LASL EXPLOSIVE PROPERTY DATA
# CONTENTS

## PART I. EXPLOSIVES PROPERTIES BY EXPLOSIVES

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This volume of the Los Alamos Series on Dynamic Materials Properties is designed to provide a single source of reliable data on high explosives in use or formerly used at the Los Alamos National Scientific Laboratory (LASL). These are the best LASL data available and, as revisions are made, new or better data will be added.

The volume is divided into two major parts for the user's convenience. Part I presents in one place the properties of explosives by explosive and summarizes all the property data and the results of various tests generally used to characterize explosives. It covers only pure explosives and explosive formulations that have been well characterized. However, for many of these materials there are some properties or test results that have not been determined and in those cases the section normally used to list the property or test result has been omitted. Part II presents the properties of explosives by property or method of determination. It covers many more materials, often those for which only one property has been determined. Part II permits ready comparison of explosives and, for a number of properties, contains detailed data that permit use of other data reduction methods, such as the user's own fitting techniques.

Because many explosives properties depend upon the exact details of charge preparation, and their determination depends upon the exact details of the testing procedures, many of the test procedures used in gathering these data are described. References on the test procedures and data are cited where possible; however, much of the data has been taken from unpublished internal LASL reports. If more than one group of data or conflicting data were available, we selected the most credible. Also, because almost all of these explosives are heterogeneous polycrystalline materials, some of their properties, especially initiation by strong shocks, depend upon such factors as charge density, the particle size distribution of the crystals, and the degree of crystal perfection. Therefore, Part II includes detailed descriptions of the test explosives wherever possible.

In Part I the explosives are discussed alphabetically and the various plastic-bonded explosives, PBXs, and extrudable explosives, XTXs, are discussed in numerical order. Part II, because it covers many more explosives formulations,
treats pure explosives first, alphabetically; then castables; then plastic-bonded explosives, alphabetically by major explosive constituent; and, finally, propellants. An explosives table gives the composition of each material covered in this volume, and a glossary defines acronyms and unusual terms.

The authors gratefully acknowledge the help that was provided by Margaret M. Cox and Jeanne Stein in producing many of the graphics.
PART I
EXPLOSIVES PROPERTIES
BY EXPLOSIVE
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<th>Explosive</th>
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</thead>
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</tr>
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<td>TATB</td>
<td>152</td>
</tr>
<tr>
<td>Tetryl</td>
<td>163</td>
</tr>
<tr>
<td>TNT</td>
<td>172</td>
</tr>
<tr>
<td>XTX 8003</td>
<td>188</td>
</tr>
<tr>
<td>XTX 8004</td>
<td>196</td>
</tr>
</tbody>
</table>
1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. Baratol, a mixture of barium nitrate, \( \text{Ba(NO}_3\text{)}_2 \), and TNT, \( \text{C}_7\text{H}_5\text{N}_3\text{O}_6 \), is off-white to gray.

1.2 Common Use. During World War II, the British developed baratols that contained about 20 wt\% barium nitrate to replace TNT. The United States used baratols that contained slightly more barium nitrate in depth charges and other limited munitions. Baratols that contain up to 76 wt\% barium nitrate are now used as the low detonation velocity explosive in waveshaping devices such as plane-wave lenses.

1.3 Toxicity. Barium nitrate can irritate skin and mucous membranes.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. Finely ground barium nitrate is added to molten TNT to form a castable slurry. To lower the slurry viscosity, which increases with the percentage of barium nitrate, about 0.1 wt\% of nitrocellulose (11.8-12.2 wt\% nitrogen, 18-25 centipoise) is added to the TNT before the addition of the barium nitrate. After the barium nitrate is added, just before vacuum is applied to the melt, 0.05-0.1 wt\% of either decylgallophenone or stearoxyacetic acid is added to prevent cracking. Vacuum is applied to the melt just before casting to remove dissolved and occluded gas and to provide higher, more uniform density. Carefully controlled cooling of the casting also promotes uniform density and composition.

2.2 Procurement. There are no purchase specifications for baratol. It is produced to the user's specific requirements at ordnance plants that have TNT-casting facilities.
BARATOL

2.3 Shipping. Baratol is shipped as a Class A explosive, as defined by the Code of Federal Regulations.

2.4 Storage. Baratol is stored in Compatibility Group D, Storage Class 1.1, as required by US Army Materiel Command regulation.

3. CHEMICAL PROPERTIES

3.1 Composition. Unless otherwise specified, the properties given are for the following composition.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Weight Percent</th>
<th>Volume Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barium nitrate</td>
<td>76.0</td>
<td>62.8</td>
</tr>
<tr>
<td>TNT</td>
<td>24.0</td>
<td>37.2</td>
</tr>
</tbody>
</table>

3.2 Molecular Weight.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barium nitrate</td>
<td>Ba(NO₃)₂</td>
<td>261.38</td>
</tr>
<tr>
<td>TNT</td>
<td>C₇H₅N₃O₆</td>
<td>227.13</td>
</tr>
</tbody>
</table>

3.3 Solubility. Barium nitrate solubility in water is given.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Solubility (g/100 ml of solvent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>8.7</td>
</tr>
</tbody>
</table>
4. PHYSICAL PROPERTIES

4.2 Density.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical</td>
<td>2.634</td>
</tr>
<tr>
<td>Vacuum cast</td>
<td>2.60-2.62</td>
</tr>
</tbody>
</table>

4.3 Infrared Spectrum. See Fig. 1.

5. THERMAL PROPERTIES

5.1 Phase Changes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-liquid</td>
<td>79-80</td>
<td>6.1</td>
</tr>
</tbody>
</table>

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Heat Capacity at Constant Pressure (cal/g°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.192</td>
<td>18 &lt; T &lt; 75</td>
</tr>
</tbody>
</table>

Fig. 1. Infrared spectrum.
5.4 Thermal Conductivity.

<table>
<thead>
<tr>
<th>Conductivity (cal/s-cm-°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.184 \times 10^{-4}$</td>
<td>$18 &lt; T &lt; 75$</td>
</tr>
</tbody>
</table>

5.5 Coefficient of Thermal Expansion.

<table>
<thead>
<tr>
<th>Coefficient of Expansion (1/°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3.4 \times 10^{-6} + 2.8 \times 10^{-7} T$</td>
<td>$-40 &lt; T &lt; 60$</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>(\Delta H^\circ) (kcal/mole)</th>
<th>(\Delta H_f^\circ) (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNT</td>
<td>-817.2</td>
<td>-12.0</td>
</tr>
<tr>
<td>Ba(NO₃)₂</td>
<td>---</td>
<td>-238.23</td>
</tr>
</tbody>
</table>

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.1-0.4 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
</tbody>
</table>
6. DETONATION PROPERTIES

6.1 Detonation Velocity. The composition of baratol cast to approximately 97% of its theoretical density affects its detonation velocity as follows.

Effect of Composition

<table>
<thead>
<tr>
<th>Weight Percent $\text{Ba(NO}_3)_2$</th>
<th>Detonation Velocity (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>5.12</td>
</tr>
<tr>
<td>72</td>
<td>5.03</td>
</tr>
<tr>
<td>74</td>
<td>4.95</td>
</tr>
<tr>
<td>76</td>
<td>4.86</td>
</tr>
</tbody>
</table>
6.2 Detonation Pressure.

<table>
<thead>
<tr>
<th>Weight Percent</th>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ba(NO₃)₂</td>
<td>76</td>
<td>2.61</td>
<td>4.925</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14</td>
</tr>
</tbody>
</table>

6.4 Plate Dent Test Results.

<table>
<thead>
<tr>
<th>Charge Diameter (mm)</th>
<th>Density (g/cm³)</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.3</td>
<td>2.61</td>
<td>3.21</td>
<td>203</td>
</tr>
</tbody>
</table>

7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.

<table>
<thead>
<tr>
<th>Weight Percent</th>
<th>Density (g/cm³)</th>
<th>G₀ (mm)</th>
<th>L₀₀ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ba(NO₃)₂</td>
<td>76</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.597</td>
<td>27.3</td>
<td>0.20</td>
</tr>
</tbody>
</table>

No data because sample was below failure diameter.

7.2 Wedge Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Distance, x*, and Time, t*, to Detonation (mm and μs)</th>
<th>Pressure Range (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.61</td>
<td>( \log P = (1.2\pm0.03)-(0.30\pm0.03) \log x^* ) ( \log P = (1.01\pm0.01)-(0.27\pm0.02) \log t^* ), where ( P ) = pressure in gigapascals.</td>
<td>( 6.9 &lt; P &lt; 11.8 )</td>
</tr>
</tbody>
</table>
7.3 Shock Hugoniot\textsuperscript{4}

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Shock Hugoniot (mm/(\mu)s)</th>
<th>Particle Velocity Range (mm/(\mu)s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.611</td>
<td>(U_s = 2.40 + 1.66 U_p), (U_s = 1.50 + 2.16 U_p)</td>
<td>(0 &lt; U_p &lt; 0.75) (0.75 &lt; U_p &lt; 1.2)</td>
</tr>
<tr>
<td>2.63</td>
<td>(U_s = 2.79 + 1.25 U_p)</td>
<td>(0 &lt; U_p &lt; 1)</td>
</tr>
</tbody>
</table>

where \(U_s\) = shock velocity  
and \(U_p\) = particle velocity.

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>(H_{50}) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>110</td>
</tr>
<tr>
<td>12B</td>
<td>140</td>
</tr>
</tbody>
</table>

9. MECHANICAL PROPERTIES

9.2 Tensile Strength and Modulus.

<table>
<thead>
<tr>
<th>Ultimate Tensile Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>380-450</td>
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</table>

9.3 Compressive Strength and Modulus.

<table>
<thead>
<tr>
<th>Ultimate Compressive Strength (psi)</th>
<th>Compressive Modulus (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5700-8100</td>
<td>((1.5 \text{ to } 2.0) \times 10^6)</td>
</tr>
</tbody>
</table>
REFERENCES


COMPOSITION B

1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. Composition B (Comp B), a mixture of 60 wt% RDX and 40 wt% TNT, with or without a wax desensitizer, is yellow-brown. Mixtures of RDX and TNT are generally called cyclotols in the United States, Hexolite in France, Füllpulver in Germany, Tritolite in Italy, Tritolita in Spain, and Hexotol in Sweden.

Comp B desensitized with 1 wt% wax is available in grades A and B. Grade A is more fluid than Grade B when molten. Comp B-3 contains no desensitizer. It is more viscous than Grade A or B when molten because its median RDX particle diameter is smaller.

1.2 Common Use. Comp B is used as the explosive fill in almost all types of explosive ordnance.

1.3 Toxicity. The toxicity of Comp B is like that of RDX and TNT. Workers who inhaled RDX dust for several months have become unconscious and have suffered loss of reflexes. The suggested maximum permissible airborne concentration is 1.5 mg/m³.

Inhaled TNT vapor or dust may irritate mucous membranes and cause sneezing, coughing, and sore throat. TNT may produce toxic hepatitis and aplastic anemia, and it yellows the exposed skin, hair, and nails of workers. Dermatitis, erythema, papules, and itchy eczema can be severe. Ingestion of 1-2 g of TNT is estimated to be an acute fatal dose to humans. The suggested maximum permissible airborne dust concentration is 0.5 mg/m³.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. Comp B-type explosives, including cyclotols, are manufactured from TNT and water-wet RDX. The TNT is melted in a steam-jacketed kettle equipped with a stirrer and is brought to about 100°C. The wet RDX is added
COMP B

slowly. Heating and stirring are continued until most of the water is evaporated. The appropriate desensitizing wax or other additive is then thoroughly mixed with the other ingredients. After cooling to satisfactory fluidity, the Comp B is cast into strips or chips. The chips are shipped to an ordnance plant, remelted, and cast into ammunition or into desired shapes. During this melting, other additives may be introduced. To increase the density of cast charges, a vacuum may be applied to the molten Comp B before casting.

2.2 Procurement. Comp B is purchased from the US Army Armament Readiness Command under military specification MIL-C-401C, dated May 15, 1968, or, as Comp B-3, under MIL-C-45113, dated June 19, 1958.

2.3 Shipping. Comp B is shipped as a Class A explosive.

2.4 Storage. Comp B is stored in Compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Composition.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Comp B, Grades A and B</th>
<th>Comp B-3</th>
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<tbody>
<tr>
<td></td>
<td>Weight Percent</td>
<td>Volume Percent</td>
</tr>
<tr>
<td>RDX</td>
<td>59.5</td>
<td>56.9</td>
</tr>
<tr>
<td>TNT</td>
<td>39.5</td>
<td>41.2</td>
</tr>
<tr>
<td>Wax</td>
<td>1.0</td>
<td>1.9</td>
</tr>
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</table>
3.2 Molecular Weight.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td><img src="image" alt="RDX Structure" /></td>
<td>222.13</td>
</tr>
<tr>
<td></td>
<td>$\text{C}<em>\text{H}</em>\text{N}<em>\text{O}</em>\text{O}$</td>
<td></td>
</tr>
<tr>
<td>TNT</td>
<td><img src="image" alt="TNT Structure" /></td>
<td>227.13</td>
</tr>
<tr>
<td></td>
<td>$\text{C}<em>\text{H}</em>\text{N}<em>\text{O}</em>\text{O}$</td>
<td></td>
</tr>
<tr>
<td>Wax</td>
<td>$\text{CH}<em>\text{CH}</em>\text{CH}_\text{CH}$</td>
<td>$30.07 + (14.02)_n$</td>
</tr>
</tbody>
</table>
### 3.3 Solubility

The solubility is that of the components RDX and TNT.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid 99.6%</td>
<td>0.46</td>
<td>0.56</td>
<td>1.22</td>
</tr>
<tr>
<td>Acetic acid 71.0%</td>
<td>0.22</td>
<td>0.37</td>
<td>0.74</td>
</tr>
<tr>
<td>Acetone</td>
<td>6.81</td>
<td>10.34</td>
<td>---</td>
</tr>
<tr>
<td>Isoamyl alcohol</td>
<td>0.026</td>
<td>0.060</td>
<td>0.210</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.045</td>
<td>0.085</td>
<td>0.195</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>0.33</td>
<td>0.554</td>
<td>---</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>4.94</td>
<td>9.20</td>
<td>13.9</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>---</td>
<td>41.5</td>
<td>60.6</td>
</tr>
<tr>
<td>Ethanol</td>
<td>0.12</td>
<td>0.24</td>
<td>0.58</td>
</tr>
<tr>
<td>Methyl acetate</td>
<td>2.9</td>
<td>4.1</td>
<td>---</td>
</tr>
<tr>
<td>Methylcyclohexanone</td>
<td>6.81</td>
<td>10.34</td>
<td>---</td>
</tr>
<tr>
<td>Methyl ethyl ketone</td>
<td>3.23</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.020</td>
<td>0.050</td>
<td>0.125</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>0.20</td>
<td>0.24</td>
<td>---</td>
</tr>
<tr>
<td>Water</td>
<td>0.005</td>
<td>0.0127</td>
<td>0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>109.0</td>
<td>228.0</td>
<td>600.0</td>
</tr>
<tr>
<td>Benzene</td>
<td>67.0</td>
<td>180.0</td>
<td>478.0</td>
</tr>
<tr>
<td>Butyl carbinol acetate</td>
<td>24.0</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td>0.48</td>
<td>1.53</td>
<td>---</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>0.65</td>
<td>1.75</td>
<td>6.90</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>33.9</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Chloroform</td>
<td>19.0</td>
<td>66.0</td>
<td>302.0</td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>3.29</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Ethanol (95%)</td>
<td>1.23</td>
<td>2.92</td>
<td>8.30</td>
</tr>
<tr>
<td>Ethylene chloride</td>
<td>18.7</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Hexane</td>
<td>0.16</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Methyl acetate</td>
<td>72.1</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Toluene</td>
<td>55.0</td>
<td>130.0</td>
<td>367.0</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>3.04</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Water</td>
<td>0.0130</td>
<td>0.0285</td>
<td>0.0675</td>
</tr>
</tbody>
</table>
4. PHYSICAL PROPERTIES

4.2 Density

Theoretical Density (g/cm³)

<table>
<thead>
<tr>
<th>Material</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp B, Grades A and B</td>
<td>1.737</td>
</tr>
<tr>
<td>Comp B-3</td>
<td>1.750</td>
</tr>
</tbody>
</table>

Density of Typical Casting (g/cm³)

<table>
<thead>
<tr>
<th></th>
<th>Open Melt</th>
<th>Vacuum Melt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.68-1.70</td>
<td>1.715-1.720</td>
</tr>
<tr>
<td></td>
<td>---</td>
<td>1.725-1.730</td>
</tr>
</tbody>
</table>

4.3 Infrared Spectrum. See Fig. 1.

5. THERMAL PROPERTIES

5.1 Phase Change.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-slurry</td>
<td>79</td>
<td>14.1</td>
</tr>
</tbody>
</table>

Fig. 1. Infrared spectrum.
COMP B

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Heat Capacity at Constant Pressure (cal/g·°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.234 + 1.03 x 10^{-3} T</td>
<td>7 &lt; T &lt; 76</td>
</tr>
</tbody>
</table>

5.4 Thermal Conductivity.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Conductivity (cal/s-cm·°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.730</td>
<td>5.23 x 10^{-1}</td>
</tr>
</tbody>
</table>

5.5 Coefficient of Thermal Expansion.

<table>
<thead>
<tr>
<th>Coefficient of Expansion (1/°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.46 x 10^{-8}</td>
<td>6 &lt; T &lt; 25</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>ΔH°_f (kcal/mole)</th>
<th>ΔH°_c (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNT</td>
<td>-817.2</td>
<td>-12.0</td>
</tr>
<tr>
<td>RDX</td>
<td>-501.8</td>
<td>14.7</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Decomposition energy (cal/g)</th>
<th>Activation energy (kcal/mole)</th>
<th>Pre-exponential factor (10^11/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNT</td>
<td>300</td>
<td>34.4</td>
<td>2.51 x 10^{11}</td>
</tr>
<tr>
<td>RDX</td>
<td>500</td>
<td>47.1</td>
<td>2.02 x 10^{13}</td>
</tr>
</tbody>
</table>
5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.2-0.6 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, Tm</td>
<td>214°C</td>
</tr>
<tr>
<td>Charge radius, a</td>
<td>3.0 mm</td>
</tr>
</tbody>
</table>

6. DETONATION PROPERTIES

6.1 Detonation Velocity.

Effect of Charge Radius
Charge radius affects the detonation velocity of unconfined Grade A Comp B, cast to a density of 1.700 g/cm³, as follows.

\[
D(R) = 7.859 \left(1 - 2.84 \times 10^{-3}/R\right) - 5.51 \times 10^{-3}/R(R - 1.94),
\]

where \(D\) = detonation velocity in millimeters per microsecond and \(R\) = charge radius in millimeters.

The experimentally determined failure diameter is 4.28 mm.

![Fig. 2. Comp B DTA and pyrolysis test results.](image)
6.2 Detonation Pressure.\(^8\)

<table>
<thead>
<tr>
<th>Grade A Comp B (Weight Percent RDX)</th>
<th>Density (g/cm(^3))</th>
<th>Detonation Velocity (mm/(\mu)s)</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>64.0</td>
<td>1.713</td>
<td>8.018</td>
<td>29.22</td>
</tr>
</tbody>
</table>

6.3 Cylinder Test Results.

<table>
<thead>
<tr>
<th>Density(^a) (g/cm(^3))</th>
<th>Detonation Velocity (mm/(\mu)s)</th>
<th>Cylinder Wall Velocity (mm/(\mu)s) at R - R(_o) = 5 mm</th>
<th>R - R(_o) = 19 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.700(^b)</td>
<td>7.915</td>
<td>1.377</td>
<td>1.625</td>
</tr>
<tr>
<td>1.715</td>
<td>7.911</td>
<td>1.378</td>
<td>1.628</td>
</tr>
</tbody>
</table>

\(^a\) Grade A Comp B.

\(^b\) Scaled from a 4-in.-diam shot.

6.4 Plate Dent Test Results.\(^9\)

<table>
<thead>
<tr>
<th>Charge Diameter (mm)</th>
<th>Weight Percent RDX</th>
<th>Density (g/cm(^3))</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.3</td>
<td>60.7</td>
<td>1.730</td>
<td>8.64</td>
<td>203</td>
</tr>
<tr>
<td>41.3</td>
<td>64.0</td>
<td>1.714</td>
<td>8.47</td>
<td>203</td>
</tr>
</tbody>
</table>
7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.\(^{10}\)

<table>
<thead>
<tr>
<th>Type</th>
<th>Density (g/cm(^2))</th>
<th>Weight Percent RDX</th>
<th>(G_{50}) (mm)</th>
<th>(L_{95}) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp B-3</td>
<td>1.727</td>
<td>60.0</td>
<td>50.34</td>
<td>0.81</td>
</tr>
<tr>
<td>Grade A Comp B</td>
<td>1.710</td>
<td>64.0</td>
<td>45.69</td>
<td>0.45</td>
</tr>
<tr>
<td>Grade A Comp B</td>
<td>1.714</td>
<td>64.0</td>
<td>45.18</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Small Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp B-3</td>
<td>1.720</td>
<td>60.0</td>
<td>1.22</td>
<td>---</td>
</tr>
<tr>
<td>Grade A Comp B</td>
<td>1.710</td>
<td>---</td>
<td>1.5</td>
<td>0.08</td>
</tr>
</tbody>
</table>

7.2 Wedge Test Results.\(^{11}\)

<table>
<thead>
<tr>
<th>Density (g/cm(^2))</th>
<th>Distance, (x^*), to Detonation (mm)</th>
<th>Pressure Range(^{a}) (kbar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.72</td>
<td>2100 (P^{-1.26})</td>
<td>(40 &lt; P &lt; 100)</td>
</tr>
</tbody>
</table>

where \(P\) = pressure in kilobars.\(^{a}\)

\(^a\)Users should note that this is the only wedge data fit in this volume where pressure is in units of kilobars.
## COMP B

### 7.3 Shock Hugoniots\(^{12,13}\)

<table>
<thead>
<tr>
<th>Comp B-3 Density (g/cm(^3))</th>
<th>Shock Hugoniot (mm/(\mu s))</th>
<th>Particle Velocity Range (mm/(\mu s))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.680</td>
<td>(U_s = 2.71 + 1.86 U_p)</td>
<td>0 &lt; (U_p) &lt; 1.0</td>
</tr>
<tr>
<td>1.70</td>
<td>(U_s = 3.03 + 1.73 U_p)</td>
<td>0 &lt; (U_p) &lt; 1.0</td>
</tr>
</tbody>
</table>

where \(U_s\) = shock velocity and \(U_p\) = particle velocity.

### 7.4 Minimum Priming Charge\(^{10}\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>(W_{90}) (mg of XTX 8003)</th>
<th>(L_{90}) (± log mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.727(^a)</td>
<td>245</td>
<td>0.070</td>
</tr>
<tr>
<td>1.725(^b)</td>
<td>623</td>
<td>0.027</td>
</tr>
</tbody>
</table>

\(^a\)Comp B-3.
\(^b\)Grade A Comp B.

### 7.5 Detonation Failure Thickness\(^{10}\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Failure Thickness (mm)</th>
<th>(L_{95}) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.729(^a)</td>
<td>0.785</td>
<td>0.086</td>
</tr>
<tr>
<td>1.729(^a)</td>
<td>0.881</td>
<td>0.297</td>
</tr>
<tr>
<td>1.727(^a)</td>
<td>0.805</td>
<td>0.081</td>
</tr>
<tr>
<td>1.727(^a)</td>
<td>0.813</td>
<td>0.051</td>
</tr>
<tr>
<td>1.713(^b)</td>
<td>1.42</td>
<td>0.07</td>
</tr>
</tbody>
</table>

\(^a\)Comp B-3
\(^b\)Grade A Comp B.
8. SENSITIVITY

8.1 Drop Weight Impact Height

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>H_{60} (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>59</td>
</tr>
<tr>
<td>12B</td>
<td>109</td>
</tr>
</tbody>
</table>

8.2 Large-Scale Drop Test Height.

<table>
<thead>
<tr>
<th>Density (g/cm^3)</th>
<th>H_{60} (ft)</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.725</td>
<td>85</td>
<td>Partial</td>
</tr>
</tbody>
</table>

8.3 Skid Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm^3)</th>
<th>Impact Angle (degrees)</th>
<th>Target Surface</th>
<th>H_{50} (ft)</th>
<th>Reaction Overpressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.727</td>
<td>15</td>
<td>Sand and epoxy</td>
<td>9.8</td>
<td>&lt; 0.5</td>
</tr>
</tbody>
</table>

8.4 Susan Test Results.\(^{14}\)

<table>
<thead>
<tr>
<th>Projectile Impact Velocity (ft/s)</th>
<th>Relative Energy Release (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>0</td>
</tr>
<tr>
<td>800</td>
<td>5</td>
</tr>
<tr>
<td>1000</td>
<td>20</td>
</tr>
<tr>
<td>1200</td>
<td>30</td>
</tr>
<tr>
<td>1400</td>
<td>38</td>
</tr>
</tbody>
</table>
COMP B

9. MECHANICAL PROPERTIES

9.2 Tensile Strength and Modulus.

Ultimate Tensile Strength (psi)

135-150

9.3 Compressive Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Ultimate Compressive Strength (psi)</th>
<th>Compressive Modulus (psi x 10^-6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1400 ± 96</td>
<td>0.63 ± 0.1</td>
</tr>
<tr>
<td>0</td>
<td>1860 ± 200</td>
<td>2.40 ± 0.3</td>
</tr>
<tr>
<td>-40</td>
<td>2150 ± 280</td>
<td>2.50 ± 0.2</td>
</tr>
</tbody>
</table>
REFERENCES


1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. Cyclotol is the generic term for mixtures of TNT and RDX. In the United States, the term is used for mixtures of 75 wt% RDX and 25 wt% TNT (Type I) or 70 wt% RDX and 30 wt% TNT (Type II), also called Cyclotol 75/25 and Cyclotol 70/30. Neither mixture contains a desensitizer. To improve the flow of the molten form, a bimodal distribution of RDX crystals generally is used.

1.2 Common Use. Cyclotol is generally used as an explosive fill in military applications that require slightly more energy than Comp B can provide.

1.3 Toxicity. Cyclotol toxicity is like that of RDX and TNT. Workers who inhaled RDX dust for several months have become unconscious and have suffered loss of reflexes. The suggested maximum permissible airborne concentration of RDX is 1.5 mg/m³.

Inhaled TNT vapor or dust may irritate mucous membranes and cause sneezing, coughing, and sore throat. TNT may produce toxic hepatitis and aplastic anemia, and it yellows the exposed skin, hair, and nails of workers. Dermatitis, erythema, papules, and itchy eczema can be severe. Ingestion of 1-2 g of TNT is estimated to be an acute fatal dose to humans. The suggested maximum permissible airborne dust concentration is 0.5 mg/m³.
2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. Cyclotols are manufactured from TNT and water-wet RDX. The TNT is melted in a steam-jacketed kettle equipped with a stirrer and is brought to about 100°C. The wet RDX is added slowly, and heating and stirring are continued until the water is evaporated. Upon cooling to satisfactory fluidity, the cyclotol is cast into strips or chips. The chips are shipped to an ordnance plant, remelted, and cast into ammunition or into desired shapes. During this melting, other additives may be introduced. To increase the density of cast charges, a vacuum may be applied to the molten cyclotol before casting.

2.2 Procurement. Cyclotol is purchased from the US Army Armament Readiness Command under military specification MIL-C-13477A, dated March 31, 1965.

2.3 Shipping. Cyclotol is shipped as a Class A explosive.

2.4 Storage. Cyclotol is stored in Compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Composition.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Type I</th>
<th></th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight Percent</td>
<td>Volume Percent</td>
<td>Weight Percent</td>
</tr>
<tr>
<td>RDX</td>
<td>75.0</td>
<td>73.2</td>
<td>70.0</td>
</tr>
<tr>
<td>TNT</td>
<td>25.0</td>
<td>26.8</td>
<td>30.0</td>
</tr>
</tbody>
</table>
3.2 Molecular Weight.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td><img src="image" alt="RDX Structure" /></td>
<td>222.13</td>
</tr>
<tr>
<td></td>
<td>$C_9H_6N_6O_6$</td>
<td></td>
</tr>
<tr>
<td>TNT</td>
<td><img src="image" alt="TNT Structure" /></td>
<td>227.13</td>
</tr>
<tr>
<td></td>
<td>$C_7H_5N_2O_6$</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Solubility. The solubility is that of the components, RDX and TNT.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Grams of RDX Dissolved/100 g of Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C</td>
</tr>
<tr>
<td>Acetic acid</td>
<td></td>
</tr>
<tr>
<td>99.6%</td>
<td>0.46</td>
</tr>
<tr>
<td>71.0%</td>
<td>0.22</td>
</tr>
<tr>
<td>Acetone</td>
<td>6.81</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.045</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>0.33</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>4.94</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>---</td>
</tr>
<tr>
<td>Ethanol</td>
<td>0.12</td>
</tr>
<tr>
<td>Isoamyl alcohol</td>
<td>0.026</td>
</tr>
<tr>
<td>Methyl acetate</td>
<td>2.9</td>
</tr>
<tr>
<td>Methylcyclohexanone</td>
<td>6.81</td>
</tr>
<tr>
<td>Methyl ethyl ketone</td>
<td>3.23</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.020</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>0.20</td>
</tr>
<tr>
<td>Water</td>
<td>0.005</td>
</tr>
</tbody>
</table>
4. PHYSICAL PROPERTIES

4.2 Density.

<table>
<thead>
<tr>
<th>Material</th>
<th>Theoretical Density (g/cm³)</th>
<th>Density of Typical Casting (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I, Cyclotol 75/25</td>
<td>1.776</td>
<td>Open Melt: ---</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vacuum Melt: 1.74-1.75</td>
</tr>
<tr>
<td>Type II, Cyclotol 70/30</td>
<td>1.765</td>
<td>Open Melt: 1.71-1.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vacuum Melt: ---</td>
</tr>
</tbody>
</table>
4.3 Infrared Spectrum. See Fig. 1.

