm Hg (Pa)): 2.14×10^{-4} at 25°C
(2.85×10^{-2} at 298 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.45 (6.07)	1.39 (5.82)
Exp:	1.28 (5.36)	1.21 (5.06)

ΔH_f (kcal/mol (kJ/mol)): -178 (-743)

Solubility (s-sol., sl-sl. sol., i-insol.):
s—acetone, chloroform, DMFA, DMSO, ethanol, ethyl acetate, ethyl ether, pyridine
i—carbon tetrachloride, water

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.36 at 25°C (1.507 at 298 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.04-0.10

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): — (ρ=)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)): 12 tool: 28; 12B tool: —

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ=)

See Table 9-6.

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

High.

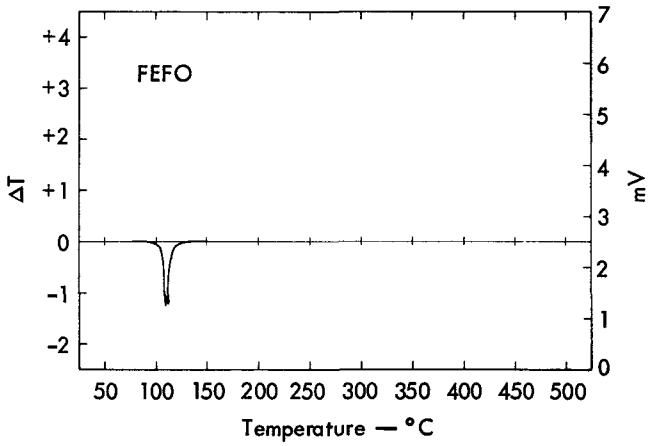
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

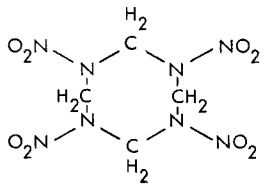


DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: 1,3,5,7-TETRANITRO-1,3,5,7-TETRAZACYCLOOCTANE

DESIGNATION: **HMX**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_4H_8N_8O_8$

MW: 296.2

Density (g/cm^3): TMD: 1.900

Nominal: 1.89

m.p. (°C (K)): 285-287 (558-560)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 3×10^{-9} at 100°C

(4×10^{-7} at 373 K)

Crystal data:

I: monoclin. ($P2_1/c$)	II: orthorh. (Fdd2)	III: monoclin. (Pc_1P2/c)	IV: hexag. ($P6_122$)
a = 6.54	a = 15.14	a = 10.95	a = 7.66
b = 11.05	b = 23.89	b = 7.93	
c = 8.70	c = 5.91	c = 14.61	c = 32.49

R: I: 58 calc., 56.1 obs.; II: 58 calc., 55.7 obs.; III: 58 calc., 55.4 obs.; IV: 58 calc., 55.9 obs.

n: See Table 4-4

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.62 (6.78)	1.48 (6.19)
Exp:	1.48 (6.19)	1.37 (5.73)

ΔH_f (kcal/mol (kJ/mol)): +17.93 (+75)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—DMSO

sl—acetone, DMFA, pyridine

i—carbon disulfide, carbon tetrachloride, chloroform, ethyl ether, water

6. THERMAL PROPERTIES

k: —

CTE: α = 22.0 × 10^{-6} in./in.-°F at -65 to 165°F

α = 50.4 μm/m-K at 219-347 K

β = 162.5 μm/m-K at 243-343 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): none

C_p (cal/g-°C (kJ/kg-K)):

Exp.: 0.265 at 20°C (1.109 at 293 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: < 0.01

1 g for 48 hr: 0.07

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 9.11 (ρ = 1.89)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.90)

Meas.: —

Calc.: 387

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.894)

6 mm: 1.40

19 mm: 1.745

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	33	40

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

Large scale: 2.783 (70.7) (ρ = 1.07)

10. ELECTRICAL PROPERTIES:

ϵ: I: 3.087 (ρ = 1.90)

II: 4.671 (ρ = 1.87)

III: 3.867 (ρ = 1.82)

11. TOXICITY

Slight.

HMX 1,3,5,7-TETRANITRO-1,3,5,7-TETRAZACYCLO-OCTANE

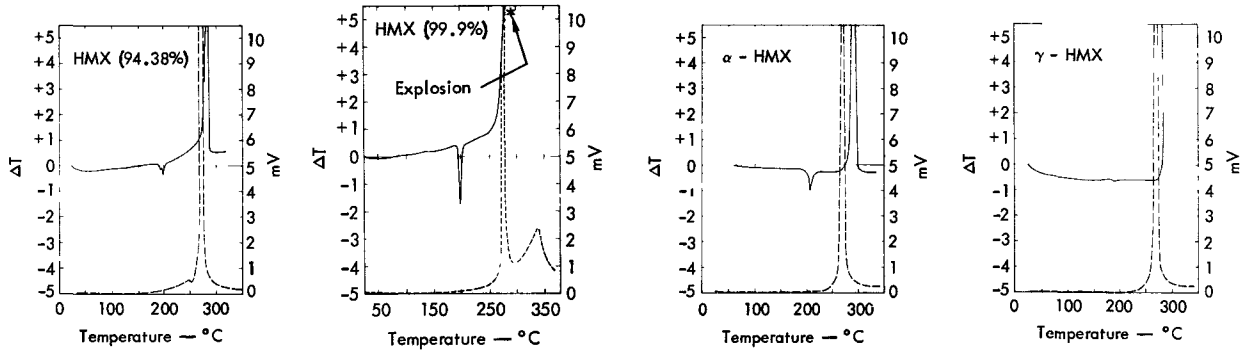
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

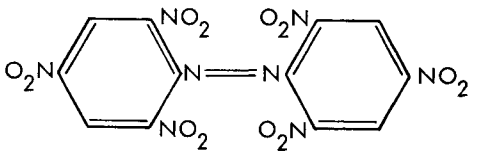


DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: 2,2',4,4',6,6'- HEXANITROAZOBENZENE

DESIGNATION: **HNAB**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: orange

At. comp.: $C_{12}H_4N_8O_{12}$

MW: 452.21

Density (g/cm^3): TMD: Calc.: I: 1.795; II: 1.744; III: —
Obs.: I: 1.799; II: 1.750; III: 1.718

m.p. (°C (K)): 215-216 (488-489)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 1×10^{-7} at 100°C
(1.33×10^{-5} at 373 K)

Crystal data:

I: ($P2_1/c$)	II: ($P2_1/a$)
a = 10.15	a = 10.63
b = 8.26	b = 21.87
c = 10.06	c = 7.59

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.47 (6.15)	1.42 (5.94)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +57.8 (+241.8)

Solubility (s-sol., sl-sl. sol., i-insol.):
s—acetone
sl—carbon tetrachloride, chloroform, ethyl acetate

6. THERMAL PROPERTIES

k: —

CTE: α = 80 μm/m-K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): II: 7.6-7.7 (ρ= 1.77)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

Slight.

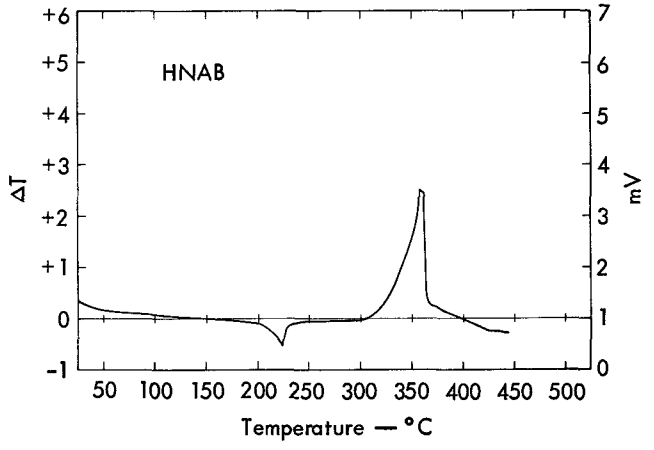
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

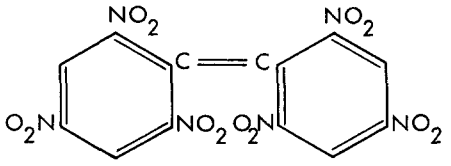


DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: 2,2',4,4',6,6'-HEXANITROSTILBENE

DESIGNATION: **HNS**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_{14}H_6N_6O_{12}$

MW: 450.3

Density (g/cm^3): TMD: 1.74

Nominal: 1.72

m.p. (°C (K)): 316 (589); I: 313 (586); II: 318 (591)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)):

I: $\log_{10} P_{mm} = 14.084 - (9347/T\ (K))$

II: 1×10^{-9} at 100°C (1.33×10^{-7} at 373 K)

Crystal data: orthorhombic

a = 20.93
b = 5.57
c = 14.67

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.42 (5.94)	1.36 (5.69)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +13.88 (+58.1)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—DMFA

sl—acetone

6. THERMAL PROPERTIES

k: —

CTE: α = 92 μm/m-K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.40 (1.67)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.01

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.00 (ρ= 1.70)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

Slight.

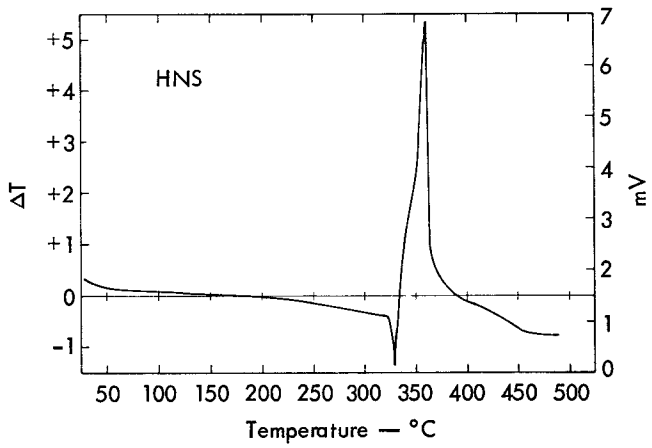
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

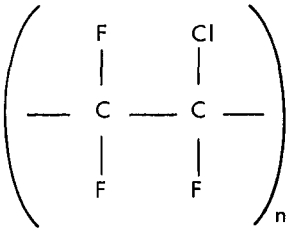
NOTES



DTA (-) and pyrolysis (---) curves.

MATERIAL: POLY(TRIFLUOROCHLOROETHYLENE (Binder)	DESIGNATION: **Kel-F 800** SUPPLIER: 3M

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid
Color: off-white
At. comp.: $(C_2ClF_3)_n$
MW:
Density (g/cm^3): TMD:
Nominal: 2.02
m.p. (°C (K)):
b.p. (°C (K)):
v.p. (mm Hg (Pa)):
Brittle point (°C (K)):
f.p. (°C (K)):

Crystal data:

R:
n: 1.416
Shore hardness: D 64

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)):

Solubility (s-sol., sl-sl. sol., i-insol.):
s – acetone, butyl acetate, ethyl acetate, MEK, MIBK, THF
i – toluene, water

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):
1500 (10)
Elongation (%): 350

6. THERMAL PROPERTIES

k:
CTE:

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

10. ELECTRICAL PROPERTIES

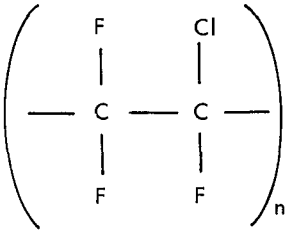
ϵ: 300 (ρ = 2.02)

11. TOXICITY

NOTES

MATERIAL: POLY(TRIFLUOROCHLOROETHYLENE (Binder)	DESIGNATION: **Kel-F 3700** SUPPLIER: 3 M

2. STRUCTURAL FORMULATION



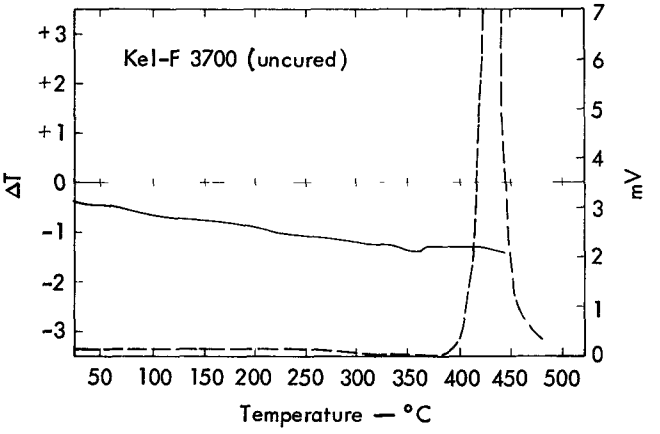
4. PHYSICAL PROPERTIES

Physical state: solid Color: off-white At. comp.: $(C_2ClF_3)_n$ MW: $(116.48)_n$ Density (g/cm^3): TMD: Nominal: 1.85 m.p. (°C (K)): b.p. (°C (K)): v.p. (mm Hg (Pa)): Brittle point (°C (K)): -64 (209) f.p. (°C (K)):	Crystal data: R: n: Shore hardness: A 45

5. CHEMICAL PROPERTIES	7. MECHANICAL PROPERTIES
ΔH_f (kcal/mol (kJ/mol)): -161 (-674) Solubility (s-sol., sl-sl. sol., i-insol.):	Tensile strength (psi (kPa)): 350-600 (2.41-4.14) Elongation (%): 500-800

6. THERMAL PROPERTIES	10. ELECTRICAL PROPERTIES
k: CTE:	ϵ: (ρ =
	11. TOXICITY
T_g (°F (K)): -15 (258) C_p (cal/g-°C (kJ/kg-K)):	

NOTES



DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: LX-01

DESIGNATION: **LX-01**

2. STRUCTURE OR FORMULATION

	wt%
NM	51.7
TNM	33.2
1-Nitropropane	15.1

4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_{1.52}H_{3.73}N_{1.69}O_{3.39}$

MW: 100

Density (g/cm^3): TMD: 1.23

Nominal: —

m.p. (°C (K)): -54 (219)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 29.0 at 25°C (3866 at 298 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.72 (7.20)	1.52 (6.36)
Exp:	—	—

ΔH_f (kcal/mol (kj/mol)): -27.5 (-115.2)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: 1.8 at 80°C (353)

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.84 (ρ= 1.24)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.31)

Meas.: 156

Calc.: 177

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE: LX-02-1

DESIGNATION: **LX-02**

2. STRUCTURE OR FORMULATION

	wt%
PETN	73.5
Butyl rubber	17.6
Acetyltributyl citrate	6.9
Cab-O-Sil	2.0

4. PHYSICAL PROPERTIES

Physical state: puttylike solid

Color: buff

At. comp.: $C_{2.77}H_{4.86}N_{0.93}O_{2.99}Si_{0.03}$

MW: 100

Density (g/cm^3): TMD: 1.44

Nominal: 1.43-1.44

m.p. (°C (K)): no fixed m.p.

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.42 (5.94)	1.16 (4.85)
Exp:	—	—

ΔH_f (kcal/mol (kj/mol)): -49.1 (-205.3)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE: α = 128.7 m/m-K at 244-253 K

β = 385 m/m-K at 243-343 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): none above -4 (253)

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.29 (1.213)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: 0.3-0.6

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.37 (ρ= 1.44)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	80	—

Susan test: Very difficult to ignite; small probability of building to a violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE: LX-04-1

DESIGNATION: **LX-04**

2. STRUCTURE OR FORMULATION

	wt%
HMX	85
Viton A	15

4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_{1.55}H_{2.58}N_{2.30}O_{2.30}F_{0.52}$

MW:

Density (g/cm^3): TMD: 1.889

Nominal: 1.860-1.870

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.42 (5.94)	1.31 (5.49)
Exp:	1.31 (5.49)	1.25 (5.23)

ΔH_f (kcal/mol (kJ/mol)): -21.5 (-90.1)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: 9.25×10^{-4} cal/sec-cm-°C; 0.22 BTU/hr-ft-°F (0.380 W/m-K)

CTE:

α = 28.5×10^{-6} in./in.-°F at -65 to -18°F (51.3 μm/m-K at 219-245 K)

α = 39.5×10^{-6} in./in.-°F at -18 to 165°F (71.1 μm/m-K at 245-347 K)

β = 228.2 μm/m-K at 243-343 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -18 (245)

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.30 (1.25)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.01-0.04

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.46 (ρ = 1.86)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.865)

Meas.: 350

Calc.: 330

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ = 1.865)

6 mm: 1.170

19 mm: 1.470

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	41	55

Susan test: Threshold velocity 140-150 ft/sec (43-46 m/s); moderately easy to ignite; low probability of building to a violent reaction. Some geometries detonate high-order.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	14.1 (4.30)	2
45 (0.79)	5.0 (1.52)	3

Gap test (mils (mm)): (ρ = 1.865)

Small-scale:

Pre-1965: 60-80 (1.5-2.0)

Post-1965: 40-60 (1.0-1.5)

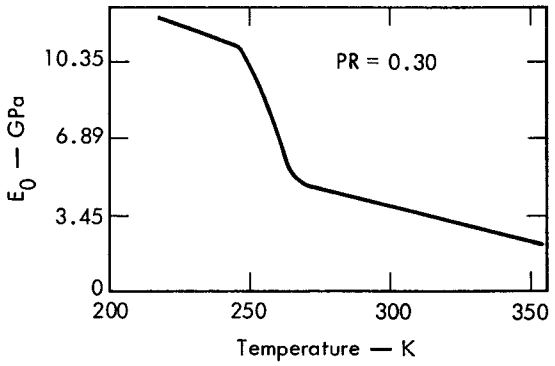
10. ELECTRICAL PROPERTIES:

ϵ: 3.44 (ρ = 1.86)