5. THERMAL PROPERTIES

5.1 Phase Changes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-slurry</td>
<td>79</td>
<td>5.87 7.05</td>
</tr>
</tbody>
</table>

5.4 Thermal Conductivity.

<table>
<thead>
<tr>
<th>Type</th>
<th>Density (g/cm³)</th>
<th>Conductivity (cal/s·cm·°C⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75/25</td>
<td>1.760</td>
<td>5.41 x 10⁻⁴</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>$\Delta H_f^\circ$ (kcal/mole)</th>
<th>$\Delta H_f^\circ$ (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNT</td>
<td>-817.2</td>
<td>-12.0</td>
</tr>
<tr>
<td>RDX</td>
<td>-501.8</td>
<td>14.7</td>
</tr>
</tbody>
</table>

Fig. 1. Infrared spectrum.
5.7 Thermal Decomposition Kinetics.⁶

<table>
<thead>
<tr>
<th></th>
<th>TNT</th>
<th>RDX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition energy</td>
<td>300 cal/g</td>
<td>500 cal/g</td>
</tr>
<tr>
<td>Activation energy</td>
<td>34.4 kcal/mole</td>
<td>47.1 kcal/mole</td>
</tr>
<tr>
<td>Pre-exponential factor</td>
<td>$2.51 \times 10^{11}$/s</td>
<td>$2.02 \times 10^{11}$/s</td>
</tr>
</tbody>
</table>

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.4-0.5 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, Tm</td>
<td>208°C</td>
</tr>
<tr>
<td>Charge radius, a</td>
<td>3.5 mm</td>
</tr>
</tbody>
</table>

6. DETONATION PROPERTIES

6.1 Detonation Velocity.⁷

**Effect of Charge Radius**

Charge radius affects the detonation velocity of unconfined Cyclotol 75/25 cast to a density of 1.740 g/cm³ as follows.

$$D(R) = 8.210\left[(1 - 4.89 \times 10^{-2}/R) - 0.119/R(R - 2.44)\right],$$

![Fig. 2. Cyclotol 75/25 DTA and pyrolysis test results.](image-url)
where $D = \text{detonation velocity in millimeters per microsecond}$, 
and $R = \text{charge radius in millimeters}$.

The experimentally determined failure diameter is 6.0 mm.

### 6.2 Detonation Pressure

<table>
<thead>
<tr>
<th>Weight Percent RDX</th>
<th>Density (g/cm$^3$)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>77.0</td>
<td>1.743</td>
<td>8.252</td>
<td>31.25</td>
</tr>
</tbody>
</table>

### 6.4 Plate Dent Test Results

(See Part II for additional data.)

<table>
<thead>
<tr>
<th>Charge Diameter (mm)</th>
<th>Weight Percent RDX</th>
<th>Density (g/cm$^3$)</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.3</td>
<td>77</td>
<td>1.200</td>
<td>5.38</td>
<td>203</td>
</tr>
<tr>
<td>41.3</td>
<td>77</td>
<td>1.743</td>
<td>9.24</td>
<td>203</td>
</tr>
</tbody>
</table>

### 7. SHOCK INITIATION PROPERTIES

#### 7.1 Gap Test Results

<table>
<thead>
<tr>
<th>Density (g/cm$^3$)</th>
<th>Weight Percent RDX</th>
<th>$G_{50}$ (mm)</th>
<th>$L_{95}$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.756</td>
<td>77.0</td>
<td>42.85</td>
<td>0.23</td>
</tr>
<tr>
<td>1.757</td>
<td>76.1</td>
<td>43.15</td>
<td>0.15</td>
</tr>
<tr>
<td>1.744</td>
<td>77.3</td>
<td>44.93</td>
<td>0.08</td>
</tr>
<tr>
<td>1.750</td>
<td>77.9</td>
<td>44.17</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>Small Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.737</td>
<td>---</td>
<td>0.38</td>
<td>0.05</td>
</tr>
<tr>
<td>1.746</td>
<td>77</td>
<td>0.18</td>
<td>0.05</td>
</tr>
<tr>
<td>1.752</td>
<td>77</td>
<td>0.34</td>
<td>0.06</td>
</tr>
</tbody>
</table>
7.3 Shock Hugoniot

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Shock Hugoniot (mm/μs)</th>
<th>Particle Velocity Range (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.752</td>
<td></td>
<td>0 &lt; U_p &lt; 1.0</td>
</tr>
</tbody>
</table>

\[ U_s = 2.63 + 1.85 U_p \]

where \( U_s \) = shock velocity
and \( U_p \) = particle velocity.

7.4 Minimum Priming Charge.\(^{10}\)

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Weight Percent RDX</th>
<th>W_{50} (mg of XTX 8003)</th>
<th>L_{05} (± log mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.749</td>
<td>75</td>
<td>785</td>
<td>0.054</td>
</tr>
<tr>
<td>1.739</td>
<td>70</td>
<td>898</td>
<td>0.024</td>
</tr>
</tbody>
</table>

7.5 Detonation Failure Thickness.\(^{10}\)

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Weight Percent RDX</th>
<th>Failure Thickness (mm)</th>
<th>L_{95} (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.752</td>
<td>77</td>
<td>1.51</td>
<td>0.11</td>
</tr>
</tbody>
</table>

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>( H_{30} ) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>36</td>
</tr>
<tr>
<td>12B</td>
<td>108</td>
</tr>
</tbody>
</table>

8.2 Large-Scale Drop Test Height.\(^{11}\)

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>( H_{90} ) (ft)</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.750</td>
<td>&gt;150</td>
<td>No events</td>
</tr>
</tbody>
</table>
8.3 Skid Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Weight Percent RDX</th>
<th>Impact Angle (degrees)</th>
<th>Target Surface</th>
<th>H₂o (ft)</th>
<th>Overpressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.758</td>
<td>77</td>
<td>15</td>
<td>Sand and epoxy</td>
<td>4</td>
<td>&lt; 1.0</td>
</tr>
</tbody>
</table>

8.4 Susan Test Results. ¹²

<table>
<thead>
<tr>
<th>Projectile Impact Velocity (ft/s)</th>
<th>Relative Energy Release (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>5</td>
</tr>
<tr>
<td>500</td>
<td>25</td>
</tr>
<tr>
<td>1000</td>
<td>50</td>
</tr>
</tbody>
</table>

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>3</td>
<td>27</td>
<td>0.38</td>
<td>23</td>
</tr>
<tr>
<td>Brass</td>
<td>10</td>
<td>27</td>
<td>3.29</td>
<td>23</td>
</tr>
</tbody>
</table>

9. MECHANICAL PROPERTIES

9.3 Compressive Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Ultimate Compressive Strength (psi)</th>
<th>Compressive Modulus (psi x 10⁻⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>650 ± 150</td>
<td>0.74 ± 0.3</td>
</tr>
<tr>
<td>0</td>
<td>856 ± 200</td>
<td>2.39 ± 0.3</td>
</tr>
<tr>
<td>-40</td>
<td>993 ± 354</td>
<td>1.47 ± 0.06</td>
</tr>
</tbody>
</table>
REFERENCES


12. L. Green, Lawrence Livermore Laboratory, private communication (1975).
1. GENERAL PROPERTIES

1.1 **Chemical and Physical Description.** DATB (1,3-diamino-2,4,6-trinitrobenzene), \( \text{C}_9\text{H}_6\text{N}_6\text{O}_6 \), is a yellow crystalline solid.

1.2 **Common Use.** DATB is a relatively insensitive, temperature-resistant high explosive of limited military application. To be used effectively, it must be coated with a plastic (plastic-bonded explosive) or be mixed with liquid ingredients.

1.3 **Toxicity.** Industrial health data on DATB toxicity are virtually nil. Animal exposure indicated no immediate hazard even at 80°C. Although DATB is relatively safe, it is from a homologous group that has caused skin sensitivity, cancer, and internal physical damage.

2. MANUFACTURE AND PROCUREMENT

2.1 **Manufacture.** DATB is synthesized from m-nitroaniline in two steps. The nitroaniline is nitrated with mixed sulfuric and nitric acids to give tetranitroaniline, which is then aminated using ammonia in methanol. DATB is insoluble in methanol and precipitates as it is formed. It may be recrystallized from dimethylformamide or dimethylsulfoxide.
2.2 Procurement. There is no dedicated DoD facility for DATB manufacture. It can be procured, on special order, from a few US chemical companies that have facilities for synthesizing energetic materials.

2.3 Shipping. DATB is shipped as a Class A explosive.

2.4 Storage. DATB is stored dry in Compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Structural Formula.

\[
\text{C}_6\text{H}_6\text{N}_5\text{O}_8
\]

3.2 Molecular Weight. 243.14

3.3 Solubility.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Grams Dissolved/100 g of Solvent</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic anhydride</td>
<td>0.492</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>γ-Butyrolactone</td>
<td>0.810</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>0.355</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>2.96</td>
<td>4.88</td>
<td></td>
</tr>
<tr>
<td>Dimethylsulfoxide</td>
<td>4.56</td>
<td>8.15</td>
<td></td>
</tr>
<tr>
<td>Formamide</td>
<td>0.282</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Nitromethane</td>
<td>0.362</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>22.2</td>
<td>22.9</td>
<td></td>
</tr>
</tbody>
</table>
DATB

4. PHYSICAL PROPERTIES

4.1 Crystal Structure. Two crystalline polymorphs of DATB have been identified. The cell parameters of Form I, stable to 217°C, and of Form II are given.

<table>
<thead>
<tr>
<th>Cell Parameters</th>
<th>Form I</th>
<th>Form II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit cell edge length (Å)</td>
<td>7.30 ± 0.01</td>
<td>7.76</td>
</tr>
<tr>
<td>a</td>
<td>5.20 ± 0.01</td>
<td>9.04</td>
</tr>
<tr>
<td>b</td>
<td>11.63 ± 0.02</td>
<td>12.84</td>
</tr>
<tr>
<td>Angle β</td>
<td>95.90 ± 0.3°</td>
<td>103.0</td>
</tr>
<tr>
<td>Molecules per unit cell</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

4.2 Density.

<table>
<thead>
<tr>
<th>Method of Determination</th>
<th>State</th>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray</td>
<td>Solid</td>
<td>23</td>
<td>1.838</td>
</tr>
<tr>
<td>Direct measurement</td>
<td>Solid</td>
<td>23</td>
<td>1.837</td>
</tr>
</tbody>
</table>

DATB powder can be pressed into pellets. No quantitative pressing data is available.

4.3 Infrared Spectrum. See Fig. 1.

![Fig. 1. Infrared spectrum.](image)
5. THERMAL PROPERTIES

5.1 Phase Changes.\textsuperscript{a,5}

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-solid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Form I to Form II</td>
<td>217</td>
<td>---</td>
</tr>
<tr>
<td>Solid-to-liquid</td>
<td>286</td>
<td>---</td>
</tr>
<tr>
<td>Solid-to-gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Form I</td>
<td>---</td>
<td>33.47\textsuperscript{a}</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Computed from vapor pressure data presented in Sec. 5.2.

5.2 Vapor Pressure.\textsuperscript{5}

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Vapor Pressure (mm Hg \times 10')</th>
</tr>
</thead>
<tbody>
<tr>
<td>62.6</td>
<td>0.081</td>
</tr>
<tr>
<td>78.2</td>
<td>0.879</td>
</tr>
<tr>
<td>85.3</td>
<td>2.09-2.36</td>
</tr>
<tr>
<td>97.6</td>
<td>9.12-9.80</td>
</tr>
<tr>
<td>108.1</td>
<td>34</td>
</tr>
</tbody>
</table>

A least squares fit to these data gives

\[ \log_{10} P(\text{mm Hg}) = 13.73 - \frac{33470}{4.576} T(\text{K}) \]

5.3 Heat Capacity.

Heat Capacity at Constant Pressure (cal/g-°C)

\[ 0.261 + 1.11 \times 10^{-3} T \]
5.4 Thermal Conductivity.

<table>
<thead>
<tr>
<th>Conductivity (cal/s-cm-°C)</th>
<th>6.19 x 10^{-4}</th>
</tr>
</thead>
</table>

5.6 Heats of Combustion and Formation at 25°C.

<table>
<thead>
<tr>
<th>( \Delta H^0 )</th>
<th>( \Delta H^r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kcal/mole)</td>
<td>(kcal/mole)</td>
</tr>
<tr>
<td>-711.5</td>
<td>-23.6</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.

- Decomposition energy: 300 cal/g
- Activation energy: 46.3 kcal/mole
- Pre-exponential factor: \( 1.17 \times 10^{16}/s \)

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.1-0.3 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, ( T_m )</td>
<td>322 °C</td>
</tr>
<tr>
<td>Charge radius, ( a )</td>
<td>3.5 mm</td>
</tr>
<tr>
<td>Density, ( \rho )</td>
<td>1.74 g/cm³</td>
</tr>
</tbody>
</table>

6. DETONATION PROPERTIES

6.1 Detonation Velocity.

**Effect of Density**

The infinite-diameter detonation velocity as a function of density is given by

\[
D = 2.480 + 2.852 \rho_o ,
\]

where \( D \) = detonation velocity in millimeters per microsecond

and \( \rho_o \) = charge density in grams per cubic centimeter.
The failure diameter of unconfined DATB pressed to a density of 1.816 g/cm³ is approximately 5.3 mm.

6.2 Detonation Pressure.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.780</td>
<td>7.60</td>
<td>25.1</td>
</tr>
</tbody>
</table>

7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Gₚ₀ (mm)</th>
<th>Lₚ₀ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.81</td>
<td>49.27</td>
<td>0.23</td>
</tr>
<tr>
<td>1.705</td>
<td>45.36</td>
<td>0.08</td>
</tr>
<tr>
<td>1.786</td>
<td>41.68</td>
<td>0.18</td>
</tr>
<tr>
<td>Small Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.801</td>
<td>0.36</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Fig. 2. DATB DTA and pyrolysis test results.
7.3 Shock Hugoniot.

\[
U_s = (2.449 \pm 0.043) + (1.892 \pm 0.058) U_p,
\]

where \(U_s\) = shock velocity and \(U_p\) = particle velocity.

7.4 Minimum Priming Charge.

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>(W_{50}) (mg of XTX 8003)</th>
<th>(L_{95}) (± log mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.783</td>
<td>57.1</td>
<td>0.108</td>
</tr>
</tbody>
</table>

7.5 Detonation Failure Thickness.

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Failure Thickness (mm)</th>
<th>(L_{95}) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.708</td>
<td>0.630</td>
<td>0.069</td>
</tr>
<tr>
<td>1.724</td>
<td>0.732</td>
<td>0.145</td>
</tr>
</tbody>
</table>

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>(H_{95}) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>&gt;320</td>
</tr>
<tr>
<td>12B</td>
<td>230</td>
</tr>
</tbody>
</table>
REFERENCES


1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. HMX, an explosive similar to RDX, was a byproduct in the production of RDX by the process that W. E. Bachmann and J. E. Sheehan developed. It has a higher density and much higher melting point than RDX. It was named HMX for High Melting Explosive.

HMX, \( \text{C}_2\text{H}_5\text{N}_6\text{O}_4 \), is a colorless polycrystalline material. It is also known as octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine, cyclotetramethylene-tetranitramine, and Octogen.

1.2 Common Use. Because of its higher density, HMX has replaced RDX in explosive applications for which energy and volume are important. It is used in castable TNT-based binary explosives called Octols; as the main ingredient in high-performance plastic-bonded explosives, and in high-performance solid propellants.

1.3 Toxicity.¹ The suggested maximum concentration of HMX in air is 1.5 mg/m³.

---

¹Unless otherwise specified, the properties listed are for the \( \beta \) polymorph.
2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. A modified Bachmann batch process is used to produce HMX. Solutions of hexamine in acetic acid and ammonium nitrate in nitric acid are added to a base of acetic acid, acetic anhydride, and paraformaldehyde. A first period of continuous addition is followed by 15 minutes of aging, and a second period of continuous addition is followed by 1 hour of aging. Then the reaction mixture is diluted with hot water and heated to boiling to destroy all linear compounds. Cooling, filtering, and water washing complete preparation of the product. The crude HMX is purified by recrystallization from acetone solution to give a final product that is up to 99% beta HMX.


2.3 Shipping. HMX is shipped as a Class A explosive and must be shipped wet with not less than 10% water.

2.4 Storage. HMX may be stored dry in Compatibility Group A or wet in Compatibility Group D. Either wet or dry, it is in Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Structural Formula.

\[
\begin{align*}
\text{C}_4\text{H}_8\text{N}_8\text{O}_8
\end{align*}
\]
3.2 Molecular Weight. 296.17

3.3 Solubility.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Grams Dissolved/100 g of Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C</td>
</tr>
<tr>
<td>Acetic acid Glacial</td>
<td>0.037</td>
</tr>
<tr>
<td>70%</td>
<td>---</td>
</tr>
<tr>
<td>Acetic anhydride</td>
<td>---</td>
</tr>
<tr>
<td>Acetone Anhydrous</td>
<td>2.4</td>
</tr>
<tr>
<td>70%</td>
<td>0.66</td>
</tr>
<tr>
<td>Acetonitrile</td>
<td>---</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>---</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>---</td>
</tr>
<tr>
<td>Dimethylsulfoxide</td>
<td>---</td>
</tr>
</tbody>
</table>

4. PHYSICAL PROPERTIES

4.1 Crystal Structure. The cell parameters of the four polymorphic forms of HMX are given.

<table>
<thead>
<tr>
<th>Cell Parameters</th>
<th>α</th>
<th>β</th>
<th>γ</th>
<th>δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit cell edge length (Å)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>15.14</td>
<td>6.54</td>
<td>10.95</td>
<td>7.66</td>
</tr>
<tr>
<td>b</td>
<td>23.89</td>
<td>11.05</td>
<td>7.93</td>
<td>---</td>
</tr>
<tr>
<td>c</td>
<td>5.91</td>
<td>7.37</td>
<td>14.61</td>
<td>32.49</td>
</tr>
<tr>
<td>Angle β</td>
<td>---</td>
<td>102.8°</td>
<td>119.4°</td>
<td>---</td>
</tr>
<tr>
<td>Molecules per unit cell</td>
<td>8</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>
4.2 Density.

<table>
<thead>
<tr>
<th>Method of Determination</th>
<th>State</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>( \gamma )</th>
<th>( \delta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray</td>
<td>Solid</td>
<td>1.838</td>
<td>1.902</td>
<td>1.78</td>
<td>1.786</td>
</tr>
<tr>
<td>Direct measurement</td>
<td>Solid</td>
<td>1.84</td>
<td>1.905</td>
<td>1.76</td>
<td>1.80</td>
</tr>
</tbody>
</table>

HMX cannot be consolidated into charges by conventional pressing. Obtaining large pieces of polycrystalline HMX requires solvent pressing techniques.

4.3 Infrared Spectrum. See Fig. 1.

4.4 Refractive Index. The refractive indices of the four polymorphs in sodium light are shown.

<table>
<thead>
<tr>
<th>HMX Polymorph</th>
<th>Face</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>( \gamma )</th>
<th>( \delta )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alpha</td>
<td>1.561-1.565</td>
<td>1.589</td>
<td>1.537</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Beta</td>
<td>1.562-1.566</td>
<td>1.594-1.595</td>
<td>1.585</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Gamma</td>
<td>1.720-1.740</td>
<td>1.730-1.773</td>
<td>1.666</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Epsilon</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1.566</td>
</tr>
<tr>
<td></td>
<td>Omega</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1.607</td>
</tr>
<tr>
<td></td>
<td>Double refraction</td>
<td>pos</td>
<td>pos</td>
<td>pos</td>
<td>neg</td>
</tr>
</tbody>
</table>

Fig. 1. Infrared spectrum.
HMX

5. THERMAL PROPERTIES

5.1 Phase Changes.6-8

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature°C</th>
<th>Latent Heat (cal/g)</th>
<th>(kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-solid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&amp;to; α</td>
<td>102-104</td>
<td>2.0</td>
<td>0.6</td>
</tr>
<tr>
<td>α to γ</td>
<td>Metastable</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>α to δ</td>
<td>160-164</td>
<td>7.8</td>
<td>2.3</td>
</tr>
<tr>
<td>Solid-to-liquid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>α</td>
<td>256-257</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>β</td>
<td>246-247</td>
<td>50.0</td>
<td>17.0</td>
</tr>
<tr>
<td>γ</td>
<td>279-280</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>δ</td>
<td>280-281</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Solid-to-gas</td>
<td>---</td>
<td>141.4</td>
<td>41.89b</td>
</tr>
</tbody>
</table>

*There is some controversy about the temperature stability ranges of the four HMX polymorphs. These data are from Ref. 8.

*Computed from the vapor pressure data presented in Sec. 5.2.

5.2 Vapor Pressure.9

<table>
<thead>
<tr>
<th>Temperature°C</th>
<th>Vapor Pressure (mm Hg x 10⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td>97.6</td>
<td>0.032</td>
</tr>
<tr>
<td>108.2</td>
<td>0.164</td>
</tr>
<tr>
<td>115.6</td>
<td>0.385 0.419</td>
</tr>
<tr>
<td>129.3</td>
<td>2.830-2.870</td>
</tr>
</tbody>
</table>

A least squares fit to these data gives

\[
\log_{10} P(\text{mm Hg}) = 16.18 - 41.890/4.576 T(K) .
\]
5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Heat Capacity at Constant Pressure (cal/g·°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.231 + 5.5 × 10⁻⁴ T</td>
<td>37 &lt; T &lt; 167</td>
</tr>
</tbody>
</table>

5.4 Thermal Conductivity.¹⁰

<table>
<thead>
<tr>
<th>Conductivity (cal/s·cm·°C)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2 × 10⁻³</td>
<td>25</td>
</tr>
<tr>
<td>9.7 × 10⁻⁴</td>
<td>160</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation at 25°C.¹¹

<table>
<thead>
<tr>
<th>∆H° c kcal/mole</th>
<th>∆H° f kcal/mole</th>
</tr>
</thead>
<tbody>
<tr>
<td>−660.7</td>
<td>11.3</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.¹²

Decomposition energy 500 cal/g  
Activation energy 52.7 kcal/mole  
Pre-exponential factor 5 × 10¹⁹/s

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.1-0.4 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, Tm</td>
<td>253°C</td>
</tr>
<tr>
<td>Charge radius, a</td>
<td>3.3 mm</td>
</tr>
<tr>
<td>Density, ρ</td>
<td>1.81 g/cm³</td>
</tr>
</tbody>
</table>
6. DETONATION PROPERTIES

6.1 Detonation Velocity.\textsuperscript{13}

<table>
<thead>
<tr>
<th>Density (g/cm\textsuperscript{3})</th>
<th>Detonation Velocity* (mm/\mu s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.89</td>
<td>9.110</td>
</tr>
</tbody>
</table>

*Because HMX is a high-density version of RDX, their detonation velocities should be identical if they are compared at the same density.

6.2 Detonation Pressure.\textsuperscript{13}

<table>
<thead>
<tr>
<th>Density (g/cm\textsuperscript{3})</th>
<th>Computed Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.900</td>
<td>39.5</td>
</tr>
</tbody>
</table>

Fig. 2. HMX DTA and pyrolysis test results.
6.3 Cylinder Test Results.

<table>
<thead>
<tr>
<th>Density ((g/cm^3))</th>
<th>Cylinder Wall Velocity ((mm/\mu s)) at (R - R_o = 5 \text{ mm})</th>
<th>Cylinder Wall Velocity ((mm/\mu s)) at (R - R_o = 19 \text{ mm})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.891</td>
<td>1.65</td>
<td>1.86</td>
</tr>
</tbody>
</table>

7. SHOCK INITIATION

7.1 Gap Test Results.

<table>
<thead>
<tr>
<th>Density ((g/cm^3))</th>
<th>(G_{so}) ((mm))</th>
<th>(L_{so}) ((mm))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.07</td>
<td>70.68</td>
<td>0.71</td>
</tr>
<tr>
<td>Small Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.20</td>
<td>8.53</td>
<td>0.05</td>
</tr>
<tr>
<td>1.79</td>
<td>4.23</td>
<td>0.10</td>
</tr>
<tr>
<td>1.83</td>
<td>4.04</td>
<td>0.13</td>
</tr>
</tbody>
</table>

7.2 Wedge Test Results.

<table>
<thead>
<tr>
<th>Density ((g/cm^3))</th>
<th>Distance, (x^*), to Detonation ((mm))</th>
<th>Pressure Range ((\text{GPa}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.891</td>
<td>(\log P = (1.18 \pm 0.02) - (0.59 \pm 0.03) \log x^*), where (P = \text{pressure in gigapascals}).</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.41 &lt; P &lt; 9.55)</td>
</tr>
</tbody>
</table>
7.3 Shock Hugoniot.\textsuperscript{15}

<table>
<thead>
<tr>
<th>Density (g/cm(^2))</th>
<th>Shock Hugoniot (mm/(\mu)s)</th>
<th>Particle Velocity Range (mm/(\mu)s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.903</td>
<td>(U_s = 2.74 + 2.6 , U_p)\textsuperscript{a}</td>
<td></td>
</tr>
<tr>
<td>1.89</td>
<td>(U_s = (2.901 \pm 0.407) + (2.058 \pm 0.490) , U_p)</td>
<td>0.59 &lt; (U_p) &lt; 1.04</td>
</tr>
</tbody>
</table>

where \(U_s\) = shock velocity
and \(U_p\) = particle velocity.

\textsuperscript{a}Computed from isothermal compression data,

\[U_{st} = 2.67 + 2.6 \, U_{pt},\]

where the subscripts "st" and "pt" indicate the shock and particle velocities, respectively, at constant temperature.

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>(H_{so}) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>12B</td>
<td>37</td>
</tr>
</tbody>
</table>

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>3</td>
<td>66.9</td>
<td>0.2</td>
<td>50</td>
</tr>
<tr>
<td>Brass</td>
<td>10</td>
<td>66.9</td>
<td>1.03</td>
<td>50</td>
</tr>
<tr>
<td>Steel</td>
<td>1</td>
<td>75.0</td>
<td>0.12</td>
<td>50</td>
</tr>
<tr>
<td>Steel</td>
<td>10</td>
<td>75.0</td>
<td>0.87</td>
<td>50</td>
</tr>
</tbody>
</table>
REFERENCES

1. Committee on Threshold Limit Values: *Documentation of Threshold Limit Values*, 3rd Ed. (American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati, Ohio, 1971).


1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. Nitroguanidine (NQ), CH₃N₄O₂, is a colorless polycrystalline material, generally in the form of a low-density matted structure. It is also known as Picrite.

1.2 Common Use. NQ is used extensively as an ingredient in gun propellants, because the combustion products of such propellants are less erosive than those of other propellants of equivalent energy.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture.¹² The procedures used to produce NQ are the British aqueous fusion (BAF) and the urea/ammonium nitrate processes. The United States uses a modified BAF process. Calcium carbide is reacted with nitrogen to form calcium cyanamide. The calcium cyanamide is reacted with carbon dioxide and water to form cyanamide. This is reacted with ammonium nitrate to form guanidine nitrate (GuN). GuN is reacted with 40 wt% oleum to form nitroguanidine. Final purification of the NQ is by crystallization from water.


2.3 Shipping.¹ NQ is shipped dry as a Class A explosive.

2.4 Storage.¹ NQ is stored dry in Compatibility Group D, Storage Class 1.1.
3. CHEMICAL PROPERTIES

3.1 Structural Formula.\textsuperscript{5,6}

\[
\text{CH}_2\text{N}_2\text{O}_2
\]

3.2 Molecular Weight. 104.1

3.3 Solubility.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.36</td>
<td>0.75</td>
<td>1.6</td>
</tr>
<tr>
<td>Dimethyl sulfoxide</td>
<td>24</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Dimethyl formamide</td>
<td>14</td>
<td>---</td>
<td>20</td>
</tr>
<tr>
<td>Methanol</td>
<td>0.3</td>
<td>0.6</td>
<td>---</td>
</tr>
<tr>
<td>Methyl ethyl ketone</td>
<td>0.13</td>
<td>0.20</td>
<td>---</td>
</tr>
<tr>
<td>Butyl acetate</td>
<td>0.07</td>
<td>0.08</td>
<td>0.1</td>
</tr>
<tr>
<td>n-octane</td>
<td>0.003</td>
<td>0.008</td>
<td>---</td>
</tr>
</tbody>
</table>

4. PHYSICAL PROPERTIES

4.1 Crystal Structure.\textsuperscript{7,8} Only one polymorph of NQ has been observed. The orthorhombic unit cell parameters are given.

<table>
<thead>
<tr>
<th>Cell Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of unit cell edge (Å)</td>
</tr>
<tr>
<td>a</td>
</tr>
<tr>
<td>b</td>
</tr>
<tr>
<td>c</td>
</tr>
</tbody>
</table>

Molecules per unit cell 16
4.2 Density.  

**Crystal**

<table>
<thead>
<tr>
<th>Method of Determination</th>
<th>State</th>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray</td>
<td>Solid</td>
<td>---</td>
<td>1.78</td>
</tr>
<tr>
<td>Direct measurement</td>
<td>---</td>
<td>25</td>
<td>1.77</td>
</tr>
</tbody>
</table>

**Pressed**

NQ can be pressed to a density of 1.70 g/cm³ at a pressure of 20000 psi.

4.3 Infrared Spectrum. See Fig. 1.

4.4 Refractive Index.  

**Refractive Index in 5893-Å Light**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>α</td>
<td>1.526</td>
</tr>
<tr>
<td>β</td>
<td>1.694</td>
</tr>
<tr>
<td>γ</td>
<td>1.81</td>
</tr>
</tbody>
</table>

Fig. 1. Infrared spectrum.
5. THERMAL PROPERTIES

5.1 Phase Change.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-liquid</td>
<td>245-250°</td>
</tr>
</tbody>
</table>

*Melting is usually preceded by decomposition, which is very rapid in the liquid phase.

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Material</th>
<th>Heat Capacity at Constant Pressure (cal/g·°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBD NQ</td>
<td>$0.242 + 0.0011 T(°C)$</td>
<td>$37 &lt; T &lt; 167$</td>
</tr>
<tr>
<td>HBD NQ</td>
<td>$0.269 + 0.0007 T(°C)$</td>
<td>$37 &lt; T &lt; 167$</td>
</tr>
</tbody>
</table>

*Low-bulk density, in accordance with material specification MIL-N-494A.

*High-bulk density NQ recrystallized from water, median particle diameter ~300 μm.

5.4 Thermal Conductivity.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
<th>Conductivity (cal/cm·s·°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBD NQ</td>
<td>1.65</td>
<td>$10.1 \times 10^{-4}$</td>
<td>$25 &lt; T &lt; 50$</td>
</tr>
<tr>
<td></td>
<td>1.69</td>
<td>$9.8 \times 10^{-4}$</td>
<td>$25 &lt; T &lt; 50$</td>
</tr>
</tbody>
</table>
5.6 Heats of Combustion and Formation at 25°C.

<table>
<thead>
<tr>
<th>$\Delta H^o_c$ (kcal/mole)</th>
<th>$\Delta H^o_r$ (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-210.4</td>
<td>-20.29</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.\textsuperscript{10,11}

<table>
<thead>
<tr>
<th>Source</th>
<th>\textsuperscript{10} Ref. 10</th>
<th>\textsuperscript{11} Ref. 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition energy</td>
<td>500 cal/g</td>
<td>---</td>
</tr>
<tr>
<td>Activation energy</td>
<td>20.9 kcal/mole</td>
<td>57.1 kcal/mole</td>
</tr>
<tr>
<td>Pre-exponential factor</td>
<td>$2.84 \times 10^7$/s</td>
<td>$8.75 \times 10^{22}$/s</td>
</tr>
</tbody>
</table>

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>Gas evolved after 48 h at 120°C (ml/g)</td>
</tr>
<tr>
<td>NQ per MIL-N-494A</td>
<td>0.0-1.0</td>
</tr>
<tr>
<td>Water recrystallized HBD NQ</td>
<td>1.4-3.6</td>
</tr>
<tr>
<td>DMF recrystallized HBD NQ</td>
<td>0.6-1.2</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, $T_m$</td>
<td>198°C</td>
</tr>
<tr>
<td>Charge radius, $a$</td>
<td>3.9 mm</td>
</tr>
<tr>
<td>Density, $\rho$</td>
<td>1.63 g/cm$^3$</td>
</tr>
</tbody>
</table>
6. DETONATION PROPERTIES

6.1 Detonation Velocity.\textsuperscript{12}

**Effect of Density**

The effect of density on the infinite-diameter detonation velocity is given by

\[ D_\infty = 1.44 + 4.015 \rho_0 \text{ for } 0.3 < \rho_0 < 1.78, \]

where \( D_\infty \) = infinite-diameter detonation velocity in millimeters per microsecond,

and \( \rho_0 \) = density in grams per cubic centimeter.

**Failure Diameter**

The LBD NQ failure diameter as a function of charge density is shown.

<table>
<thead>
<tr>
<th>Charge Density (g/cm(^3))</th>
<th>Charge Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>25.4</td>
</tr>
<tr>
<td>1.21</td>
<td>15.9</td>
</tr>
<tr>
<td>1.52</td>
<td>14.3</td>
</tr>
</tbody>
</table>

---

Fig. 2. NQ DTA and pyrolysis test results.
6.2 Detonation Pressure. There are no experimental data on NQ detonation pressure. However, there is one data point from a mixture of 95 wt% NQ and 5 wt% Estane. The results are as follows.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>95 wt% NQ/5 wt% Estane</td>
<td>1.704</td>
<td>8.28</td>
<td>26.8</td>
</tr>
</tbody>
</table>

6.4 Plate Dent Test Results.

<table>
<thead>
<tr>
<th>Charge Diameter (mm)</th>
<th>Density (g/cm³)</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.7</td>
<td>0.25</td>
<td>0.56</td>
<td>76.2</td>
</tr>
<tr>
<td>12.7</td>
<td>0.40</td>
<td>0.79</td>
<td>76.2</td>
</tr>
</tbody>
</table>

7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>G₅₀ (mm)</th>
<th>L₉₅ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Scale</td>
<td>1.609</td>
<td>5.00</td>
</tr>
</tbody>
</table>
7.2 Wedge Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Distance, x*, and Time, t*, to Detonation (mm and μs)</th>
<th>Pressure Range (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.659 to 1.723a</td>
<td>( \log P = (1.44±0.07)-(0.15±0.08) \log x^* ) ( \log P = (1.32±0.03)-(0.15±0.07) \log t^* )</td>
<td>13.35 &lt; P &lt; 26.28</td>
</tr>
<tr>
<td>1.688b</td>
<td>( \log P = (1.51±0.02)-(0.26±0.03) \log x^* )</td>
<td>21.2 &lt; P &lt; 27.1</td>
</tr>
</tbody>
</table>

aNQ median particle diameter, 300 μm, as cubic crystals.
bNQ as long needle crystals with a needle diameter of a few micrometers.

7.3 Shock Hugoniots.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Shock Hugoniots (mm/μs)</th>
<th>Particle Velocity Range (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.659 to 1.723</td>
<td>( U_s=(3.544±0.524)+(1.459±0.276) U_p, )</td>
<td>1.337 &lt; U_p &lt; 2.220</td>
</tr>
<tr>
<td>1.688b</td>
<td>( U_s=(3.048±0.254)+(1.725±0.135) U_p, )</td>
<td>1.172 &lt; U_p &lt; 2.336</td>
</tr>
</tbody>
</table>

where \( U_s = \) shock velocity and \( U_p = \) particle velocity.

aNQ median particle diameter, 300 μm, as cubic crystals.
bNQ as long needle crystals with a needle diameter of a few micrometers.
8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>$H_{so}$ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>&gt;320</td>
</tr>
<tr>
<td>12B</td>
<td>&gt;320</td>
</tr>
</tbody>
</table>

REFERENCES


1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. Octol is the generic term for mixtures of TNT and HMX. In the United States, the mixtures consist of 75 wt% HMX and 25 wt% TNT (Type I) or 70 wt% HMX and 30 wt% TNT (Type II), also called Octol 75/25 and Octol 70/30. Neither mixture contains a desensitizer. To improve the flow characteristics of the molten form, a bimodal distribution of HMX crystals generally is used.

1.2 Common Use. Octol is often used as an explosive fill in military applications that require more energy than either Comp B or Type I Cyclotol can provide.

1.3 Toxicity. Octol toxicity is like that of HMX and TNT.
   The suggested maximum concentration of HMX in air is 1.5 mg/m³.
   Inhaled TNT vapor or dust may irritate mucous membranes and cause sneezing, coughing, and sore throat. TNT may produce toxic hepatitis and aplastic anemia. TNT yellows the exposed skin, hair, and nails of workers. Dermatitis, erythema, papules, and itchy eczema can be severe. Ingestion of 1-2 g of TNT is estimated to be an acute fatal dose to humans. The suggested maximum permissible airborne dust concentration is 0.5 mg/m³.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. Octols are manufactured from TNT and water-wet HMX. The TNT is melted in a steam-jacketed kettle equipped with a stirrer and brought to about 100°C. The wet HMX is added slowly, and stirring is continued until the water is evaporated. The slurry temperature is reduced until the viscosity is satisfactory for casting. The octol is cast onto a continuous belt as strips or chips.
OCTOL

These are shipped to an ordnance plant, remelted, and cast into ammunition or into other desired shapes. During this melting, other additives may be introduced. To increase the density of the cast charges, a vacuum may be applied to the molten octol before casting.


2.3 Shipping. Octol is shipped as a Class A explosive.

2.4 Storage. Octol is stored in Compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Composition.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Type I</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight Percent</td>
<td>Volume Percent</td>
</tr>
<tr>
<td>HMX</td>
<td>75</td>
<td>72.3</td>
</tr>
<tr>
<td>TNT</td>
<td>25</td>
<td>27.7</td>
</tr>
</tbody>
</table>
3.2 Molecular Weight.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td><img src="image" alt="HMX Structure" /></td>
<td>296.17</td>
</tr>
<tr>
<td></td>
<td>C$<em>{6}$H$</em>{7}$N$<em>{4}$O$</em>{6}$</td>
<td></td>
</tr>
<tr>
<td>TNT</td>
<td><img src="image" alt="TNT Structure" /></td>
<td>227.13</td>
</tr>
<tr>
<td></td>
<td>C$<em>{5}$H$</em>{3}$N$<em>{3}$O$</em>{6}$</td>
<td></td>
</tr>
</tbody>
</table>
### 3.3 Solubility

The solubility is that of the components, HMX and TNT.

#### Grams of HMX Dissolved/100 g of Solvent

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glacial</td>
<td>0.037</td>
<td>0.044</td>
<td>0.090</td>
</tr>
<tr>
<td>70%</td>
<td>---</td>
<td>0.033</td>
<td>0.103</td>
</tr>
<tr>
<td>Acetic anhydride</td>
<td>---</td>
<td>1.29</td>
<td>1.94</td>
</tr>
<tr>
<td>Acetone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anhydrous</td>
<td>2.4</td>
<td>3.4</td>
<td>---</td>
</tr>
<tr>
<td>70%</td>
<td>0.66</td>
<td>1.20</td>
<td>---</td>
</tr>
<tr>
<td>Acetonitrile</td>
<td>---</td>
<td>3.07</td>
<td>4.34</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>---</td>
<td>5.91</td>
<td>7.17</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>---</td>
<td>6.1</td>
<td>11.1</td>
</tr>
<tr>
<td>Dimethylsulfoxide</td>
<td>---</td>
<td>45.5</td>
<td>47.2</td>
</tr>
</tbody>
</table>

#### Grams of TNT Dissolved/100 g Solvent

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>109.0</td>
<td>228.0</td>
<td>600.0</td>
</tr>
<tr>
<td>Benzene</td>
<td>67.0</td>
<td>180.0</td>
<td>478.0</td>
</tr>
<tr>
<td>Butyl carbinol acetate</td>
<td>24.0</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td>0.48</td>
<td>1.53</td>
<td>---</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>0.65</td>
<td>1.75</td>
<td>6.90</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>33.9</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Chloroform</td>
<td>19.0</td>
<td>66.0</td>
<td>302.0</td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>3.29</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Ethanol (95%)</td>
<td>1.23</td>
<td>2.92</td>
<td>8.30</td>
</tr>
<tr>
<td>Ethylene chloride</td>
<td>18.7</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Hexane</td>
<td>0.16</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Methyl acetate</td>
<td>72.1</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Toluene</td>
<td>55.0</td>
<td>130.0</td>
<td>367.0</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>3.04</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Water</td>
<td>0.0130</td>
<td>0.0285</td>
<td>0.0675</td>
</tr>
</tbody>
</table>
4. PHYSICAL PROPERTIES

4.2 Density.

<table>
<thead>
<tr>
<th>Material</th>
<th>Theoretical Density (g/cm³)</th>
<th>Density of Typical Casting (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Open Melt</td>
</tr>
<tr>
<td>Type I, Octol 75/25</td>
<td>1.835</td>
<td>1.800</td>
</tr>
<tr>
<td>Type II, Octol 70/30</td>
<td>1.822</td>
<td>1.790</td>
</tr>
</tbody>
</table>

4.3 Infrared Spectrum. See Fig. 1.

Fig. 1. Infrared spectrum.
OCTOL

5. THERMAL PROPERTIES

5.1 Phase Changes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>75/25</td>
</tr>
<tr>
<td>Solid-to-slurry</td>
<td>79</td>
<td>5.87</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation.6

<table>
<thead>
<tr>
<th>Constituent</th>
<th>(\Delta H_f^o) (kcal/mole)</th>
<th>(\Delta H_f^o) (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNT</td>
<td>-817.2</td>
<td>-12.2</td>
</tr>
<tr>
<td>HMX</td>
<td>-660.7</td>
<td>11.3</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.7

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Decomposition energy</th>
<th>Activation energy</th>
<th>Pre-exponential factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNT</td>
<td>300 cal/g</td>
<td>34.4 kcal/mole</td>
<td>2.5 x 10^{11}/s</td>
</tr>
<tr>
<td>HMX</td>
<td>500 cal/g</td>
<td>52.7 kcal/mole</td>
<td>5 x 10^{16}/s</td>
</tr>
</tbody>
</table>

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.1-0.4 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, Tm</td>
<td>281°C</td>
</tr>
<tr>
<td>Charge radius, a</td>
<td>3.7 mm</td>
</tr>
<tr>
<td>Density, (\rho)</td>
<td>1.70 g/cm^3</td>
</tr>
</tbody>
</table>
6. DETONATION PROPERTIES

6.1 Detonation Velocity.

Effect of Charge Radius

Charge radius affects the detonation velocity of unconfined Octol 77/23 cast to a density of 1.814 g/cm³ as follows.

\[ D(R) = 8.481\left(1 - 6.9 \times 10^{-2}/R\right) - (9.25 \times 10^{-2})/R(R - 1.34) \]

where \( D \) = detonation velocity in millimeters per microsecond

and \( R \) = charge radius in millimeters.

The experimentally determined failure diameter is \(<6.4\) mm.

6.2 Detonation Pressure.

<table>
<thead>
<tr>
<th>Weight Percent HMX</th>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>76.3</td>
<td>1.809</td>
<td>8.452</td>
<td>33.8</td>
</tr>
</tbody>
</table>
6.4 Plate Dent Test Results.

<table>
<thead>
<tr>
<th>Charge Diameter (mm)</th>
<th>Weight Percent HMX</th>
<th>Density (g/cm³)</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.3</td>
<td>76.3</td>
<td>1.809</td>
<td>10.06</td>
<td>203</td>
</tr>
<tr>
<td>41.3</td>
<td>76.4</td>
<td>1.802</td>
<td>9.99</td>
<td>127</td>
</tr>
</tbody>
</table>

7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.\(^a\)

<table>
<thead>
<tr>
<th>Weight Percent HMX</th>
<th>Density (g/cm³)</th>
<th>(G_{30}) (mm)</th>
<th>(L_{90}) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>76.0</td>
<td>1.822</td>
<td>49.45</td>
<td>0.2</td>
</tr>
<tr>
<td>a</td>
<td>1.726</td>
<td>48.69</td>
<td>0.41</td>
</tr>
<tr>
<td>a</td>
<td>1.795</td>
<td>43.56</td>
<td>0.46</td>
</tr>
<tr>
<td>Small Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>76.0</td>
<td>1.803</td>
<td>0.71</td>
<td>0.08</td>
</tr>
<tr>
<td>76.0</td>
<td>1.810</td>
<td>0.58</td>
<td>---</td>
</tr>
<tr>
<td>78.6</td>
<td>1.800(^b)</td>
<td>0.56</td>
<td>0.06</td>
</tr>
<tr>
<td>c</td>
<td>1.775</td>
<td>0.41</td>
<td>0.05</td>
</tr>
<tr>
<td>d</td>
<td>1.791</td>
<td>0.36</td>
<td>0.05</td>
</tr>
</tbody>
</table>

\(^a\)UK EDC-1 nominal 75 wt% HMX with some RDX.

\(^b\)With 1 wt% wax.

\(^c\)UK EDC-1 cast in the United Kingdom.

\(^d\)UK EDC-1 vacuum cast in the United States.

7.3 Shock Hugoniots.\(^10\)

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Weight Percent HMX</th>
<th>Shock Hugoniot (mm/(\mu)s)</th>
<th>Particle Velocity Range (mm/(\mu)s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.80</td>
<td>75</td>
<td>(U_s = 3.01 + 1.72 U_p), where (U_s) = shock velocity and (U_p) = particle velocity</td>
<td>0 &lt; (U_p) &lt; 1.5</td>
</tr>
</tbody>
</table>

68
### 7.4 Minimum Priming Charge

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Weight Percent HMX</th>
<th>W₅₀ (mg of XTX 8003)</th>
<th>L₉₅ (± log mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.818</td>
<td>75</td>
<td>292</td>
<td>0.028</td>
</tr>
</tbody>
</table>

### 7.5 Detonation Failure Thickness

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Weight Percent HMX</th>
<th>Failure Thickness (mm)</th>
<th>L₉₅ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.791</td>
<td>75</td>
<td>1.43</td>
<td>0.21</td>
</tr>
</tbody>
</table>

### 8. SENSITIVITY

#### 8.1 Drop Weight Impact Height

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>H₅₀ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>38</td>
</tr>
<tr>
<td>12B</td>
<td>93</td>
</tr>
</tbody>
</table>

#### 8.2 Large-Scale Drop Test Height

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Weight Percent HMX</th>
<th>H₅₀ (ft)</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.310</td>
<td>75</td>
<td>45</td>
<td>Low-order partial</td>
</tr>
<tr>
<td>1.805</td>
<td>75</td>
<td>~150</td>
<td>Low-order partial</td>
</tr>
<tr>
<td>1.766</td>
<td>b</td>
<td>~110</td>
<td>Low-order partial</td>
</tr>
</tbody>
</table>

*Octol 75/25 with 1 wt% wax.
*UK EDC-1 cast in the United Kingdom.
8.3 Skid Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Weight Percent HMX</th>
<th>Impact Angle (degrees)</th>
<th>Target Surface</th>
<th>H₁₀₀ (ft)</th>
<th>Reaction Overpressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.810</td>
<td>75</td>
<td>45</td>
<td>Sand and epoxy</td>
<td>~75</td>
<td>0.1</td>
</tr>
<tr>
<td>1.805</td>
<td>a</td>
<td>45</td>
<td>Sand and epoxy</td>
<td>&gt;150</td>
<td>---</td>
</tr>
</tbody>
</table>

*aCast with 1 wt % wax.

8.4 Susan Test Results.

<table>
<thead>
<tr>
<th>Projectile Impact Velocity (ft/s)</th>
<th>Relative Energy Release (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>400</td>
<td>20</td>
</tr>
<tr>
<td>1000</td>
<td>60</td>
</tr>
</tbody>
</table>

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>3</td>
<td>29</td>
<td>0.82</td>
<td>17</td>
</tr>
<tr>
<td>Brass</td>
<td>10</td>
<td>29</td>
<td>4.36</td>
<td>17</td>
</tr>
</tbody>
</table>

9. MECHANICAL PROPERTIES

9.3 Compressive Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Weight Percent HMX</th>
<th>Ultimate Compressive Strength (psi)</th>
<th>Compressive Modulus (psi x 10⁻⁵)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>1.821-1.824</td>
<td>76</td>
<td>2000-2340</td>
<td>8.0 to 13.4</td>
</tr>
</tbody>
</table>
REFERENCES

1. Commitee on Threshold Limit Values, *Documentation of Threshold Limit Values*, 3rd Ed. (American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati, Ohio, 1971).


12. L. Green, Lawrence Livermore Laboratory, private communication (1975).
1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. PBX 9011 is composed of HMX bonded with Estane 5703. The molding powder is off-white to light brown.

1.2 Common Use. PBX 9011 is a high-performance explosive that is used in a variety of special applications in nuclear ordnance.

1.3 Toxicity. Estane 5703 is not toxic. The suggested maximum concentration of HMX in air is 1.5 mg/m³.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. PBX-9011 molding powder is prepared by the water slurry process. An Estane lacquer is prepared in a water-immiscible solvent. This is added to a water slurry containing a bimodal distribution of HMX crystals. During solvent removal by distillation, the plastic uniformly coats and agglomerates the HMX crystals in the water phase. The process variables must be controlled closely to produce satisfactory agglomerates, composition, and bulk density.

2.3 Shipping. PBX-9011 molding powder is shipped as a Class A explosive.

2.4 Storage. PBX 9011 is stored in Compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Composition.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Weight Percent</th>
<th>Volume Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td>90</td>
<td>84.9</td>
</tr>
<tr>
<td>Estane 5703</td>
<td>10</td>
<td>15.1</td>
</tr>
</tbody>
</table>

3.2 Molecular Weight.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td><img src="image" alt="HMX Structure" /></td>
<td>296.17</td>
</tr>
<tr>
<td>Estane</td>
<td><img src="image" alt="Estane Structure" /></td>
<td>100.0</td>
</tr>
</tbody>
</table>

\[ C_{6.14}H_{7.8}N_{0.187}O_{1.76} \]
3.3 Solubility. The solubility is that of HMX.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glacial</td>
<td>0.037</td>
<td>0.044</td>
<td>0.090</td>
</tr>
<tr>
<td>70%</td>
<td>----</td>
<td>0.033</td>
<td>0.103</td>
</tr>
<tr>
<td>Acetic anhydride</td>
<td>----</td>
<td>1.29</td>
<td>1.94</td>
</tr>
<tr>
<td>Acetone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anhydrous</td>
<td>2.4</td>
<td>3.4</td>
<td>---</td>
</tr>
<tr>
<td>70%</td>
<td>0.66</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>Acetonitrile</td>
<td>----</td>
<td>3.07</td>
<td>4.34</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>----</td>
<td>5.91</td>
<td>7.17</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>----</td>
<td>6.1</td>
<td>11.1</td>
</tr>
<tr>
<td>Dimethylsulfoxide</td>
<td>----</td>
<td>45.5</td>
<td>47.2</td>
</tr>
</tbody>
</table>

4. PHYSICAL PROPERTIES

4.2 Density.

<table>
<thead>
<tr>
<th>Theoretical Density (g/cm³)</th>
<th>Density of Typical Pressed Charges (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.795</td>
<td>1.770</td>
</tr>
</tbody>
</table>

The following densities are obtained by vacuum pressing (residual pressure <10⁸ µm Hg) molding powder with a 3-min dwell.

<table>
<thead>
<tr>
<th>Density (g/cm³) with Powder Preheated to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (psi)</td>
</tr>
<tr>
<td>10 000</td>
</tr>
<tr>
<td>12 500</td>
</tr>
<tr>
<td>15 000</td>
</tr>
<tr>
<td>20 000</td>
</tr>
</tbody>
</table>
4.3 Infrared Spectrum. See Fig. 1.

5. THERMAL PROPERTIES

5.1 Phase Changes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>β-to-δ solid-to-solid in HMX</td>
<td>190</td>
<td>9.2</td>
</tr>
</tbody>
</table>

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Heat Capacity at Constant Pressure (cal/g·°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.259 + 6.3 \times 10^{-4} T$</td>
<td>$17 &lt; T &lt; 167$</td>
</tr>
</tbody>
</table>

5.4 Thermal Conductivity.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Conductivity (cal/s·cm·°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.772</td>
<td>$9.08 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Fig. 1. Infrared spectrum.
5.5 Coefficient of Thermal Expansion.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Coefficient of Expansion (1/°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.752</td>
<td>22.2 x 10⁻⁴</td>
<td>25 &lt; T &lt; 74</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>ΔH° (kcal/mole)</th>
<th>ΔH° (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td>-660.7</td>
<td>11.3</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.

<table>
<thead>
<tr>
<th>Property</th>
<th>HMX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition energy</td>
<td>500 cal/g</td>
</tr>
<tr>
<td>Activation energy</td>
<td>52.7 kcal/mole</td>
</tr>
<tr>
<td>Pre-exponential factor</td>
<td>5 x 10²%/s</td>
</tr>
</tbody>
</table>

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.3-0.9 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
</tbody>
</table>
6. DETONATION PROPERTIES

6.1 Detonation Velocity.

Effect of Charge Radius
At a density of 1.767 g/cm³, the infinite-radius detonation velocity of unconfined charges is 4.25 mm/μs. The failure radius has not been determined.

6.2 Detonation Pressure.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.767</td>
<td>8.5</td>
<td>25.8</td>
</tr>
</tbody>
</table>

Fig. 2. PBX 9011 DTA and pyrolysis test results.
6.3 Cylinder Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/µs)</th>
<th>Cylinder Wall Velocity (mm/µs) at R−R₀ = 5 mm</th>
<th>R−R₀ = 19 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.777</td>
<td>8.50</td>
<td>1.46</td>
<td>1.69</td>
</tr>
</tbody>
</table>

6.4 Plate Dent Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Dent Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.785</td>
<td>9.86</td>
</tr>
</tbody>
</table>

7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>G₅₀ (mm)</th>
<th>L₄₀₂ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.85</td>
<td>67.81</td>
<td>0.20</td>
</tr>
<tr>
<td>1.761</td>
<td>51.97</td>
<td>0.41</td>
</tr>
<tr>
<td>1.766</td>
<td>51.96</td>
<td>0.33</td>
</tr>
</tbody>
</table>

| Small Scale    |          |           |
| 0.88           | 5.16     | 0.07      |
| 1.759          | 1.19     | 0.15      |
| 1.766          | 1.27     | 0.13      |
| 1.775          | 0.64     | 0.08      |
| 1.788          | 0.56     | 0.08      |
7.2 Wedge Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Distance, x*, and Time, t*, to Detonation (mm and µs)</th>
<th>Pressure Range (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.790</td>
<td>log P = (1.18±0.01)-(0.66±0.02)log x*, log P = (0.74±0.01)-(0.55±0.01)log t*, where P = pressure in gigapascals.</td>
<td>4.82 &lt; P &lt; 15.65</td>
</tr>
</tbody>
</table>

7.3 Shock Hugoniot.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Shock Hugoniot (mm/µs)</th>
<th>Particle Velocity Range (mm/µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.790</td>
<td>Uₕ = (2.363±0.131)+(2.513±0.141) Uₚ, where Uₕ = shock velocity and Uₚ = particle velocity.</td>
<td>0.65 &lt; Uₚ &lt; 1.43</td>
</tr>
</tbody>
</table>

7.4 Minimum Priming Charge.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>W₅₀ (mg of XTX 8003)</th>
<th>L₅₀ (± log mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.772</td>
<td>163</td>
<td>0.021</td>
</tr>
<tr>
<td>1.765*</td>
<td>58</td>
<td>0.058</td>
</tr>
</tbody>
</table>

*Prepared with 1/4 Class A and 3/4 Class B HMX.
PBX 9011

7.5 Detonation Failure Thickness.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Failure Thickness (mm)</th>
<th>H₀₀ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.770</td>
<td>0.610</td>
<td>0.081</td>
</tr>
</tbody>
</table>

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>H₀₀ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>55</td>
</tr>
<tr>
<td>12R</td>
<td>67</td>
</tr>
</tbody>
</table>

8.2 Large-Scale Drop Test Height.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>H₀₀ (ft)</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.773</td>
<td>96</td>
<td>Very small partial, overpressure, &lt;0.2 psi</td>
</tr>
</tbody>
</table>

8.3 Skid Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Impact Angle (degrees)</th>
<th>Target Surface</th>
<th>H₀₀ (ft)</th>
<th>Reaction Overpressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.773</td>
<td>45</td>
<td>Garnet paper</td>
<td>78</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>1.773</td>
<td>45</td>
<td>Garnet paper</td>
<td>4³</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

*HE cooled to −29°C.
8.4 Susan Test Results.⁷

<table>
<thead>
<tr>
<th>Projectile Impact Velocity (ft/s)</th>
<th>Relative Energy Release (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>190</td>
<td>0</td>
</tr>
<tr>
<td>400</td>
<td>5</td>
</tr>
<tr>
<td>600</td>
<td>22</td>
</tr>
<tr>
<td>800</td>
<td>40</td>
</tr>
<tr>
<td>1000</td>
<td>50</td>
</tr>
</tbody>
</table>

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>3</td>
<td>30</td>
<td>1.09</td>
<td>33</td>
</tr>
<tr>
<td>Brass</td>
<td>10</td>
<td>30</td>
<td>2.77</td>
<td>33</td>
</tr>
</tbody>
</table>

9. MECHANICAL PROPERTIES

9.2 Tensile Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Tensile Strength (psi)</th>
<th>Tensile Modulus (psi x 10⁻⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1.780</td>
<td>52</td>
<td>0.7</td>
</tr>
<tr>
<td>49</td>
<td>1.780</td>
<td>108</td>
<td>3.0</td>
</tr>
<tr>
<td>24</td>
<td>1.780</td>
<td>508</td>
<td>29.0</td>
</tr>
<tr>
<td>-18</td>
<td>1.780</td>
<td>920</td>
<td>91.0</td>
</tr>
<tr>
<td>-54</td>
<td>1.780</td>
<td>1118</td>
<td>138.0</td>
</tr>
</tbody>
</table>
9.3 Compressive Strength and Modulus

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Compressive Strength (psi)</th>
<th>Compressive Modulus (psi x 10⁻⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1.783</td>
<td>180</td>
<td>2.1</td>
</tr>
<tr>
<td>49</td>
<td>1.786</td>
<td>370</td>
<td>3.0</td>
</tr>
<tr>
<td>24</td>
<td>1.782</td>
<td>1070</td>
<td>17.9</td>
</tr>
<tr>
<td>-18</td>
<td>1.786</td>
<td>3520</td>
<td>48.0</td>
</tr>
<tr>
<td>-54</td>
<td>1.783</td>
<td>9580</td>
<td>124.0</td>
</tr>
</tbody>
</table>

9.4 Shear Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Shear Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1.780</td>
<td>130</td>
</tr>
<tr>
<td>49</td>
<td>1.780</td>
<td>190</td>
</tr>
<tr>
<td>24</td>
<td>1.780</td>
<td>530</td>
</tr>
<tr>
<td>-18</td>
<td>1.780</td>
<td>910</td>
</tr>
<tr>
<td>-54</td>
<td>1.780</td>
<td>2790</td>
</tr>
</tbody>
</table>
REFERENCES

1. Committee on Threshold Limit Values, *Documentation of Threshold Limit Values*, 3rd Ed. (American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati, Ohio, 1971).


PBX 9404

1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. Plastic-bonded explosive PBX 9404 is composed of HMX bonded with nitrocellulose (NC) and with tris-beta chloroethylphosphate (CEF) as the plasticizer. A small quantity of diphenylamine (DPA) is added to stabilize the NC. The molding powder is off-white at time of manufacture. As the NC decomposes, the DPA reacts with the decomposition products, and the color changes from white to light blue, dark blue, and finally a yellow-brown. The color can be used to estimate the temperature storage history of the powder or molded piece.