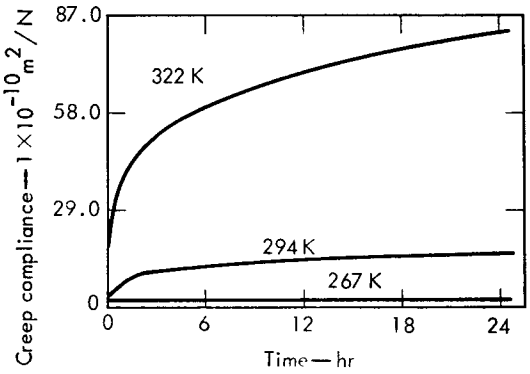
11. TOXICITY

—

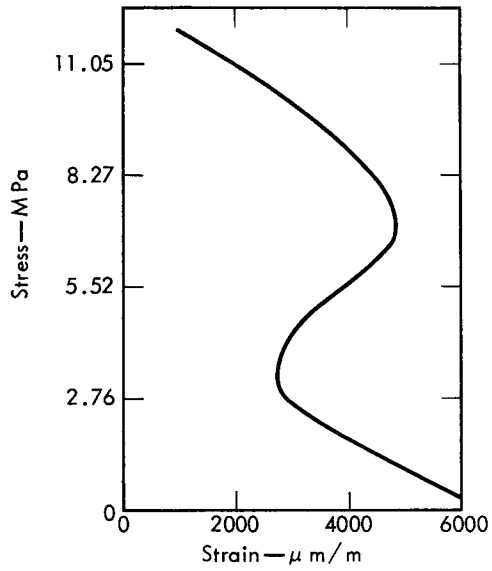
7. MECHANICAL PROPERTIES



Initial modulus

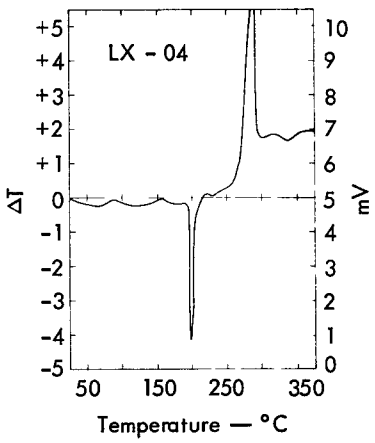


Creep



Failure envelope

NOTES



DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: LX-07

DESIGNATION: **LX-07**

2. STRUCTURE OR FORMULATION

	wt%
HMX	90
Viton A	10

4. PHYSICAL PROPERTIES

Physical state: solid

Color: orange

At. comp.: $C_{1.48}H_{2.62}N_{2.43}O_{2.43}F_{0.35}$

MW: 100

Density (g/cm^3): TMD: 1.892

Nominal: 1.860-1.870

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.49 (6.23)	1.37 (5.73)
Exp:	—	—

ΔH_f (kcal/mol (kj/mol)): -12.3 (-51.7)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: 0.23 BTU/hr-ft-°F (0.398 W/m-K)

CTE:

α = 26.7 × 10^{-6} in./in.-°F at -65 to -18°F (48 m/m-K at 219-245 K)

α = 34.8 × 10^{-6} in./in.-°F at -18 to 165°F (63 m/m-K at 245-347 K)

β = 182.9 m/m-K at 243-343 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -18 (245)

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.28 (1.172)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: 0.01-0.04

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.64 (ρ= 1.87)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.865)

Meas.: —

Calc.: 346

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.857)

6 mm: 1.250 (LX-07-1)

19 mm: 1.575 (LX-07-1)

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	38	—

Susan test: Threshold velocity ~125 ft/sec (~38 m/s); has moderate buildup to violent reaction. (LX-07-2).

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
*14 (0.24)	2.5 (0.76)	6
*45 (0.79)	7.1 (2.16)	5

*LX-07-1

Gap test (mils (mm)): (ρ= 1.857)

70-90 (1.8-2.3) (LX-07-1)

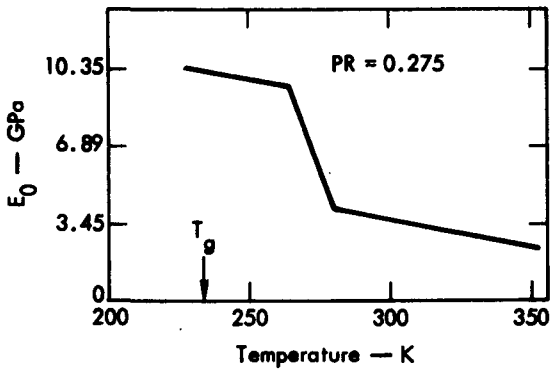
10. ELECTRICAL PROPERTIES:

ϵ: —

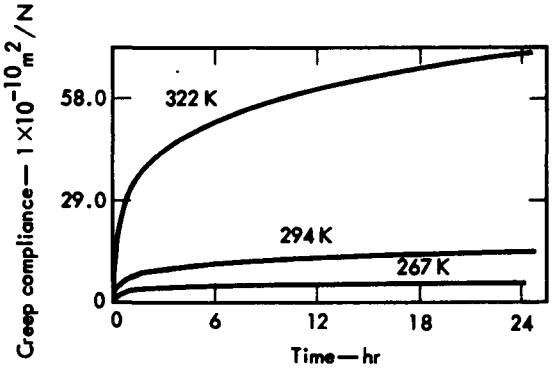
11. TOXICITY

—

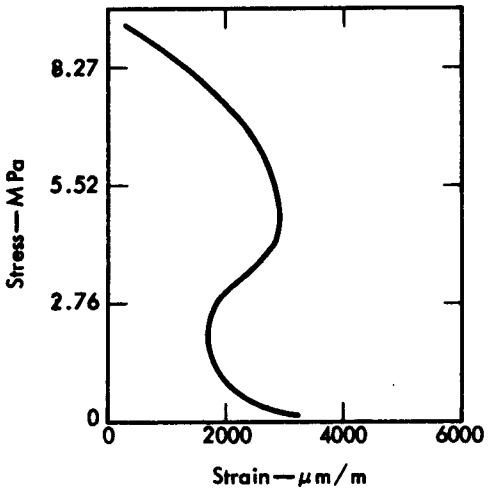
7. MECHANICAL PROPERTIES



Initial modulus



Creep



Failure envelope

NOTES

EXPLOSIVE: LX-08-0

DESIGNATION: **LX-08**

2. STRUCTURE OR FORMULATION

	wt%
PETN	63.7
Sylgard	34.3
Cab-O-Sil	2.0

4. PHYSICAL PROPERTIES

Physical state: puttylike solid

Color: blue

At. comp.: $C_{1.93}H_{4.39}N_{0.81}O_{2.95}Si_{0.50}$

MW: 100

Density (g/cm^3): TMD: 1.439

Nominal: ≥1.42

m.p. (°C (K)): 129-135 (402-408) with dec.

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.98 (8.27)	1.77 (7.41)
Exp:	—	—

ΔH_f (kcal/mol (kj/mol)): -44 (-185.9)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE:

α = 104.5 × 10^{-6} in./in.-°F (188 m/m-K)

β = 565 m/m-K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.56 (ρ= ≥1.42)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE LX-09-0

DESIGNATION: **LX-09-0**

2. STRUCTURE OR FORMULATION

	wt%	
	LX-09-0	LX-09-1
HMX	93	93.3
pDNPA	4.6	4.4
FEFO	2.4	2.3

4. PHYSICAL PROPERTIES

Physical state: solid

Color: purple

At. comp.: $C_{1.43}H_{2.74}N_{2.59}O_{2.72}F_{0.02}$ (See also Table 4-2)

MW: 100 LX-09-1

Density (g/cm^3): TMD: 1.867

Nominal: 1.837-1.845

m.p. (°C (K)): dec. >280 (>553)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.60 (6.69)	1.46 (6.11)
Exp:	—	—

ΔH_f (kcal/mol (kj/mol)): +1.82 (+7.61) (LX-09-0)
+2.004 (+8.38) (LX-09-1)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: 0.25 BTU/hr-ft-°F (0.432 W/m-K)

CTE:

α = 27.1 × 10^{-6} in./in.-°F at -65 to -20°F (48.8 m/m-K at 219-244 K)

α = 31.0 × 10^{-6} in./in.-°F at -20 to 165°F (55.8 m/m-K at 244-347 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -20 (244)

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.28 (1.172)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: 0.03-0.07

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.81 (ρ= 1.84)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.837)

Meas.: 377

Calc.: 373

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.836)

6 mm: 1.320

19 mm: 1.675

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	32	—

Susan test: Threshold velocity ~110 ft/sec (~34 m/s); has high probability of rapid buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	1.25 (0.38)	6
45 (0.79)	5.0 (1.52)	6

Gap test (mils (mm)): (ρ= 1.835)

75-105 (1.9-2.7)

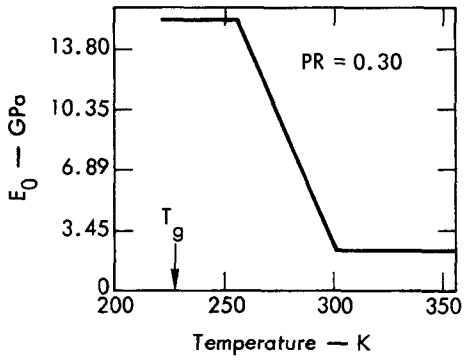
10. ELECTRICAL PROPERTIES:

ϵ: —

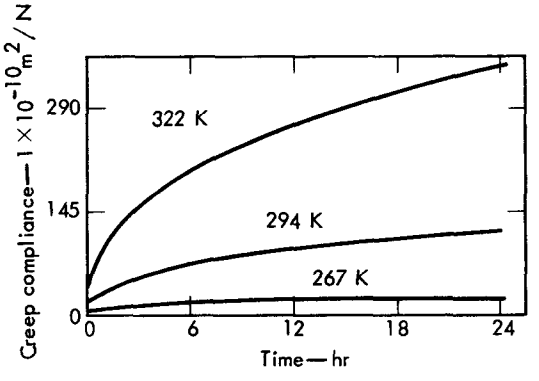
11. TOXICITY

—

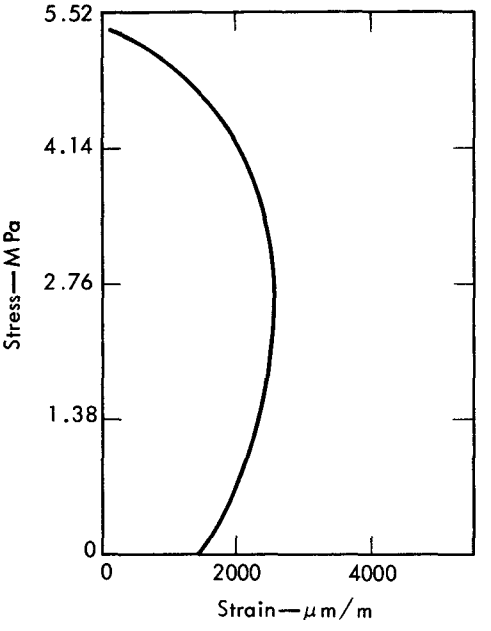
7. MECHANICAL PROPERTIES



Initial modulus



Creep



Failure envelope

NOTES

EXPLOSIVE: LX-10-0

DESIGNATION: **LX-10**

2. STRUCTURE OR FORMULATION

	wt% LX-10-0	LX-10-1
HMX	95	94.5
Viton A	5	4.5

4. PHYSICAL PROPERTIES

Physical state: solid LX-10-1: $C_{1.410}H_{2.663}N_{2.579}O_{2.579}F_{0.156}$

Color: blue-green spots on white

At. comp.: LX-10-0: $C_{1.42}H_{2.66}N_{2.57}O_{2.57}F_{0.17}$

MW: 100

Density (g/cm^3):	LX-10-0	LX-10-1
TMD:	1.896	1.895
Nominal:	1.858-1.868	1.870

m.p. (°C (K)): dec. >250 (>523)
b.p. (°C (K)): —
v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.55 (6.49)	1.42 (5.94)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -3.14 (-13.1)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: 0.25 BTU/hr-ft-°F (0.432 W/m-K)

CTE:

α = 24.8 × 10^{-6} in./in.-°F at -65 to 0°F (44.6 μm/m-K at 219-255 K)

α = 26.2 × 10^{-6} in./in.-°F at 0 to 165°F (47.0 μm/m-K at 255-347 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -18 (245)

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.28 (1.17)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

	LX-10-0	LX-10-1
0.25 g for 22 hr:	0.02	0.04-0.06

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.82 (ρ= 1.86)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.860)

Meas.: 375

Calc.: 360

E_{cyl} ((mm/μsec)²/2 (MJ/kg)): (ρ= 1.862)

6 mm: 1.315

19 mm: 1.670

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
LX-10-0 5 kg:	35	—
LX-10-0 2.5 kg:	—	40
LX-10-1 2.5 kg:	—	35

Susan test: Threshold velocity ~120 ft/sec (~37 m/s); has high probability of rapid buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	0.88 (0.27)	0
45 (0.79)	3.5 (1.07)	6

Gap test (mils (mm)): (ρ= 1.872)

Small-scale: 80-100 (2.0-2.5)

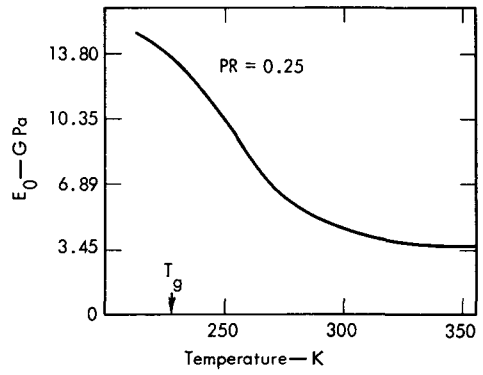
10. ELECTRICAL PROPERTIES:

ϵ: —

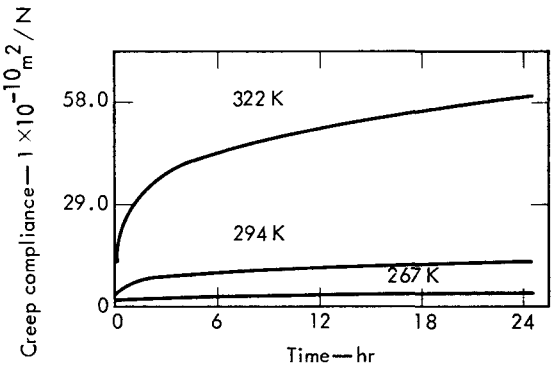
11. TOXICITY

—

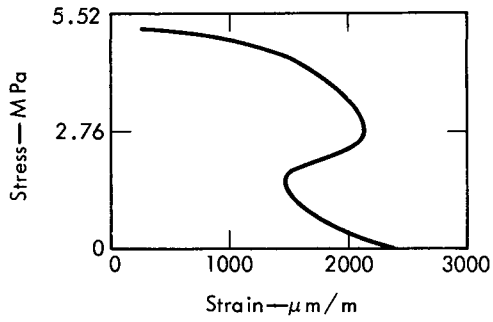
7. MECHANICAL PROPERTIES



Initial modulus



Creep



Failure envelope

NOTES

EXPLOSIVE: LX-11-0

DESIGNATION: **LX-11**

2. STRUCTURE OR FORMULATION

	wt%
HMX	80
Viton A	20

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_{1.61}H_{2.53}N_{2.16}O_{2.16}F_{0.70}$

MW: 100

Density (g/cm^3): TMD: —

Nominal: 1.87-1.876

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.38 (5.77)	1.28 (5.36)
Exp:	1.23 (5.15)	1.16 (4.85)

ΔH_f (kcal/mol (kj/mol)): -30.73 (-128.6)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: (est.) 0.21 BTU/hr-ft-°C (0.363 W/m-K)

CTE:

α = (est.) 31 × 10^{-6} in./in.-°F at -65 to -10°F (56 m/m-K at 219-249 K)

α = (est.) 46 × 10^{-6} in./in.-°F at 10-165°F (83 m/m-K at 261-347 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -18 (245)

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.28 (1.172)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: 0.01-0.04

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.32 (ρ= 1.87)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.87)

Meas.: —

Calc.: 310

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.876)

6 mm: 1.105

19 mm: 1.360

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	59	—

Susan test: Threshold velocity ~170 ft/sec (~53 m/s); is moderately difficult to ignite and has very low probability of buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ= 1.867)

45-65 (1.1-1.7)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE: LX-14

DESIGNATION: **LX-14**

2. STRUCTURE OR FORMULATION

	wt%
HMX	95.5
Estane 5702-F1	4.5

4. PHYSICAL PROPERTIES

Physical state: solid

Color: violet spots on white

At. comp.: $C_{1.521}H_{2.917}N_{2.587}O_{2.658}$

MW: 100

Density (g/cm^3): TMD: 1.849

Nominal: 1.833

m.p. (°C (K)): dec. >270 (>543)

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.576 (6.594)	(1.432 (5.954)
Exp:		

ΔH_f (kcal/mol (kJ/mol)): +1.50 (+6.28)

Solubility (s-sol., sl-sl. sol., i-insol.): ___

6. THERMAL PROPERTIES

k: ___

CTE: α = 27 × 10^{-6} in./in.-°F <30°F
(48.5 μm/m-K <239 K)

α = 31 × 10^{-6} in./in.-°F > 30°F
(55.8 μm/m-K >239 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): ___

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.02

1 g for 48 hr: 0.025

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.837 (ρ= 1.833)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.833)

Meas.: 370

Calc.: ___

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: ___

19 mm: ___

9. SENSITIVITY

H_{50} (cm (10^{-2} mm)): 2.5 kg:	12 tool	12B tool
		51

Susan test: Threshold velocity ~48 m/s; is moderately easy to ignite. Accidental mechanical ignition would have moderately low probability of building to violent reaction or detonation.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event

Gap test (mils (mm)): (ρ= 1.833)

Small-scale: 60-80 (1.5-2.0)

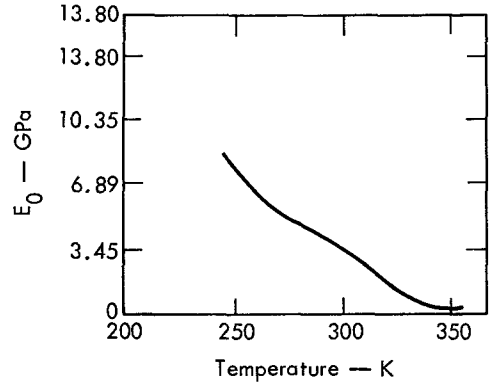
10. ELECTRICAL PROPERTIES:

ϵ:

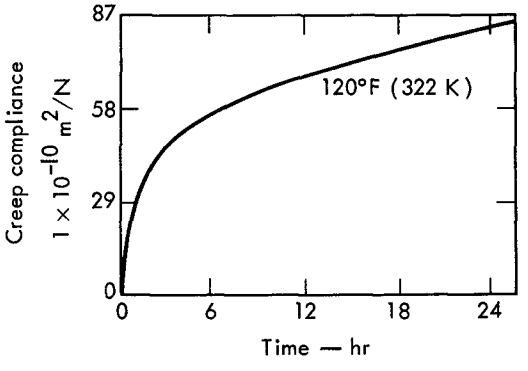
11. TOXICITY

LX-14

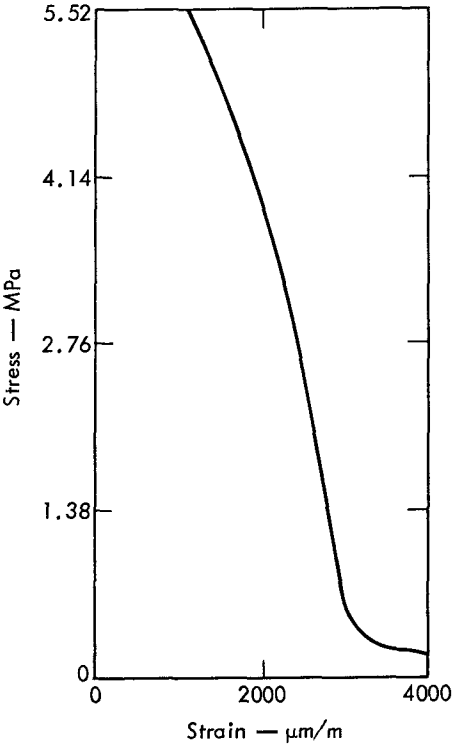
7. MECHANICAL PROPERTIES



Initial modulus



Creep



Failure envelope

NOTES

EXPLOSIVE: NITROCELLULOSE (12% N)

DESIGNATION: **NC (12% N)**

2. STRUCTURE OR FORMULATION

$[C_6H_7O_2(ONO_2)_3]_n$

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_6H_7N_{2.25}O_{9.5}$

MW: 262.6

Density (g/cm^3): TMD: —

Nominal: 1.58

m.p. (°C (K)): dec. 135 (408)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.16 (4.85)	1.02 (4.27)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -216 (-904)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—acetone, ethanol

i—carbon tetrachloride, chloroform, ethyl ether, water

6. THERMAL PROPERTIES

k: 5.5×10^{-4} cal/sec-cm-°C (0.230 W/m-K)

CTE: α = 80-120 μm/m-K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 1.0-1.2

1 g for 48 hr: 5.0

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): — (ρ=)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.58)

Meas.: —

Calc.: 200

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

None.

NC (12% N)

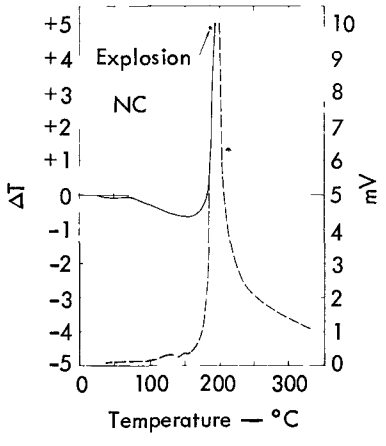
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: NITROCELLULOSE (13.35% N, min)

DESIGNATION: **NC (13.35% N)**

2. STRUCTURE OR FORMULATION

$[C_6H_7O_2(ONO_2)_3]_n$

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_6H_7N_{2.5}O_{10}$

MW: 274.1

Density (g/cm^3): TMD: —

Nominal: 1.58

m.p. (°C (K)): dec. 135 (408)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.16 (4.85)	1.02 (4.27)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -200 (-837)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—acetone, ethanol

i—carbon tetrachloride, chloroform, ethyl ether, water

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.30 (ρ= 1.20)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.58)

Meas.: —

Calc.: 210

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

(See Table 9-6)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

None.

NC (13.35% N)

NITROCELLULOSE (13.35% N, min)

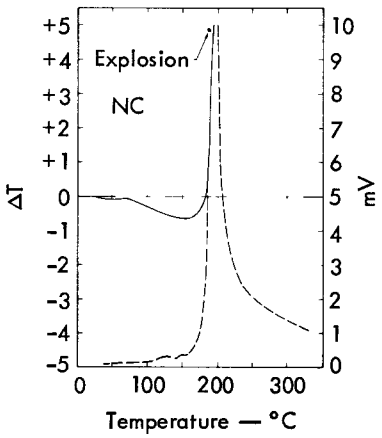
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

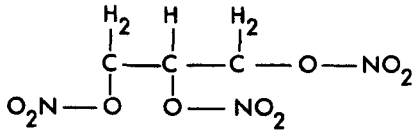


DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: 1,2,3-PROPANETRIOL TRINITRATE

DESIGNATION: **NG**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_3H_5N_3O_9$

MW: 227.1

Density (g/cm^3): TMD: 1.59

Nominal: —

m.p. (°C (K)): 13.2 (286)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 0.0015 at 20°C (0.2 at 293 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.59 (6.65)	1.48 (6.19)
Exp:	—	—

ΔH_f (kcal/mol (kj/mol)): -90.8 (-380)

Solubility (s-sol., sl-sl. sol., i-insol.):
s—acetone, benzene, chloroform, ethanol, ethyl acetate, ethyl ether, nitric acid, sulfuric acid, pyridine
sl—carbon disulfide, carbon tetrachloride, water

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.70 (ρ= 1.60)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.60)

Meas.: 253

Calc.: 251

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

See Table 9-6.

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

Very high.

7. MECHANICAL PROPERTIES

Initial modulus

Creep

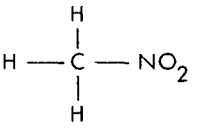
Failure envelope

NOTES

EXPLOSIVE: NITROMETHANE

DESIGNATION: **NM**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_1H_3N_1O_2$

MW: 61.0

Density (g/cm^3): TMD: 1.13 at 293 K

Nominal: —

m.p. (°C (K)): -29 (244)
b.p. (°C (K)): 101-101.5 (374-375)
v.p. (mm Hg (Pa)): 37 at 25°C (4933 at 298 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.62 (6.78)	1.36 (5.69)
Exp:	1.23 (5.15)	1.06 (4.44)

ΔH_f (kcal/mol (kj/mol)): -27 (-113)

Solubility (s-sol., sl-sl. sol., i-insol.):

s — DMFA, DMSO, ethanol, ethyl ether, water

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.41 at 30°C (1.715 at 303 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.32 (ρ = 1.13)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.135)

Meas.: 130

Calc.: 144

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.14)

6 mm: 0.560
19 mm: 0.745
} at 284-288 K

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (modified) (ρ = —)

7-17 (0.18-0.43)
2-8 (0.05-0.20)

See also Table 9-6.

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

Moderate.

7. MECHANICAL PROPERTIES

Initial modulus

Creep

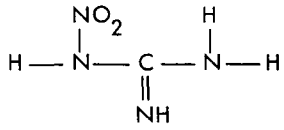
Failure envelope

NOTES

EXPLOSIVE: NITROGUANIDINE

DESIGNATION: **NQ**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_1H_4N_4O_2$

MW: 104.1

Density (g/cm^3): TMD: 1.72

Nominal: 1.55

m.p. (°C (K)): 246-247 (519-520) with dec.

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: orthorhombic (Fdd2)

a = 17.58
b = 24.84
c = 3.58

R: 25.2 (calc.), 22.2 (obs.)

n: 16

5. CHEMICAL PROPERTIES

Δ H_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.06 (4.44)	0.88 (3.68)
Exp:	—	—

Δ H_f (kcal/mol (kJ/mol)): -23.6 (-98.7)

Solubility (s-sol., sl-sl. sol., i-insol.):
s—sulfuric acid; sl—ethanol, nitric acid;
i—acetone, benzene, carbon disulfide, carbon tetrachloride, chloroform, ethyl acetate, ethyl ether, water

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.02-0.05

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.65 (ρ= 1.55)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
>177	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

Slight.

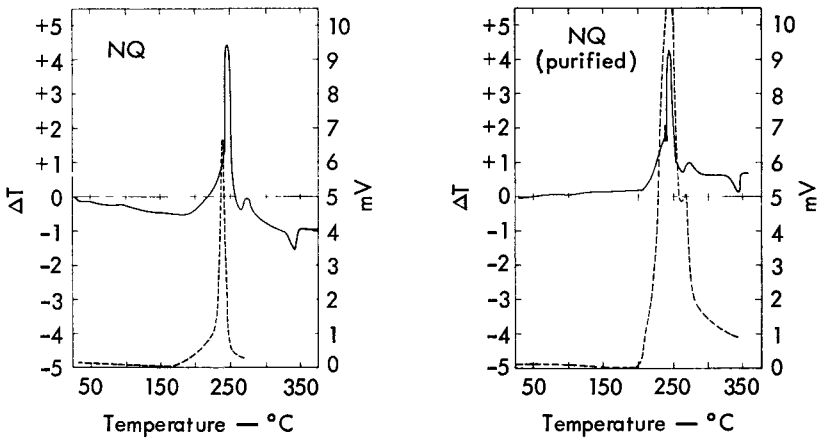
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: OCTOL

DESIGNATION: **Octol**

2. STRUCTURE OR FORMULATION

	wt%
HMX	75
TNT	25

4. PHYSICAL PROPERTIES

Physical state: solid

Color: —

At. comp.: $C_{1.78}H_{2.58}N_{2.36}O_{2.69}$

MW: 100

Density (g/cm^3): TMD: 1.83

Nominal: 1.80-1.82

m.p. (°C (K)): 79-80 (352-353)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 0.1 at 100°C (13.33 at 373 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.57 (6.57)	1.43 (5.98)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +2.57 (+11.9)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: 0.18

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.48 (ρ= 1.81)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.821)

Meas.: 342

Calc.: —

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.813)

6 mm: 1.215

19 mm: 1.535

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
41	—

Susan test: Threshold velocity ~180 ft/sec (~55 m/s); is rather difficult to ignite accidentally, but capable of large reaction once ignited.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	3.5 (1.07)	6

Gap test (mils (mm)):
Small-scale: 22-28 (0.56-0.71) (ρ = 1.810)
Large-scale: 1.947 (49.5) (ρ = 1.822)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

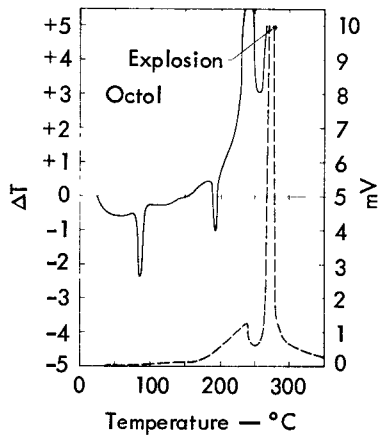
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: PBX-9007

DESIGNATION: **PBX-9007**

2. STRUCTURE OR FORMULATION

	wt%
RDX	90
Polystyrene	9.1
Di-2-ethylhexylphthalate	0.5
Rosin	0.4

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white or mottled gray

At. comp.: $C_{1.97}H_{3.22}N_{2.43}O_{2.44}$

MW: 100

Density (g/cm^3): TMD: 1.697

Nominal: 1.66

m.p. (°C (K)): dec. >200 (>473)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.56 (6.53)	1.39 (5.82)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +7.13 (+29.8)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.28 (1.17)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.03-0.07

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.09 (ρ= 1.64)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.60)

Meas.: 265

Calc.: —

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
35	28

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ= 1.665)

Small-scale: 45-55 (1.1-1.4)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

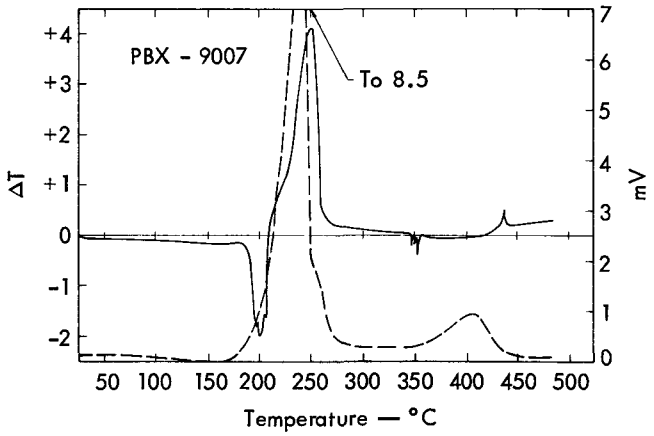
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: PBX-9010

DESIGNATION: **PBX-9010**

2. STRUCTURE OR FORMULATION

	wt%
RDX	90
Kel F	10

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_{1.39}H_{2.43}N_{2.43}O_{2.43}Cl_{0.09}F_{0.26}$

MW: 100

Density (g/cm^3): TMD: 1.822

Nominal: 1.789

m.p. (°C (K)): dec. >200 (>473)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.47 (6.15)	1.36 (5.69)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -7.87 (-32.9)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: 5.14×10^{-4} cal/cm-sec-°C (0.215 W/m-K)

CTE: α = 66 μm/m-K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.02-0.04

1 g for 48 hr: 0.2-0.3

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.37 (ρ= 1.78)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.783)

Meas.: 328 ± 5

Calc.: —

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ= 1.788)

6 mm: 1.160

19 mm: 1.470

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
30	45

Susan test: Threshold velocity ~110 ft/sec (~34 m/s); has high probability of rapid buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	1.25 (0.38)	6

Gap test (mils (mm)):
Small-scale: 75-95 (1.9-2.4) (ρ = 1.783)
Large-scale: 2.107 (53.5) (ρ = 1.781)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

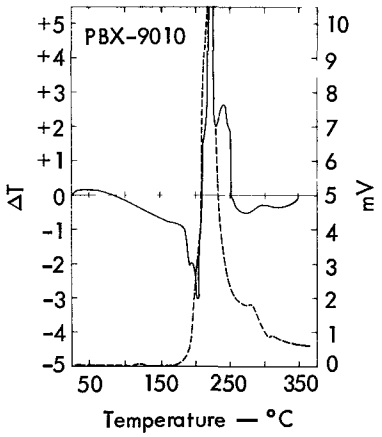
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: PBX-9011

DESIGNATION: **PBX-9011**

2. STRUCTURE OR FORMULATION

	wt%
HMX	90
Estane	10

4. PHYSICAL PROPERTIES

Physical state: solid

Color: off-white

At. comp.: $C_{1.73}H_{3.18}N_{2.45}O_{2.61}$

MW: 100

Density (g/cm^3): TMD: 1.795

Nominal: 1.770

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.53 (6.40)	1.36 (5.69)
Exp:	—	—

ΔH_f (kcal/mol (kj/mol)): -4.05 (-17)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: 10.0×10^{-4} cal/sec-cm-°C; 0.25 BTU/hr-ft-°F (0.432 W/m-K)

CTE:

α = 28.7×10^{-6} in./in.-°F at -65 to -40°F (51.7 m/m-K at 219-233 K)

α = 37.3×10^{-6} in./in.-°F at -30 to 165°F (67.1 m/m-K at 243-347 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -35 (236)

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.28 (1.172)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: 0.024

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.50 (ρ= 1.77)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.767)

Meas.: 324 ± 5

Calc.: —

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ= 1.777)

6 mm: 1.120

19 mm: 1.415

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	44	98

Susan test: Threshold velocity ~165 ft/sec (~50 m/s); is moderately difficult to ignite and has very low probability of buildup to a violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	20.0 (6.10)	2
45 (0.79)	20.0 (6.10)	0

Gap test (mils (mm)): (ρ= 1.783)

55-70 (1.4-1.8)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE: PBX-9205

DESIGNATION: **PBX-9205**

2. STRUCTURE OR FORMULATION

	wt%
RDX	92
Polystyrene	6
Di-2-ethylhexylphthalate	2

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_{1.83}H_{3.14}N_{2.49}O_{2.51}$

MW: 100

Density (g/cm^3): TMD: 1.72

Nominal: 1.68

m.p. (°C (K)): dec. >200 (>473)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.46 (6.11)	1.41 (5.90)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +5.81 (+24.30)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.28 (1.17)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.025

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.17 (ρ= 1.67)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.69)

Meas.: —

Calc.: 288

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	42	36

Susan test: Threshold velocity ~120 ft/sec (~37 m/s); has moderate probability of buildup to a violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	1.25 (0.38)	2
45 (0.79)	2.5 (0.76)	4

Gap test (mils (mm)): (ρ= 1.682)

Small-scale: 25-35 (0.64-0.89)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

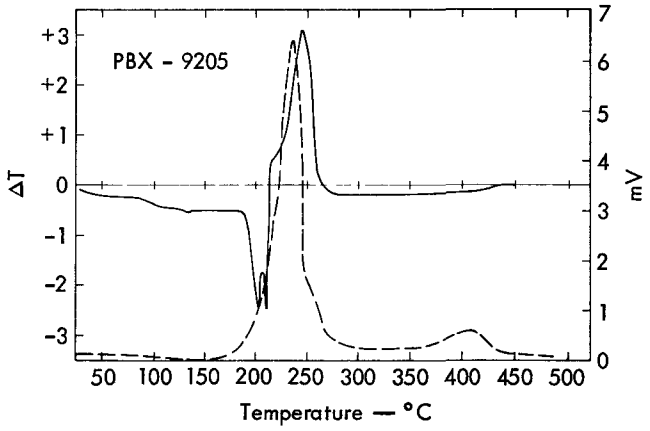
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: PBX-9404-03

DESIGNATION: **PBX-9404**

2. STRUCTURE OR FORMULATION

	wt%
HMX	94
NC	3
Tris-β-chloroethylphosphate	3

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white or blue

At. comp.: $C_{1.40}H_{2.75}N_{2.57}O_{2.69}Cl_{0.03}P_{0.01}$

MW: 100

Density (g/cm^3): TMD: 1.865

Nominal: 1.831-1.844

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

Δ H_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.56 (6.53)	1.42 (5.94)
Exp:	1.38 (5.77)	1.28 (5.36)

Δ H_f (kcal/mol (kJ/mol)): +0.08 (+0.331)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: 10.1×10^{-4} cal/sec-cm-°C; 0.25 BTU/hr-ft-°F (0.432 W/m-K)

CTE:

$\alpha = 28.1 \times 10^{-6}$ in./in.-°F at -65 to -30°F (50.6 μm/m-K at 219-239 K)