1.2 Common Use. PBX 9404 is a high-performance high explosive used in nuclear ordnance.

1.3 Toxicity. The suggested maximum concentration of HMX in air is 1.5 mg/m³. We have no data on NC toxicity. The toxicity of CEF is unknown; DPA is highly toxic if inhaled or absorbed through the skin.
2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. PBX-9404 molding powder is prepared by the water slurry process. A lacquer of NC, CEF, and DPA is prepared in a water-immiscible solvent. This is added to a water slurry containing a bimodal distribution of HMX crystals. During solvent removal by distillation, the plastic, plasticizer, and stabilizer uniformly coat and agglomerate the HMX crystals in the water phase. The process variables must be closely controlled to produce satisfactory agglomerates, composition, and bulk density.


2.3 Shipping. PBX-9404 molding powder is shipped as a Class A explosive.

2.4 Storage. PBX 9404 is stored in Compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Composition.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Weight Percent</th>
<th>Volume Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td>94.0</td>
<td>92.5</td>
</tr>
<tr>
<td>NC</td>
<td>3.0</td>
<td>3.6</td>
</tr>
<tr>
<td>CEF</td>
<td>3.0</td>
<td>3.9</td>
</tr>
<tr>
<td>DPA</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>
### 3.2 Molecular Weight.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td><img src="image" alt="HMX Structure" /></td>
<td>296.17</td>
</tr>
<tr>
<td>NC</td>
<td><img src="image" alt="NC Structure" /></td>
<td>(262.64)(_n)</td>
</tr>
<tr>
<td>CEF</td>
<td>(ClCH₂CH₂O)₃-P=0 C₆H₁₂O₃Cl₃P</td>
<td>286.0</td>
</tr>
<tr>
<td>DPA</td>
<td><img src="image" alt="DPA Structure" /></td>
<td>C₁₂H₁₁N</td>
</tr>
</tbody>
</table>
3.3 Solubility. The solubility is that of HMX.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glacial</td>
<td>0.037</td>
<td>0.044</td>
<td>0.090</td>
</tr>
<tr>
<td>70%</td>
<td>---</td>
<td>0.033</td>
<td>0.103</td>
</tr>
<tr>
<td>Acetic anhydride</td>
<td>---</td>
<td>1.29</td>
<td>1.94</td>
</tr>
<tr>
<td>Acetone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anhydrous</td>
<td>2.4</td>
<td>3.4</td>
<td>---</td>
</tr>
<tr>
<td>70%</td>
<td>0.66</td>
<td>1.20</td>
<td>---</td>
</tr>
<tr>
<td>Acetonitrile</td>
<td>---</td>
<td>3.07</td>
<td>4.34</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>---</td>
<td>5.91</td>
<td>7.17</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>---</td>
<td>6.1</td>
<td>11.1</td>
</tr>
<tr>
<td>Dimethylsulfoxide</td>
<td>---</td>
<td>45.5</td>
<td>47.2</td>
</tr>
</tbody>
</table>

4. PHYSICAL PROPERTIES

4.2 Density.

<table>
<thead>
<tr>
<th>Theoretical Density (g/cm³)</th>
<th>Density of Typical Pressed Charges (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.873</td>
<td>1.840</td>
</tr>
</tbody>
</table>

The following densities are obtained by vacuum pressing (residual pressure <10⁸ μm Hg) hot (80°C) molding powder with a 4-min dwell.

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 000</td>
<td>1.820-1.825</td>
</tr>
<tr>
<td>12 000</td>
<td>1.830-1.835</td>
</tr>
<tr>
<td>15 000</td>
<td>1.835-1.845</td>
</tr>
</tbody>
</table>
4.3 Infrared Spectrum. See Fig. 1.

5. THERMAL PROPERTIES

5.1 Phase Changes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>β-to-δ solid-to-solid in HMX</td>
<td>190</td>
<td>9.2</td>
</tr>
</tbody>
</table>

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Heat Capacity at Constant Pressure (cal/g-°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.224 + 7 × 10^{-4} T</td>
<td>7 &lt; T &lt; 147</td>
</tr>
</tbody>
</table>

5.4 Thermal Conductivity.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Conductivity (cal/s-cm-°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.845</td>
<td>9.2 × 10^{-4}</td>
</tr>
</tbody>
</table>

Fig. 1. Infrared spectrum.
5.5 Coefficient of Thermal Expansion.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Coefficient of Expansion (1/°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.840</td>
<td>4.7 × 10⁻⁶</td>
<td>25 &lt; T &lt; 70</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>ΔH°f (kcal/mole)</th>
<th>ΔH°r (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td>-660.7</td>
<td>11.3</td>
</tr>
<tr>
<td>NC</td>
<td>---</td>
<td>-200</td>
</tr>
<tr>
<td>CEF</td>
<td>---</td>
<td>-300.0</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.⁶

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Property</th>
<th>PBX 9404°</th>
<th>HMX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Decomposition energy</td>
<td>---</td>
<td>500 cal/g</td>
</tr>
<tr>
<td></td>
<td>Activation energy</td>
<td>31.3 kcal/mole</td>
<td>52.7 kcal/mole</td>
</tr>
<tr>
<td></td>
<td>Pre-exponential factor</td>
<td>4.3 × 10¹¹/s</td>
<td>5 × 10¹⁹/s</td>
</tr>
</tbody>
</table>

⁶Reflects NC decomposition.

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>1.3-4.0 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
</tbody>
</table>
6. DETONATION PROPERTIES

6.1 Detonation Velocity.

Effect of Charge Radius

Charge radius affects the detonation velocity of unconfined PBX-9404 charges pressed to a density of 1.846 g/cm³ as follows.

\[ D(R) = 8.776 \left[ (1 - 0.89 \times 10^{-7}/R) - 4.9 \times 10^{-7}/R(R - 0.533) \right], \]

where \( D \) = detonation velocity in millimeters per microsecond and \( R \) = charge radius in millimeters.

The experimentally determined failure diameter is 1.18 mm.

6.2 Detonation Pressure.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.844</td>
<td>8.802*</td>
<td>36.8</td>
</tr>
</tbody>
</table>

*Note that this value is greater than the infinite-diameter velocity reported in Section 6.1.
### 6.3 Cylinder Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/µs)</th>
<th>Cylinder Wall Velocity (mm/µs) at</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.846</td>
<td>8.781</td>
<td>R - R⁰ = 5 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.556</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R - R⁰ = 19 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.787</td>
</tr>
</tbody>
</table>

### 6.4 Plate Dent Test Results.

<table>
<thead>
<tr>
<th>Charge Diameter (mm)</th>
<th>Density (g/cm³)</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.3</td>
<td>1.844</td>
<td>10.9</td>
<td>203</td>
</tr>
</tbody>
</table>
7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.*

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>G₅₀ (mm)</th>
<th>L₉₅ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large Scale</td>
<td></td>
</tr>
<tr>
<td>0.920</td>
<td>68.43</td>
<td>0.20</td>
</tr>
<tr>
<td>1.230</td>
<td>64.16</td>
<td>1.85</td>
</tr>
<tr>
<td>1.400</td>
<td>63.07</td>
<td>0.18</td>
</tr>
<tr>
<td>1.585</td>
<td>62.76</td>
<td>0.30</td>
</tr>
<tr>
<td>1.798</td>
<td>59.21</td>
<td>0.30</td>
</tr>
<tr>
<td>1.821</td>
<td>58.34</td>
<td>0.56</td>
</tr>
<tr>
<td>1.825</td>
<td>56.46</td>
<td>0.38</td>
</tr>
<tr>
<td>1.833</td>
<td>56.44</td>
<td>0.51</td>
</tr>
<tr>
<td>1.847</td>
<td>55.86</td>
<td>0.10</td>
</tr>
<tr>
<td>1.865</td>
<td>51.94</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Small Scale</td>
<td></td>
</tr>
<tr>
<td>0.96</td>
<td>0.58</td>
<td>0.10</td>
</tr>
<tr>
<td>1.792</td>
<td>3.40</td>
<td>0.15</td>
</tr>
<tr>
<td>1.812</td>
<td>3.23</td>
<td>0.13</td>
</tr>
<tr>
<td>1.826</td>
<td>3.23</td>
<td>0.10</td>
</tr>
<tr>
<td>1.830</td>
<td>2.90</td>
<td>0.08</td>
</tr>
<tr>
<td>1.836</td>
<td>2.69</td>
<td>0.18</td>
</tr>
<tr>
<td>1.843</td>
<td>2.67</td>
<td>0.13</td>
</tr>
<tr>
<td>1.860</td>
<td>2.36</td>
<td>0.25</td>
</tr>
</tbody>
</table>

These results seem inconsistent.
7.2 Wedge Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Distance, x*, and Time, t*, to Detonation (mm and µs)</th>
<th>Pressure Range (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.84</td>
<td>( \log P = (1.11 \pm 0.01) - (0.65 \pm 0.02) \log x^* ) ( \log P = (0.69 \pm 0.01) - (0.54 \pm 0.01) \log t^* ),</td>
<td>2.27 &lt; P &lt; 25.72</td>
</tr>
<tr>
<td>1.72</td>
<td>( \log P = (0.96 \pm 0.03) - (0.71 \pm 0.04) \log x^* ) ( \log P = (0.54 \pm 0.01) - (0.57 \pm 0.02) \log t^* ), where P = pressure in gigapascals.</td>
<td>1.19 &lt; P &lt; 6.34</td>
</tr>
</tbody>
</table>

7.3 Shock Hugoniots.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Shock Hugoniot (mm/µs)</th>
<th>Particle Velocity Range (mm/µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.840</td>
<td>( U_s = (2.494 \pm 0.039) + (2.093 \pm 0.045) U_p ),</td>
<td>0.133 &lt; U_p &lt; 2.063</td>
</tr>
<tr>
<td>1.721</td>
<td>( U_s = (1.890 \pm 0.197) + (1.565 \pm 0.353) U_p ),</td>
<td>0.172 &lt; U_p &lt; 0.995</td>
</tr>
</tbody>
</table>

where \( U_s \) = shock velocity and \( U_p \) = particle velocity.

7.4 Minimum Priming Charge.⁸

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>( W_{50} ) (mg of XTX 8003)</th>
<th>( I_{log} ) (±log mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.800</td>
<td>16.2</td>
<td>0.108</td>
</tr>
<tr>
<td>1.840</td>
<td>23.9</td>
<td>0.132</td>
</tr>
</tbody>
</table>
PBX 9404

7.5 Detonation Failure Thickness.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Failure Thickness (mm)</th>
<th>L₉₅ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.785</td>
<td>0.439</td>
<td>0.069</td>
</tr>
<tr>
<td>1.800</td>
<td>0.589</td>
<td>0.074</td>
</tr>
<tr>
<td>1.814</td>
<td>0.404</td>
<td>0.056</td>
</tr>
<tr>
<td>1.828</td>
<td>0.510</td>
<td>0.061</td>
</tr>
<tr>
<td>1.844</td>
<td>0.503</td>
<td>0.185</td>
</tr>
<tr>
<td>1.844</td>
<td>0.368</td>
<td>0.028</td>
</tr>
<tr>
<td>1.844</td>
<td>0.396</td>
<td>0.112</td>
</tr>
<tr>
<td>1.845</td>
<td>0.457</td>
<td>0.033</td>
</tr>
</tbody>
</table>

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>H₅₀ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>42</td>
</tr>
<tr>
<td>12B</td>
<td>47</td>
</tr>
</tbody>
</table>

8.2 Large-Scale Drop Test Height.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>H₅₀ (ft)</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.835</td>
<td>49</td>
<td>Explosion</td>
</tr>
<tr>
<td>1.800*</td>
<td>110</td>
<td>Explosion</td>
</tr>
</tbody>
</table>

*PBX 9404 + 1wt% wax.
### 8.3 Skid Test Results.\(^9\)\(^,\)\(^10\)

<table>
<thead>
<tr>
<th>Density (g/cm(^2))</th>
<th>Impact Angle (degrees)</th>
<th>Target Surface</th>
<th>H(_{50}) (ft)</th>
<th>Reaction Overpressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.847</td>
<td>45</td>
<td>Sand and epoxy</td>
<td>~4.5</td>
<td>&gt;20</td>
</tr>
<tr>
<td>1.837</td>
<td>45</td>
<td>Garnet paper</td>
<td>~4.0</td>
<td>15</td>
</tr>
<tr>
<td>1.866</td>
<td>45</td>
<td>Garnet paper</td>
<td>~5.0</td>
<td>8</td>
</tr>
<tr>
<td>1.837</td>
<td>15</td>
<td>Garnet paper</td>
<td>~3.0</td>
<td>15</td>
</tr>
<tr>
<td>1.838</td>
<td>15</td>
<td>Quartz</td>
<td>1.8</td>
<td>15</td>
</tr>
<tr>
<td>1.838</td>
<td>15</td>
<td>Alumina(^a)</td>
<td>~11.0</td>
<td>15</td>
</tr>
<tr>
<td>1.838</td>
<td>15</td>
<td>Alumina(^b)</td>
<td>19.0</td>
<td>15</td>
</tr>
<tr>
<td>1.838</td>
<td>45</td>
<td>Gold</td>
<td>&gt;150.0</td>
<td>---</td>
</tr>
</tbody>
</table>

\(^a\)Surface finish, 1.2-2.0 \(\mu\)m.  
\(^b\)Surface finish, 0.5-0.9 \(\mu\)m.

### 8.4 Susan Test Results.\(^11\)

<table>
<thead>
<tr>
<th>Projectile Impact Velocity (ft/s)</th>
<th>Relative Energy Release (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>0</td>
</tr>
<tr>
<td>110</td>
<td>82</td>
</tr>
<tr>
<td>&gt;110</td>
<td>82</td>
</tr>
</tbody>
</table>
PBX 9404

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>3</td>
<td>28</td>
<td>0.42</td>
<td>0</td>
</tr>
<tr>
<td>Brass</td>
<td>10</td>
<td>28</td>
<td>3.13</td>
<td>0</td>
</tr>
</tbody>
</table>

9. MECHANICAL PROPERTIES

9.2 Tensile Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Tensile Strength* (psi)</th>
<th>Tensile Modulus* (psi × 10⁻⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1.848</td>
<td>97</td>
<td>1.3</td>
</tr>
<tr>
<td>49</td>
<td>1.848</td>
<td>170</td>
<td>1.4</td>
</tr>
<tr>
<td>24</td>
<td>1.848</td>
<td>482</td>
<td>2.5</td>
</tr>
<tr>
<td>-18</td>
<td>1.848</td>
<td>698</td>
<td>11.75</td>
</tr>
<tr>
<td>-54</td>
<td>1.848</td>
<td>533</td>
<td>15.40</td>
</tr>
</tbody>
</table>

*These properties vary with the HMX particle-size distribution. They are time dependent; if PBX 9404 is exposed to temperatures >40°C for long periods, its strength and modulus decrease.
9.3 Compressive Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Compressive Strengtha (psi)</th>
<th>Compressive Modulusa (psi × 10⁻⁰)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1.848</td>
<td>658</td>
<td>1.2</td>
</tr>
<tr>
<td>49</td>
<td>1.848</td>
<td>1289</td>
<td>2.6</td>
</tr>
<tr>
<td>24</td>
<td>1.848</td>
<td>2479</td>
<td>2.9</td>
</tr>
<tr>
<td>-18</td>
<td>1.848</td>
<td>4859</td>
<td>9.9</td>
</tr>
<tr>
<td>-54</td>
<td>1.848</td>
<td>8510</td>
<td>16.0</td>
</tr>
</tbody>
</table>

*These properties vary with the HMX particle-size distribution. They are time dependent; if PBX 9404 is exposed to temperatures >40°C for long periods, its strength and modulus decrease.

9.4 Shear Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Shear Strengtha (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1.844</td>
<td>523</td>
</tr>
<tr>
<td>49</td>
<td>1.844</td>
<td>834</td>
</tr>
<tr>
<td>24</td>
<td>1.844</td>
<td>1251</td>
</tr>
<tr>
<td>-18</td>
<td>1.844</td>
<td>1454</td>
</tr>
<tr>
<td>-54</td>
<td>1.844</td>
<td>2261</td>
</tr>
</tbody>
</table>

*This property varies with the HMX particle-size distribution. It is time dependent; if PBX 9404 is exposed to temperatures >40°C for long periods, its strength decreases.
REFERENCES

1. Committee on Threshold Limit Values, *Documentation of Threshold Limit Values*, 3rd Ed. (American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati, Ohio, 1971).


1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. PBX 9407 is composed of RDX coated with Exon 461, a chlorotrifluoroethylene/tetrafluoroethylene/vinylidene fluoride copolymer. The molding powder is off-white.

1.2 Common Use. PBX 9407 is generally used as a booster explosive.

1.3 Toxicity. Workers who inhaled RDX dust for several months have become unconscious and have suffered loss of reflexes. The suggested maximum permissible airborne concentration is 1.5 mg/m$^3$. Inhaling hot Exon vapor should be avoided.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. PBX-9407 molding powder is prepared by the water slurry process. An Exon lacquer is prepared in a water-immiscible solvent and added to a water slurry containing Type II Class 5 RDX crystals. During solvent removal by distillation, the plastic uniformly coats and agglomerates the RDX crystals in the water phase. The process variables must be carefully controlled to produce satisfactory agglomerates, composition, and bulk density.

2.3 **Shipping.** PBX-9407 molding powder is shipped as a Class A explosive.

2.4 **Storage.** PBX 9407 is stored in Compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Composition.


<table>
<thead>
<tr>
<th>Constituent</th>
<th>Weight Percent</th>
<th>Volume Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td>94.0</td>
<td>93.6</td>
</tr>
<tr>
<td>Exon 461</td>
<td>6.0</td>
<td>6.4</td>
</tr>
</tbody>
</table>

3.2 Molecular Weight.


<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td><img src="image" alt="RDX Structure" /></td>
<td>222.13</td>
</tr>
<tr>
<td>Exon 461</td>
<td><img src="image" alt="Exon 461 Structure" /></td>
<td>(97.05) _n</td>
</tr>
</tbody>
</table>
3.3 Solubility. The solubility is like that of RDX.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Grams RDX Dissolved/100 g of Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C</td>
</tr>
<tr>
<td>Acetic acid</td>
<td></td>
</tr>
<tr>
<td>99.6%</td>
<td>0.46</td>
</tr>
<tr>
<td>71.0%</td>
<td>0.22</td>
</tr>
<tr>
<td>Acetone</td>
<td>6.81</td>
</tr>
<tr>
<td>Isoamyl alcohol</td>
<td>0.026</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.045</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>0.33</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>4.94</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>---</td>
</tr>
<tr>
<td>Ethanol</td>
<td>0.12</td>
</tr>
<tr>
<td>Methyl acetate</td>
<td>2.9</td>
</tr>
<tr>
<td>Methylcyclohexanone</td>
<td>6.81</td>
</tr>
<tr>
<td>Methyl ethyl ketone</td>
<td>3.23</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.020</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>0.20</td>
</tr>
<tr>
<td>Water</td>
<td>0.005</td>
</tr>
</tbody>
</table>

4. PHYSICAL PROPERTIES

4.2 Density.

<table>
<thead>
<tr>
<th>Theoretical Density (g/cm³)</th>
<th>Density of Typical Pressed Charge (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.809</td>
<td>1.65</td>
</tr>
</tbody>
</table>
4.3 Infrared Spectrum. See Fig. 1.

5. THERMAL PROPERTIES

5.1 Phase Changes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX (solid-to-liquid)</td>
<td>204.1</td>
<td>33.37</td>
</tr>
</tbody>
</table>

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Heat Capacity at Constant Pressure (cal/g·°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.66</td>
<td>0.241 + 7.7 × 10⁻⁴ T</td>
<td>37 &lt; T &lt; 167</td>
</tr>
</tbody>
</table>

Fig. 1. Infrared spectrum.
5.4 Thermal Conductivity.

\[
\begin{array}{cc}
\text{Conductivity} & \text{Temperature Range} \\
(\text{cal/s-cm-}^\circ\text{C}) & (\circ\text{C}) \\
0.241 + 7.7 \times 10^{-4} & 37 < T < 167
\end{array}
\]

5.6 Heats of Combustion and Formation.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>$\Delta H_c^0$ (kcal/mole)</th>
<th>$\Delta H_f^0$ (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td>-501.8</td>
<td>14.7</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.¹

<table>
<thead>
<tr>
<th>Property</th>
<th>RDX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition energy</td>
<td>500 cal/g</td>
</tr>
<tr>
<td>Activation energy</td>
<td>47.1 kcal/mole</td>
</tr>
<tr>
<td>Pre-exponential factor</td>
<td>$2.02 \times 10^{18}$/s</td>
</tr>
</tbody>
</table>

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.1-0.3 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
</tbody>
</table>
6. DETONATION PROPERTIES

6.1 Detonation Velocity. A detonation velocity of 8.1 mm/µs was obtained at a density of 1.60 g/cm³. The charge radius was unspecified.
7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>G₅₀ (mm)</th>
<th>L₉₅ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.60</td>
<td>62.4</td>
<td>---</td>
</tr>
<tr>
<td>1.772</td>
<td>54.72</td>
<td>0.15</td>
</tr>
<tr>
<td>1.773</td>
<td>53.85</td>
<td>0.08</td>
</tr>
<tr>
<td>Small Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.538</td>
<td>4.75</td>
<td>0.25</td>
</tr>
<tr>
<td>1.555</td>
<td>4.80</td>
<td>0.15</td>
</tr>
<tr>
<td>1.598</td>
<td>5.13</td>
<td>0.08</td>
</tr>
<tr>
<td>1.598</td>
<td>4.95</td>
<td>0.13</td>
</tr>
<tr>
<td>1.603</td>
<td>4.75</td>
<td>0.18</td>
</tr>
<tr>
<td>1.650</td>
<td>4.72</td>
<td>0.10</td>
</tr>
<tr>
<td>1.663</td>
<td>4.72</td>
<td>0.10</td>
</tr>
<tr>
<td>1.664</td>
<td>4.78</td>
<td>0.13</td>
</tr>
<tr>
<td>1.696</td>
<td>3.91</td>
<td>0.13</td>
</tr>
</tbody>
</table>

*With 0.8 wt% graphite added.*
7.2 Wedge Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Distance, x*, and Time, t*, to Detonation (mm and µs)</th>
<th>Pressure Range (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.60</td>
<td>log P = (0.57 ± 0.02) − (0.49 ± 0.03) log x*</td>
<td>1.14 &lt; P &lt; 4.69</td>
</tr>
<tr>
<td></td>
<td>log P = (0.33 ± 0.13) − (0.41 ± 0.03) log t*</td>
<td></td>
</tr>
</tbody>
</table>

where P = pressure in gigapascals.

7.3 Shock Hugoniot.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Shock Hugoniot (mm/µs)</th>
<th>Particle Velocity Range (mm/µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.60</td>
<td>Uₚ = 1.328 + 1.993 Uₚ</td>
<td>0.35 &lt; Uₚ &lt; 0.93</td>
</tr>
</tbody>
</table>

where Uₚ = shock velocity and Uₚ = particle velocity.

7.4 Minimum Priming Charge.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>W₅₀ (mg of XTX 8003)</th>
<th>L₉₅ (± log mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.764</td>
<td>12.4</td>
<td>0.054</td>
</tr>
</tbody>
</table>

7.5 Detonation Failure Thickness.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Failure Thickness (mm)</th>
<th>L₉₅ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.767</td>
<td>0.305</td>
<td>0.089</td>
</tr>
</tbody>
</table>
8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>$H_{50}$ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>33</td>
</tr>
<tr>
<td>12B</td>
<td>35</td>
</tr>
</tbody>
</table>

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>3</td>
<td>30</td>
<td>0.77</td>
<td>50</td>
</tr>
<tr>
<td>Brass</td>
<td>10</td>
<td>30</td>
<td>1.50</td>
<td>50</td>
</tr>
</tbody>
</table>

9. MECHANICAL PROPERTIES

9.2 Tensile Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature ($^\circ$C)</th>
<th>Density (g/cm$^3$)</th>
<th>Ultimate Tensile Strength (psi)</th>
<th>Tensile Modulus (psi $\times 10^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1.653</td>
<td>287</td>
<td>8.88</td>
</tr>
<tr>
<td>24</td>
<td>1.653</td>
<td>364</td>
<td>10.87</td>
</tr>
<tr>
<td>-18</td>
<td>1.653</td>
<td>747</td>
<td>---</td>
</tr>
</tbody>
</table>

aThe ultimate strength varies as much as 75 psi.
9.3 Compressive Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Ultimate* Compressive Strength (psi)</th>
<th>Compressive Modulus (psi × 10^-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1729</td>
<td>3.81</td>
</tr>
<tr>
<td>49</td>
<td>3250</td>
<td>5.75</td>
</tr>
<tr>
<td>20</td>
<td>6770</td>
<td>12.47</td>
</tr>
<tr>
<td>-18</td>
<td>8970</td>
<td>12.48</td>
</tr>
<tr>
<td>-54</td>
<td>9300</td>
<td>13.18</td>
</tr>
</tbody>
</table>

*The ultimate strength varies as much as a few hundred psi.

9.4 Shear Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate* Shear Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1.636</td>
<td>1080</td>
</tr>
<tr>
<td>60</td>
<td>1.636</td>
<td>1775</td>
</tr>
<tr>
<td>24</td>
<td>1.636</td>
<td>2120</td>
</tr>
<tr>
<td>-18</td>
<td>1.636</td>
<td>1840</td>
</tr>
<tr>
<td>-54</td>
<td>1.636</td>
<td>1990</td>
</tr>
</tbody>
</table>

*The ultimate shear strength varies as much as a few hundred psi below 0°C, and about 100 psi above 0°C.

REFERENCES

PBX 9501

1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. PBX 9501 is composed of HMX bonded with Estane and the eutectic mixture of bis(2,2-dinitropropyl)acetal and bis(2,2-dinitropropyl)formal (BDNPA/BDNPF). At time of manufacture the molding powder is off-white. With time, it changes to a light buff.

1.2 Common Use. PBX 9501 is a high-performance explosive more thermally stable and less hazardous to handle than any other explosive of equivalent energy. It is used in nuclear ordnance.

1.3 Toxicity. The suggested maximum airborne HMX concentration\(^1\) is 1.5 mg/m\(^3\). BDNPA/BDNPF is considered slightly to moderately toxic,\(^2\) and Estane is not toxic.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. PBX-9501 molding powder is prepared by the slurry process. A lacquer of Estane and BDNPA/BDNPF is prepared in a solvent partially immiscible in water. This is added to a solvent-saturated water slurry containing a bimodal distribution of HMX crystals. During solvent removal by distillation, the Estane and BDNPA/BDNPF uniformly coat and agglomerate the HMX crystals in the water phase. The process variables must be controlled closely to produce satisfactory agglomerates, composition, and bulk density.

2.2 Procurement. PBX 9501 is purchased from the US Army Armament Readiness Command under LASL material specification 13Y-109643 Rev. C, dated March 1, 1977. The DOE furnishes the BDNPA/BDNPF.
PBX 9501

2.3 Shipping. PBX-9501 molding powder is shipped as a Class A explosive.

2.4 Storage. PBX 9501 is stored in Compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Composition.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Weight Percent</th>
<th>Volume Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td>95.0</td>
<td>92.7</td>
</tr>
<tr>
<td>Estane</td>
<td>2.5</td>
<td>3.9</td>
</tr>
<tr>
<td>BDNPA/BDNPF</td>
<td>2.5</td>
<td>3.3</td>
</tr>
</tbody>
</table>

3.2 Molecular Weight.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Estane 5703 F-1              | \{HO-(CH\_2)\_4-O[\(\text{C-O-(CH\_2)\_4-O}\)]\_m \text{C-N-O-C-C} \}\_m | 100.0            |

| BDNPA/BDNPF                  | \{[\text{CH}\_2-\text{C-(NO\_2)\_2-CH}_2-\text{O}]\_m \text{CH}\_2/\[\text{CH}\_2-\text{C-(NO\_2)\_2-CH}_2-\text{O}]\_m \text{CH}\_2\text{CH}\_2] \}C\_xH\_yN\_zO\_w | 100.0            |
3.3 Solubility. The solubility is that of HMX.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>0.037</td>
<td>0.044</td>
<td>0.090</td>
</tr>
<tr>
<td>Glacial</td>
<td>---</td>
<td>0.033</td>
<td>0.103</td>
</tr>
<tr>
<td>70%</td>
<td>---</td>
<td>1.29</td>
<td>1.94</td>
</tr>
<tr>
<td>Acetic anhydride</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Acetone</td>
<td>2.4</td>
<td>3.4</td>
<td>---</td>
</tr>
<tr>
<td>Anhydrous</td>
<td>0.66</td>
<td>1.29</td>
<td>---</td>
</tr>
<tr>
<td>70%</td>
<td>3.07</td>
<td>4.34</td>
<td></td>
</tr>
<tr>
<td>Acetonitrile</td>
<td>---</td>
<td>5.91</td>
<td>7.17</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>---</td>
<td>6.1</td>
<td>11.1</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>---</td>
<td>45.5</td>
<td>47.2</td>
</tr>
<tr>
<td>Dimethylsulfoxide</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
</tbody>
</table>

4. PHYSICAL PROPERTIES

4.2 Density.

<table>
<thead>
<tr>
<th>Theoretical Density (g/cm³)</th>
<th>Density of Typical Pressed Charge (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.860</td>
<td>1.830</td>
</tr>
</tbody>
</table>

The following densities are obtained by vacuum pressing (residual pressure ≤10⁶ μm of Hg) with three 3-min intensifications.

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Density (g/cm³) with Powder Preheated to 85°C</th>
<th>95°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 000</td>
<td>1.836</td>
<td>1.836</td>
</tr>
<tr>
<td>20 000</td>
<td>1.840</td>
<td>1.840</td>
</tr>
</tbody>
</table>
PBX 9501

5. THERMAL PROPERTIES

5.1 Phase Changes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>β-to-δ solid-to-solid in HMX</td>
<td>190</td>
<td>9.2</td>
</tr>
</tbody>
</table>

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Heat Capacity at Constant Pressure (cal/g-°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.238 + 7.9 × 10⁻⁴ T</td>
<td>5 &lt; T &lt; 175</td>
</tr>
</tbody>
</table>

5.4 Thermal Conductivity.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Conductivity (cal/s-cm-°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.847</td>
<td>1.084 × 10⁻⁴</td>
</tr>
</tbody>
</table>

5.5 Coefficient of Thermal Expansion.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Coefficient of Expansion (1/°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.835</td>
<td>49.1 × 10⁻⁶</td>
<td>54 &lt; T &lt; 74</td>
</tr>
</tbody>
</table>
5.6 Heats of Combustion and Formation.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>$\Delta H_c^0$ (kcal/mole)</th>
<th>$\Delta H_f^0$ (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMX</td>
<td>-660.7</td>
<td>11.3</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Property</th>
<th>PBX 9501</th>
<th>HMX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Decomposition energy</td>
<td>40.1 kcal/mole</td>
<td>52.7 kcal/mole</td>
</tr>
<tr>
<td></td>
<td>Activation energy</td>
<td>$5.9 \times 10^{14}$/s</td>
<td>$5 \times 10^{19}$/s</td>
</tr>
<tr>
<td></td>
<td>Pre-exponential factor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.8 Other Thermal Stability Test Results

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.3-0.7 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 1</td>
</tr>
</tbody>
</table>

Fig. 1. PBX 9501 DTA and pyrolysis test results.
6. DETONATION PROPERTIES

6.1 Detonation Velocity.

**Effect of Charge Radius**

Charge radius affects the detonation velocity of unconfined PBX 9501 charges pressed to a density of 1.832 g/cm³ as follows.

\[ D(R) = 8.802 \left[ \frac{(1 - 1.9 \times 10^{-2})}{R} - 9.12 \times 10^{-8} \right] / R(R - 0.48) \]

where \( D \) = detonation velocity in millimeters per microsecond

and \( R \) = charge radius in millimeters.

The experimentally determined failure diameter is slightly less than 1.52 mm.

6.3 Cylinder Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/µs)</th>
<th>Cylinder Wall Velocity (mm/µs) at R - R₀</th>
<th>R - R₀ = 5 mm</th>
<th>R - R₀ = 19 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.834</td>
<td>8.792</td>
<td></td>
<td>1.534</td>
<td>1.776</td>
</tr>
</tbody>
</table>

6.4 Plate Dent Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Dent Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.853</td>
<td>10.47</td>
</tr>
</tbody>
</table>
7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.\(^7\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>G(_{90}) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large Scale</strong></td>
<td></td>
</tr>
<tr>
<td>1.834</td>
<td>55.52</td>
</tr>
<tr>
<td><strong>Small Scale</strong></td>
<td></td>
</tr>
<tr>
<td>1.843</td>
<td>1.52</td>
</tr>
</tbody>
</table>

7.2 Wedge Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Distance, (x^<em>), and Time, (t^</em>), to Detonation (mm and (\mu)s)</th>
<th>Pressure Range (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.833</td>
<td>(\log P = (1.15 \pm 0.05) - (0.64 \pm 0.06) \log x^*)</td>
<td>(2.38 &lt; P &lt; 7.32)</td>
</tr>
<tr>
<td></td>
<td>(\log P = (0.73 \pm 0.01) - (0.53 \pm 0.03) \log t^*),</td>
<td></td>
</tr>
<tr>
<td>1.844</td>
<td>(\log P = (1.10 \pm 0.04) - (0.51 \pm 0.03) \log x^*)</td>
<td>(2.47 &lt; P &lt; 7.21)</td>
</tr>
<tr>
<td></td>
<td>(\log P = (0.76 \pm 0.01) - (0.45 \pm 0.03) \log t^*),</td>
<td></td>
</tr>
<tr>
<td></td>
<td>where (P) = pressure in gigapascals.</td>
<td></td>
</tr>
</tbody>
</table>
7.3 Shock Hugoniot.

\[
\begin{array}{ccc}
\text{Density (g/cm}^3\text{)} & \text{Shock Hugoniot (mm/μs)} & \text{Particle Velocity Range (mm/μs)} \\
1.833 & U_s = (2.501 \pm 0.131) + (2.261 \pm 0.233) U_p & 0.07 < U_p < 0.89 \\
1.844 & U_s = (2.953 \pm 0.098) + (1.507 \pm 0.179) U_p & 0.1 < U_p < 0.9 \\
\end{array}
\]

where \( U_s \) = shock velocity
and \( U_p \) = particle velocity.

7.4 Minimum Priming Charge.

\[
\begin{array}{ccc}
\text{Density (g/cm}^3\text{)} & W_{50} (\text{mg of XTX 8003}) & I_{95} (±\log \text{mg}) \\
1.837 & 67.0 & 0.04 \\
1.834 & 44.8 & 0.05 \\
\end{array}
\]

8. SENSITIVITY

8.1 Drop Weight Impact Height.

\[
\begin{array}{cccc}
\text{Tool Type} & H_{50} (\text{cm}) \\
12 & 48 \\
12B & 44 \\
\end{array}
\]
8.2 Large-Scale Drop Test Height.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>$H_{so}$ (ft)</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.830</td>
<td>&gt;150</td>
<td>One partial reaction in eight 150-ft drops</td>
</tr>
</tbody>
</table>

8.3 Skid Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Impact Angle (degrees)</th>
<th>Target Surface</th>
<th>$H_{so}$ (ft)</th>
<th>Reaction Overpressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.830</td>
<td>45</td>
<td>Garnet paper</td>
<td>26</td>
<td>1.0</td>
</tr>
<tr>
<td>1.830</td>
<td>15</td>
<td>Quartz*</td>
<td>&gt;14</td>
<td>---</td>
</tr>
</tbody>
</table>

*200-μ in. finish on quartz.

8.4 Susan Test Results.

<table>
<thead>
<tr>
<th>Projectile Impact Velocity (ft/s)</th>
<th>Relative Energy Release (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>175</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>210</td>
<td>60</td>
</tr>
</tbody>
</table>
9. MECHANICAL PROPERTIES*

9.2 Tensile Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Tensile Strength (psi)</th>
<th>Tensile Modulus (psi × 10⁻⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1.844</td>
<td>100</td>
<td>1.05</td>
</tr>
<tr>
<td>24</td>
<td>1.844</td>
<td>320</td>
<td>2.24</td>
</tr>
<tr>
<td>-18</td>
<td>1.844</td>
<td>645</td>
<td>7.63</td>
</tr>
<tr>
<td>-54</td>
<td>1.845</td>
<td>1000</td>
<td>13.38</td>
</tr>
</tbody>
</table>

9.3 Compressive Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Compressive Strength (psi)</th>
<th>Compressive Modulus (psi × 10⁻⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>1.844</td>
<td>520</td>
<td>0.64</td>
</tr>
<tr>
<td>24</td>
<td>1.844</td>
<td>1140</td>
<td>1.93</td>
</tr>
<tr>
<td>-18</td>
<td>1.843</td>
<td>2100</td>
<td>3.30</td>
</tr>
<tr>
<td>-54</td>
<td>1.843</td>
<td>4700</td>
<td>6.52</td>
</tr>
</tbody>
</table>

*Above 50°C, the polyester polyurethane, Estane, depolymerizes so its strength decreases with time. The data given are initial values.
REFERENCES

1. Committee on Threshold Limit Values, *Documentation of Threshold Limit Values*, 3rd Ed. (American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati, Ohio, 1971).


PBX 9502

1. GENERAL PROPERTIES

1.1 Chemical and Physical Properties. PBX 9502 is a plastic-bonded explosive composed of TATB bonded with Kel-F 800. The molding powder is yellow to tan or light brown.

1.2 Common Use. PBX 9502 is extremely difficult to initiate either deliberately or accidentally. It is used as the explosive in nuclear ordnance.

1.3 Toxicity. The toxicity is that of TATB. The maximum permissible concentration of TATB in air is 1.5 mg/m³. TATB was not mutagenic when tested in five strains of Salmonella typhimurium and in Escherichia coli strain WP.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. PBX-9502 molding powder is prepared by the water slurry process. A Kel-F 800 lacquer is prepared in a solvent that is partially immiscible in water. This is added to a water slurry containing TATB. The solvent is extracted from the lacquer by adding water. The TATB particles are plastic coated and agglomerated during the extraction process. A simmering period is used to adjust the agglomerate size. The process variables must be carefully controlled to produce satisfactory agglomerates, composition, and bulk density.
2.2 Procurement. PBX 9502 is purchased from the US Army Armament Readiness Command under LASL material specification 13Y-188727, Rev. A, dated September 12, 1977. The DOE supplies the TATB.

2.3 Shipping. PBX-9502 molding powder is shipped as a Class A explosive.

2.4 Storage. PBX 9502 is stored in Compatibility Group D, Storage Class 1.1

3. CHEMICAL PROPERTIES

3.1 Composition.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Weight Percent</th>
<th>Volume Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>TATB</td>
<td>95</td>
<td>95.2</td>
</tr>
<tr>
<td>Kel-F 800</td>
<td>5</td>
<td>4.8</td>
</tr>
</tbody>
</table>

3.2 Molecular Weight.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
</table>
| TATB        | \[
\begin{align*}
\text{O}_2\text{N} & \\
\text{H}_2\text{N} & \\
\text{NH}_2 & \\
\text{NO}_2 & \\
\text{NO}_2 & \\
\text{NH}_2 & \\
\end{align*}
\] \quad \text{C}_7\text{H}_8\text{N}_4\text{O}_6 |
|             | 258.18            |
| Kel-F 800   | \[(\text{CFCICF}_2\text{CH}_2\text{CF}_2)_n\] \quad \[(\text{C}_5\text{H}_3\text{F}_3\text{Cl})_n\] |
|             | \[(180.51)_n\]    |
### 3.3 Solubility

The solubility is like that of TATB, which is practically insoluble in all organic solvents but is soluble in some superacids.

#### Solubility in Organic Solvents

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Solubility$^a$ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanesulfonic acid</td>
<td>820</td>
</tr>
<tr>
<td>Hexamethylphosphoric triamide</td>
<td>150</td>
</tr>
<tr>
<td>Ethanesulfonic acid</td>
<td>120</td>
</tr>
<tr>
<td>Dimethylsulfoxide</td>
<td>100</td>
</tr>
<tr>
<td>Hexafluoroacetone sesquihydrate</td>
<td>68</td>
</tr>
<tr>
<td>N-methyl-2-pyrrolidinone</td>
<td>58</td>
</tr>
<tr>
<td>N, N-dimethylacetamide</td>
<td>33</td>
</tr>
<tr>
<td>N, N-dimethylacetamide</td>
<td>27</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>26</td>
</tr>
</tbody>
</table>

$^a$Temperature not reported.

#### Solubility in Sulfuric Acid and Water Mixtures

<table>
<thead>
<tr>
<th>Acid (vol%)</th>
<th>Maximum Quantity Dissolved (grams of TATB/100 ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>66.7</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>80</td>
<td>0.24</td>
</tr>
<tr>
<td>85</td>
<td>0.32</td>
</tr>
<tr>
<td>87.5</td>
<td>&gt;1.28</td>
</tr>
<tr>
<td>90</td>
<td>3.84</td>
</tr>
<tr>
<td>100</td>
<td>&gt;24.0</td>
</tr>
</tbody>
</table>
4. PHYSICAL PROPERTIES

4.2 Density.

<table>
<thead>
<tr>
<th>Theoretical Density (g/cm³)</th>
<th>Density of Typical Pressed Charges (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.942</td>
<td>1.895</td>
</tr>
</tbody>
</table>

The following densities are obtained by vacuum pressing (residual pressure ≤10⁻⁸ µm Hg) hot molding powder (110°C) with a 4-min dwell and three pressure intensifications.

<table>
<thead>
<tr>
<th>Pressure (lb/in.²)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 000</td>
<td>1.890 ± 0.005</td>
</tr>
<tr>
<td>20 000</td>
<td>1.895 ± 0.005</td>
</tr>
</tbody>
</table>

5. THERMAL PROPERTIES

5.1 Phase Changes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-liquid in TATB</td>
<td>448-449</td>
<td>---</td>
</tr>
<tr>
<td>Solid-to-gas in TATB</td>
<td>---</td>
<td>163.9</td>
</tr>
</tbody>
</table>
5.3 Heat Capacity.

Heat Capacity
at Constant Pressure
(cal/g-°C)

\[ 0.249 + 5.9 \times 10^{-4} T \]

5.4 Thermal Conductivity.

Conductivity
(cal/cm-s-°C)

\[ 13.4 \times 10^{-4} \]

5.6 Heats of Combustion and Formation.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>( \Delta H^o ) (kcal/mole)</th>
<th>( \Delta H^o_f ) (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TATB</td>
<td>-735.9</td>
<td>-33.4</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.

<table>
<thead>
<tr>
<th>Property</th>
<th>TATB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition energy</td>
<td>600 cal/g</td>
</tr>
<tr>
<td>Activation energy</td>
<td>59.9 kcal/mole</td>
</tr>
<tr>
<td>Pre-exponential factor</td>
<td>( 3.18 \times 10^{19} ) /s</td>
</tr>
</tbody>
</table>
5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.0-0.2 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 1</td>
</tr>
<tr>
<td>Critical temperature, $T_m$</td>
<td>331°C</td>
</tr>
<tr>
<td>Charge radius, $a$</td>
<td>3.3 mm</td>
</tr>
<tr>
<td>Density, $\rho$</td>
<td>1.84 g/cm³</td>
</tr>
</tbody>
</table>

6. DETONATION PROPERTIES

6.1 Detonation Velocity. 

**Effect of Charge Radius**

Charge radius affects the detonation velocity of unconfined PBX-9502 charges pressed to a density of 1.895 g/cm³ as follows.

$$D(R) = 7.706(1 - 19.4 \times 10^{-9}/R) ,$$

where $D$ = detonation velocity in millimeters per microsecond

and $R$ = charge radius in millimeters.

The experimentally determined failure diameter is 9 mm.

![Fig. 1. PBX 9502 DTA and pyrolysis test results.](image)
6.3 Cylinder Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Cylinder Wall Velocity (mm/μs) at R – R₀ = 5 mm</th>
<th>Cylinder Wall Velocity (mm/μs) at R – R₀ = 19 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.894</td>
<td>7.589</td>
<td>1.241</td>
<td>1.436</td>
</tr>
</tbody>
</table>

7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>G₀₀ (mm)</th>
<th>Lₑₑ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.895</td>
<td>22.33</td>
<td>1.0</td>
</tr>
<tr>
<td>Small Scale</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This scale is too close to the detonation failure diameter.

7.2 Wedge Test Results.

$$\log P = (1.37 \pm 0.05) - (0.31 \pm 0.05) \log x^*$$

$$\log P = (1.15 \pm 0.01) - (0.28 \pm 0.04) \log t^*,$$

where P = pressure in gigapascals.
7.3 Shock Hugoniot.

<table>
<thead>
<tr>
<th>Density (g/cm²)</th>
<th>Shock Hugoniot (mm/µs)</th>
<th>Particle Velocity Range (mm/µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.896</td>
<td>𝑈̇ = (3.263 ± 0.977) + (1.678 ± 0.777) 𝑈ₚ,</td>
<td>1.08 &lt; 𝑈ₚ &lt; 1.42</td>
</tr>
<tr>
<td></td>
<td>where 𝑈̇ = shock velocity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and 𝑈ₚ = particle velocity</td>
<td></td>
</tr>
</tbody>
</table>

7.4 Minimum Priming Charge.

<table>
<thead>
<tr>
<th>Density (g/cm²)</th>
<th>W₉₀ (mg of XTX 8003)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.920*</td>
<td>&gt;1.53 × 10⁴</td>
</tr>
</tbody>
</table>

*For 90 wt% TATB and 10 wt% Kel-F 800. Pure TATB gave a similar result.

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>H₉₀ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>&gt;320</td>
</tr>
<tr>
<td>12B</td>
<td>&gt;320</td>
</tr>
</tbody>
</table>

8.3 Skid Test Results. A formulation of 50 wt% HMX, 40 wt% TATB, and 10 wt% Kel-F gave no events in four 64-ft drops at a 45° impact angle on a garnet-paper target.

8.4 Susan Test Results. At an impact velocity of 1500 ft/s, the relative energy release was equivalent to the kinetic energy of the test vehicle. A similar result was obtained with an inert fill.
9. MECHANICAL PROPERTIES

9.2 Tensile Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Tensile Strength (psi)</th>
<th>Tensile Modulus (psi × 10⁻⁵)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-54</td>
<td>1.884</td>
<td>1340</td>
<td>6.51</td>
</tr>
<tr>
<td>24</td>
<td>1.886</td>
<td>1000</td>
<td>5.60</td>
</tr>
<tr>
<td>74</td>
<td>1.886</td>
<td>430</td>
<td>2.38</td>
</tr>
</tbody>
</table>

9.3 Compressive Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Compressive Strength (psi)</th>
<th>Compressive Modulus (psi × 10⁻⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-54</td>
<td>1.886</td>
<td>5170</td>
<td>4.97</td>
</tr>
<tr>
<td>24</td>
<td>1.886</td>
<td>3360</td>
<td>3.41</td>
</tr>
<tr>
<td>74</td>
<td>1.885</td>
<td>1640</td>
<td>1.67</td>
</tr>
</tbody>
</table>
REFERENCES


1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. PETN, C₆H₁₂N₄O₁₂, forms colorless prismatic crystals that together appear white and opaque. Its name differs in various countries: PETN, Penthrite, and Penta in English-speaking countries; Pentrit, Niperyth, Nitropenta, and NP in Germany; and TEN in the Union of Soviet Socialist Republics.

1.2 Common Use. PETN is used extensively in detonators, detonating fuzes, and priming compositions. Mixed with another explosive or an inert material, it is used as the main explosive charge in grenades, small-caliber projectiles, and demolition devices. For example, Primacord, a detonating fuze, consists of a tube of waterproofed textile filled with finely powdered PETN.

1.3 Toxicity. Because PETN is insoluble in water, it is slightly toxic. The recommended maximum atmospheric concentration for an 8-h period is 15 mg/m³.
2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. Acetaldehyde, aldol, or crotonaldehyde is condensed with formaldehyde in aqueous solution, in the presence of lime, to form pentaerythritol, which is nitrated with 96% nitric acid at 22-23°C to give PETN. The PETN is filtered, washed with water, and recrystallized from acetone by running acetone solution into water.


2.3 Shipping. Bulk PETN is shipped by common carrier as a Class A explosive. It must be shipped wet with at least 40 wt% water.

2.4 Storage. PETN is stored wet in Compatibility Group D. In certain conditions, it may be stored dry in Compatibility Group A. Wet or dry, PETN is in Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Structural Formula.

\[
\begin{align*}
\text{NO}_2 & \\
\text{O} & \\
\text{CH}_2 & \\
\text{O}_2\text{N} & \text{O} & \text{CH}_2 & \text{C} & \text{CH}_2 & \text{O} & \text{NO}_2 \\
\text{CH}_2 & \\
\text{O} & \\
\text{NO}_2
\end{align*}
\]

\[\text{C}_5\text{H}_8\text{N}_4\text{O}_{12}\]
PETN

3.2 Molecular Weight. 316.15

3.3 Solubility.6

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Grams Dissolved/ 100 g of Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C</td>
</tr>
<tr>
<td>Acetone</td>
<td>24.8</td>
</tr>
<tr>
<td>Acetone and water</td>
<td></td>
</tr>
<tr>
<td>(wt% water)</td>
<td></td>
</tr>
<tr>
<td>6.23</td>
<td>16.29</td>
</tr>
<tr>
<td>12.30</td>
<td>9.31</td>
</tr>
<tr>
<td>18.22</td>
<td>5.22</td>
</tr>
<tr>
<td>23.99</td>
<td>2.87</td>
</tr>
<tr>
<td>35.11</td>
<td>0.68</td>
</tr>
<tr>
<td>55.80</td>
<td>0.03</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.27</td>
</tr>
<tr>
<td>Ethanol</td>
<td>0.13</td>
</tr>
<tr>
<td>Ethyl acetate</td>
<td>10.6</td>
</tr>
</tbody>
</table>

4. PHYSICAL PROPERTIES

4.1 Crystal Structure.7 There are two polymorphs of PETN. The most common, PETN I, transforms to PETN II at 130°C. Unit cell parameters for the two forms are as follows.

<table>
<thead>
<tr>
<th>Polymorphic Form</th>
<th>Unit cell edge length (Å)</th>
<th>Molecules per unit cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>PETN I at 22°C</td>
<td>a: 9.38</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>b: 9.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c: 6.71</td>
<td></td>
</tr>
<tr>
<td>PETN II at 136°C</td>
<td>a: 13.29</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>b: 13.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c: 6.83</td>
<td></td>
</tr>
</tbody>
</table>
4.2 Density.

Crystal Density

<table>
<thead>
<tr>
<th>Method of Determination</th>
<th>Temperature (°C)</th>
<th>Crystal Form</th>
<th>Crystal Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray calculation</td>
<td>22</td>
<td>I</td>
<td>1.778</td>
</tr>
<tr>
<td>X-ray calculation</td>
<td>136</td>
<td>II</td>
<td>1.716</td>
</tr>
<tr>
<td>Experimental</td>
<td>22</td>
<td>I</td>
<td>1.778</td>
</tr>
</tbody>
</table>

Compression gives the following densities:\(^1\)

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 000</td>
<td>1.58</td>
</tr>
<tr>
<td>10 000</td>
<td>1.64</td>
</tr>
<tr>
<td>20 000</td>
<td>1.71</td>
</tr>
<tr>
<td>30 000</td>
<td>1.73</td>
</tr>
<tr>
<td>40 000</td>
<td>1.74</td>
</tr>
</tbody>
</table>

4.3 Infrared Spectrum. See Fig. 1.

---

Fig. 1. Infrared spectrum.
PETN

4.4 Refractive Indices.\textsuperscript{8}

<table>
<thead>
<tr>
<th>PETN Polymorph\textsuperscript{a}</th>
<th>Form I</th>
<th>Form II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omega</td>
<td>1.556</td>
<td>1.556</td>
</tr>
<tr>
<td>Epsilon</td>
<td>1.551</td>
<td>1.551</td>
</tr>
<tr>
<td>Birefringence</td>
<td>0.005</td>
<td>0.02</td>
</tr>
<tr>
<td>Double refraction</td>
<td>negative</td>
<td>---</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Form I is also called Alpha, and Form II is also called Beta.

5. THERMAL PROPERTIES

5.1 Phase Changes.\textsuperscript{7,8,10}

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (\degree C)</th>
<th>Latent Heat (cal/g)</th>
<th>(kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PETN I-to-PETN II</td>
<td>130.0</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Solid-to-liquid</td>
<td>142.9</td>
<td>37.4\textsuperscript{a}</td>
<td>11.82</td>
</tr>
<tr>
<td>Solid-to-gas</td>
<td>---</td>
<td>91.9\textsuperscript{b}</td>
<td>29.1</td>
</tr>
</tbody>
</table>

\textsuperscript{*Reference 9 indicates that the heat of fusion varies with the method of crystallization. Imperfect or very disordered crystals had heats of fusion as low as 31 kcal/g.}

\textsuperscript{b}The latent heat of sublimation was computed from the vapor pressure data given in Ref. 10.

5.2 Vapor Pressure.\textsuperscript{10,11}

\begin{align*}
\log_{10} P(\text{mm Hg}) &= 14.44 - 6352/T(\text{K}) \quad \text{for } 323 < T < 371 \text{ K.} \\
\log_{10} P(\text{mm Hg}) &= 17.73 - 7750/T(\text{K}) \quad \text{for } 383 < T < 412 \text{ K.}
\end{align*}
5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Heat Capacity at Constant Pressure (cal/g·°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.239 + 0.008 T</td>
<td>32 &lt; T &lt; 127</td>
</tr>
</tbody>
</table>

5.5 Coefficients of Thermal Expansion.12

### Linear Expansion Coefficient

<table>
<thead>
<tr>
<th>Crystal Face</th>
<th>Coefficient of Expansion (1/°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α(001)</td>
<td>$8.55 \times 10^{-5} + 1.82 \times 10^{-7} T$ $+ 6.30 \times 10^{-10} T^2 + 2.17 \times 10^{-12} T^3$</td>
<td>$-160 &lt; T &lt; 100$</td>
</tr>
<tr>
<td>α(100)</td>
<td>$6.75 \times 10^{-5} + 1.28 \times 10^{-7} T$ $+ 0.74 \times 10^{-10} T^2 + 1.27 \times 10^{-12} T^3$</td>
<td>$-160 &lt; T &lt; 100$</td>
</tr>
</tbody>
</table>

### Volume Expansion Coefficient

<table>
<thead>
<tr>
<th>Coefficient of Expansion (1/°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$22.05 \times 10^{-5} + 4.38 \times 10^{-7} T$ $+ 7.78 \times 10^{-10} T^2 + 4.71 \times 10^{-12} T^3$</td>
<td>$-160 &lt; T &lt; 100$</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation at 25°C.

<table>
<thead>
<tr>
<th>Energy</th>
<th>kcal/mole</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta H^\circ$</td>
<td>$-618.7$</td>
</tr>
<tr>
<td>$\Delta H_f$</td>
<td>$-110.34$</td>
</tr>
</tbody>
</table>
5.7 Thermal Decomposition Kinetics. Decomposition energy 300 cal/g  
Activation energy 47.0 kcal/mole  
Frequency factor $6.3 \times 10^{19}/s$

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.2-0.5 ml/g of gas evolved after 48 h at 100°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, Tm</td>
<td>192 °C</td>
</tr>
<tr>
<td>Charge radius, a</td>
<td>3.4 mm</td>
</tr>
<tr>
<td>Density, ρ</td>
<td>1.74 g/cm³</td>
</tr>
</tbody>
</table>

6. DETONATION PROPERTIES

6.1 Detonation Velocity. Effect of Density

\[ D = 1.608 + 3.933 \rho \quad \text{for} \ 0.57 < \rho < 1.585, \]

where D is in millimeters per microsecond, and \( \rho \) is in grams per cubic centimeter.

Fig. 2. PETN DTA and pyrolysis test results.
### 6.2 Detonation Pressure\(^6\)\(^,\)\(^6\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Detonation Velocity (mm/(\mu)s)</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.67</td>
<td>7.975</td>
<td>31</td>
</tr>
</tbody>
</table>

### 6.3 Cylinder Test Results\(^6\)\(^,\)\(^6\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Detonation Velocity (mm/(\mu)s)</th>
<th>Cylinder Wall Velocity (mm/(\mu)s) at R - R(_o) = 5 mm</th>
<th>Cylinder Wall Velocity (mm/(\mu)s) at R - R(_o) = 19 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.765</td>
<td>8.16</td>
<td>1.56</td>
<td>1.79</td>
</tr>
</tbody>
</table>

### 6.4 Plate Dent Test Results\(^6\)\(^,\)\(^6\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.670</td>
<td>9.80</td>
<td>---</td>
</tr>
<tr>
<td>1.665</td>
<td>9.75</td>
<td>203</td>
</tr>
</tbody>
</table>

### 7. SHOCK INITIATION PROPERTIES

#### 7.1 Gap Test Results\(^6\)\(^,\)\(^6\)

<table>
<thead>
<tr>
<th>Small Scale</th>
<th>Density (g/cm(^3))</th>
<th>G(_{50}) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.757</td>
<td>5.21</td>
</tr>
</tbody>
</table>
7.2 Wedge Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Distance, x*, and Time, t*, to Detonation (mm and μs)</th>
<th>Valid Pressure Range (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>log P = (0.14 ± 0.03) − (0.4 ± 0.05) log x*</td>
<td>0.66 &lt; P &lt; 0.99</td>
</tr>
<tr>
<td></td>
<td>log P = (0.04 ± 0.02) − (0.33 ± 0.04) log t*</td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>log P = (0.40 ± 0.03) − (0.54 ± 0.05) log x*</td>
<td>1.2 &lt; P &lt; 2.0</td>
</tr>
<tr>
<td></td>
<td>log P = (0.18 ± 0.02) − (0.44 ± 0.09) log t*</td>
<td></td>
</tr>
<tr>
<td>1.72</td>
<td>log P = (0.61 ± 0.03) − (0.49 ± 0.05) log x*</td>
<td>1.7 &lt; P &lt; 3.9</td>
</tr>
<tr>
<td></td>
<td>log P = (0.34 ± 0.02) − (0.50 ± 0.09) log t*</td>
<td></td>
</tr>
<tr>
<td>1.75</td>
<td>log P = (0.57 ± 0.04) − (0.41 ± 0.06) log x*</td>
<td>1.7 &lt; P &lt; 2.54</td>
</tr>
<tr>
<td></td>
<td>log P = (0.33 ± 0.02) − (0.22 ± 0.16) log t*</td>
<td></td>
</tr>
</tbody>
</table>

where P = pressure in gigapascals.

7.3 Shock Hugoniots.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Shock Hugoniot¹⁹ (mm/μs)</th>
<th>Particle Velocity Range (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.60</td>
<td>Uₛ = 1.32 + 2.58 Uₚ</td>
<td>0.1 &lt; Uₚ &lt; 0.7</td>
</tr>
<tr>
<td>1.72</td>
<td>Uₛ = 1.83 + 3.45 Uₚ</td>
<td>0.1 &lt; Uₚ &lt; 0.7</td>
</tr>
<tr>
<td>1.77</td>
<td>Uₛ = 2.87 + 1.69 Uₚ</td>
<td>0.5 &lt; Uₚ &lt; 1.5</td>
</tr>
</tbody>
</table>

Isothermal Hugoniot²⁰

| 1.774          | Uₛ = 2.24 + 2.95 Uₚ − 0.600 Uₚ² | Uₚ > 1.0                        |
|                | Uₛ = 2.81 + 1.75 Uₚ             |                                |

where Uₛ = shock velocity and Uₚ = particle velocity.
8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Type Tool</th>
<th>$H_{50}$ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>12B</td>
<td>37</td>
</tr>
</tbody>
</table>

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>3</td>
<td>47.2</td>
<td>0.19</td>
<td>50</td>
</tr>
<tr>
<td>Brass</td>
<td>10</td>
<td>47.2</td>
<td>0.36</td>
<td>50</td>
</tr>
<tr>
<td>Steel</td>
<td>1</td>
<td>50.0</td>
<td>0.10</td>
<td>50</td>
</tr>
<tr>
<td>Steel</td>
<td>10</td>
<td>50.0</td>
<td>0.41</td>
<td>50</td>
</tr>
</tbody>
</table>

REFERENCES


2. Committee on Threshold Limit Values, *Documentation of Threshold Limit Values*, 3rd Ed. (American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1971).