$\alpha = 32.2 \times 10^{-6}$ in./in.-°F at -10 to 165°F (58.0 μm/m-K at 250-347 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -29 (239)

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.36-0.40

1 g for 48 hr: 3.2-4.9

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.80 (ρ= 1.84)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.840)

Meas.: 375

Calc.: 354

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.843)

6 mm: 1.295

19 mm: 1.620

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
34	35

Susan test: Threshold velocity 105 ft/sec (32 m/s); has very large probability of buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	1.25 (0.38)	6
45 (0.79)	3.5 (1.07)	6

Gap test (mils (mm)):

Small-scale: 85-105 (2.2-2.7) (ρ - 1.850)

Large-scale: 2.268 (57.6) (ρ = 1.841)

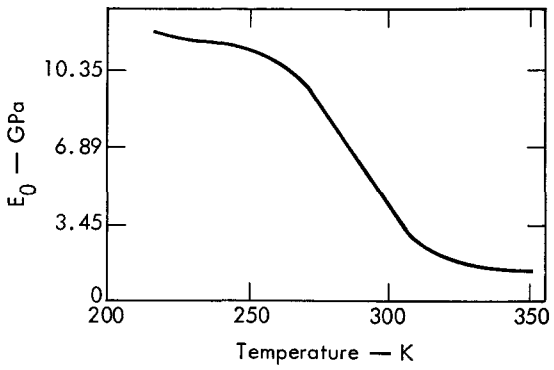
10. ELECTRICAL PROPERTIES:

ϵ: 3.52 (ρ = 1.84)

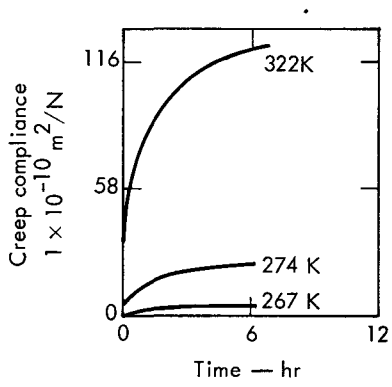
11. TOXICITY

—

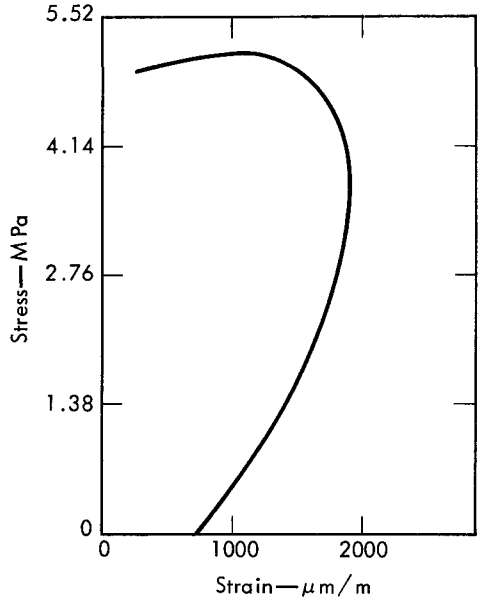
7. MECHANICAL PROPERTIES



Initial modulus

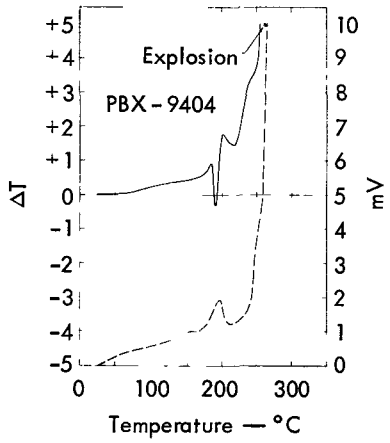


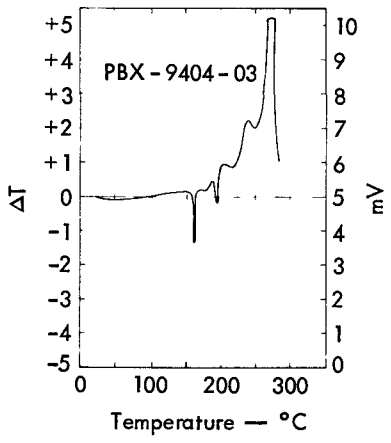
Creep



Failure envelope

NOTES





DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: PBX-9407

DESIGNATION: **PBX-9407**

2. STRUCTURE OR FORMULATION

	wt%
RDX	94
Exon 461	6

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white or black

At. comp.: $C_{1.41}H_{2.66}N_{2.54}O_{2.54}Cl_{0.07}F_{0.09}$

MW: 100

Density (g/cm^3): TMD: 1.81

Nominal: 1.60-1.62

m.p. (°C (K)): dec. >200 (>473)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.60 (6.69)	1.46 (6.11)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +11.6 (+48.4)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.06

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.91 (ρ= 1.60)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.60)

Meas.: 287

Calc.: 300

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	33	30

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

Small-scale: 90-120 (2.3-3.1) (ρ = 1.770)

Large-scale: 2.120 (53.9) (ρ = 1.773)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

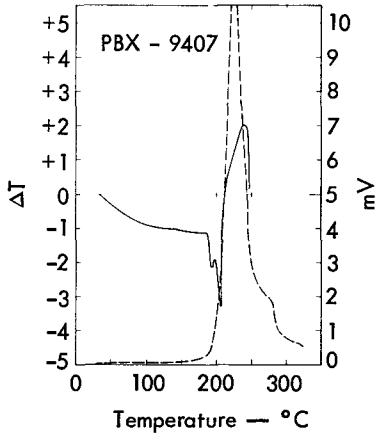
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: PBX-9501

DESIGNATION: **PBX-9501**

2. STRUCTURE OR FORMULATION

	wt%
HMX	95
Estane	2.5
BDNPA	1.25
BDNPF	1.25

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_{1.47}H_{2.86}N_{2.60}O_{2.69}$

MW: 100

Density (g/cm^3): TMD: 1.855

Nominal: 1.843

m.p. (°C (K)): dec. >240 (>513)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.59 (6.65)	1.44 (6.03)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +2.3 (+9.5)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: 10.8 cal/cm-sec-°C (0.451 W/m-K)

CTE:

α = 30.6 × 10^{-6} in./in.-°F at -80 to 160°F
(55.1 μm/m-K at 211-344 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.07

1 g for 48 hr: 0.8

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.83 (ρ= 1.84)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: ~358

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.843)

6 mm: 1.288

19 mm: 1.656

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

	12 tool	12B tool
5 kg:	44	80

Susan test: Threshold velocity ~ 200 ft/sec (~61 m/s); once this velocity is exceeded, reactions become violent over a narrow range. Small reactions do not automatically grow to large ones.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	10 (3.05)	3
45 (0.79)	10 (3.05)	0

Gap test (mils (mm)):

Small-scale: 50-70 (1.3-1.8) (ρ = 1.843)

10. ELECTRICAL PROPERTIES:

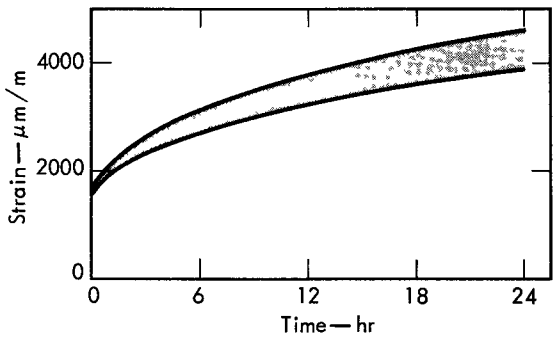
ϵ: —

11. TOXICITY

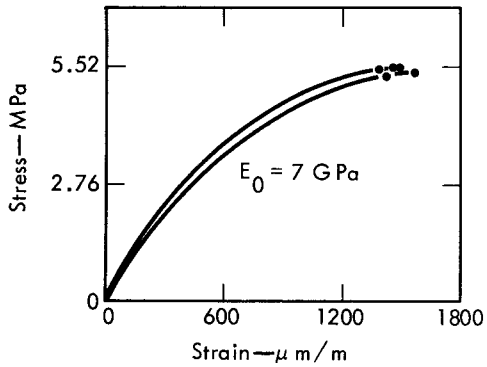
—

7. MECHANICAL PROPERTIES

Initial modulus

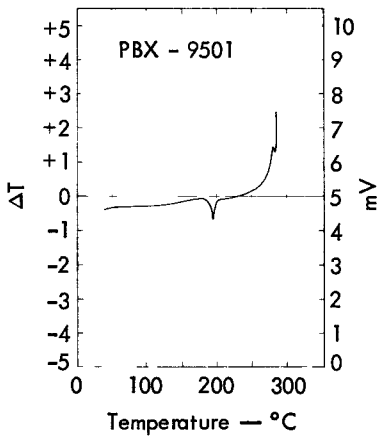


Creep



Failure envelope

NOTES



DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: PENTOLITE 50/50

DESIGNATION: **Pentolite 50/50**

2. STRUCTURE OR FORMULATION

	wt%
PETN	50
TNT	50

4. PHYSICAL PROPERTIES

Physical state: solid

Color: —

At. comp.: $C_{2.33}H_{2.37}N_{1.29}O_{3.22}$

MW: 100

Density (g/cm^3): TMD: 1.71

Nominal: 1.67

m.p. (°C (K)): 76 (349)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 0.1 at 100°C (13.33 at 373 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.53 (6.40)	1.40 (5.86)
Exp:	1.23 (5.15)	1.16 (4.85)

ΔH_f (kcal/mol (kJ/mol)): -24.3 (-99.4)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.26 (1.09)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: 3.0 at 100°C (373 K)

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.47 (ρ= 1.67)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.66)

Meas.: —

Calc.: 280

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.696)

6 mm: 0.960

19 mm: 1.260

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	~35	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):
Small-scale: 105-140 (2.7-3.6) (hot pressed) (ρ = 1.676)
32-38 (0.76-0.97 (cast) (ρ = 1.700)
Large-scale: 2.549 (64.8) (ρ = 1.702)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

Pentolite 50/50

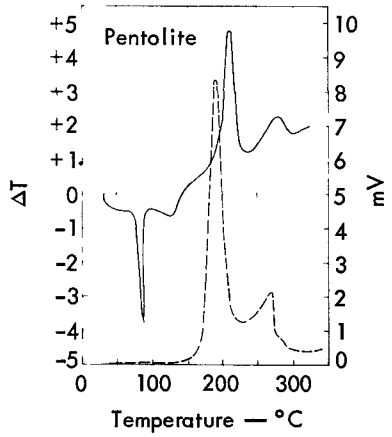
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

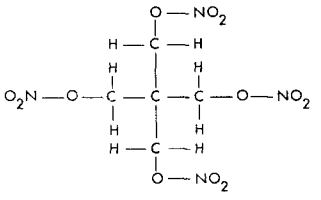


DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: PENTAERYTHRITOL TETRANITRATE

DESIGNATION: **PETN**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_5H_8N_4O_{12}$

MW: 316.2

Density (g/cm^3): TMD: 1.77

Nominal: 1.76

m.p. (°C (K)): 139-142 (412-415)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)):

8×10^{-5} at 100°C (1.1×10^{-3} at 373 K)

$\log_{10} P_{mm} = 14.44 - [6352/T\ (K)]$

Crystal data:

I: tetragonal ($P42_1/c$)	II: orthorhombic (Pcnb)
a = 9.38	a = 13.22
b = 9.38	b = 13.49
c = 6.71	c = 6.83

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.65 (6.90)	1.51 (6.32)
Exp:	1.49 (6.23)	1.37 (5.73)

ΔH_f (kcal/mol (kJ/mol)): -128.7 (-593)

Solubility (s-sol., sl-sl. sol., i-insol.):
s—acetone, DMFA, DMSO, ethyl acetate, pyridine
sl—benzene, ethyl ether
i—carbon disulfide, carbon tetrachloride, chloroform, ethanol, water

6. THERMAL PROPERTIES

k: —

CTE:

$\alpha = 46.1 \times 10^{-6}$ in./in.-°F (83.0 m/m-K)

α = 76.5-89.9 μm/m-K at 244-363 K

β = 249.2 μm/m-K at 243-343 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): none

C_p (cal/g-°C (kJ/kg-K)):

Exp.: 0.26 (1.088)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.10-0.14

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.26 (ρ = 1.76)

P_{CJ} (kbar (10^{-1} GPa)):

	ρ = 1.77	ρ = 1.67	ρ = 0.99
Meas.:	340	300	87
Calc.:	326	280	100

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.765)

6 mm: 1.255

19 mm: 1.575

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
11	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

Small-scale: 190-220 (4.8-5.6) (ρ = 1.757)

Large-scale: 2.732 (69.4) (ρ = 0.81)

10. ELECTRICAL PROPERTIES:

ϵ: 2.447 (ρ = 1.4)
2.577 (ρ = 1.5) 2.897 (ρ = 1.7)
2.727 (ρ = 1.6) 2.95 (ρ = 1.75)

11. TOXICITY

High.

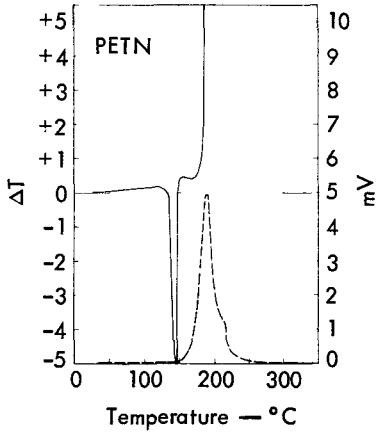
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

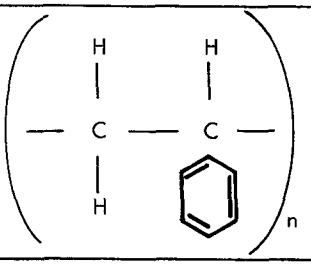
NOTES



DTA (-) and pyrolysis (---) curves.

MATERIAL: POLYSTYRENE (Binder)	DESIGNATION: **Polystyrene** SUPPLIER:

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid
Color: clear
At. comp.: $(C_8H_8)_n$
MW: $(104.15)_n$
Density (g/cm^3): TMD: 1.12
Nominal: 1.05
m.p. (°C (K)): 240 (513)
b.p. (°C (K)):
v.p. (mm Hg (Pa)):
Brittle point (°C (K)):
f.p. (°C (K)):

Crystal data: rhombohedral, amorphous
a = 21.90
b = 21.90
c = 6.63

R:
n: 1.59-1.60
Shore hardness:

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)): +18.19 (+79.1)

Solubility (s-sol., sl-sl. sol., i-insol.):
s – benzene, toluene

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%):

6. THERMAL PROPERTIES

k: 2.51×10^{-4} cal/sec-cm-°C (0.105 W/m-K) at 273 K

CTE: α = 60-80 μm/m-K < T_g
β = 170-210 μm/m-K < T_g
= 510-600 μm/m-K > T_g

T_g (°F (K)): 373 K

C_p (cal/g-°C (kJ/kg-K)):
0.300 at 50°C (1.255 at 323 K)

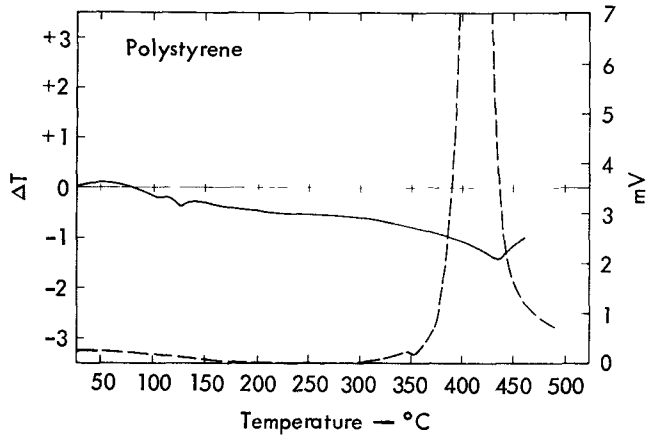
10. ELECTRICAL PROPERTIES

ϵ:
2.49-2.55 (amorph., ρ = 1.05)
2.61 (cryst., ρ = 1.12)

11. TOXICITY

NOTES

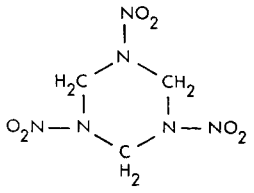
Polystyrene



EXPLOSIVE: 1,3,5-TRINITRO-1,3,5-TRIAZACYCLOHEXANE

DESIGNATION: **RDX**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_3H_6N_6O_6$

MW: 222.1

Density (g/cm^3): TMD: 1.806

Nominal: —

m.p. (°C (K)): 205 (478)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)):

$\log_{10} P_{cm}$ = 10.87 - [3850/T (K)] from 111 to 130°C (384 to 403 K)

Crystal data:

I: orthorhombic (Pbca) II: unstable

a = 13.18
b = 11.57
c = 10.71

R: 43.7 (calc.), 41.4 (obs.)
n = 8

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.62 (6.78)	1.48 (6.19)
Exp:	1.51 (6.32)	1.42 (5.94)

ΔH_f (kcal/mol (kJ/mol)): +14.71 (+61.55)

Solubility (s-sol., sl-sl. sol., i-insol.):
s—acetone, DMFA, DMSO
sl—ethanol, pyridine
i—benzene, carbon disulfide, carbon tetrachloride, chloroform, ethyl acetate, ethyl ether, water

6. THERMAL PROPERTIES

k: —

CTE:

α = 63.6 μm/m-K at 244 K

β = 191 μm/m-K at 244 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Exp.: 0.274 (1.146)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.02-0.025

1 g for 48 hr: 0.12-0.9

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.70 (ρ = 1.77)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.767)

Meas.: 338

Calc.: 348

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):

12 tool	12B tool
28	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

Small-scale: 190-220 (4.8-5.6) (ρ = 1.735)

Large-scale: 2.434 (61.8) (ρ = 1.750)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

Slight.

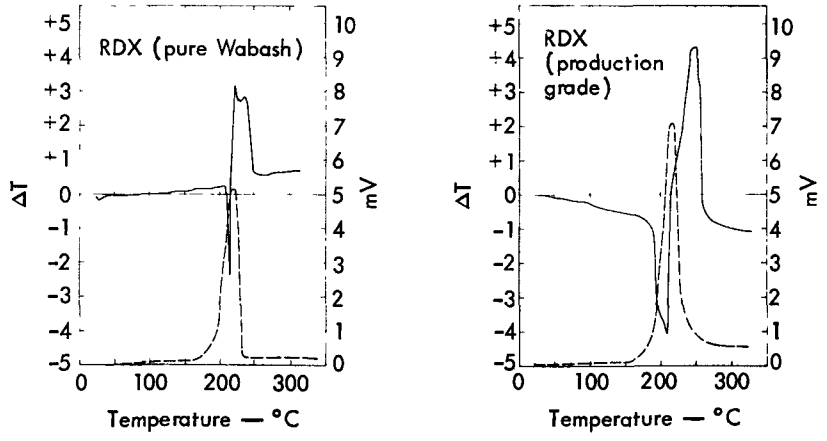
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

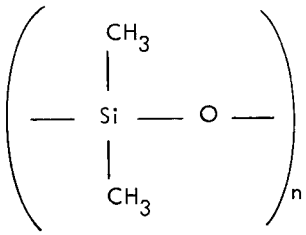
NOTES



DTA (-) and pyrolysis (---) curves.

MATERIAL: SILICON RESIN (Binder)	DESIGNATION: **Sylgard 182** SUPPLIER: Dow Corning

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid Color: light straw At. comp.: $(C_2H_6OSi)_n$ MW: $(74.16)_n$ Density (g/cm^3): TMD: 1.05 at 25°C (298 K) Nominal: m.p. (°C (K)): b.p. (°C (K)): v.p. (mm Hg (Pa)): Brittle point (°C (K)): <-70°C (<203 K) (cured) f.p. (°C (K)):	Crystal data: R: n: 1.430 at 25°C (298 K) Shore hardness: A 40-50 (cured)

5. CHEMICAL PROPERTIES	7. MECHANICAL PROPERTIES
ΔH_f (kcal/mol (kJ/mol)): -24.9 (-104.18) Solubility (s-sol., sl-sl. sol., i-insol.):	Tensile strength (psi (kPa)): 800-1200 (55-83) Elongation (%): 80-140

6. THERMAL PROPERTIES	10. ELECTRICAL PROPERTIES
k: 3.5×10^{-5} cal/sec-cm-°C (0.146 W/m-K) (cured) CTE: 180 μin./in.-°F at -65 to +65°F (324 μm/m-K at 219-347 K)	ε: 2.77 (ρ = 1.05)
	11. TOXICITY
T_g (°F (K)): C_p (cal/g-°C (kJ/kg-K)): 0.34 at 25°C (1.423 at 298 K)	

NOTES

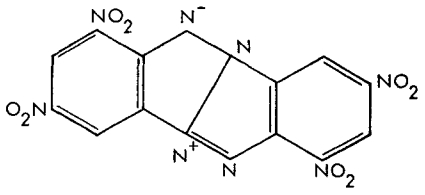
Replaces Q-93-022.

Sylgard 182

EXPLOSIVE: TETRANITRO-1,2,5,6-TETRAZADIBENZOCYCLOOCTATETRENE

DESIGNATION: **TACOT**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: red-orange

At. comp.: $C_{12}H_4N_8O_8$

MW: 388.2

Density (g/cm^3): TMD: 1.85

Nominal: 1.61

m.p. (°C (K)): dec. >380 (>653)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.41 (5.90)	1.35 (5.64)
Exp:	0.98 (4.10)	0.96 (4.02)

ΔH_f (kcal/mol (kJ/mol)): +128 (+536)

Solubility (s-sol., sl-sl. sol., i-insol.):

sl—DMFA, DMSO, nitric acid, pyridine

i—chloroform, ethanol, water

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.25 (ρ= 1.85)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.61)

Meas.: —

Calc.: 181

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

TACOT — TETRANITRO-1,2,5,6-TETRAZADIBENZOCYCLO-OCTATETRENE

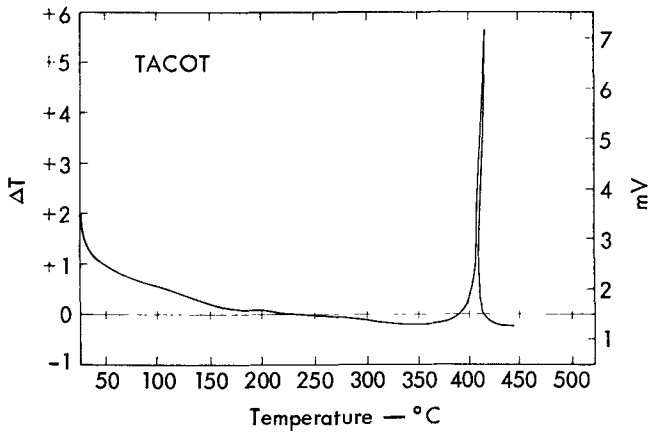
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

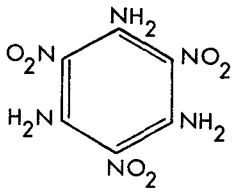


DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: 1,3,5-TRIAMINO-2,4,6-TRINITRO-BENZENE

DESIGNATION: **TATB**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: bright yellow

At. comp.: $C_6H_6N_6O_6$

MW: 258.2

Density (g/cm^3): TMD: 1.938

Nominal: 1.88

m.p. (°C (K)): dec. >325 (>598)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: triclinic ($P\bar{1}$)

a = 9.01
b = 9.03
c = 6.81

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.20 (5.02)	1.08 (4.52)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -36.85 (-154.2)

Solubility (s-sol., sl-sl. sol., i-insol.):
sl — DMFA, DMSO, H_2SO_4
i — acetone, benzene, carbon disulfide, carbon tetrachloride, chloroform, ethanol, ethyl acetate, ethyl ether, water

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.25 at 25°C (1.05 at 298 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.76 (ρ= 1.88)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.88)

Meas.: —

Calc.: 291

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	>100	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ= 1.872)

Small-scale: 2-8 (0.05-0.2)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

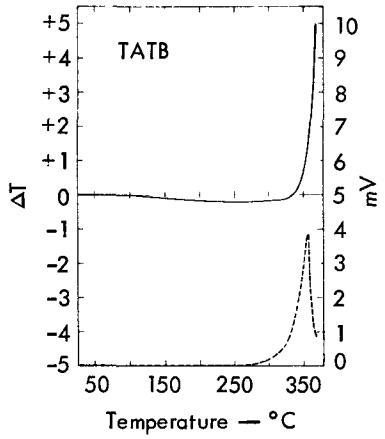
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

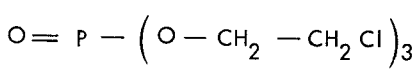
NOTES



DTA (-) and pyrolysis (---) curves.

MATERIAL: TRIS-β-CHLOROETHYL PHOSPHATE (Plasticizer)	DESIGNATION: **TEF** SUPPLIER:

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid Color: clear At. comp.: $C_6H_{12}Cl_3O_4P$ MW: 285.5 Density (g/cm^3): TMD: 1.425 Nominal: m.p. (°C (K)): b.p. (°C (K)): 203 (476) v.p. (mm Hg (Pa)): Brittle point (°C (K)): -60 (213 K) f.p. (°C (K)):	Crystal data: R: n: Shore hardness:
5. CHEMICAL PROPERTIES	7. MECHANICAL PROPERTIES
ΔH_f (kcal/mol (kJ/mol)): -300 (-1255) Solubility (s-sol., sl-sl. sol., i-insol.): s — alcohols, benzene, carbon tetrachloride, chloroform, esters, ethers, ketones, toluene, xylene sl — water i — aliphatic hydrocarbons	Tensile strength (psi (kPa)): Elongation (%):
6. THERMAL PROPERTIES	10. ELECTRICAL PROPERTIES
k: CTE: β = 840 μm/m-K T_g (°F (K)): C_p (cal/g-°C (kJ/kg-K)):	ϵ: (ρ = 11. TOXICITY Low.

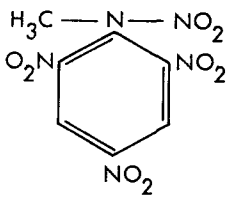
NOTES

TEF

EXPLOSIVE: 2,4,6-TRINITROPHENYLMETHYL-NITRAMINE

DESIGNATION: **Tetryl**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_7H_5N_5O_8$

MW: 287.0

Density (g/cm^3): TMD: 1.73

Nominal: 1.71

m.p. (°C (K)): 130 (403)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: monoclinic ($P2_1/c$)

a = 14.13
b = 7.37
c = 10.61

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.51 (6.32)	1.45 (6.07)
Exp:	1.14 (4.77)	1.09 (4.56)

ΔH_f (kcal/mol (kJ/mol)): +4.67 (+19.1)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—acetone, benzene, ethyl acetate, nitric acid
sl—chloroform, ethanol, ethyl ether
i—carbon disulfide, carbon tetrachloride, water

6. THERMAL PROPERTIES

k: 6.83×10^{-4} cal/sec-cm-°C (0.286 W/m-K)

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.036

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.85 (ρ = 1.71)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.71)

Meas.: —

Calc.: 260

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	28	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

Small-scale: 135-165 (3.4-4.2) (ρ = 1.684)

Large-scale: 2.386 (60.6) (ρ = 1.666)

10. ELECTRICAL PROPERTIES:

ϵ: 2.728 (ρ = 1.4) 3.097 (ρ = 1.6)
2.905 (ρ = 1.5) 3.304 (ρ = 1.7)

11. TOXICITY

High.

Tetryl 2,4,6-TRINITROPHENYLMETHYLNITRAMINE

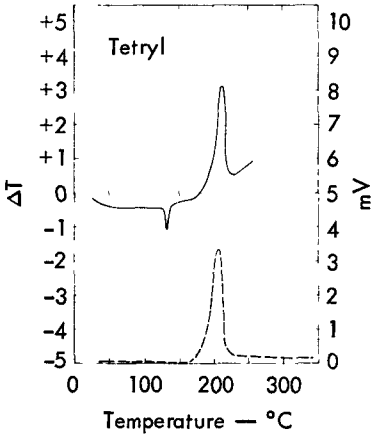
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

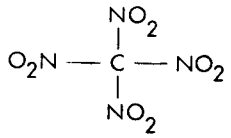


DTA (-) and pyrolysis (---) curves.

EXPLOSIVE: TETRANITROMETHANE

DESIGNATION: **TNM**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_1N_4O_8$

MW: 196.0

Density (g/cm^3): TMD: 1.650 at 286 K

Nominal: —

m.p. (°C (K)): 14.2 (287)
b.p. (°C (K)): 125.7 (399)
v.p. (mm Hg (Pa)): 13 at 25°C (1733 at 298 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	0.55 (2.30)	0.55 (2.30)
Exp:	—	—

ΔH_f (kcal/mol (kj/mol)): +13.0 (+54.4)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—benzene, ethanol, ethyl ether
sl—water

6. THERMAL PROPERTIES

k: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.4 (ρ= 1.6)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.65)

Meas.: —

Calc.: 144

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

(See Table 9-6.)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

Very high.

7. MECHANICAL PROPERTIES

Initial modulus

Creep

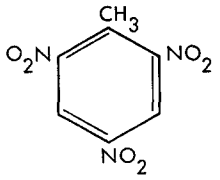
Failure envelope

NOTES

EXPLOSIVE: 2,4,6-TRINITROTOLUENE

DESIGNATION: **TNT**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: buff to brown

At. comp.: $C_7H_5N_3O_6$

MW: 227.1

Density (g/cm^3): TMD: 1.654

Nominal: 1.5-1.6 (cast)
1.63-1.64 (pressed)

m.p. (°C (K)): 80.9 (354)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 0.106 at 100°C (14.13 at 373 K)

$\log_{10} P_{cm}$ = 9.11 - [3850/T (K)] from 200 to 350°C (473-623 K)

Crystal data:

a = 14.99
b = 40.00
c = 6.10

R: 44.3 (calc.), 49.6 (obs.)

n: 16

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.41 (5.90)	1.29 (5.40)
Exp:	1.09 (4.56)	1.02 (4.27)

ΔH_f (kcal/mol (kJ/mol)): -15 (-64.4)

Solubility (s-sol., sl-sl. sol., i-insol.):
s—acetone, benzene, chloroform, DMFA, ethyl acetate, nitric acid, sulfuric acid, pyridine
sl—carbon disulfide, carbon tetrachloride, ethanol, ethyl ether; i—water

6. THERMAL PROPERTIES

k: 6.22 × 10^{-4} cal/sec-cm-°C (0.260 W/m-K)

CTE:

α = 50.0 + 0.007T μm/m-K at below m.p.

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.00-0.012

1 g for 48 hr: ~0.005

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.93 (ρ = 1.64)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.630)

Meas.: 190

Calc.: 207

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.630)

6 mm: 0.735

19 mm: 0.975

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
	80	>177

Susan test: Threshold velocity ~235 ft/sec (~72 m/s); very difficult to ignite accidentally, and has very low probability of buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

Small-scale: 8-16 (0.20-0.41) (ρ = 1.624)

Large-scale: 1.944 (49.4) (ρ = 1.626)

10. ELECTRICAL PROPERTIES:

ϵ: 2.629 (ρ = 1.4)
2.795 (ρ = 1.5)

11. TOXICITY

Moderate.

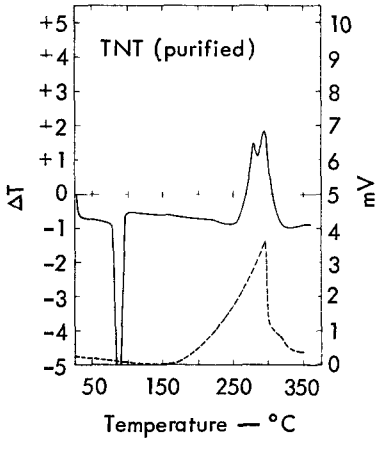
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

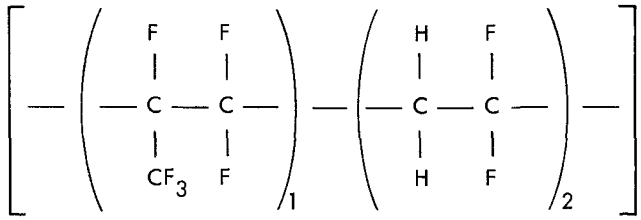
NOTES



DTA (-) and pyrolysis (---) curves.

MATERIAL: HEXAFLUOROPROPYLENE/ VINYLIDINE FLUORIDE 1:2 (Binder)	DESIGNATION : **Viton A** SUPPLIER : DuPont

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state : rubbery solid

Color : white

At. comp. : $(C_5H_{3.5}F_{6.5})_n$

MW : $(187.08)_n$

Density (g/cm^3) : TMD :

Nominal : 1.815

m.p. (°C (K)) :

b.p. (°C (K)) :

v.p. (mm Hg (Pa)) :

Brittle point (°C (K)) :

f.p. (°C (K)) :

Crystal data :

R :

n :

Shore hardness : A 40-60 (71 cured)

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)) : -332.7 (-1392)

Solubility (s-sol., sl-sl. sol., i-insol.) :

s – acetone, MEK, MIBK, n-butyl acetate, THF

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%) :

6. THERMAL PROPERTIES

k :

CTE : α = 65.0×10^{-6} in./in.-°F at <6°F
(117 μm/m-K at <225 K)
= 145.2×10^{-6} in./in.-°F at -6 to 165°F
(254.8 μm/m-K at 252-347 K)

β = ~450 μm/m-K at <-253 K
= 728 μm/m-K at 253-343 K

T_g (°F (K)) : -27°C (246 K)

C_p (cal/g-°C (kJ/kg-K)) : 0.35 (1.464)

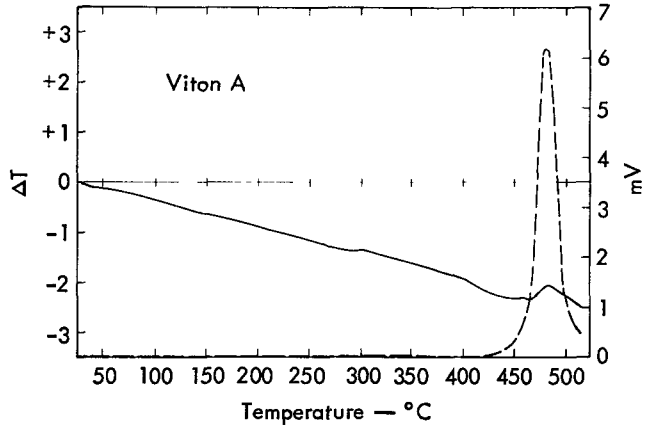
10. ELECTRICAL PROPERTIES

ϵ : (ρ =

11. TOXICITY

NOTES

Viton A



GPO 692 001

EXPLOSIVE: XTX-8003

DESIGNATION: **XTX-8003**

2. STRUCTURE OR FORMULATION

	wt%
PETN	80
Silicone rubber	20

4. PHYSICAL PROPERTIES

Physical state: putty curable to rubbery solid

Color: white

At. comp.: $C_{1.80}H_{3.64}N_{1.01}O_{3.31}Si_{0.27}$

MW: 100

Density (g/cm^3): TMD: 1.556

Nominal: ≈1.53

m.p. (°C (K)): 129-135 (402-408)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.86 (7.80)	1.67 (7.00)
Exp:	1.16 (4.85)	1.05 (4.39)

ΔH_f (kcal/mol (kj/mol)): -44.4 (-185.9)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

k: —

CTE:

α = 68.8 × 10^{-6} in./in.-°F at -22 to 158°F (123.8 m/m-K at 243-343 K)

α = 77 × 10^{-6} in./in.-°F at 75 to 150°F (139 m/m-K at 297-339 K)

β - 413.7 m/m-K at 219-296 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: >0.02 at 100°C (373)

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.30 (ρ= ≈1.53)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.546)

Meas.: 170

Calc.: 210

E_{cyl} ((mm/μsec)²/2 (MJ/kg)): (ρ= 1.554)

6 mm: 0.710

19 mm: 0.950

9. SENSITIVITY

H_{50} (cm (10^{-2} m)):	12 tool	12B tool
Cured:	21	—
Uncured:	25	—

Susan test: Threshold velocity ~160 ft/sec (~49 m/s); has very small probability of buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ= 1.53)

Cured: 130-160 (3.3-4.1)

Uncured: 160-190 (4.1-4.8)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

V. Bibliography

CHEMICAL ANALYSIS

Anderson, D. M., F. B. Kistner, and M. J. Schwarz, The Mass Spectra of Volatile Constituents in Military Explosives, Cold Regions Research and Engineering Lab., Hanover, N. H., Final Rept. AD-699325 (1969).