RDX

1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. The British first used "RDX" to identify a new chemical explosive developed for use during World War II. During its development, the new explosive was called "Research Department Explosive."

RDX, C₃H₆N₆O₆, is a colorless polycrystalline material. It is also known as hexahydro-1,3,5-trinitro-s-triazine, cyclotrimethylenetrinitramine, 1,3,5-trinitro-1,3,5-triazocyclohexane, Hexogen, cyclonite, and T4.

1.2 Common Use. RDX is used extensively as the base charge in detonators. Its most common uses are as an ingredient in castable TNT-based binary explosives such as cyclotols and Comp B, and as the primary ingredient in plastic-bonded explosives or plastic explosives such as Composition A and Composition C. Either the castable or plastic-coated mixture is used as the explosive fill in almost all types of munitions.

1.3 Toxicity. Workers who inhaled RDX dust for several months have become unconscious and have suffered loss of reflexes. The suggested maximum permissible airborne concentration of RDX is 1.5 mg/m³.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. RDX is manufactured in two ways. In the British process, hexamethylenetetramine is nitrated directly; in the Bachmann process, it is nitrated by a mixture of nitric acid, ammonium nitrate, acetic anhydride, and acetic acid. The former process produces relatively pure RDX; the latter has been
RDX

developed into a continuous high-yield process that gives about 10% HMX as an impurity. The crude RDX is purified by washing it with water and recrystallizing it from either acetone or cyclohexanone.


2.3 Shipping. RDX is shipped as a Class A explosive and must be shipped wet with not less than 10% water.

2.4 Storage. RDX may be stored dry in Compatibility Group A or wet in Compatibility Group D. Wet or dry, it is in Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Structural Formula.

\[
\begin{align*}
\text{O}_2\text{N} & - \text{H}_2 \\
\text{C} & - \text{N} \quad \text{N} \quad \text{N} \\
\text{N} & - \text{C} \\
\text{H}_2 & - \text{N} \quad \text{NO}_2 \\
\text{H}_2 & - \text{C} \\
\text{H}_2 & - \text{NO}_2 \\
\text{C}_3\text{H}_6\text{N}_6\text{O}_8
\end{align*}
\]
3.2 Molecular Weight. 222.13

3.3 Solubility.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>0.46</td>
<td>0.56</td>
<td>1.22</td>
</tr>
<tr>
<td>99.6%</td>
<td>0.22</td>
<td>0.37</td>
<td>0.74</td>
</tr>
<tr>
<td>71.0%</td>
<td>6.81</td>
<td>10.34</td>
<td>---</td>
</tr>
<tr>
<td>Acetone</td>
<td>0.026</td>
<td>0.060</td>
<td>0.210</td>
</tr>
<tr>
<td>Isoamyl alcohol</td>
<td>0.045</td>
<td>0.085</td>
<td>0.195</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.33</td>
<td>0.554</td>
<td>---</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>4.94</td>
<td>9.20</td>
<td>13.9</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>---</td>
<td>41.5</td>
<td>60.6</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>0.12</td>
<td>0.24</td>
<td>0.58</td>
</tr>
<tr>
<td>Ethanol</td>
<td>2.9</td>
<td>4.1</td>
<td>---</td>
</tr>
<tr>
<td>Methyl acetate</td>
<td>6.81</td>
<td>10.34</td>
<td>---</td>
</tr>
<tr>
<td>Methylcyclohexanone</td>
<td>3.23</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.020</td>
<td>0.050</td>
<td>0.125</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>0.20</td>
<td>0.24</td>
<td>---</td>
</tr>
<tr>
<td>Water</td>
<td>0.005</td>
<td>0.0127</td>
<td>0.03</td>
</tr>
</tbody>
</table>
4. PHYSICAL PROPERTIES

4.1 Crystal Structure. RDX is orthorhombic. It also has a very unstable polymorph that has been isolated only in very small quantities for very short periods during fusion.

The cell parameters of orthorhombic form are given.

<table>
<thead>
<tr>
<th>Unit cell edge length (Å)</th>
<th>RDX</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>13.18</td>
</tr>
<tr>
<td>b</td>
<td>11.57</td>
</tr>
<tr>
<td>c</td>
<td>10.71</td>
</tr>
</tbody>
</table>

Molecules per unit cell: 8

4.2 Density.

Crystal Method of Determination | State | Temperature (°C) | Density (g/cm³) |
--------------------------------|-------|-----------------|-----------------|
X-ray data                      | Solid | ---             | 1.806           |
Direct measurement              | Solid | 22.8            | 1.799           |

Pressed Charges

RDX powder can be pressed to various densities. The pressures required to produce a given density are as follows.

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Density* (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 000</td>
<td>1.52</td>
</tr>
<tr>
<td>10 000</td>
<td>1.60</td>
</tr>
<tr>
<td>20 000</td>
<td>1.68</td>
</tr>
<tr>
<td>30 000</td>
<td>1.70</td>
</tr>
</tbody>
</table>

*These data are typical and will vary with particle-size distribution, time under pressure, and temperature.
4.3 Infrared Spectrum. See Fig. 1.

4.4 Refractive Index. In light whose wave length varied between 4470 and 6680 Å, the following refractive indices have been reported.

Refractive Index

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
<th>Latent Heat (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-liquid</td>
<td>204.1</td>
<td>35.5</td>
<td>7.89</td>
</tr>
<tr>
<td>Solid-to-gas* (vaporization)</td>
<td>---</td>
<td>---</td>
<td>31.1</td>
</tr>
</tbody>
</table>

*Computed from vapor pressure data taken at 55-98°C.

Fig. 1. Infrared spectrum.
5.2 Vapor Pressure. \(^8\)

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Vapor Pressure (mm Hg × 10°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>55.7</td>
<td>3.24-3.5</td>
</tr>
<tr>
<td>62.6</td>
<td>7.14-8.6</td>
</tr>
<tr>
<td>78.2</td>
<td>69.30-78.7</td>
</tr>
<tr>
<td>97.7</td>
<td>667-735</td>
</tr>
</tbody>
</table>

A least squares fit to these data gives the following.

\[
\log_{10} P(\text{mm Hg}) = 14.18 - 31 \frac{100}{4.576} T(\text{K}),
\]

where \(P\) = vapor pressure in millimeters of mercury

and \(T\) = temperature in Kelvin.

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Heat Capacity at Constant Pressure (cal/g-°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.232 + 7.5 × 10⁻⁷ T</td>
<td>37 &lt; T &lt; 167</td>
</tr>
</tbody>
</table>

5.5 Coefficient of Thermal Expansion. \(^9\)

<table>
<thead>
<tr>
<th>Coefficient of Expansion (1/°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(18.33 × 10^{-6} + 3.625 \times 10^{-7} T + 5.48 \times 10^{-10} T^2)</td>
<td>(-100 &lt; T &lt; 135)</td>
</tr>
</tbody>
</table>
5.6 Heats of Combustion and Formation at 25°C.\textsuperscript{10}

\[
\begin{array}{cc}
\Delta H^\circ & \Delta H_f^\circ \\
-501.8 \text{ kcal/mole} & 14.7 \text{ kcal/mole}
\end{array}
\]

5.7 Thermal Decomposition Kinetics.\textsuperscript{11}

- Decomposition energy: 500 cal/g
- Activation energy: 47.1 kcal/mole
- Pre-exponential factor: \(2.02 \times 10^{14}/s\)

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.1-0.3 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, T_m</td>
<td>217°C</td>
</tr>
<tr>
<td>Charge radius, a</td>
<td>3.5 mm</td>
</tr>
<tr>
<td>Density, ( \rho )</td>
<td>1.72 g/cm\textsuperscript{3}</td>
</tr>
</tbody>
</table>

Fig. 2. RDX DTA and pyrolysis test results.
6. DETONATION PROPERTIES

6.1 Detonation Velocity.

Effect of Density

\[ D = 2660 + 3400 \rho_o, \]

where \( D \) = detonation velocity in meters per second

and \( \rho_o \) = density in grams per cubic centimeter.

6.2 Detonation Pressure.\(^{12}\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Detonation Velocity (mm/µs)</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.767 ± 0.011</td>
<td>8.639 ± 0.041</td>
<td>33.79 ± 0.31</td>
</tr>
</tbody>
</table>

6.4 Plate Dent Test Results.

<table>
<thead>
<tr>
<th>Charge Diameter (mm)</th>
<th>Density (g/cm(^3))</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.3</td>
<td>1.754</td>
<td>10.35</td>
<td>203</td>
</tr>
<tr>
<td>41.3</td>
<td>1.744</td>
<td>10.14</td>
<td>203</td>
</tr>
<tr>
<td>41.3</td>
<td>1.587</td>
<td>8.20</td>
<td>203</td>
</tr>
</tbody>
</table>
7. SHOCK INITIATION

7.1 Gap Test Results.18

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Gap₅₀ (mm)</th>
<th>L₅₀ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large Scale</td>
<td></td>
</tr>
<tr>
<td>1.09</td>
<td>7.02</td>
<td>0.10</td>
</tr>
<tr>
<td>1.750</td>
<td>6.17</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Small Scale</td>
<td></td>
</tr>
<tr>
<td>1.00ᵃ</td>
<td>7.82</td>
<td>0.15</td>
</tr>
<tr>
<td>1.11ᵇ</td>
<td>8.86</td>
<td>0.15</td>
</tr>
<tr>
<td>1.704</td>
<td>0.50</td>
<td>---</td>
</tr>
<tr>
<td>1.735</td>
<td>5.18</td>
<td>0.18</td>
</tr>
<tr>
<td>1.752</td>
<td>0.36</td>
<td>0.01</td>
</tr>
</tbody>
</table>

ᵃMedian RDX particle diameter is ~110 μm.
ᵇMedian RDX particle diameter is ~25 μm.
7.3 Shock Hugoniot.\textsuperscript{14}

<table>
<thead>
<tr>
<th>Density (g/cm\textsuperscript{3})</th>
<th>Shock Hugoniot\textsuperscript{a} (mm/\mu s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.799</td>
<td>( U_s = 2.78 + 1.9 , U_p )</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Computed from the isothermal volume compression data. Two RDX phases were observed in the course of determining its isothermal volume compression. The shock Hugoniot tabulated is that for the orthorhombic form described previously in Sec. 4.1. Another RDX polymorph, Form III, occurs at pressures of 4.4 GPa. The volume change between the two polymorphs was about 1.6% (from 0.4651 to 0.4566 cm\textsuperscript{3}/g). The isothermal Hugoniots of the two polymorphs were

- RDX(I) \( U_{st} = 2.68 + 1.9 \, U_{pt} \)
- RDX(II) \( U_{st} = 2.49 + 1.8 \, U_{pt} \)

where the subscript "t" denotes isothermal conditions.

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>( H_{50} ) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>22</td>
</tr>
<tr>
<td>12B</td>
<td>41</td>
</tr>
</tbody>
</table>

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>3</td>
<td>61.1</td>
<td>0.22</td>
<td>50</td>
</tr>
<tr>
<td>Brass</td>
<td>10</td>
<td>61.1</td>
<td>0.55</td>
<td>50</td>
</tr>
<tr>
<td>Steel</td>
<td>1</td>
<td>64.0</td>
<td>0.12</td>
<td>50</td>
</tr>
<tr>
<td>Steel</td>
<td>10</td>
<td>64.0</td>
<td>0.87</td>
<td>50</td>
</tr>
</tbody>
</table>
REFERENCES


1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. TATB (1,3,5-trinitrobenzene), C₈H₈N₈O₈, is a yellow polycrystalline material. Exposure to sunlight or UV light turns it light green, and prolonged exposure eventually turns it dark brown to black.

1.2 Common Use. The excellent thermal stability and extreme resistance to accidental initiation by impact or shock make TATB useful for special applications. To be used effectively, it is generally coated with a thermoplastic polymer and pressed into desired shapes.

1.3 Toxicity. The maximum permissible concentration of TATB in air is 1.5 mg/m³. It was not mutagenic when tested in five strains of Salmonella typhimurium and in Escherichia coli strain WP.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. TATB is synthesized by reacting 1,3,5-trichlorobenzene with SO₃ (30% oleum) and sodium nitrate to give 1,3,5-trichloro-2,4,6-trinitrobenzene. The reaction mixture is then quenched in a large volume of ice, and the 1,3,5-trichloro-2,4,6-trinitrobenzene is recovered by filtration and reacted with ammonia gas in the presence of toluene to give TATB.

2.2 Procurement. There is no dedicated DoD or DOE facility for TATB manufacture. It can be procured, on special order, from a few chemical companies in the United States which have facilities for synthesizing energetic materials. The DOE procures TATB under LASL material specification 13Y-188025, dated August 23, 1978.

2.3 Shipping. TATB is shipped dry or wet as a Class A explosive.
2.4 Storage. TATB is stored dry or wet in Compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Structural Formula.

![Structural formula of TATB]

3.2 Molecular Weight. 258.18

3.3 Solubility. TATB is practically insoluble in all organic solvents, but it is soluble in some superacids.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Solubility* (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanesulfonic acid</td>
<td>820</td>
</tr>
<tr>
<td>Hexamethylphosphoric triamide</td>
<td>150</td>
</tr>
<tr>
<td>Ethanesulfonic acid</td>
<td>120</td>
</tr>
<tr>
<td>Dimethylsulfoxide</td>
<td>100</td>
</tr>
<tr>
<td>Hexafluoroacetone sesquihydrate</td>
<td>68</td>
</tr>
<tr>
<td>N-methyl-2-pyrrolidinone</td>
<td>68</td>
</tr>
<tr>
<td>N, N-dimethylacetamide</td>
<td>27</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>26</td>
</tr>
</tbody>
</table>

*aTemperature not reported.*
TATB

TATB solubility in sulfuric acid and water mixtures.

<table>
<thead>
<tr>
<th>Acid (vol%)</th>
<th>Maximum Quantity Dissolved (grams of TATB/100 ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>66.7</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>80</td>
<td>0.24</td>
</tr>
<tr>
<td>85</td>
<td>0.32</td>
</tr>
<tr>
<td>87.5</td>
<td>&gt;1.28</td>
</tr>
<tr>
<td>90</td>
<td>3.84</td>
</tr>
<tr>
<td>100</td>
<td>&gt;24.0</td>
</tr>
</tbody>
</table>

4. PHYSICAL PROPERTIES

4.1 Crystal Structure. Only one TATB polymorph has been observed. The triclinic unit cell parameters are given.

<table>
<thead>
<tr>
<th>Cell Parameters</th>
<th>TATB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of unit cell edge (Å)</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>9.010 ± 0.003</td>
</tr>
<tr>
<td>b</td>
<td>9.028 ± 0.003</td>
</tr>
<tr>
<td>c</td>
<td>6.812 ± 0.003</td>
</tr>
<tr>
<td>Angle (°)</td>
<td></td>
</tr>
<tr>
<td>α</td>
<td>108.590 ± 0.02</td>
</tr>
<tr>
<td>β</td>
<td>91.820 ± 0.03</td>
</tr>
<tr>
<td>γ</td>
<td>119.970 ± 0.01</td>
</tr>
</tbody>
</table>

Molecules per unit cell 2

4.2 Density.

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Method of Determination</th>
<th>State</th>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X-ray</td>
<td>Solid</td>
<td>23</td>
<td>1.937</td>
</tr>
<tr>
<td></td>
<td>Direct measurement</td>
<td>Solid</td>
<td>23</td>
<td>1.93 ± 0.01</td>
</tr>
</tbody>
</table>

Pressed

TATB powder at 120°C can be pressed to a density of 1.860 g/cm³ at a pressure of 30 000 psi.
4.3 Infrared Spectrum. See Fig. 1.

4.4 Refractive Index. TATB crystals are pleochroic, being colorless parallel to the X-axis and yellow in the Y-Z plane. They are anisotropic. The indices of refraction are $N_x = 1.45$, $N_y = 2.3$, and $N_z = 3.1$.

5. THERMAL PROPERTIES

5.1 Phase Change.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-liquid$^a$</td>
<td>448-449</td>
<td>---</td>
</tr>
<tr>
<td>Solid-to-gas$^b$</td>
<td>---</td>
<td>40.21</td>
</tr>
<tr>
<td>(vaporization)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$Determined on a hot bar melting apparatus. Rapid decomposition was observed in both solid and liquid states.

$^b$Determined from the vapor pressure data listed in Section 5.2.

Fig. 1. Infrared spectrum.
TATB

5.2 Vapor Pressure. The TATB crystals are extremely anisotropic. The linear coefficient of expansion in the three unit cell directions has been estimated from the following x-ray data.

<table>
<thead>
<tr>
<th>Cell Direction</th>
<th>Coefficient of Expansion (1/°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>$9.50 \times 10^{-6}$</td>
<td>−60 to +100</td>
</tr>
<tr>
<td>b</td>
<td>$2.10 \times 10^{-6}$</td>
<td>−60 to +100</td>
</tr>
<tr>
<td>c</td>
<td>$2.25 \times 10^{-4}$</td>
<td>−60 to +100</td>
</tr>
</tbody>
</table>

A least squares fit to the data gives

$$\log_{10} P = 14.73 - 402 \frac{100}{4.576} T(\text{K})$$

5.3 Heat Capacity.

Heat Capacity at Constant Pressure (cal/g-°C)

$$0.215 + 1.324 \times 10^{-3} T$$

5.4 Thermal Conductivity.

Conductivity (cal/s-cm-°C)

$$1.3 \times 10^{-3}$$

5.5 Coefficient of Thermal Expansion. The TATB crystals are extremely anisotropic. The linear coefficient of expansion in the three unit cell directions has been estimated from the following x-ray data.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>129.3</td>
</tr>
<tr>
<td>136.2</td>
</tr>
<tr>
<td>150.0</td>
</tr>
<tr>
<td>161.4</td>
</tr>
<tr>
<td>166.4</td>
</tr>
<tr>
<td>177.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vapor Pressure (mm Hg × 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.06-4.10</td>
</tr>
<tr>
<td>6.36-6.50</td>
</tr>
<tr>
<td>10.41-11.02</td>
</tr>
<tr>
<td>29.00-29.28</td>
</tr>
<tr>
<td>42.09</td>
</tr>
<tr>
<td>49.16</td>
</tr>
</tbody>
</table>

A least squares fit to the data gives

$$\log_{10} P = 14.73 - 402 \frac{100}{4.576} T(\text{K})$$
The volume coefficient of expansion is estimated from the same x-ray data.

<table>
<thead>
<tr>
<th>Coefficient of Expansion (1/°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.36 \times 10^{-4}</td>
<td>-60 to +10</td>
</tr>
<tr>
<td>3.67 \times 10^{-4}</td>
<td>10 to 100</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation at 25°C.

\[ \Delta H^\circ_c = -735.9 \text{ kcal/mole} \]
\[ \Delta H^\circ_f = -33.4 \text{ kcal/mole} \]

5.7 Thermal Decomposition Kinetics.

- Decomposition energy: 600 cal/g
- Activation energy: 59.9 kcal/mole
- Pre-exponential factor: \(3.18 \times 10^{10}/\text{s}\)

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.0-0.2 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, Tm</td>
<td>347°C</td>
</tr>
<tr>
<td>Charge radius, a</td>
<td>3.3 mm</td>
</tr>
<tr>
<td>Density, (\rho)</td>
<td>1.84 g/cm³</td>
</tr>
</tbody>
</table>

6. DETONATION PROPERTIES

6.1 Detonation Velocity.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Charge Diameter (mm)</th>
<th>Average Detonation Velocity (mm/μs)</th>
<th>Confinement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.860</td>
<td>25.35</td>
<td>7.619 ± 0.001</td>
<td>Copper tube with a 2.54-mm wall</td>
</tr>
</tbody>
</table>
Effect of Densities

Density affects the infinite diameter detonation velocity as follows:
\[ D = 2.480 + 2.852 \rho_0, \]
where \( D \) = infinite diameter velocity in millimeters per microseconds, and \( \rho_0 \) = density in grams per cubic centimeter.

Effect of Charge Diameter

Charge diameter affects the detonation velocity of unconfined TATB pressed to a density of 1.860 g/cm\(^3\) as follows:
\[ D = 7.758 - 0.472/d \quad \text{for} \quad d \geq 4 \text{ mm} \]
where \( D \) = the detonation velocity in millimeters per microsecond, and \( d \) = charge diameter in millimeters.

Failure Diameter

The failure diameter of TATB pressed to a density of 1.860 g/cm\(^3\) is 4.0 mm.

6.2 Detonation Pressure.\(^{11}\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Detonation Velocity (mm/(\mu)s)</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.847</td>
<td>7.66</td>
<td>25.9</td>
</tr>
<tr>
<td>1.50</td>
<td>---</td>
<td>17.5</td>
</tr>
</tbody>
</table>
6.3 Cylinder Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Cylinder Wall Velocity (mm/μs) at R - R₀ = 5 mm</th>
<th>R - R₀ = 19 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.860</td>
<td>1.268</td>
<td>1.446</td>
</tr>
</tbody>
</table>

6.4 Plate Dent Test Results.

<table>
<thead>
<tr>
<th>Charge Diameter (mm)</th>
<th>Density (g/cm³)</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>41.3</td>
<td>1.87</td>
<td>8.31</td>
</tr>
</tbody>
</table>

7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Gₜ₀ (mm)</th>
<th>Lₜ₀ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large Scale</td>
<td></td>
</tr>
<tr>
<td>1.870</td>
<td>21.92</td>
<td>0.43</td>
</tr>
<tr>
<td>1.872</td>
<td>0.127</td>
<td>0.10</td>
</tr>
</tbody>
</table>

7.2 Wedge Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Distance, x*, and Time, t*, to Detonation (mm and μs)</th>
<th>Pressure Range (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.714</td>
<td>log P = (1.09 ± 0.02) − (0.41 ± 0.17) log x*</td>
<td>3.27 &lt; P &lt; 5.64</td>
</tr>
<tr>
<td></td>
<td>log P = (0.8 ± 0.07) − (0.32 ± 0.12) log t*,</td>
<td></td>
</tr>
<tr>
<td>1.841</td>
<td>log P = (1.39 ± 0.07) − (0.52 ± 0.07) log x*</td>
<td>5.93 &lt; P &lt; 16.5</td>
</tr>
<tr>
<td></td>
<td>log P = (1.01 ± 0.02) − (0.46 ± 0.05) log t*,</td>
<td></td>
</tr>
<tr>
<td>1.876</td>
<td>log P = (1.42 ± 0.02) − (0.40 ± 0.03) log x*</td>
<td>11.4 &lt; P &lt; 16.22</td>
</tr>
<tr>
<td></td>
<td>log P = (1.11 ± 0.01) − (0.36 ± 0.03) log t*,</td>
<td></td>
</tr>
</tbody>
</table>

where P = pressure in gigapascals.
7.3 Shock Hugoniot.\textsuperscript{11-13} A number of TATB shock Hugoniot at various densities have been determined using different experimental techniques.

<table>
<thead>
<tr>
<th>Density (g/cm\textsuperscript{3})</th>
<th>Shock Hugoniot (mm/\textmu s)</th>
<th>Particle Velocity Range (mm/\textmu s)</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.847</td>
<td>(U_s = 2.34 + 2.316 U_p)</td>
<td>0 &lt; (U_p) &lt; 1.5</td>
<td>a</td>
</tr>
<tr>
<td>1.876</td>
<td>(U_s = 1.46 + 3.68 U_p)</td>
<td>0 &lt; (U_p) &lt; 0.48</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>(U_s = 2.037 + 2.497 U_p)</td>
<td>0.48 &lt; (U_p) &lt; 1.54</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(U_s = (1.663 \pm 0.123) + (2.827 \pm 0.132) U_p)</td>
<td>0.15 &lt; (U_p) &lt; 1.47</td>
<td>a</td>
</tr>
<tr>
<td>1.937</td>
<td>(U_s = 1.73 + 6.56 U_p - 4.14 U_p^2)</td>
<td>0 &lt; (U_p) &lt; 0.35</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>(U_s = 2.93 + 1.69 U_p)</td>
<td>0.35 &lt; (U_p)</td>
<td></td>
</tr>
</tbody>
</table>

\*Direct measurement of shock velocity.
\textsuperscript{b}Isothermal compression x-ray computation.

7.4 Minimum Priming Charge.\textsuperscript{14}

<table>
<thead>
<tr>
<th>Density (g/cm\textsuperscript{3})</th>
<th>(W_{50}) (mg of XTX 8003)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.876</td>
<td>(&gt;1.53 \times 10^4)</td>
<td>Pressed charge</td>
</tr>
</tbody>
</table>

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>(H_{50}) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>&gt;320</td>
</tr>
<tr>
<td>12B</td>
<td>&gt;320</td>
</tr>
</tbody>
</table>
8.4 Susan Test Results.

<table>
<thead>
<tr>
<th>Projectile Impact Velocity (m/s)</th>
<th>Relative Energy Release*</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>Threshold for reaction</td>
</tr>
</tbody>
</table>

*Measured in terms of overpressure relative to the overpressure achieved in a detonation.

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>31</td>
<td>4.25</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>31</td>
<td>18.1</td>
<td>0</td>
</tr>
</tbody>
</table>

9. MECHANICAL PROPERTIES

9.2 Tensile Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Ultimate Tensile Strength (psi)</th>
<th>Tensile Modulus (psi × 10⁻⁵)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>1.864</td>
<td>370</td>
<td>6.91</td>
</tr>
</tbody>
</table>

9.3 Compressive Strength and Modulus.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Ultimate Compressive Strength (psi)</th>
<th>Compressive Modulus (psi × 10⁻⁵)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.804</td>
<td>1360</td>
<td>2.62</td>
</tr>
</tbody>
</table>
REFERENCES


TETRYL

1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. Tetryl (2,4,6-trinitrophenylmethylnitramine), \( \text{C}_7\text{H}_5\text{N}_6\text{O}_6 \), is a light yellow crystalline solid. Other accepted names are 2,4,6-trinitro-N-methylaniline; picrylmethylnitramine; Tetrylite; Tetralite; Tetralita; and C. E.

1.2 Common Use. Tetryl is no longer commonly used as a US military explosive. It was used as a booster explosive, in binary mixtures of TNT and tetryl (Tetratola), and as the base charge in detonators.

1.3 Toxicity. Tetryl can yellow human skin and sometimes cause dermatitis. Some workers' eyes and nasal membranes may become irritated, which can lead to excessive sneezing and nosebleeds. The suggested maximum permissible concentration of tetryl dust in air is 1.5 mg/m³.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. Two processes have been used extensively in tetryl production. In the first, \( \text{N},\text{N}-\text{dimethylaniline} \) is dissolved in concentrated sulfuric acid and the mixture is run slowly into nitric acid. Cooling precipitates the crude tetryl, which is then purified by washing with water and recrystallization from benzene or
acetone. In the second process, methylamine is reacted with 2,4- or 2,6-dinitrochlorobenzene to dinitrophenyl methylamine, which is then nitrated to tetryl.


2.3 Shipping. Tetryl may be shipped dry as a Class A explosive.

2.4 Storage. Tetryl is stored dry in Compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Structural Formula.

\[ \text{C}_7\text{H}_5\text{N}_4\text{O}_4 \]

3.2 Molecular Weight. 287.15

3.3 Solubility.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>50°C</th>
<th>60°C</th>
<th>75°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.0075</td>
<td>0.0195</td>
<td>0.035</td>
<td>0.066</td>
</tr>
<tr>
<td>Ethanol (95 vol%)</td>
<td>0.563</td>
<td>1.72</td>
<td>2.64</td>
<td>5.33</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>0.025</td>
<td>0.095</td>
<td>0.154</td>
<td>0.297</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.57</td>
<td>1.78</td>
<td>2.65</td>
<td>---</td>
</tr>
<tr>
<td>Ethylene chloride</td>
<td>3.8</td>
<td>12.0</td>
<td>18.8</td>
<td>45.0</td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td>0.021</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Ether</td>
<td>0.418</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
4. PHYSICAL PROPERTIES

4.1 Crystal Structure. The tetryl crystal is monoclinic and has the following cell parameters.

<table>
<thead>
<tr>
<th>Cell Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of unit cell edge (Å)</td>
</tr>
<tr>
<td>a</td>
</tr>
<tr>
<td>b</td>
</tr>
<tr>
<td>c</td>
</tr>
<tr>
<td>Angle β</td>
</tr>
</tbody>
</table>

Molecules per unit cell 4

4.2 Density.  

<table>
<thead>
<tr>
<th>Method of Determination</th>
<th>State</th>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray data</td>
<td>Solid</td>
<td>21</td>
<td>1.731</td>
</tr>
<tr>
<td>Flotation</td>
<td>Solid</td>
<td>21</td>
<td>1.74</td>
</tr>
</tbody>
</table>

**Pressed Tetryl**

Compression usually gives the following densities.