Chasan, D. E., and G. Norwitz, Qualitative Analysis of Primers, Tracers, Igniters, Incendiaries, Boosters, and Delay Compositions on a Micro Scale by Use of Infrared Spectroscopy, Department of the Army, Frankford Arsenal, Philadelphia, Pa., Rept. T-71-6-1 (AD-729337) (1971).

Crossman, G. L., and W. Selig, A Rapid Determination of Tris(chloroethylphthalate) in PBX-9404 Explosive, Lawrence Livermore Laboratory, Rept. UCID-15444 (1969).

Doali, J. O. and A. A. Juhasz, High Speed Liquid Chromatographic Separations of Thermally Labile High Energy Compounds. Part I. Application of High Speed Liquid Chromatography to the Qualitative Analysis of Compounds of Propellant and Explosives Interest, Ballistic Research Laboratories, Aberdeen, Md., Rept. BRL-1644 (1973).

Hoffsommer, J. C., and J. M. Rosen, Ultramicroanalysis of Explosives in Seawater, U. S. Naval Ordnance Lab., White Oak, Md., NOL-TR-71-151, AD-730444 (1971).

Jenkins, R., and H. J. Gallop, "The Identification of Explosives in Trace Quantities on Objects near an Explosion," Explosivstoffe 18, 139-141 (1970).

Kegler, W., and D. Grune, Determining the Synthetic Content of Explosive Synthetic Mixtures, Institut Franco-Allemand de Recherches, St. Louis, France, Rept. ISL-N-8/67 (1967). (In German.)

Norwitz, G., Spectrophotometric Determination of Sulfate in Propellants and Nitrocellulose, U. S. Dept of the Army, Frankford Arsenal, Philadelphia, Pa., Rept. FA-TR-T-70-10-1 (1970).

Pristera, F. and W. E. Fredericks, Compilation of Infrared Spectra of Ingredients of Propellants and Explosives, Picatinny Arsenal, Dover, N. J., Rept. PA-TM-1887 (AD-859846) (1969).

Schubert, H., F. Volk, and H. Roszinski, "Analytical Study of RDX-HMX Mixtures," Explosivstoffe 14, 265-273 (1966).

Selig, W., Some Analytical Methods for Explosives and Explosive Simulants, Lawrence Livermore Laboratory, Rept. UCRL-7873 (1964); Pt. 2 (1965); Pt.3 (1969); Pt. 4 (1973).

Selig, W., The Analysis of FEFO in Plastic-Bonded Explosives, Lawrence Livermore Laboratory, Rept. UCID-5118 (1966).

Selig, W., Fluorine Analysis of Plastic-Bonded Explosives and Plastics, Fresenius Z. Anal. Chem. 234, 261-269 (1968).

Selig, W., The Semimicro Determination of Fluorine in Plastic-Bonded Explosives, Lawrence Livermore Laboratory, Rept. UCID-15074 (1967).

Selig, W., The Analysis of Cyclomethylenetetranitramine (HMX) and Ammonium Perchlorate in Plastic-Bonded Explosives, Lawrence Livermore Laboratory, Rept. UCID-15173 (1967).

Selig, W., The Infrared Determination of Poly(2,2,-dinitropropyl Acrylate) in LX-09, Lawrence Livermore Laboratory, Rept. UCID-15202 (1967).

Selig, W., The Analysis of 1, 3, 5, 7-Tetranitro-1, 3, 5, 7-tetrazacyclooctane (HMX) and Potassium Perchlorate in Plastic-Bonded Explosives, Lawrence Livermore Laboratory, Rept. UCID-15208 (1967).

Selig, W., The Analysis of the Explosive LX-09-0, Lawrence Livermore Laboratory, Rept. UCID-15330 (1968).

Selig, W., The Analysis of Bis(2, 2-dinitro-2-fluoroethyl) Formal (FEFO) in LX-09-0, Lawrence Livermore Laboratory, Rept. UCID-15452 (1969).

Selig, W., "Microdetermination of Chloride and Azide by Sequential Titration," Mikrochim. Acta 1971, 46-53 (1971).

Snell, F. D., and L. S. Ehre, Eds., Encyclopedia of Industrial Chemical Analysis (Interscience, New York, 1971), Vol. 12, pp. 405-471.

Wright, I., "The Rapid Micro Combustion Determination of Carbon, Hydrogen, and Nitrogen in High Explosives," Explosivstoffe 16, 176-178 (1968).

GENERAL REFERENCE WORKS

Agard Combustion and Combustion Panel, The Chemistry of Propellants (Pergamon Press, London, 1959).

Alder, B., S. Fernbach, and M. Rotenberg, Methods in Computational Physics, Vol. 3 of Fundamental Methods in Hydrodynamics, Academic Press, New York, 1964).

Altshuler, L. V., "Use of Shock Waves in High-Pressure Physics," Sov. Phys.-Uspekhi 8, 52-91 (1965).

Andreev, K. K., and A. F. Belyaev, Theory of Explosive Substances, Transl. AD-643597 (1966).

Army Materiel Command, Principles of Explosives Behavior, U.S. Army Materiel Command, Rept. AMCP-706-180 (1972).

Army Materiel Command, Properties of Explosives of Military Interest, U. S. Army Materiel Command, Rept. AMCP-706-177 (1967). (Supersedes W. R. Tomlinson, Jr., Picatinny Arsenal Rept. PA-TR-1740 (1958)).

Ascani, D. C., "Literature of Explosives," in Advances in Chemistry Ser., No. 78, pp. 565-580 (1968).

Avanesov, D. S., Manual of Physical and Chemical Testing of Explosives, Gosndarstvennoe Izdatel. Oboron. Promyshl. (Transl. by H. G. Condor, U. K. Atomic Energy Authority, Rept. AWRE-TRANS-30 (1962)).

Beach, N. E., M. C. St. Cyr, and V. K. Canfield, Compatibility of Explosives with Polymers I, Picatinny Arsenal, Dover, N. J., Rept. PA-TR-2595 (AD-207076, PB-168175, 1959).

Beach, N. E., M. C. St. Cyr, and V. K. Canfield, Compatibility of Explosives with Polymers II, Picatinny Arsenal, Dover, N. J., Plastec Rept. 33 (AD-672061) (1968).

Beach, N. E., M. C. St. Cyr, and V. K. Canfield, Compatibility of Explosives with Polymers III, Picatinny Arsenal, Dover, N. J., Plastec Rept. 40 (AD-721004) (1971).

Bebie, J., Manual of Explosives, Military Pyrotechnics, and Chemical Warfare Agents, (MacMillan, New York, 1943).

Berger, J., and J. Viard, Physics of Solid Explosives (Dunod, Paris, 1962). (In French.)

Bowden, F. P., and A. D. Yoffe, Fast Reactions in Solids (Butterworths, London, 1858).

Bradley, J. N., Flame and Combustion Phenomena (Methuen, London, 1969).

Bradley, J. N., Shock Waves in Chemistry and Physics (Wiley, London, 1962).

Bradley, R. S., High Pressure Physics and Chemistry, Vols. 1 and 2 (Academic Press, New York, 1963).

Coates, A. D., E. Freedman, and L. P. Kuhn, Characteristics of Certain Military Explosives, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., Rept. BRL-1507 (1970).

Cook, M. A., The Science of High Explosives (Reinhold, New York, 1958).

Cook, S. G., J. M. Rosen, and C. N. Bernstein, Manual for Ammunition Quality Evaluation Surveillance Laboratories (U. S. Naval Powder Factory, Indian Head, Md., 1964).

Combustion Institute, Symposium on Combustion, Vols. 1- (Academic Press, New York, 1929-).

Davis, T. L., The Chemistry of Powder and Explosives (Wiley, New York, 1953).

Department of the Army, Military Explosives, Dept. of the Army, Rept. TM-9-1910 (1955). (Identical to Dept. of Air Force Rept. TO-11-A-1-34).

Dunston, I., "Chemistry in the Technology of Explosives and Propellants," Chem. in Britain 7, 62-79 (1971).

DuPont De Nemours, E. I., and Company, Blasters Handbook, 15th ed., (E. I. DuPont De Nemours and Company, Wilmington, Del., 1967).

Elban, W. L., Development of Inert Simulants for Castable Plastic Bonded Explosives, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-71-192 (1971).

Ellern, H., Military and Civilian Pyrotechnics (Chemical Publishing Company, New York, 1968).

Ellern, H., Modern Pyrotechnics (Chemical Publishing Company, New York, 1961).

Evans, B. L., A. D. Yoffe, and P. Gray, "Physics and Chemistry of the Organic Azides," Chem. Rev. 59, 515-568 (1959).

Fedoroff, B. T., Encyclopedia of Explosives and Related Items, Vols. 1- (Picatinny Arsenal, Dover, N. J., 1960-).

Fordham, S., High Explosives and Propellants (Pergamon Press, New York, 1966).

Frank-Kamenetskii, D. A., Diffusion and Heat Exchange in Chemical Kinetics (Plenum Press, New York, 1969).

Hammann, S. D., "The Use of Explosions in High Pressure Research," Rev. Pure Appl. Chem. 10, 139-168 (1960).

Hammer, W., Explosions and Explosives, Norton Air Force Base, Calif., Rept. AD-839310 (1968).

Hayes, T. J., Elements of Ordnance—A Textbook for Use of Cadets of the United States Military Academy (Wiley, New York, 1938).

Jacobs, S. J., "Recent Advances in Condensed Media Detonations," Am. Rocket Soc. J. 30, 151-158 (1960).

Jaffe, B., A Primer on Ferroelectricity and Piezoelectric Ceramics (Clevite Corporation, Cleveland, Ohio, 1960).

Johansson, C. H., and P. A. Persson, Detonics of High Explosives (Academic Press, New York, 1970).

Kantz, M. R., Pentaerythritol Tetranitrate: A Bibliography, Mound Laboratory, Miamisburg, Ohio, Rept. MLM-1252 (1965).

Khitrin, L. N., Physics of Combustion and Explosion (National Science Foundation, Washington, D. C., 1962).

Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed., Vol. 8, pp. 581-719 (Interscience, New York, 1965).

Levich, V. G., Physicochemical Hydrodynamics (Prentice-Hall, Englewood Cliffs, N. J., 1962).

Lewis, B. T., and G. Von Elbe, Combustion, Flames, and Explosions of Gases, 2nd ed. (Academic Press, New York, 1961).

Arthur D. Little, Inc., Punch Card Recording of Data on Explosives, Final Report 1961, AD-275022, AD-275023, AD-275024, AD-329073, Vols. 1-4 (1961). (Vol. 2 CDI).

Mason, C. M., and E. G. Aiken, Methods for Evaluating Explosives and Hazardous Materials, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa., Rept. BM-IC-8541 (1972).

McGarry, W. F., and T. W. Stevens, Detonation Rates of the More Important Military Explosives at Several Different Temperatures (Picatinny Arsenal, Dover, N. J., 1956).

Marshall, A., Explosives, Vols. 1-3 (Churchill, London, Vols. 1, 2, 1917, Vol. 3, 1932).

Muraour, H., Poudres et Explosifs (Presses Universitaires de France, 1947). (In French.)

Office of Naval Research, Symposium on Detonation, No. 1-, Office of Naval Research, Arlington, Va. (1951, 1955, 1960, 1965, 1970-). (Some volumes are classified.)

Ordnance Technical Intelligence Agency, Encyclopedia of Explosives, Ordnance Technical Intelligence Agency, Durham, N. C., Rept. AD-274026 (1960).

Orlova, Y. Y., The Chemistry and Technology of High Explosives (Moscow, 1960).

Paushkin, Y. M., The Chemistry of Reaction Fuels, Transl., Foreign Technology Division Air Force Systems Command, Wright-Patterson Air Force Base, Ohio (1962).

Pokrovskiy, G. I., The Explosion and Its Utilization (Moscow, 1910; Joint Publications Research Service, Washington, D. C., 1960).

Porzel, F. B., A Unified Theory of Explosions (UTE), U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-72-209 (AD-758000) (1972).

Ribaud, G., Detonation Waves (Centre National des Recherches Scientifiques, Paris, France, 1962). (In French.)

Rogers, J. T., Physical and Chemical Properties of RDX and HMX, Holston Defense Corporation, Kingston, Tenn., Rept. HD-20-P-26 (1962).

Rosen, J. M., and C. Dickenson, Vapor Pressures and Heats of Sublimation of Some High Melting Organic Explosives, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-69-67 (1969).

Tavernier, P., Powders and Explosives (Presses Universitaires de France, 1969). (In French.)

Urbanski, T., Chemistry and Technology of Explosives, Vols. 1-3 (McMillan, New York, 1964-1967).

Urbanski, T., ed., Nitro Compounds (McMillan, New York, 1964).

Walbrecht, E. E., Dielectric Properties of Some Common High Explosives, Picatinny Arsenal, Dover, N.J., Rept. PA-TM-1170 (1963).

Warren, F. A., Rocket Propellants (Reinhold, New York, 1958).

Weich, R. E., Fundamentals of Rocket Propulsion (Reinhold, New York, 1960).

Zaehringer, A. J., "Solid Propellant Bibliography," Jet Propulsion 27, 900-927 (1957).

Zeldovich, Ya. B., "On the Theory of Combustion of Powder and Explosives," Zh. Eksper. Teoret. Fiz. 12, 498-524 (1942); transl. PA-TM-1597, AD-486286.

Armed Services Explosives Safety Board, Explosives Safety Seminars, Minutes (Armed Services Explosives Safety Board, Washington, D. C., 1958-).

Cohen, E., Ed., "Prevention of and Protection against Accidental Explosion of Munitions, Fuels and Other Hazardous Materials," Ann. N. Y. Acad. Sci. 152, 1-913 (1968).

Cook, M. A., "Explosives and the Hazards and Testing of Explosives," Ind. Eng. Chem. 56 (2), 31-35 (1964).

Deichmann, W. B., and H. W. Gerarde, Toxicity of Drugs and Chemicals (Academic Press, New York, 1969).

Dodrill, J. P., C. E. Green, J. F. Hester, and C. R. Wells, An Evaluation of Safety Devices for Laboratories Handling Explosive Compounds, Redstone Arsenal Branch, Rohm and Haas, Huntsville, Ala. (1961).

Hallam, J. S., and K. J. Scribner, Explosion during Pressing of LX-04-1 at Site 300 on October 17, 1968, Lawrence Livermore Laboratory, Rept. UCRL-50567 (1969).

Hanna, H. A., and J. R. Polson, Investigation of Static Electrical Phenomena in Lead Azide Handling, Mason and Hanger, Silas Mason Co., Inc. Burlington AEC Plant, Burlington, Iowa, Rept. IAAP-TR-98-A (1967).

Mason and Hanger, Silas Mason Co., Inc., Recommended Safe Handling Methods for Plastic Bonded Explosives 9010 and 9404 (1961).

McGill, R., Explosives, Propellants, and Pyrotechnic Safety Covering Laboratory, Pilot Plant and Production Operations, U. S. Naval Ordnance Lab., White Oak, Md., Rept. NOL-TR-61-138 (AD-272424) (1962).

McNamara, B. P., H. P. Averill, E. J. Owens, J. F. Callaghan, D. G. Fairchild, H. P. Ciuchta, R. H. Rengstorff, and R. K. Biskup, The Toxicology of Cyclotrimethylenetrinitramine (RDX) and Cyclotetramethylenetetranitramine (HMX) Solutions in Dimethylsulfoxide (DMSO), Cyclohexanone, and Acetone, Edgewood Arsenal, Md. (1970).

Picatinny Arsenal, Manual for Design of Protective Structures Used in Explosive Processing and Storage Facilities, Picatinny Arsenal, Dover, N. J., Rept. AD-834465 (1968).

Pryde, A. W., and I. Dunston, "Processing of Dangerous Chemicals," Chem. Ind. (London) 1972 (2), 67-69 (1972).

Sax, N. I., Dangerous Properties of Industrial Materials (Reinhold Publishing Company, 1968).

Sensitiveness Collaboration Committee, Explosives Hazard Assessment, U. K. Explosives Research and Development Establishment, Waltham Abbey, Essex, Rept. SCC-3 (1969).

Skaar, K. S., Fundamentals of Safety for Processing, Handling, and Storage of High-Energy Materials, U. S. Naval Ordnance Testing Station, China Lake, Calif., Rept. NOTS-TP-2866 (1962).

Sunshine, I., Ed., Handbook of Analytical Toxicology (The Chemical Rubber Company, Cleveland, Ohio, 1969).

Africano, A., Maximum Rate Theory of Impact Sensitivity (Space Technology Laboratories, Inc., Los Angeles, 1959).

Barbarisi, M. J., and E. G. Kessler, Initiation of Secondary Explosives by Means of Laser Radiation, Picatinny Arsenal, Dover, N.J., Rept. PA-TR-3861 (AD-688585) (1969).

Bowden, F. P., discussion leader, "A Discussion of the Initiation and Growth of Explosions in Solids," Proc. Roy. Soc. (London) A246, 145-297 (1958).

Bowden, F. P., and A. D. Yoffe, Initiation and Growth of Explosions in Liquids and Solids (Cambridge University Press, Cambridge, 1952).

Brownlee, K. A., J. L. Hodges, and M. Rosenblatt, "The Up-and-Down Method with Small Samples," J. Am. Statist. Assoc. 43, 262-277 (1953).

Campbell, A. W., W. C. Davis, and J. R. Travis, "Shock Initiation of Detonation in Liquid Explosives," Phys. Fluids 4, 498-510 (1961).

Campbell, A. W., W. C. Davis, J. B. Ramsey, and J. R. Travis, "Shock Initiation of Solid Explosives," Phys. Fluids 4, 511-521 (1961).

Chaiken, R. F., "Comments on Hypervelocity Wave Phenomena in Condensed Explosives," J. Chem. Phys. 33, 760-761 (1960).

Chase, W. E., and H. K. Moore, eds., Exploding Wires, Vols. 1- (Plenum Press, New York, 1959-).

Clear, A. J., Standard Laboratory Procedures for Determining Sensitivity, Brisance, and Stability of Explosives, Picatinny Arsenal, Dover, N. J., Rept. PA-TR-3278 (1965).

Dixon, W. J., and F. J. Massey, Introduction to Statistical Analysis, 2nd ed., (McGraw-Hill, New York, 1957).

Dorough, G. D., L. G. Green, and D. T. Gray, The Susan Test for Evaluating the Impact Safety of Explosive Materials, Lawrence Livermore Laboratory, Rept. UCRL-7394 (1965).

Enig, J. W., and F. T. Metcalf, Theoretical Calculations on the Shock Initiation of Liquid TNT, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-62-159 (1962).

Evans, M. W., "Detonation Sensitivity and Failure Diameter in Homogeneous Condensed Materials," J. Chem. Phys. 36, 193-200 (1962).

Grant, R. L., A Combination Statistical Design for Sensitivity Testing, U. S. Bureau of Mines, Pittsburgh, Pa., Rept. BM-IC-8324 (1967).

Green, L. G., and G. D. Dorough, "Further Studies on the Ignition of Explosives," in Proc. 4th Symp. (Intern.) on Detonation, U. S. Office of Naval Research, Washington, D.C., Rept. ACR-126 (1965), pp. 477-486.

Green, L. G., R. J. Wasley, and P. E. Kramer, Shock Initiation of LX-04-1 and LX-09-0, Lawrence Livermore Laboratory, Rept. UCRL-50672 (1969).

Green, L. G., R. J. Wasley, and P. E. Kramer, Shock Initiation of LX-07-2 and LX-10-0, Lawrence Livermore Laboratory, Rept. UCRL-50851 (1970).

Green, L. G., and A. M. Weston, Data Analysis of the Reaction Behavior of Explosive Materials Subjected to Susan Test Impacts, Lawrence Livermore Laboratory, Rept. UCRL-13480 (1970).

Green, L. G., A. M. Weston, and J. H. Van Velkinburg, Mechanical Behavior of Hemispherical Billets of Plastic-Bonded Explosives Vertically Dropped on a Smooth, Rigid, Steel Target Surface, Lawrence Livermore Laboratory, Rept. UCRL-51022 (1971).

Green, L. G., A. M. Weston, and J. H. Van Velkinburg, Mechanical and Frictional Behavior of Skid Test Hemispherical Billets, Lawrence Livermore Laboratory, Rept. UCRL-51085 (1971).

Hubbard, H. W., and M. H. Johnson, "Initiation of Detonation," J. Appl. Phys. 30, 765-769 (1959).

Jaffe, I., G. Roberson, and J. Toscana, Calibration for the Gap Test with a Pentolite Donor, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-63-19 (1963).

Jones, M. M., and H. J. Jackson, "Heat Sensitization of Explosives," Explosivstoffe 7, 177-183 (1959).

Liddiard, T. P., and D. Price, Recalibration of the Standard Card-Gap Test, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-65-43 (1965).

Lindstrom, I. E., "The Planar Shock Initiation of Porous Tetryl,: J. Appl. Phys. 41, 337-350 (1970).

Macek, A., "Sensitivity of Explosives," Chem. Rev. 62, 41-63 (1962).

Mader, C., A Hydrodynamic Hot Spot Calculation, Los Alamos Scientific Laboratory, N. Mex., Rept. LA-2703 (1962).

Mason, C. M., R. W. Van Dolah, and M. L. Weiss, Drop Weight Testing of Explosive Liquids, Explosives Research Center, U. S. Bureau of Mines, Pittsburgh, Pa., Rept. BM-RI-6799 (1966).

Napadensky, H., Experimental Studies of the Effects of Impact Loading on Plastic-Bonded Explosive Materials, Armour Research Foundation, Illinois Institute of Technology, Chicago, Ill., Rept. DASA-1391 (1963).

Price, D., and T. P. Liddiard, Jr., The Small Scale Gap Test—Calibration and Comparison with the Large Scale Gap Test, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-66-87 (AD-487353) (1966).

Schimmel, M. L., QUEST—Quantitative Understanding of Explosive Stimulus Transfer, Summary Report—Task 1 through 6, McDonnell Aircraft Company, St. Louis, Mo., Rept. MDC-A-1021 (1971).

Sensitiveness Collaboration Committee, Manual of Explosive Safety Certificate Sensitiveness Tests, U. K. Explosives Research and Development Establishment, Waltham Abbey, Essex, Rept. WAC-158-06 with suppl., WAE-325-03 with suppl. (1963).

Slade, D. C., and J. Dewey, High Order Initiation of Two Military Explosives, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., Rept. BRL-1021 (1957).

Statistical Research Group, Princeton University, Statistical Analysis for a New Procedure in Sensitivity Experiments, Naval Defense Research Committee, Office of Scientific Research and Development, Washington, Rept. OSRD-4040 (1944).

Tucker, T. J., "Spark Initiation Requirements of a Secondary Explosive," Ann. N. Y. Acad. Sci. 152, 643-653 (1968).

Walker, F. E., and R. J. Wasley, "Critical Energy for Shock Initiation of Heterogeneous Explosives," Explosivstoffe 17, 9-13 (1969).

Walker, F. E., and R. J. Wasley, "Initiation of Nitromethane with Relatively Long-Duration, Low-Amplitude Shock Waves," Combust. Flame 15, 233-246 (1970).

Archibald, P. B., "Isostatic Solvent Pressing," Ind. Eng. Chem. 53, 737-738 (1961).

Bryden, J. H., The Density of Crystalline Cyclotetramethylenetetranitramine (HMX), U. S. Naval Ordnance Test Station, China Lake, Calif., Rept. NOTS-1652, (NAVORD-5398) (1957).

Goldsmith, W., and T. A. Reitter, Static and Dynamic Properties of Two Explosive Materials, U. S. Naval Weapons Center, China Lake, Calif., Rept. NWC-TP-4805, (AD-864750) (1970).

Hamstad, M. A., Complex Shear Modulus of a High Explosive, Lawrence Livermore Laboratory, Rept. UCRL-50357 (1967).

Hoge, K. G., Friction and Wear of Explosive Materials, Lawrence Livermore Laboratory, Rept. UCRL-50134 (1966).

Hoge, K. G., "The Behavior of Plastic-Bonded Explosives under Dynamic Compressive Loads," in Appl. Polymer Symp. 5, 19-40 (1967).

Hoge, K. G., "Friction and Viscoelastic Properties of Highly Filled Polymers—Plastic-Bonded Explosives," 4th Southeastern Conf. on Theoretical and Applied Mechanics, New Orleans, Feb. 29-Mar. 1, 1968.

Murray, R. C., and W. G. Moen, The Linear Viscoelastic Response of LX-07-1, Lawrence Livermore Laboratory, Rept. UCRL-50751 (1969).

Murray, R. C., and R. Jaeger, Mechanical Properties Testing of High Explosives, Lawrence Livermore Laboratory, Rept. (16-mm color sound film (1969)).

Scribner, K., A Physical Properties Mock for LX-04-1, Lawrence Livermore Laboratory, Rept. UCID-15495 (1965).

Wasley, R. J., and F. E. Walker, "Dynamic Compressive Rheological Behavior of a Brittle, Strain Rate Sensitive, Polycrystalline, Organic Solid," J. Appl Phys. 40, 2639-2648 (1969).

Wasley, R. J., and F. E. Walker, A Method for the Numerical Analysis of Pressure Transducer Records, Lawrence Livermore Laboratory, Rept. UCRL-50233 (1967).

Wasley, R. J., K. G. Hoge, and J. C. Cast, "Combined Strain Gauge-Quartz Crystal Instrumented Hopkinson Split Bar," Rev. Sci. Instr. 40, 889-894 (1969).

Wilkins, M. L., and R. Giroux, The Calculation of Stress Waves in Solids, Lawrence Livermore Laboratory, Rept. UCRL-7271 (1963).

Adler, J., and J. W. Enig, The Critical Conditions in Thermal Explosions Theory for Nth Order Reactions, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-64-180 (1964).

Brinkley, S. R., and E. B. Wilson, Revised Method of Predicting the Detonation Velocities in Solid Explosives, Office of Scientific Research and Development, National Defense Research Committee, Washington, D. C., Rept. OSRD-905 (1942).

Burnham, M. W., Investigation of Flow Kinematics of Detonating Explosive Slabs, Falcon Research Corp., Denver, Colo., Rept. AFATL-TR-67-33 (1967).

Burnham, M. W., Research on Detonation Wave Mechanics, Falcon Research Corp., Denver, Colo., Rept. ARL-TR-66-2 (1966).

Campbell, A. W., M. E. Malin, T. J. Boyd, Jr., and J. A. Hull, "Precision Measurement of Detonation Velocities in Liquid and Solid Explosives," Rev. Sci. Instr. 27, 567-574 (1956).

Catalano, E., and H. C. Hornig, Time-Resolved Emission Spectra of the Detonation Products of PETN, Lawrence Livermore Laboratory, Rept. UCRL 50328 (1967).

Christian, E. A., and H. G. Snay, Analysis of Experimental Data on Detonation Velocities, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NAVORD-1508 (1956).

Cole, R., Underwater Explosions, Princeton University Press, Princeton, NJ (1948).

Coleburn, N. L., Chapman-Jouguet Pressures of Several Pure and Mixed Explosives, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-64-58 (1964).

Cook, M. A., Detonation Velocities of "Ideal" Explosives with Inert Additives, University of Utah, Salt Lake City, Rept. AD-16380 (1953).

Cook, M. A., Velocity-Diameter Measurements and Reaction Rates of PETN, RDX, and EDNA, University of Utah, Salt Lake City, Rept. AD-44634 (1954).

Cook, M. A., R. I. Keyes, and W. O. Ursenbach, Measurements of Shock and Detonation Pressures, University of Utah, Salt Lake City, Rept. AD-258201 (1961).

Cook, M. A., R. I. Keyes, and W. O. Ursenbach, "Measurement of Detonation Pressure," J. Appl. Phys. 33, 3413-3421 (1962).

Cowperthwaite, M., Theoretical Studies of Detonation, Final Report, February 1966—February 1971, Stanford Research Institute, Menlo Park, Calif., Rept. AD-730642 (1971).

Courant, R., and K. O. Friedrichs, Supersonic Flow and Shock Waves (Interscience, New York, 1948).

Cowan, R. D., and W. Fickett, "Calculation of the Detonation Properties of Solid Explosives with the Kistiakowsky-Wilson Equation of State," J. Chem. Phys. 24, 932-939 (1956).

Crouch, M. R., and N. E. Hoskin, "Detonation of Explosive Slabs of Finite Dimensions," J. Appl. Phys. 42, 264-267 (1971).

Deal, W. E., "Measurement of Chapman-Jouguet Pressure for Explosives," J. Chem. Phys. 27, 796-800 (1957).

Deal, W. E., "Measurement of Reflected Shock Hugoniot and Isentrope for Explosive Reaction Products," Phys. Fluids 1, 523-527 (1958).

Derzhavets, A. S., "Increased Susceptibility of Explosives to a Detonation Impulse," in Termostoikie Vzryvchatye Veshchestva ikh Deistvie v Glubokikh Skavzhinakh, F. A. Baum, Ed. (1969), pp. 37-52 (Transl. by H. J. Dahlby, Los Alamos Scientific Laboratory, N. Mex., Rept. LA-TR-71-32 (1971)).

Dremin, A. N., and K. K. Shvedov, "Determination of the Chapman-Jouguet Pressure and the Reaction Duration in a Shock Wave of High Power Explosives," Zh. Priklad. Mekh. Tekh. Fiz. 3, 139-144 (1964). (Transl. PA-TT-15 (AD-688247).)

Duff, R. E., and E. Houston, "Measurement of the Chapman-Jouguet Pressure and Reaction Zone Length in a Detonating High Explosive," J. Chem. Phys. 23, 1268-1273 (1955).

Enig, J. W., and F. J. Petrone, On Equations of State in Shock Initiation Problems, U. S. Naval Ordnance Laboratory, White Oak, Md., Informal Rept. (1964).

Evans, M. W., and C. M. Ablow, "Theories of Detonation," Chem. Rev. 61, 129-178 (1961).

Evans, M. W., C. M. Ablow, B. O. Reese, and A. B. Amster, Shock Sensitivity of Low Density Granular Explosives, Stanford Research Institute, Menlo Park, Calif., Rept. AD-417863 (1963).

Eyring, H., R. E. Powell, G. H. Duffy, and R. B. Parlin, "The Stability of Detonation," Chem. Rev. 45, 69-181 (1949).

Fickett, W., Detonation Properties of Condensed Explosives Calculated with an Equation of State Based on Intermolecular Potentials, Los Alamos Scientific Laboratory, N. Mex., Rept. LA-2712 (1962).

Fickett, W., and W. W. Wood, "A Detonation-Product Equation of State Obtained from Hydrodynamic Data," Phys. Fluids 1, 528-534 (1958).

Finger, M., H. C. Hornig, E. L. Lee, and J. W. Kury, "Metal Acceleration by Composite Explosives," in Proc. 5th Symp. (Intern.) on Detonation, Office of Naval Research, Arlington, Va., Rept. ACR-184 (1970), pp. 137-151.

Garn, W. B., "Detonation Pressure of Liquid TNT," J. Chem. Phys. 32, 653-655 (1960).

Gipson, R. W., and A. Macek, Transition from Slow Burning to Detonation—Flame Fronts and Compression Waves during Growth of Detonation, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NAVORD-6759 (1959).

Goodman, H. J., Compiled Free-Air Blast Data on Bare Spherical Pentolite, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., Rept. BRL-1092 (1960).

Goodman, H. J., and R. E. Shear, Pressure, Density and Internal Energy of Pentolite Explosion Products, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., Rept. BRL-1212 (1963).

Gruschka, H. D., and F. Wecken, Gasdynamic Theory of Detonation (Gordon and Breach Science Publishers, New York, 1971).

Hauver, G. E., and P. H. Netherwood, Pressure Profiles of Detonating Baratol Measured with Sulphur Gauges, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., Rept. BRL-TN-1452 (AD-276986) (1962).

Howe, P. M., Detonation Structure in Condensed Phase Explosives, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., Rept. AD-713541 (1969).

Hurwitz, H., Calculation of Detonation Parameters with the RUBY Code, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-63-205 (1965).

Hurwitz, H., and M. J. Kamlet, "The Chemistry of Detonations. V. A Simplified Method for Calculation of Pressures of C-H-N-O Explosives on K-W Isentrope," Israel J. Technol. 7, 431-430 (1969).

Jacobs, S. J., On the Equation of State of Compressed Liquids and Solids, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-68-214 (1968).

Jacobs, S. J., "Equation of State for Detonation Products at High Density," 12th Symp. (Intern.) on Combustion, The Combustion Institute, Philadelphia, Pa. (1969), pp. 501-510.

Jacobs, S. J., T. P. Liddiard, Jr., and B. E. Drimmer, "The Shock-to-Detonation Transition in Solid Explosives," 9th Symp. (Intern.) on Combustion, The Combustion Institute, Philadelphia, Pa. (1963), pp. 499-516.

Jameson, R. L., and A. L. Hawkins, Detonation Pressure Measurements in TNT and Octol, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., Rept. AD-713547 (1970).

Kamlet, M. J., and S. J. Jacobs, "The Chemistry of Detonations. I. A Simple Method for Calculating Detonation Properties of C-H-N-O Explosives," J. Chem. Phys. 48, 23-35 (1968).

Kamlet, M. J., and J. E. Ablard, "The Chemistry of Detonations. II. Buffered Equilibria," J. Chem. Phys. 48, 36-42 (1968).

Kamlet, M. J., and C. Dickinson, "The Chemistry of Detonations. III. Evaluation of the Simplified Calculational Method for Chapman-Jouguet Detonation Pressures on the Basis of Available Experimental Information," J. Chem. Phys. 48, 43-50, (1968).

Kamlet, M. J., "The Chemistry of Detonation. IV. Evaluation of a Simple Predictional Method for Detonation Velocities of C-H-N-O Explosives," J. Chem. Phys. 48, 3685-3692 (1968).

Kamlet, M. J., see also H. Hurwitz.

Kandiner, H. J., and S. R. Brinkley, "Calculation of Complex Equilibrium Relations," Ind. Eng. Chem. 42, 850-855 (1949).

Kirkwood, K. G., and W. W. Wood, "Structure of a Steady-State Plane Detonation Wave with Finite Reaction Rate," J. Chem. Phys. 22, 1915-1919 (1954).

Kury, J. W., H. C. Hornig, E. L. Lee, J. M. McDonnel, D. L. Ornellas, M. Finger, F. M. Strange, and M. L. Wilkins, "Metal Acceleration by Chemical Explosives," in 4th Symp. (Intern.) on Detonation, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. ACR-126 (1965), pp. 3-13.

Lee, E. L., H. C. Hornig, and J. W. Kury, Adiabatic Expansion of High Explosive Detonation Products, Lawrence Livermore Laboratory, Rept. UCRL-50422 (1968).

Lee, E. L., and H. C. Hornig, "Equation of State of Detonation Product Gases," in 12th Symp. (Intern.) on Combustion, The Combustion Institute, Philadelphia, Pa. (1969), pp. 493-499.

Leger, E. G., and K. Park, A Zig-Zag Oscilloscope Presentation for Detonation Velocity Measurements in Explosives, Canadian Armament Research and Development Establishment, Rept. CARDE-TM-170-58 (1958).

Leopold, H. S., The Growth of Low Density Explosive Mixtures, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-62-89 (1962).

Los Alamos Scientific Laboratory, Studies on Binders and Desensitizers (Los Alamos Scientific Laboratory, N. Mex., 1962).

Lutzky, M., The Flow Field behind a Spherical Detonation in TNT Using the Landauer-Stanyukovich Equation of State for Detonation Products, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-64-40 (1964).

McGarry, W. F., and T. W. Stevens, Detonation Rates of the More Important Military Explosives at Several Different Temperatures, Picatinny Arsenal, Dover, N. J., Rept. PA-TR-2383 (1956).

Mader, C. L., Detonation Properties of Condensed Explosives Computed Using the Becker-Kistiakowsky-Wilson Equation of State, Los Alamos Scientific Laboratory, N. Mex., Rept. LA-2900 (1963).

Mader, C. L., FORTRAN BKW—A Code for Computing the Detonation Properties of Explosives, Los Alamos Scientific Laboratory, N. Mex., Rept. LA-3704 (1967).