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 000</td>
<td>1.40</td>
</tr>
<tr>
<td>5 000</td>
<td>1.47</td>
</tr>
<tr>
<td>10 000</td>
<td>1.57</td>
</tr>
<tr>
<td>20 000</td>
<td>1.67</td>
</tr>
<tr>
<td>30 000</td>
<td>1.71</td>
</tr>
</tbody>
</table>

4.3 Infrared Spectrum. See Fig. 1.
TETRYL

4.4 Refractive Indices.

\[
\begin{align*}
\text{alpha} & \quad 1.546 \\
\text{beta} & \quad 1.632
\end{align*}
\]

5. THERMAL PROPERTIES

5.1 Phase Changes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
<th>Latent Heat (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-liquid</td>
<td>129.45</td>
<td>22.2</td>
<td>6.37</td>
</tr>
</tbody>
</table>

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Heat Capacity at Constant Pressure (cal/g·°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0.211 + 2.6 \times 10^{-4} T)</td>
<td>(-100 &lt; T &lt; 100)</td>
</tr>
</tbody>
</table>

Fig. 1. Infrared spectrum.
5.4 Thermal Conductivity.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Conductivity (cal/s·cm·°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.53</td>
<td>6.83 × 10⁻⁴</td>
</tr>
<tr>
<td>1.39</td>
<td>5.81 × 10⁻⁴</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation at 25°C:

\[ \Delta H_f^0 = -836.8 \text{ kcal/mole} \]
\[ \Delta H_f = 7.6 \text{ kcal/mole} \]

5.7 Thermal Decomposition Kinetics.

Activation energy 38.4 k cal/mole
Frequency factor \(2.51 \times 10^{16}/s\)

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum stability</td>
<td>0.4-1.0 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, Tm</td>
<td>187°C</td>
</tr>
</tbody>
</table>

![Graph showing DTA and pyrolysis test results.](image-url)

Fig. 2. Tetryl DTA and pyrolysis test results.
TETRYL

6. DETONATION PROPERTIES

6.1 Detonation Velocity.

Effect of Density

\[ D = 2.742 + 2.935 \rho_o \quad (1.3 \leq \rho_o \leq 1.69), \]

where \( D \) = detonation velocity in millimeters per microsecond, and \( \rho_o \) = charge density in grams per cubic centimeter.

6.2 Detonation Pressure.\(^\text{12}\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Detonation Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.614</td>
<td>22.64</td>
</tr>
</tbody>
</table>

6.4 Plate Dent Test Results.

<table>
<thead>
<tr>
<th>Charge Diameter (mm)</th>
<th>Density (g/cm(^3))</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.3</td>
<td>1.681</td>
<td>8.10</td>
<td>203</td>
</tr>
</tbody>
</table>

7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.\(^\text{13}\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>( G_{oo} ) (mm)</th>
<th>( L_{oo} ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.85</td>
<td>69.21</td>
<td>0.61</td>
</tr>
<tr>
<td>1.666</td>
<td>60.60</td>
<td>0.63</td>
</tr>
<tr>
<td>1.682</td>
<td>59.38</td>
<td>0.18</td>
</tr>
</tbody>
</table>

| Small Scale           |                   |                   |
| 0.93                  | 7.44              | 0.05              |
| 1.678                 | 4.04              | 0.20              |
| 1.684                 | 3.83              | 0.30              |
7.2 Wedge Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Distance, x*, and Time, t*, to Detonation (mm and µs)</th>
<th>Pressure Range (GPa)</th>
</tr>
</thead>
</table>
| 1.70           | \[ \log P = (0.79 \pm 0.01) - (0.42 \pm 0.01) \log x^* \]  
|                | \[ \log P = (0.55 \pm 0.01) - (0.39 \pm 0.01) \log t^* \]  
|                | 2.22 < P < 8.53                                       |
| 1.60           | \[ \log P = (0.73 \pm 0.01) - (0.65 \pm 0.01) \log x^* \]  
|                | \[ \log P = (0.4 \pm 0.01) - (0.55 \pm 0.01) \log t^* \]  
|                | 1.08 < P < 8.02                                       |
| 1.50           | \[ \log P = (0.75 \pm 0.01) - (0.81 \pm 0.01) \log x^* \]  
|                | \[ \log P = (0.35 \pm 0.01) - (0.64 \pm 0.01) \log t^* \]  
|                | 0.62 < P < 7.09                                       |
| 1.40           | \[ \log P = (0.84 \pm 0.01) - (0.99 \pm 0.02) \log x^* \]  
|                | \[ \log P = (0.35 \pm 0.01) - (0.75 \pm 0.01) \log t^* \]  
|                | 0.51 < P < 6.84                                       |
| 1.30           | \[ \log P = (0.87 \pm 0.05) - (1.11 \pm 0.07) \log x^* \]  
|                | \[ \log P = (0.33 \pm 0.02) - (0.83 \pm 0.03) \log t^* \]  
|                | 0.37 < P < 6.91                                       |

where P = pressure in gigapascals.

7.3 Shock Hugoniots.¹⁴

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Shock Hugoniot (mm/µs)</th>
<th>Particle Velocity Range (mm/µs)</th>
</tr>
</thead>
</table>
| 1.70           | \[ U_s = 2.476 + 1.416 U_p \]  
|                | \[ U_s = 2.362 + 1.528 U_p - 0.255/U_p \]  
| 1.60           | \[ U_s = 2.167 + 1.662 U_p - 0.341/U_p \]  
| 1.50           | \[ U_s = 1.611 + 1.966 U_p - 0.278/U_p \]  
| 1.40           | \[ U_s = 2.162 + 1.427 U_p - 0.499/U_p \]  
| 1.30           | \[ U_s = 2.162 + 1.427 U_p - 0.499/U_p \]  

0.428 < U_p < 1.195  
0.324 < U_p < 1.232  
0.287 < U_p < 1.231  
0.297 < U_p < 1.253  
0.296 < U_p < 1.399

7.4 Minimum Priming Charge.¹³

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>W₅₀ (mg of XTX 8003)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.692</td>
<td>1.5</td>
</tr>
</tbody>
</table>
TETRYL

7.5 Detonation Failure Thickness.\textsuperscript{18}

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Failure Thickness (mm)</th>
<th>(L_{95}) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.684</td>
<td>0.267</td>
<td>0.079</td>
</tr>
</tbody>
</table>

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>(H_{50}) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>425</td>
</tr>
<tr>
<td>12B</td>
<td>490</td>
</tr>
</tbody>
</table>

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>3</td>
<td>48.2</td>
<td>0.54</td>
<td>50</td>
</tr>
<tr>
<td>Brass</td>
<td>10</td>
<td>48.2</td>
<td>2.79</td>
<td>50</td>
</tr>
<tr>
<td>Steel</td>
<td>1</td>
<td>54.0</td>
<td>0.19</td>
<td>50</td>
</tr>
<tr>
<td>Steel</td>
<td>10</td>
<td>54.0</td>
<td>3.83</td>
<td>50</td>
</tr>
</tbody>
</table>
REFERENCES


2. Committee on Threshold Limit Values, Documentation of Threshold Limit Values, 3rd Ed. (American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati, Ohio, 1971).


1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. TNT (2,4,6-trinitrotoluene), C₇H₅N₃O₆, is a light yellow or buff crystalline solid. This isomer, also known as TNT in the United States, is the compound used in military explosives. TNT is also known by a variety of other names: Tolite in France; Tri, Trotyl, Tutol, Trinol, and Fullpulver 1902 in Germany; Tritolo in Italy; Tol, Trotil, TNT in the Union of Soviet Socialist Republics; and TNT in the United Kingdom.

1.2 Common Use. TNT is the most common military explosive because of its ease of manufacture and its suitability for melt loading, either as the pure explosive or as binary mixtures. The most common binary mixtures are cyclotols (mixtures with RDX), octols (mixtures with HMX), amatols (mixtures with ammonium nitrate), and tritonals (mixtures with aluminum).

1.3 Toxicity. Inhaled TNT vapor or dust may irritate mucous membranes and cause sneezing, coughing, and sore throat. TNT may produce toxic hepatitis and aplastic anemia. TNT yellows the exposed skin, hair, and nails of workers. Dermatitis, erythema, papules, and itchy eczema can be severe. Ingestion of 1-2 g of TNT is estimated to be an acute fatal dose to humans. The suggested maximum permissible airborne dust concentration is 0.5 mg/m³.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. Toluene is nitrated to TNT in one, two, or three stages with a mixture of nitric and sulfuric acids. The crude TNT is purified by washing with a water solution of sodium sulfite (the Sellite process). The sulfite reacts with the 2,3,4- and 2,3,5-isomers of TNT to form water soluble compounds, which are then removed.

2.3 Shipping. TNT may be shipped dry as a Class A explosive.

2.4 Storage. TNT is stored dry in compatibility Group D, Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Structural Formula.

![Structural formula of TNT](image)

$C_7H_5N_3O_6$

3.2 Molecular Weight. 227.13

3.3 Solubility.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>20°C</th>
<th>40°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>109.0</td>
<td>228.0</td>
<td>600.0</td>
</tr>
<tr>
<td>Benzene</td>
<td>67.0</td>
<td>180.0</td>
<td>478.0</td>
</tr>
<tr>
<td>Butyl carbinol acetate</td>
<td>24.0</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td>0.48</td>
<td>1.53</td>
<td>---</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>0.65</td>
<td>1.75</td>
<td>6.90</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>33.9</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Chloroform</td>
<td>19.0</td>
<td>66.0</td>
<td>302.0</td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>3.29</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Ethanol (95%)</td>
<td>1.23</td>
<td>2.92</td>
<td>8.30</td>
</tr>
<tr>
<td>Ethylene chloride</td>
<td>18.7</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Hexane</td>
<td>0.16</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Methyl acetate</td>
<td>72.1</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Toluene</td>
<td>55.0</td>
<td>130.0</td>
<td>367.0</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>3.04</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Water</td>
<td>0.0130</td>
<td>0.0285</td>
<td>0.0675</td>
</tr>
</tbody>
</table>
4. PHYSICAL PROPERTIES

4.1 Crystal Structure. Both orthorhombic and monoclinic TNT have been observed. The monoclinic form is obtained by annealing cast TNT. Crystallization of TNT from most solvents gives complex mixed-phase intergrowth and twinned crystals that usually show structural disorder. Good monocrystals of TNT have been obtained from cyclohexanone.

Cell parameters of the two polymorphs are given.

<table>
<thead>
<tr>
<th>Cell Parameters</th>
<th>Monoclinic</th>
<th>Orthorhombic*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of unit cell edges (Å)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>21.275</td>
<td>15.007</td>
</tr>
<tr>
<td>b</td>
<td>6.093</td>
<td>20.029</td>
</tr>
<tr>
<td>c</td>
<td>15.025</td>
<td>6.098</td>
</tr>
<tr>
<td>Angle β</td>
<td>110.14°</td>
<td></td>
</tr>
<tr>
<td>Molecules per unit cell</td>
<td>8.0</td>
<td>---</td>
</tr>
</tbody>
</table>

*There is some controversy about existence of the orthorhombic polymorph, which may be a disordered version of the monoclinic one (Ref. 8).

4.2 Density. Solid and Liquid

<table>
<thead>
<tr>
<th>Method of Determination</th>
<th>State</th>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray data</td>
<td>Solid</td>
<td>21</td>
<td>1.653</td>
</tr>
<tr>
<td>Direct measurement</td>
<td>Solid</td>
<td>21</td>
<td>1.654</td>
</tr>
<tr>
<td>Direct measurement</td>
<td>Liquid</td>
<td>83-120</td>
<td>1.545 - 1.016 × 10⁻⁴ T(°C)</td>
</tr>
</tbody>
</table>

174
Pressed Charges. The density of TNT in large billets or in ammunition varies with the method of preparation. Compression without application of a vacuum to remove the residual air gives the following densities.

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 000</td>
<td>1.35</td>
</tr>
<tr>
<td>5 000</td>
<td>1.40</td>
</tr>
<tr>
<td>10 000</td>
<td>1.45</td>
</tr>
<tr>
<td>15 000</td>
<td>1.52</td>
</tr>
<tr>
<td>20 000</td>
<td>1.55</td>
</tr>
<tr>
<td>50 000</td>
<td>1.60</td>
</tr>
</tbody>
</table>

Compaction with the residual air removed and the TNT preheated to 70°C gives the following density.

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Powder Temperature (°C)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 000</td>
<td>70</td>
<td>1.63-1.64</td>
</tr>
</tbody>
</table>

Cast Charges. The density of cast TNT depends on the procedures used to melt, cast, and solidify it. Typical densities are as follows.

<table>
<thead>
<tr>
<th>Preparative Procedure</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting⁴</td>
<td>Casting⁵</td>
</tr>
<tr>
<td>Open 100% liquid</td>
<td>Ambient</td>
</tr>
<tr>
<td>Open 75% liquid</td>
<td>Ambient</td>
</tr>
<tr>
<td>Vacuum 50-75% liquid</td>
<td>Ambient</td>
</tr>
</tbody>
</table>

⁴In an open melt the TNT is melted in atmospheric conditions. In a vacuum melt, the molten TNT is subjected to a vacuum (~20 mm Hg) for a few minutes.

⁵Because of the ~7% volume change associated with the liquid-to-solid transition, solid TNT is usually added to the liquid TNT. The TNT, either as a liquid or as a mixture of liquid and solids, is cast at a temperature within a degree or two of the melting point (80-82°C).
TNT

4.3 **Infrared Spectrum.** See Fig. 1.

4.4 **Refractive Indices.** The following refractive indices in sodium light have been reported.

\[
\begin{array}{ll}
\alpha & 1.5430 \\
\beta & 1.6742 \\
\gamma & 1.717 \\
\end{array}
\]

5. **THERMAL PROPERTIES**

5.1 **Phase Changes.**

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g)</th>
<th>Latent Heat (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-to-liquid</td>
<td>80.9</td>
<td>23.53</td>
<td>5.35</td>
</tr>
<tr>
<td>Solid-to-gas</td>
<td>---</td>
<td>---</td>
<td>28.3*</td>
</tr>
</tbody>
</table>

*Computed from the solid-phase vapor pressure data in Sec. 5.2.

![Fig. 1. Infrared spectrum.](image)
5.2 Vapor Pressure

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Vapor Pressure (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60.1</td>
<td>5.43 x 10^-4</td>
</tr>
<tr>
<td>78.5</td>
<td>6.44 x 10^-2</td>
</tr>
<tr>
<td>80.2</td>
<td>7.16 x 10^-2</td>
</tr>
<tr>
<td>82.4</td>
<td>7.96 x 10^-2</td>
</tr>
<tr>
<td>99.5</td>
<td>4.07 x 10^-2</td>
</tr>
<tr>
<td>110.6</td>
<td>8.26 x 10^-2</td>
</tr>
<tr>
<td>131.1</td>
<td>3.48 x 10^-1</td>
</tr>
<tr>
<td>141.4</td>
<td>6.21 x 10^-1</td>
</tr>
</tbody>
</table>

A least squares fit to these data gives

\[ \log_{10} P(\text{mm Hg}) = 15.43 - 6180/T(\text{K}) \]

5.3 Heat Capacity

<table>
<thead>
<tr>
<th>Heat Capacity at Constant Pressure (cal/g-°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.254 + 7.5 x 10^-4 T(°C)</td>
<td>17 &lt; T &lt; 67</td>
</tr>
<tr>
<td>0.309 + 5.5 x 10^-4 T(°C)</td>
<td>97 &lt; T &lt; 150</td>
</tr>
</tbody>
</table>

5.4 Thermal Conductivity

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Conductivity (cal/s-cm-°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.59</td>
<td>6.22 x 10^-4</td>
<td>10 &lt; T &lt; 45</td>
</tr>
<tr>
<td>1.59</td>
<td>5.89 x 10^-4</td>
<td>45 &lt; T &lt; 75</td>
</tr>
</tbody>
</table>
5.5 Coefficient of Thermal Expansion.

<table>
<thead>
<tr>
<th>Coefficient of Expansion (°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$5.0 \times 10^{-6} + 7.8 \times 10^{-8} T$</td>
<td>$-40 &lt; T &lt; 60$</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation at 25°C.  

$$\Delta H_e^0 = -817.2 \text{ kcal/mole}$$

5.7 Thermal Decomposition Kinetics.  

- Decomposition energy: $300 \text{ cal/g}^*$
- Activation energy: $34.4 \text{ kcal/mole}$
- Pre-exponential factor: $2.51 \times 10^{11}/s$

*$^*$The complexities of the decomposition reaction are described in Ref. 15.

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.2 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
<tr>
<td>Critical temperature, $T_m$</td>
<td>$288°C$</td>
</tr>
<tr>
<td>Charge radius, $a$</td>
<td>$0.38 \text{ mm}$</td>
</tr>
<tr>
<td>Density, $\rho$</td>
<td>$1.57 \text{ g/cm}^3$</td>
</tr>
</tbody>
</table>
6. DETONATION PROPERTIES

6.1 Detonation Velocity.\textsuperscript{16-18}

Effect of Density

\begin{align*}
\text{Density Range} & \quad \text{(g/cm}^3) \\
0.9 < \rho_0 < 1.534 \\
1.534 < \rho_0 < 1.636
\end{align*}

\begin{align*}
D &= 1.873 + 3.187 \rho_0, \\
\text{and} \\
D &= 6.762 + 3.187 (\rho_0 - 1.534) - 25.1 (\rho_0 - 1.534)^2, \\
\text{where } D &= \text{detonation velocity in millimeters per microsecond and} \\
\rho_0 &= \text{density in grams per cubic centimeter.}
\end{align*}

\[ + 115.056 (\rho - 1.534)^3 \]
The charge preparation method affects the infinite-diameter detonation velocity and failure diameter of unconfined cylindrical charges as follows.

<table>
<thead>
<tr>
<th>Method of Charge Preparation</th>
<th>Charge Density (g/cm³)</th>
<th>Detonation Velocity at Infinite &quot;D&quot; (mm/μs)</th>
<th>Critical Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum melting</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Creaming and casting</td>
<td>1.615</td>
<td>6.942 ± 0.028</td>
<td>14.6 ± 2.0</td>
</tr>
<tr>
<td>Vacuum melting and casting</td>
<td>1.620</td>
<td>6.999 ± 0.011</td>
<td>14.5 ± 0.5</td>
</tr>
<tr>
<td>Pressing</td>
<td>1.620</td>
<td>7.045 ± 0.170</td>
<td>2.6 ± 0.6</td>
</tr>
<tr>
<td>Liquid</td>
<td>1.443</td>
<td>6.574 ± 0.001</td>
<td>62.6 ± 2.6</td>
</tr>
</tbody>
</table>

**Effect of Charge Radius**

Detonation velocity varies with charge radius and preparation procedure as follows.

<table>
<thead>
<tr>
<th>Method of Charge Preparation</th>
<th>Density (g/cm³)</th>
<th>Effect of Charge Radius on Detonation Velocity (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creaming and casting</td>
<td>1.615</td>
<td>D(R) = 6.942 [(1−5.67 × 10⁻²/R)− 4.2 × 10⁻¹/R (R − 7.41)]</td>
</tr>
<tr>
<td>Vacuum melting and casting</td>
<td>1.620</td>
<td>D(R) = 6.999 [(1 − 1.3 × 10⁻²/R)− 6.2 × 10⁻¹/R (R − 5.5)]</td>
</tr>
<tr>
<td>Pressing</td>
<td>1.620</td>
<td>D(R) = 7.045 [(1 − 6.1 × 10⁻²/R)− 3.5 × 10⁻²/R (R − 0.57)]</td>
</tr>
<tr>
<td>Liquid</td>
<td>1.443</td>
<td>D(R) = 6.574 (1 − 0.291/R)</td>
</tr>
</tbody>
</table>
The detonation velocity of liquid TNT at 81°C is given.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm³)</th>
<th>Velocity (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>1.462</td>
<td>6.633</td>
</tr>
</tbody>
</table>

6.2 Detonation Pressure.19

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Pressure (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.637</td>
<td>6.942 ± 0.016</td>
<td>18.91 ± 0.1</td>
</tr>
</tbody>
</table>

6.3 Cylinder Test Results.20

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Cylinder Wall Velocity (mm/μs) at R - R₀ = 5 mm</th>
<th>Cylinder Wall Velocity (mm/μs) at R - R₀ = 19 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.630</td>
<td>6.940</td>
<td>1.18</td>
<td>1.40</td>
</tr>
</tbody>
</table>
6.4 Plate Dent Test Results.

<table>
<thead>
<tr>
<th>Charge Diameter (mm)</th>
<th>Density (g/cm³)</th>
<th>Dent Depth (mm)</th>
<th>Charge Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.7</td>
<td>1.63</td>
<td>1.57</td>
<td>12.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.70</td>
<td>16.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.93</td>
<td>84.58-508</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.90</td>
<td>203.0</td>
</tr>
<tr>
<td>25.4</td>
<td>1.631</td>
<td>1.73</td>
<td>12.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.90</td>
<td>25.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.20</td>
<td>31.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.04</td>
<td>42.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.19</td>
<td>50.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.27</td>
<td>63.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.14</td>
<td>72.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.19</td>
<td>84.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.09</td>
<td>101.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.11</td>
<td>127.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.14</td>
<td>169.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.06</td>
<td>254.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.09</td>
<td>508.0</td>
</tr>
<tr>
<td>1.626</td>
<td></td>
<td>6.73</td>
<td>63.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.01</td>
<td>101.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.60</td>
<td>169.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.01</td>
<td>203.0</td>
</tr>
<tr>
<td>1.640</td>
<td></td>
<td>6.88</td>
<td>203.0</td>
</tr>
<tr>
<td>41.3</td>
<td>1.626</td>
<td>3.02</td>
<td>16.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.01</td>
<td>25.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.67</td>
<td>31.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.41</td>
<td>42.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.05</td>
<td>50.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.90</td>
<td>63.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.06</td>
<td>72.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.14</td>
<td>76.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.18</td>
<td>101.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.06</td>
<td>127.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.81</td>
<td>169-203</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.93</td>
<td>254.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.78</td>
<td>304.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.96</td>
<td>508.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.99</td>
<td>1016.0</td>
</tr>
</tbody>
</table>
7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.\(^{21}\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>(G_{50}) (mm)</th>
<th>(L_{45}) (mm)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.800</td>
<td>61.49</td>
<td>0.38</td>
<td>Bulk density flake</td>
</tr>
<tr>
<td>1.024</td>
<td>61.54</td>
<td>0.20</td>
<td>Pressed</td>
</tr>
<tr>
<td>1.220</td>
<td>56.26</td>
<td>0.08</td>
<td>Pressed</td>
</tr>
<tr>
<td>1.356</td>
<td>56.02</td>
<td>0.25</td>
<td>Pressed</td>
</tr>
<tr>
<td>1.505</td>
<td>54.92</td>
<td>0.30</td>
<td>Pressed</td>
</tr>
<tr>
<td>1.551</td>
<td>54.46</td>
<td>0.28</td>
<td>Pressed</td>
</tr>
<tr>
<td>1.595</td>
<td>52.53</td>
<td>0.18</td>
<td>Pressed</td>
</tr>
<tr>
<td>1.631</td>
<td>46.43</td>
<td>0.30</td>
<td>Pressed</td>
</tr>
<tr>
<td>1.615</td>
<td>28.30</td>
<td>0.64</td>
<td>Cast</td>
</tr>
<tr>
<td>Small Scale*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.77</td>
<td>4.11</td>
<td>0.08</td>
<td>Granular at bulk density</td>
</tr>
<tr>
<td>0.84</td>
<td>No go at zero gap</td>
<td></td>
<td>Flake at bulk density</td>
</tr>
<tr>
<td>1.628</td>
<td>0.33</td>
<td>0.05</td>
<td>Pressed at 65°C</td>
</tr>
</tbody>
</table>

*The failure diameter of cast TNT is 14.5 mm, so it cannot be initiated in the small-scale gap test.

7.2 Wedge Test Results.\(^{22}\)

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Distance, (x^<em>), and Time, (t^</em>), to Detonation (mm and (\mu\mathrm{s}))</th>
<th>Pressure Range (GPa)</th>
</tr>
</thead>
</table>
| 1.62 to 1.634         | \[
log P = (1.40 \pm 0.03) - (0.32 \pm 0.03) \log x^* \\
log P = (1.16 \pm 0.03) - (0.31 \pm 0.05) \log t^* ,
\]
where \(P = \) pressure in gigapascals. | \(9.17 < P < 17.1\) |
### 7.3 Shock Hugoniot.\textsuperscript{23,24}

<table>
<thead>
<tr>
<th>Density (g/cm$^3$)</th>
<th>Shock Hugoniot (mm/μs)</th>
<th>Particle Velocity Range (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.614</td>
<td>$U_s = 2.390 + 2.50 U_p$,</td>
<td></td>
</tr>
<tr>
<td>1.63</td>
<td>$U_s = 2.57 + 1.88 U_p$,</td>
<td>---</td>
</tr>
</tbody>
</table>

where $U_s =$ shock velocity and $U_p =$ particle velocity.

### 7.4 Minimum Priming Charge.

<table>
<thead>
<tr>
<th>Density (g/cm$^3$)</th>
<th>$W_{50}$ (mg of XTX 8003)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.59</td>
<td>394</td>
<td>Pressed at 65°C</td>
</tr>
<tr>
<td>1.63</td>
<td>1260</td>
<td>Pressed at 65°C</td>
</tr>
</tbody>
</table>

### 7.5 Detonation Failure Thickness.\textsuperscript{21}

<table>
<thead>
<tr>
<th>Density (g/cm$^3$)</th>
<th>Failure Thickness (mm)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.568</td>
<td>1.82</td>
<td>Pressed at 65°C</td>
</tr>
<tr>
<td>1.627</td>
<td>2.16</td>
<td>Pressed at 65°C</td>
</tr>
<tr>
<td>1.629</td>
<td>1.76</td>
<td>Pressed at 65°C</td>
</tr>
<tr>
<td>1.631</td>
<td>2.00</td>
<td>Pressed at 72°C</td>
</tr>
<tr>
<td>1.635</td>
<td>2.59</td>
<td>Pressed at 72°C</td>
</tr>
</tbody>
</table>
8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>( H_{50} ) (cm)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>212</td>
<td>Flake TNT</td>
</tr>
<tr>
<td>12B</td>
<td>&gt;320</td>
<td>Flake TNT</td>
</tr>
<tr>
<td>12</td>
<td>154</td>
<td>Granular TNT</td>
</tr>
<tr>
<td>12B</td>
<td>&gt;320</td>
<td>Granular TNT</td>
</tr>
</tbody>
</table>

8.5 Spark Sensitivity.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Lead Foil Thickness (mils)</th>
<th>Sample Size (mg)</th>
<th>Energy (J)</th>
<th>Occurrence of Explosion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>3</td>
<td>47.9</td>
<td>0.46</td>
<td>50</td>
</tr>
<tr>
<td>Brass</td>
<td>10</td>
<td>47.9</td>
<td>2.75</td>
<td>50</td>
</tr>
<tr>
<td>Steel</td>
<td>1</td>
<td>53.0</td>
<td>0.19</td>
<td>50</td>
</tr>
<tr>
<td>Steel</td>
<td>10</td>
<td>53.0</td>
<td>4.00</td>
<td>50</td>
</tr>
</tbody>
</table>

9. MECHANICAL PROPERTIES

9.1 Viscosity.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Viscosity (cp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>12.0-13.7</td>
</tr>
<tr>
<td>90</td>
<td>10.6-11.8</td>
</tr>
<tr>
<td>95</td>
<td>9.4-10.2</td>
</tr>
<tr>
<td>100</td>
<td>8.6-9.0</td>
</tr>
</tbody>
</table>
9.3 Compressive Strength and Modulus.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Ultimate Compressive Strength¹ (psi)</th>
<th>Compressive Modulus¹ (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.60</td>
<td>1400</td>
<td>7.9 x 10⁴</td>
</tr>
</tbody>
</table>

¹Compressive strength is a function of density and method of charge preparation. These are cast TNT data.

REFERENCES


1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. XTX (Extex) 8003 consists of PETN coated with a low-temperature vulcanizing silicone resin, Sylgard 182. Uncured XTX 8003 is putty-like and can be extruded through small openings at modest pressures. After curing, it is white and rubbery.

1.2 Common Use. XTX 8003 is used in special applications that require explosives with small detonation failure diameters.

1.3 Toxicity. There are no known toxicity problems associated with the use of Sylgard 182. PETN, because it is insoluble in water, is slightly toxic. The recommended maximum atmospheric concentration over an 8-h period is 15 mg/m³.

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. Sylgard 182 resin and its curing agent are mixed with PETN in a high-shear vertical mixer to the consistency of wet sea sand. This material is passed through a three-roll differential paint mill until it is the consistency of glazier’s putty. After milling, XTX 8003 has a shelf life of 24 h at 25°C. Storage at −30°C increases the shelf life to 8 months. When it is to be used, the XTX 8003 is extruded into molds of the desired configuration. Curing or polymerization is achieved by exposure to 65°C for 8-12 h.
2.2 Procurement. XTX 8003 can be purchased from the DOE under LASL material specification 13Y-104481 Rev. F, dated February 6, 1978.

2.3 Shipping. Cured or uncured XTX 8003 is shipped as a Class A explosive.

2.4 Storage. Uncured XTX 8003 is in Storage Compatibility Group A. When cured, it is stored in Compatibility Group D. Either cured or in a device, it is in Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Composition.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Weight Percent</th>
<th>Volume Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>PETN</td>
<td>80</td>
<td>69.9</td>
</tr>
<tr>
<td>Sylgard 182</td>
<td>20</td>
<td>30.1</td>
</tr>
</tbody>
</table>

3.2 Molecular Weight.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>PETN</td>
<td>[ \text{NO}_2 ] \quad \text{O} \quad \text{CH}_2 \quad \text{O}_2\text{N}=\text{O}-\text{CH}_2\text{-C=CH}_2\text{-O=NO}_2 \quad \text{CH}_2 \quad \text{O} \quad \text{NO}_2 ] \quad \text{C}_6\text{H}_8\text{N}<em>4\text{O}</em>{12}</td>
<td>316.15</td>
</tr>
<tr>
<td>Sylgard 182</td>
<td>Proprietary</td>
<td></td>
</tr>
</tbody>
</table>
3.3 Solubility. The solubility is that of PETN.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Grams of PETN Dissolved/100 g of Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C</td>
</tr>
<tr>
<td>Acetone</td>
<td>24.8</td>
</tr>
<tr>
<td>Acetone and water</td>
<td></td>
</tr>
<tr>
<td>(wt% water)</td>
<td>6.23</td>
</tr>
<tr>
<td></td>
<td>12.30</td>
</tr>
<tr>
<td></td>
<td>18.22</td>
</tr>
<tr>
<td></td>
<td>23.99</td>
</tr>
<tr>
<td></td>
<td>35.11</td>
</tr>
<tr>
<td></td>
<td>55.80</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.27</td>
</tr>
<tr>
<td>Ethanol</td>
<td>0.13</td>
</tr>
<tr>
<td>Ethyl acetate</td>
<td>10.6</td>
</tr>
</tbody>
</table>

4. PHYSICAL PROPERTIES

4.2 Density.

<table>
<thead>
<tr>
<th>Theoretical Density (g/cm³)</th>
<th>Density of Typical Charges (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.556</td>
<td>1.50</td>
</tr>
</tbody>
</table>

4.3 Infrared Spectrum. See Fig. 1.
5. THERMAL PROPERTIES

5.1 Phase Change.

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature (°C)</th>
<th>Latent Heat (cal/g mix)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PETN (solid-to-liquid)</td>
<td>142.9</td>
<td>29.9</td>
</tr>
</tbody>
</table>

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Heat Capacity at Constant Pressure (cal/g-°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.50</td>
<td>$0.252 + 8.5 \times 10^{-4} T$</td>
<td>$37 &lt; T &lt; 127$</td>
</tr>
</tbody>
</table>

5.5 Coefficient of Thermal Expansion.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Coefficient of Expansion (°C)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.50</td>
<td>$1.65 \times 10^{-6}$</td>
<td>$-50 &lt; T &lt; 25$</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation.