Mader, C. L., The Time-Dependent Reaction Zone of Ideal Gases, Nitromethane, and Liquid TNT, Los Alamos Scientific Laboratory, N. Mex., Rept. LA-3764 (1967).

Melton, C. E., D. F. Strenzwilk, and P. D. Yedinak, Microscopic Theory of Detonation in Solids, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., Rept. BRL-TN-1715 (AD-688869) (1969).

Minshall, D., "Properties of Elastic and Plastic Waves Determined by Pin Contactors and Crystals," J. Appl. Phys. 26, 463-469 (1955).

Ornellas, D. L., "Detonation Calorimeter and Results Obtained with Pentaerythritol Tetranitrate (PETN)," Rev. Sci. Instr. 37, 907-912 (1966).

Ornellas, D. L., "The Heat and Products of Detonation of Cyclotetramethylene Tetranitramine (HMX), 2,4,6-Trinitrotoluene (TNT), Nitromethane (NM), and Bis-(2, 2-dinitro-2-fluoroethyl)-formal (FEFO)," J. Phys. Chem. 72, 2390-2391 (1968).

Pack, D. C., "The Reflection of a Detonation Wave at a Boundary," Phil. Mag. 2, 182-188 (1957).

Palmer, R., Initiation of Detonation. I. Simple "Hubbard and Johnson" Model, U. K. Atomic Weapons Research Establishment, Rept. SSPD-USA-56 (1962).

Piacesi, D., Jr., Numerical Hydrodynamic Calculations of the Flow of the Detonation Products from a Point-Initiated Explosive Cylinder, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-66-150 (AD-810470) (1967).

Price, D., "Dependence of Damage Effects on Detonation Parameters of Organic High Explosives," Chem. Rev. 59, 801-825 (1959).

Price, D., and F. J. Petrone, Detonation Initiated by High Pressure Loading of a Solid Explosive, U. S. Naval Ordnance, White Oak, Md., Rept. NOL-TR-63-103 (1963).

Price, D., J. F. Wehner, and G. E. Roberson, Transition from Slow Burning to Detonation—Further Studies of the Free Volume and the Low Velocity Regime in Cast Pentolite, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-63-18 (1963).

Strange, F. M., Equations of State for Six Explosives, Wm. Brobeck and Associates, Berkeley, Calif., Rept. WMBA-4500-95-2-R8 (1964).

Taylor, J., Detonation in Condensed Explosives (Oxford University Press, Oxford, 1952).

Taylor, J., "The Dynamics of the Combustion Products behind Plane and Spherical Detonation Fronts in Explosives," Proc. Roy. Soc. (London) Ser. A A200, 235-247 (1950).

Taylor, J., Solid Propellent and Exothermic Compositions (George Newnes, Ltd., London, 1959).

Taylor J., and P. F. Gay, British Coal Mining Explosives (George Newnes, Ltd., London, 1958).

Urizar, M. J., E. James, and L. C. Smith, "Detonation Velocity of Pressed TNT," Phys. Fluids 4, 262-274 (1961).

Villars, D. S., "A Method of Successive Approximations for Computing Combustion Equilibria on a High Speed Digital Computer," J. Am. Chem. Soc. 63, 521-525 (1959).

Von Neumann, J., and R. D. Richtmyer, "A Method for the Numerical Calculation of Hydrodynamic Shocks," J. Appl. Phys. 21, 232-237 (1950).

Walsh, J. M., and M. H. Rice, "Dynamic Compression of Liquids from Measurements on Strong Shock Waves," J. Chem. Phys. 26, 815-823 (1957).

Wasley, R. J., and R. H. Valentine, Shock Pulse Attenuation and Hugoniot Studies of One Explosive and Three Mock Explosives, Lawrence Livermore Laboratory, Livermore, Rept. UCRL-50950 (1970).

White, W. B., S. M. Johnston, and G. B. Dantzig, "Chemical Equilibrium in Complex Mixtures," J. Chem. Phys. 28, 751-755 (1958).

Wilkins, M.L., J. French, and R. Giroux, A Computer Program for Calculating One-Dimensional Hydrodynamic Flow—KO Code, Lawrence Livermore Laboratory, Rept. UCRL-6919 (1962).

Wilkins, M. L., B. Squier, and B. Halperin, The Equation of State of PBX-9404 and LX-04-1, Lawrence Livermore Laboratory, Rept. UCRL-7797 (1964).

Wilson, D. H., Hydrodynamics (Edward Arnold, Publ., London, 1959).

Wood, W. W., "Existence of Detonations for Small Values of the Rate Parameter," Phys. Fluids 4, 46-60 (1961).

Wood, W. W., "Existence of Detonations for Large Values of the Rate Parameter," Phys. Fluids 6, 1081-1090 (1963).

Wood, W. W., and J. G. Kirkwood, "Diameter Effect in Condensed Explosives—The Relation between Velocity and Radius of Curvature of the Detonation Wave," J. Chem. Phys. 22, 1920-1924 (1954).

Zeldovich, I. B., Theory of Detonation (Academic Press, New York, 1960).

Zovko, C. T., The Mechanism of the Transition from Deflagration to Detonation in High Explosives, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NAVWEPS-7393 (1961).

Bolt, R. O., and G. J. Carroll, Eds., Radiation Effects on Organic Materials (Academic Press, New York, 1963).

Bowden, F. P., and H. M. Montagu-Pollock, "Slow Decomposition of Explosive Crystals and Their Damage by Fission Fragments," Nature 191, 556-559 (1961).

Cerny, J., M. S. Kirshenbaum, and R. C. Nichols, "Range-Energy Relations for Protons and Alpha-Particles in Various Explosives," Nature 198, 371-372 (1963).

Clark, D., and M. J. Daniels, The Proton Irradiation of High Explosives, U. K. Atomic Weapons Research Establishment, Aldermaston, Berks., U. K., Rept. ERN-25-64 (1964).

Dobratz, B. M., Bibliography on Radiation Effects on Primary and Secondary Explosives and on Propellants, Lawrence Livermore Laboratory, Rept. UCID-16087 (1972).

Paitchel, J., J. E. Cockayne, R. S. Alger, R. T. Elsberry, W. B. Thomas, J. M. McSwain, J. P. Noonan, H. M. Shupp, and D. Wasler, Source Book of Radiation Effects on Propellants, Explosives and Pyrotechnics, Vol. 1, Picatinny Arsenal, Dover, N. J., Rept. DNA-2881F-1 (1974).

Ribaudo, C., J. Mallay, and H. J. Matsuguma, The Effects of Reactor Irradiation on the Chemical Characteristics of Solid Explosives, Picatinny Arsenal, Dover, N. J., Rept. PA-TR-3893 (1970).

Urizar, M. J., E. D. Loughran, and L. C. Smith, "The Effects of Nuclear Radiation on Organic Explosives," Explosivstoffe 4, 55-64 (1962).

THERMAL PROPERTIES

Andreev, K. K., Thermal Decomposition and Combustion of Explosives, 1st ed. (Moscow, 1960) (Transl. into German in Explosivstoffe (1960-1962); 2nd ed. (Moscow, 1966), Transl., Foreign Technology Div., Wright-Patterson AFB, Ohio, Transl. AD-693600 (1969)).

Aubertein, P., "Stability of Explosives," Mem. Poudr. 41, 111-125 (1959); in French (Transl. by F. E. Wallwork, U. K. Atomic Weapons Research Establishment, Aldermaston, Berks. U. K., Transl. AWRE-TRANS-24 (1961)).

Barrett, E. J., H. W. Hoyer, and A. V. Santoro, "Differential Thermal Analysis of Rapid High Pressure Decompositions," Anal. Lett. 1, 285-289 (1968).

Buxton, R. J., and T. M. Massio, Compatibility of Explosives with Structural Materials of Interest, Sandia Laboratories, Albuquerque, N. Mex., Rept. SC-TM-70-355 (1970).

Cady, H. H., and W. H. Rogers, Enthalpy, Density and Thermal Coefficient of Cubical Expansion of TNT, Los Alamos Scientific Laboratory, N. Mex., Rept. LA-2696 (1962).

Clink, G. L., Corrosion Effects of the Interaction of 6061 Aluminum with Aqueous Mixtures and Solutions of Selected HE's, Mason and Hanger—Silas Mason Company, Inc., Pantex Plant, Amarillo, Texas, Rept. MHSMP-71-58 (1971).

Cook, M. A., and M. T. Abegg, "Isothermal Decomposition of Explosives," Ind. Eng. Chem. 48, 1090-1095 (1956).

Frazer, J. W., and K. Ernst, Chemical Reactivity Testing of Explosives, Lawrence Livermore Laboratory, Rept. UCRL-7438 (1963).

Hansson, J., Ed., Symposium on Chemical Problems Connected with Stability of Explosives, 1st, Swedish Detonic Research Foundation, Stockholm (1967); 2nd (1970); 3rd (1973).

Lee, E. L., R. H. Sanborn, and H. D. Stromberg, "Thermal Decomposition of High Explosives at Static Pressures 10-50 Kilobars," in Proc. 5th Symp. (Intern.) on Detonation, Office of Naval Research, Arlington, Va., Rept. ACR-184 (1970), pp. 331-337.

Maycock, J. N., Applications of Thermal Analysis—Explosives and Solid Propellant Ingredients (Martin-Marietta Corp./Mettler Instrument Corp., Baltimore, Md., 1969).

Maycock, J. N., "Application of Thermal Analysis Methods to the Study of Unstable and Metastable Materials," Thermochim. Acta 4, 309-320 (1972).

Maycock, J. M., and V. R. Pai Verneker, "Characterization of Thermal and Photosublimation of Organic Explosives by Thermobarogravimetric Techniques," Thermochim. Acta 1, 191-198 (1970).

Murray, R. C., and T. E. Cooper, A Method of Measuring Thermal Diffusivity of High Explosive Materials, Lawrence Livermore Laboratory, Rept. UCRL-50827 (1970).

Rogers, R. N., "The Simple Microscale Differential Thermal Analysis of Explosives," Microchem. J. 5, 91-99 (1961).

Rogers, R. N., S. K. Yasada, and J. Zinn, "Pyrolysis as an Analytical Tool," Anal. Chem. 32, 672-678 (1960).

Schuldt, H. S., and L. C. Myers, Time-to-Explosion Thermal Initiation Test for Explosives, Mason and Hanger—Silas Mason Company, Inc., Pantex Plant, Amarillo, Texas (1964).

Simmons, H. T., Sr., The Vacuum Thermal Stability Test for Explosives, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. NOL-TR-70-142 (1970).

Zinn, J., and C. L. Mader, "Thermal Initiation of Explosives," J. Appl. Phys. 31, 323-328 (1960).

Distribution

LLL Internal Distribution

Roger E. Batzel
R. W. Anderson
C. G. Andre
P. B. Archibald
W. F. Arnold/E. R. McClure
R. H. Barlett
G. R. Baxter
C. F. Bender
W. P. Bennett
C. W. Berndt
E. R. Bissell 10
R. M. Boat
G. R. Bokanich
W. G. Boyle
R. D. Breithaupt
G. A. Broadman/C. R. Henry
W. L. Burden
R. I. Bystroff
R. B. Carr
J. C. Cast
E. Catalano
H. Cheung
W. E. Clements
J. P. Cramer
D. F. Cruff
V. E. Culler
J. D. Deligans
H. X. DiGrazia
G. L. Dittman
B. M. Dobratz 25
R. G. Dong
F. S. Eby
A. L. Edwards
R. E. Elson
R. B. Engle
K. Ernst
J. T. Ewing
D. B. Fields
M. Finger 5
P. G. Fleming
K. V. Fordyce
H. C. Forsberg
J. W. Frazer
J. L. Freiling
S. J. French
K. E. Froeschner
M. M. Fulk
R. Fyfe
B. L. Garner
L. S. Germain
E. Goldberg
H. A. Golopol
G. L. Goudreau
W. C. Grayson
L. G. Green
R. P. Guarienti
M. W. Guinan
W. A. Gummer
W. H. Gust
M. R. Gustavson
J. S. Hallam
H. G. Hammon
R. L. Heckman
F. H. Helm
G. H. Higgins
R. Henry
K. G. Hoge
B. E. Holder
A. C. Holt
A. C. Honodel
B. L. Hord
H. C. Hornig
J. R. Humphrey
W. S. Inouye
W. M. Isbell
E. James 10
F. W. Jessen
F. P. Johansen
C. V. Johnson III 5
M. Kamegai
V. N. Karpenko/C. E. Walter

LLL Internal Distribution (continued)

R. N. Keeler
J. E. Keller
H. K. Kruger
J. W. Kury
A. Kusubov
J. K. Landauer
E. L. Lee
J. K. Lepper
W. A. Lokke
J. W. Lyle
A. Maimoni
L. L. Marino
R. L. McCleskey
C. A. McDonald
J. L. McDonnel
L. M. McGrew
W. R. McKinley
G. L. Moody
J. L. Morse
R. L. Morton
P. H. Moulthrop
J. H. Moyer
R. K. Mullins
R. C. Murray 5
R. C. Myers
W. B. Myers
W. E. Nelson
P. C. Newcomb
E. J. Nidick
D. C. Oakley
R. S. Paige
H. G. Palmer
J. M. Parker
R. K. Pearson
L. E. Peck
H. N. Perl
T. Perlman/G. B. Sabine
K. A. Peterman
H. E. Pfeifer
R. L. Remillard
G. W. Repp
H. L. Reynolds
F. Rienecker
K. H. Ristad
J. B. Robison
J. W. Routh
S. Sack
K. J. Scribner
D. L. Seaton
R. W. Seldon
W. Selig
L. L. Shaw
B. L. Shroyer
D. R. Speck
G. G. Staehle
D. J. Steinberg
J. S. Steller
E. A. Stisser
R. G. Stone
J. R. Stroud
C. A. Tatro
C. L. Teevan
J. F. Tinney
A. F. Todaro
O. A. Tveitmoe
P. A. Urtiew
R. E. Varosh
O. T. Vik
K. W. Volkman
R. L. Wagner
R. L. Waldron
F. E. Walker 5
D. H. Warner
R. J. Wasley
R. C. Weingart
H. Weiss
M. L. Wilkins
J. R. Wilson
F. R. Wondolowsky
C. D. Wood
R. J. Woodworth
D. L. Woods
D. L. Wooster

LLL Internal Distribution (continued)

C. L. Wraith

M. Zaslawsky

TID File 50

External Distribution

J. Choromokos, Jr.
Defense Nuclear Agency
Washington, D.C.

E. L. Brawley
Defense Nuclear Agency
Albuquerque, New Mexico

P. E. Koentap
G. Prassinos
Defense Nuclear Agency
Livermore, California

J. Bearden
S. Wright
Holston Army Ammunition Plant
Kingsport, Tennessee

J. Aragon
M. Brooks
A. W. Campbell
W. Deal
E. Eyster
W. Meyers
A. Popolato
R. H. Rogers
L. C. Smith
R. Spaulding
J. Travis
W. C. Davis
B. Craig
P. G. Salgado
B. Hayes
T. Benziger
M. Urizer
W. Fickett
C. L. Mader
J. F. Barnes
Library
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

R. Holmberg
J. Polson
C. Poole
J. Kurrlee
J. Tash
Mason & Hanger - Silas Mason Co., Inc.
Burlington, Iowa

J. C. Drummond
J. Adams
I. Akst
R. Bailey
A. Duncan
R. Dunham
J. Higgins
L. Myers
G. Osborn
M. Ott
E. Poynor
J. Rigdon
A. Wilson
Mason & Hanger - Silas Mason Co., Inc.
Amarillo, Texas

R. Brinkman
D. Colman
L. Haws
P. J. Kiefer
Monsanto Research Corporation
Miamisburg, Ohio

D. Anderson
H. Barnett
W. Benedict
B. Grumley
J. C. King
E. Kjelgaard
J. Marron
C. H. Mauldin
C. McCampbell
T. Tucker
J. Weber
Library
Sandia Laboratories
Albuquerque, New Mexico

G. Anderson
C. R. Barncord
C. Schoenfelder
B. Worden
D. Gregson
L. Guiterrez
R. Meinken
Library
Sandia Laboratories
Livermore, California

D. M. Zimmer
V. Calbi
Air Force Systems Command
Eglin Air Force Base
Florida

H. Frazier
Ammunition Procurement and Supply Agency
Joliet, Illinois

External Distribution (continued)

S. Taylor
R. Eichelberger
R. Karpp
P. Howe
Ballistic Research Laboratories
Aberdeen Proving Ground
Maryland

A. M. Weston
William M. Brobeck
and Associates
Berkeley, California

G. Dorough
R. Thorkelsen
Department of Defense,
Research & Engineering
Washington, D. C.

R. Roberts
Office of Naval Research
Washington, D. C.

J. Hershkowitz
H. Matsaguma
L. Saffian
R. Walker
N. Slagg
H. Fair
Picatinny Arsenal
Dover, New Jersey

J. Ablard
H. Heller
M. Kamlet
C. Misener
Library
U. S. Naval Ordnance Laboratory
Silver Spring, Maryland

H. Gryting
D. Lind
N. Rumpp
R. Sewall
B. Stott
U. S. Naval Ordnance Test
Station
China Lake, California

A. Amster
B. Drimmer
R. Beauregard
Naval Ordnance Systems
Command
Washington, D. C.

J. Osborne
Air Force Weapons Laboratory
Kirtland AFB, New Mexico

VJE/md/lc

J. Bell
U. S. Atomic Energy
Commission
Berkeley, California

C. H. Smith
Bendix Corporation
Kansas City, Missouri

H. Kite
Union Carbide Corporation
Oak Ridge, Tennessee

Manager
U. S. Atomic Energy
Commission
Albuquerque, New Mexico

I. G. Gwillim 5
Atomic Weapons Research
Establishment
Aldermaston, Reading
England

C. A. Beck
Explosives Research and
Development Establishment
Waltham Abbey, Essex
England

N. Griffiths
Royal Armament Research &
Development Establishment
Fort Halstead, Kent
England

J. A. Bell
Defense Research &
Development Staff
British Embassy
Washington, D. C.

D. B. Janisch
Atomic Coordinating Office
British Embassy
Washington, D. C.

Technical Information Center 2
Oak Ridge, Tennessee

☆ GPO 790-202