<table>
<thead>
<tr>
<th></th>
<th>$\Delta H_f^o$ (kcal/mole)</th>
<th>$\Delta H_l^o$ (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PETN</td>
<td>$-618.7$</td>
<td>$-110.34$</td>
</tr>
</tbody>
</table>
5.7 Thermal Decomposition Kinetics.

<table>
<thead>
<tr>
<th>Property</th>
<th>PETN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition energy</td>
<td>300 cal/g</td>
</tr>
<tr>
<td>Activation energy</td>
<td>47.0 kcal/mole</td>
</tr>
<tr>
<td>Pre-exponential factor</td>
<td>$6.3 \times 10^{19}$/s</td>
</tr>
</tbody>
</table>

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.2 ml/g of gas evolved after 48 h at 100°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 2</td>
</tr>
</tbody>
</table>

6. DETONATION PROPERTIES

6.1 Detonation Velocity.

**Effect of Charge Radius**

Charge radius affects the detonation velocity of XTX 8003 at a density of 1.53 g/cm³, confined in polycarbonate plastic in a hemicylinder configuration, as follows.

$$D(R) = 7.260[(1 - 0.191 \times 10^{-2}/R) - 2.12 \times 10^{-4}/R (R - 0.111)]$$

where $D = $ detonation velocity in millimeters per microsecond,

and $R =$ charge radius in millimeters.

The experimentally determined failure diameter in polycarbonate confinement is 0.36 mm.

7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.

<table>
<thead>
<tr>
<th>Small Scale</th>
</tr>
</thead>
</table>
| $\begin{array}{ccc} 
\text{Density} & G_{50} & L_{55} \\
(g/cm^3) & (mm) & (mm) \\
1.50 & 4.42 & 0.28 \\
\end{array}$ |
7.2 Wedge Test Results.

\[
\text{Density (g/cm}^3) \quad \text{Distance, } x^* \text{, and Time, } t^* \text{, to Detonation (mm and } \mu\text{s}) \quad \text{Pressure Range (GPa)}
\]

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Distance, x*, and Time, t*, to Detonation (mm and μs)</th>
<th>Pressure Range (GPa)</th>
</tr>
</thead>
</table>
| 1.53            | \[
\log P = (0.74 \pm 0.01) - (0.37 \pm 0.02) \log x^*
\]
|                 | \[
\log P = (0.53 \pm 0.008) - (0.33 \pm 0.02) \log t^*,
\]            | 2.5 < P < 8.2       |
|                 | where P = pressure in gigapascals.                   |                     |

7.3 Shock Hugoniot.¹⁰

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Shock Hugoniot (mm/μs)</th>
<th>Particle Velocity Range (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.50</td>
<td>[ U_p = 1.49 + 3.03 U_v ] (Ref. 10)</td>
<td>0 &lt; U_p &lt; 0.8</td>
</tr>
<tr>
<td>1.53</td>
<td>[ U_p = (1.59 \pm 0.39) + (3.24 \pm 0.63) U_v ]</td>
<td>0.48 &lt; U_p &lt; 0.78</td>
</tr>
</tbody>
</table>

7.4 Minimum Priming Charge. XTX 8003 is used as the donor explosive in this test.
8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>$H_{10}$ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td>12B</td>
<td>35</td>
</tr>
</tbody>
</table>

*Cured or uncured.

8.4 Susan Test Results.

<table>
<thead>
<tr>
<th>Projectile Impact Velocity (ft/s)</th>
<th>Relative Energy Release (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>&lt;1</td>
</tr>
<tr>
<td>750</td>
<td>~5-8</td>
</tr>
</tbody>
</table>

9. MECHANICAL PROPERTIES

9.2 Tensile Strength and Modulus.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm²)</th>
<th>Ultimate Tensile Strength (psi)</th>
<th>Tensile Modulus (psi x 10^-6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>1.50</td>
<td>90 ± 20</td>
<td>b</td>
</tr>
</tbody>
</table>

*aCured.

bStrain-to-failure of a 0.25-in.-diam charge tested at a load rate of 0.05/min occurs after 5% elongation.
REFERENCES


2. Committee on Threshold Limit Values, Documentation of Threshold Limit Values, 3rd Ed., (American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1971).


1. GENERAL PROPERTIES

1.1 Chemical and Physical Description. XTX (Extex) 8004 consists of RDX coated with a low-temperature vulcanizing silicone resin, Sylgard 182. Uncured XTX 8004 is putty-like and can be extruded through small openings at modest pressures. After curing, it is white and rubbery.

1.2 Common Use. XTX 8004 is used in special applications that require more thermal stability than XTX 8003 can give. The detonation failure diameter is slightly greater than that of XTX 8003.

1.3 Toxicity. Sylgard 182 is not known to be toxic. Workers who inhaled RDX dust for several months have become unconscious with loss of reflexes. The suggested maximum permissible airborne concentration of RDX is 1.5 mg/m³ (Ref. 1).

2. MANUFACTURE AND PROCUREMENT

2.1 Manufacture. Sylgard 182 resin and its curing agent are mixed with RDX in a high-shear vertical mixer to the consistency of wet sea sand. This material is passed through a three-roll differential paint mill until it reaches the consistency of glazier’s putty. Milled XTX 8004 has a 24-h shelf life at 25°C. Storage at -30°C increases the shelf life to 8 months. When it is to be used, the XTX 8004 is extruded into molds of the desired configuration. Curing or polymerization is achieved by exposure to 65°C for 8-12 h.

2.2 Procurement. XTX 8004 can be purchased from the DOE under LASL material specification 13Y-189496 Rev. A, dated November 22, 1978.

2.3 Shipping. Cured or uncured, XTX 8004 is shipped as a Class A explosive.
2.4 Storage. Uncured or cured, XTX 8004 is in Storage Compatibility Group D and Storage Class 1.1.

3. CHEMICAL PROPERTIES

3.1 Composition

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Weight Percent</th>
<th>Volume Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td>80</td>
<td>69.9</td>
</tr>
<tr>
<td>Sylgard 182</td>
<td>20</td>
<td>30.1</td>
</tr>
</tbody>
</table>

3.2 Molecular Weight.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Structure</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td>H2 (\text{N}C\text{NNO}_2)</td>
<td>222.13</td>
</tr>
<tr>
<td></td>
<td>C\text{H}_2\text{N}_2\text{O}_6</td>
<td></td>
</tr>
<tr>
<td>Sylgard 182</td>
<td>Proprietary</td>
<td></td>
</tr>
</tbody>
</table>
3.3 Solubility. The solubility is that of RDX.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Grams of RDX Dissolved/100 g of Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>99.6%</td>
</tr>
<tr>
<td>99.6%</td>
<td>0.46</td>
</tr>
<tr>
<td>71.0%</td>
<td>0.22</td>
</tr>
<tr>
<td>Acetone</td>
<td>6.81</td>
</tr>
<tr>
<td>Isoamyl alcohol</td>
<td>0.026</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.045</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>0.33</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>4.94</td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td>---</td>
</tr>
<tr>
<td>Ethanol</td>
<td>0.12</td>
</tr>
<tr>
<td>Methyl acetate</td>
<td>2.9</td>
</tr>
<tr>
<td>Methylcyclohexanone</td>
<td>6.81</td>
</tr>
<tr>
<td>Methyl ethyl ketone</td>
<td>3.23</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.020</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>0.20</td>
</tr>
<tr>
<td>Water</td>
<td>0.005</td>
</tr>
</tbody>
</table>

4. PHYSICAL PROPERTIES

4.2 Density.

<table>
<thead>
<tr>
<th></th>
<th>Theoretical Density (g/cm³)</th>
<th>Density of Typical Charge (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.584</td>
<td>1.5</td>
</tr>
</tbody>
</table>

5. THERMAL PROPERTIES

5.3 Heat Capacity.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Heat Capacity at Constant Pressure (cal/g)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>0.247 + 6.2 × 10⁻⁴</td>
<td>25 &lt; T &lt; 187</td>
</tr>
</tbody>
</table>
5.4 Thermal Conductivity.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Conductivity (cal/cm-s-°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>3.4 x 10⁻⁴</td>
</tr>
</tbody>
</table>

5.6 Heats of Combustion and Formation.

<table>
<thead>
<tr>
<th></th>
<th>( \Delta H_f^o ) (kcal/mole)</th>
<th>( \Delta H_f^o ) (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td>-660.7</td>
<td>11.3</td>
</tr>
</tbody>
</table>

5.7 Thermal Decomposition Kinetics.

<table>
<thead>
<tr>
<th>Property</th>
<th>RDX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition energy</td>
<td>500 cal/g</td>
</tr>
<tr>
<td>Activation energy</td>
<td>47.1 kcal/mole</td>
</tr>
<tr>
<td>Pre-exponential factor</td>
<td>( 2.02 \times 10^{18} )/s</td>
</tr>
</tbody>
</table>

5.8 Other Thermal Stability Test Results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>0.1-0.3 ml/g of gas evolved after 48 h at 120°C</td>
</tr>
<tr>
<td>DTA and pyrolysis</td>
<td>See Fig. 1</td>
</tr>
</tbody>
</table>

Fig. 1. XTX-8004 DTA and pyrolysis test results.
6. DETONATION PROPERTIES

6.1 Detonation Velocity.

Effect of Charge Radius
Charge radius affects the detonation velocity of 1.5-g/cm³ XTX 8004 confined in polycarbonate plastic in a hemispherical configuration as follows.

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Detonation Velocity (mm/µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>∞</td>
<td>7.45</td>
</tr>
<tr>
<td>4.5</td>
<td>7.35</td>
</tr>
<tr>
<td>3.13</td>
<td>7.30</td>
</tr>
<tr>
<td>2.0</td>
<td>7.22</td>
</tr>
<tr>
<td>1.75</td>
<td>7.15</td>
</tr>
<tr>
<td>1.6</td>
<td>Failure</td>
</tr>
</tbody>
</table>

7. SHOCK INITIATION PROPERTIES

7.1 Gap Test Results.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>G₀₀ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.52</td>
<td>1.96</td>
</tr>
</tbody>
</table>

8. SENSITIVITY

8.1 Drop Weight Impact Height.

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>Cured</th>
<th>Uncured</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>70</td>
<td>65</td>
</tr>
<tr>
<td>12B</td>
<td>170</td>
<td>145</td>
</tr>
</tbody>
</table>
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EXPLOSIVES PROPERTIES
BY PROPERTIES
PART II. EXPLOSIVES PROPERTIES BY PROPERTIES

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<table>
<thead>
<tr>
<th>Explosive</th>
<th>Constituents</th>
<th>Weight Percent</th>
<th>Volume Percent</th>
<th>Molecular Formula</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alex/20</td>
<td>RDX</td>
<td>44</td>
<td>44.07</td>
<td>C(_2)H(_6)N(_5)O(_4)</td>
<td>222.13</td>
</tr>
<tr>
<td></td>
<td>TNT</td>
<td>32</td>
<td>34.93</td>
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| *W* LNO,   | 100           | 100          | 100          | 80           | 20           |
| *287.15*   | 100           | 100          | 100          | 70.3         | 29.6         |
| *80 70.3*  | 20            | 69.9         | 20           | Proprietary  | Proprietary  |
| *20 29.6*  |              |              |              |              |              |
| *80 69.3*  |              |              |              |              |              |
| *20 30.1*  |              |              |              |              |              |

### Plastic-Bonded DATB

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**Chemical Properties**

- C$_{6}$H$_{5}$N$_{6}$O$_{5}$
- C$_{2}$H$_{3}$N$_{2}$O$_{2}$
- C$_{4}$H$_{6}$N$_{15}$O$_{18}$
- C$_{3}$H$_{2}$N$_{12}$O$_{12}$
- C$_{2}$H$_{4}$N$_{18}$O$_{18}$
- C$_{6}$H$_{12}$N$_{10}$O$_{10}$
- C$_{5}$H$_{2}$F$_{5.8}$
- C$_{6}$H$_{12}$N$_{4}$O$_{4}$
- C$_{4}$H$_{12}$O$_{4}$Cl$_{3}$P
- C$_{6}$H$_{14}$N$_{10}$O$_{10}$
- C$_{6}$H$_{12}$N$_{10}$O$_{10}$
- C$_{5}$H$_{2}$F$_{5.8}$
- C$_{6}$H$_{12}$N$_{4}$O$_{4}$
- C$_{4}$H$_{12}$O$_{4}$Cl$_{3}$P
- C$_{5}$H$_{2}$F$_{5.8}$
- C$_{6}$H$_{12}$N$_{4}$O$_{4}$
- C$_{4}$H$_{12}$O$_{4}$Cl$_{3}$P

**Formulations**

- (104.15)$_n$
- (180.51)$_n$
- (187.07)$_n$
## Table 1.01 (continued)

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<td>Viton A</td>
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### HMX-Bonded Explosives

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<tr>
<th>Name</th>
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<th>HNM</th>
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<td>DNPA</td>
<td>1.477</td>
<td></td>
<td></td>
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<td></td>
<td>CEF</td>
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<tr>
<td>Explosive</td>
<td>Densities of Constituents</td>
<td>Mixture</td>
<td>Melting Point (°C)</td>
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<tr>
<td>X-0234-60</td>
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<td>1.870, 1.845</td>
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<td>X-0234-70</td>
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<td>X-0286</td>
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<td>X-0118</td>
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<td>1.915</td>
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</tr>
</tbody>
</table>

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2. THERMAL PROPERTIES

2.1 Heat Capacity Determination. Heat capacity was measured by use of a differential scanning calorimeter (DSC). In this instrument, a sample of explosive is subjected to a linearly increasing temperature and the heat flow rate, dH/dt, is monitored continuously. The heat capacity of the sample can be found from 
\[ \frac{dH}{dt} = mC_p\frac{dT}{dt}, \]
where 
\( \frac{dH}{dt} = \) heat flow rate in calories per second, 
\( m = \) sample mass in grams, 
\( C_p = \) heat capacity in calories per gram per degree Celsius, 
\( T = \) temperature in degree Celsius, and 
\( t = \) time. In using this equation to find \( C_p \), one must know both \( \frac{dH}{dt} \) and the rate at which the temperature is increased or, more commonly, use a material of known heat capacity to calibrate the instrument.

Synthetic sapphire, whose heat capacity is well known, is used as a reference.

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>Heat Capacity, ( C_p ) (cal/g·°C)</th>
<th>Valid Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Explosives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DATB</td>
<td>1.834</td>
<td>( 0.20 + (1.11 \times 10^{-3})T - (1.81 \times 10^{-5})T^2 )</td>
<td>---</td>
</tr>
<tr>
<td>DIPAM</td>
<td>1.79</td>
<td>( 0.235 + (6.2 \times 10^{-4})T - (4.75 \times 10^{-6})T^2 )</td>
<td>---</td>
</tr>
<tr>
<td>HNS</td>
<td>1.74</td>
<td>( 0.201 + (1.27 \times 10^{-3})T - (2.39 \times 10^{-5})T^2 )</td>
<td>---</td>
</tr>
<tr>
<td>HMX</td>
<td>1.90</td>
<td>( 0.231 + (5.5 \times 10^{-4})T )</td>
<td>( 37 &lt; T &lt; 167 )</td>
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<tr>
<td>PETN</td>
<td>1.770</td>
<td>( 0.239 + (8.0 \times 10^{-4})T )</td>
<td>( 37 &lt; T &lt; 127 )</td>
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<tr>
<td>RDX</td>
<td>1.804</td>
<td>( 0.232 + (7.2 \times 10^{-4})T )</td>
<td>( 37 &lt; T &lt; 167 )</td>
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<tr>
<td>TATB</td>
<td>1.938</td>
<td>( 0.215 + (1.324 \times 10^{-3})T - (2 \times 10^{-5})T^2 )</td>
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</tr>
<tr>
<td>Tetryl</td>
<td>1.73</td>
<td>( 0.213 + (2.18 \times 10^{-4})T - (3.73 \times 10^{-5})T^2 )</td>
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<td>Castable Mixtures</td>
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<tr>
<td>Comp B-3</td>
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<td>( 7 &lt; T &lt; 67 )</td>
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<tr>
<td></td>
<td></td>
<td>( 0.137 + (2.09 \times 10^{-3})T )</td>
<td>( 97 &lt; T &lt; 157 )</td>
</tr>
<tr>
<td>TNT</td>
<td>---</td>
<td>( 0.254 + (7.5 \times 10^{-4})T )</td>
<td>( 17 &lt; T &lt; 67 )</td>
</tr>
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<td></td>
<td></td>
<td>( 0.329 + (5.50 \times 10^{-4})T )</td>
<td>( 97 &lt; T &lt; 157 )</td>
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<td>Plastic-Bonded Explosives</td>
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<tr>
<td><strong>HMX-Based</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>PBX 9011</td>
<td>1.772</td>
<td>( 0.259 + (6.3 \times 10^{-4})T )</td>
<td>( 17 &lt; T &lt; 167 )</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.845</td>
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<td>( 17 &lt; T &lt; 147 )</td>
</tr>
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<td>( 50 &lt; T &lt; 175 )</td>
</tr>
<tr>
<td><strong>PETN-Based</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>XTX 8003</td>
<td>---</td>
<td>( 0.252 + (8.5 \times 10^{-4})T )</td>
<td>( 37 &lt; T &lt; 127 )</td>
</tr>
<tr>
<td><strong>RDX-Based</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>PBX 9010</td>
<td>1.785</td>
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<td>( 37 &lt; T &lt; 167 )</td>
</tr>
<tr>
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<td>( 0.241 + (7.7 \times 10^{-4})T )</td>
<td>( 37 &lt; T &lt; 167 )</td>
</tr>
<tr>
<td>XTX 8004</td>
<td>---</td>
<td>( 0.247 + (6.2 \times 10^{-4})T )</td>
<td>( 25 &lt; T &lt; 187 )</td>
</tr>
</tbody>
</table>

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standard. To determine the heat capacity of an explosive, one must establish a base line that indicates the differential heat loss of the two aluminum sample containers at the initial temperature. This is done by placing two empty sample containers in the DSC sample holders and subjecting them to a linearly increasing temperature. Next, a weighed sample of test explosive is placed in one container, both containers are subjected to the linearly increasing temperature, and the heat flow rate is recorded as a function of temperature. Then the procedure is repeated with a weighed sample of synthetic sapphire.

The heat capacity at any temperature is calculated by using \( C_p = C_{pi}(m_i) \times (h)/m_{h_i} \), where \( C_p \) = heat capacity of the explosive at temperature \( T \), \( C_{pi} \) = heat capacity of the sapphire at temperature \( T \), \( m \) = weight of the explosive sample, \( m_i \) = weight of the sapphire, \( h \) = baseline deflection of the explosive sample, and \( h_i \) = baseline deflection of the sapphire.

2.2 Thermal Conductivity. Two steady-state procedures have been used to determine the thermal conductivity of explosives. The first is the guarded hot plate (GHP) procedure that the American Society for Testing and Materials (ASTM) uses and describes to test insulating materials in ASTM Source C-177. The second procedure involves a differential scanning calorimeter. The DSC sample is much smaller and more suitable for testing high explosives than is the GHP sample.

The DSC method requires two identical right circular cylinders, one of the test material and the other of a reference material. The thermal conductivity is determined, under steady-state conditions, from the heat flow and temperature drop along the cylinder length. The following equations apply.

\[
q_1 = \frac{k_1A_1\Delta T}{L_1}
\]

and

\[
q_2 = \frac{k_2A_2\Delta T}{L_2},
\]

where

\( q_1 - q_2 = \) DSC output,
\( A = \) area of cylinder base,
\( L = \) cylinder length,
\( \Delta T = \) temperature drop along the cylinder length,
\( k_1 = \) thermal conductivity of reference material,

and

\( k_2 = \) thermal conductivity of unknown.

Because \( \Delta T, A, \) and \( L \) of both the reference and unknown are identical, the thermal conductivity of the unknown is given by


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\[
k_2 = k_1 - \frac{(q_1 - q_2) L}{A \Delta T}
\]

For thermal conductivity measurements, the DSC must have a sample-mounting structure consisting of a common metal plate or heat sink, an insulating block, an aluminum radiation shield, and sample holders. The unknown and reference samples are placed in good thermal contact with the sample holder plate and are surrounded by an aluminum radiation shield. An insulating block separates the heat sink and shield. The tops of the samples make thermal contact with a copper heat sink through two circular holes in the insulating block. Thermocouples in the heat sink and sample holders measure the temperature at the sample surfaces.

2.3 Coefficient of Thermal Expansion. Two procedures were used to measure the coefficient of thermal expansion. That used for large specimens was the

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>Thermal Conductivity (cal/cm·s·°C)</th>
<th>Test Temperature or Temperature Range (°C)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Explosives</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DATB</td>
<td>1.834</td>
<td>(6 \times 10^{-4})</td>
<td>---</td>
<td>DSC(^{a})</td>
</tr>
<tr>
<td>HMX</td>
<td>1.91</td>
<td>(1 \times 10^{-3})</td>
<td>---</td>
<td>DSC</td>
</tr>
<tr>
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<td>(1.014 \times 10^{-3})</td>
<td>41</td>
<td>DSC</td>
</tr>
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<td>---</td>
<td>GHP(^{b})</td>
</tr>
<tr>
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<td>(1.3 \times 10^{-3})</td>
<td>---</td>
<td>GHP</td>
</tr>
<tr>
<td>Tetral</td>
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<td>(6.83 \times 10^{-4})</td>
<td>---</td>
<td>GHP</td>
</tr>
<tr>
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<td>GHP</td>
</tr>
<tr>
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<td>(5 \times 10^{-4})</td>
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<td>GHP</td>
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</tr>
<tr>
<td>Comp B</td>
<td>1.730</td>
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<td>GHP</td>
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<td>Cyclotol 75/25</td>
<td>1.760</td>
<td>(5.41 \times 10^{-4})</td>
<td>45</td>
<td>GHP</td>
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<td>Plastic-Bonded Explosives</td>
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<td></td>
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<td>HMX-Based</td>
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<td></td>
</tr>
<tr>
<td>PBX 9011</td>
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<td>(9.08 \times 10^{-4})</td>
<td>43.4</td>
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</tr>
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<td>(9.2 \times 10^{-4})</td>
<td>46.2</td>
<td>GHP</td>
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<td>1.847</td>
<td>(1.084 \times 10^{-3})</td>
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<td>GHP</td>
</tr>
<tr>
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</tr>
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<td>XTX 8003</td>
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<td>(3.42 \times 10^{-4})</td>
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<td>1.875</td>
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<td>GHP</td>
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</table>

\(^{a}\)Differential scanning calorimeter.

\(^{b}\)Guarded hot plate method.
American Society for Testing and Materials procedure D696-70, "Coefficient of Linear Expansion of Plastics." A DuPont Model 900 thermal analyzer equipped with a Model 941 thermomechanical analyzer (TMA) was used for single crystals and small specimens. They are denoted by ASTM and TMA in the following tables.

2.4 Thermal Decomposition Kinetics. The thermal decomposition rate constants of explosives, discussed in detail by R. N. Rogers, are found using a differential scanning calorimeter at constant temperature.

The kinetic constants were determined using a Perkin-Elmer DSC-1B or DSC-2. Samples were sealed in Perkin-Elmer No. 219-0062 aluminum cells perforated by a single 0.15-mm-diam hole. Differential and average temperature calibrations of the DSC-1B were checked before the runs.

The recorder and the DSC with two empty cells on its supports are set at the test temperature. The sample cell is removed, and the instrument is allowed to equilibrate. The recorder is started, the instrument range switch is set, and the sample is dropped onto the support. The sharp break on the record is used to mark zero time. (The absolute position of the zero point on the time axis is unimportant because rate constants are determined from the slope of the ln deflection, b, vs time, t, plot.)

The DSC deflection above the base line, b, is directly proportional to the rate of energy evolution or absorption by the sample, dq/dt, which is proportional in turn, to the reaction rate da/dt. Therefore,

\[ \alpha b = \beta dq/dt = da/dt = k(1 - a) , \]  

where \( \alpha \) and \( \beta \) are proportionality constants and \( k \) is the rate constant. Hence,

\[ \ln b = \ln k/\alpha + \ln(1 - a) . \]  

For a first-order reaction,

\[ -\ln(1 - a) = kt + C , \]  

where \( C \) is a constant. Substituting Eq. (3) into Eq. (2) and combining constants gives

\[ \ln b = C - kt . \]

Therefore, rate constants for first-order reactions can be obtained directly from a plot of ln deflection vs time. This provides the rate constant, \( k \), as a function of temperature, since \( k \) is given by

\[ k = Z e^{-E/RT} , \]

where
<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>Coefficient of Thermal Expansion (1/°C)</th>
<th>Valid Temperature Range (°C)</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pure Explosives</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PETN</td>
<td>---</td>
<td>(8.55 × 10⁻⁵) + (1.82 × 10⁻⁷)T</td>
<td>-160 &lt; T &lt; 100</td>
<td>TMAa</td>
</tr>
<tr>
<td></td>
<td>---</td>
<td>+ (6.30 × 10⁻¹⁰)T² + (2.17 × 10⁻¹²)T³</td>
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<td></td>
</tr>
<tr>
<td>RDX</td>
<td>---</td>
<td>(6.75 × 10⁻⁶) + (1.28 × 10⁻⁸)T</td>
<td>-160 &lt; T &lt; 100</td>
<td>TMAb</td>
</tr>
<tr>
<td></td>
<td>---</td>
<td>+ (0.74 × 10⁻¹⁰)T² + (1.27 × 10⁻¹²)T³</td>
<td></td>
<td></td>
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<tr>
<td>TNT</td>
<td>---</td>
<td>(2.205 × 10⁻⁶) + (4.38 × 10⁻⁸)T</td>
<td>-160 &lt; T &lt; 100</td>
<td>TMAc</td>
</tr>
<tr>
<td></td>
<td>---</td>
<td>+ (7.78 × 10⁻¹⁰)T² + 4.71 × 10⁻¹²)T³</td>
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<tr>
<td><strong>Castable Mixtures</strong></td>
<td></td>
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<tr>
<td>Baratol</td>
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<td>(3.4 × 10⁻⁶) + (2.8 × 10⁻⁸)T</td>
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<td>ASTM</td>
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<td>Comp B</td>
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<td>5.46 × 10⁻⁵</td>
<td>6 &lt; T &lt; 25</td>
<td>ASTM</td>
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<td><strong>Plastic-Bonded Explosives</strong></td>
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</tr>
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<td>ASTM</td>
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<td>ASTM</td>
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<td>4.91 × 10⁻⁵</td>
<td>-54 &lt; T &lt; 74</td>
<td>ASTM</td>
</tr>
<tr>
<td>PETN-Based</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XTX 8003</td>
<td>---</td>
<td>1.65 × 10⁻⁴</td>
<td>-50 &lt; T &lt; 25</td>
<td>ASTM</td>
</tr>
</tbody>
</table>

*aLinear expansion along 001-axis.

*bLinear expansion along 100-axis.

*cVolume coefficient of expansions.
Z = the pre-exponential factor in reciprocal seconds,

and

E = energy in kilocalories per mole.

The chemical Arrhenius data plot, ln k as a function of 1/T, was used to obtain Z and E.

The fraction decomposed is determined by Simpson's Rule integration using closely spaced deflection measurements.

### Table 2.04 DECOMPOSITION KINETICS

<table>
<thead>
<tr>
<th>Explosive</th>
<th>State</th>
<th>Density (g/cm³)</th>
<th>Heat of Reaction, Q (cal/g)</th>
<th>Z (1/s)</th>
<th>Activation Energy, E (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Explosives</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTF</td>
<td>Liquid</td>
<td>1.901</td>
<td>600</td>
<td>4.11 x 10¹²</td>
<td>37.2</td>
</tr>
<tr>
<td>DATB</td>
<td>Liquid</td>
<td>1.834</td>
<td>300</td>
<td>1.17 x 10¹⁵</td>
<td>48.3</td>
</tr>
<tr>
<td>DIPAM</td>
<td>Liquid</td>
<td>1.79</td>
<td>---</td>
<td>2.22 x 10⁹</td>
<td>29.2</td>
</tr>
<tr>
<td>HMX</td>
<td>Liquid</td>
<td>1.81</td>
<td>500</td>
<td>5 x 10¹⁹</td>
<td>52.7</td>
</tr>
<tr>
<td></td>
<td>Vapor</td>
<td>---</td>
<td>---</td>
<td>1.51 x 10²⁰</td>
<td>52.9</td>
</tr>
<tr>
<td>HNS</td>
<td>Liquid</td>
<td>1.65</td>
<td>500</td>
<td>1.53 x 10⁹</td>
<td>30.3</td>
</tr>
<tr>
<td>NQ</td>
<td>Liquid</td>
<td>1.74</td>
<td>500</td>
<td>2.84 x 10⁷</td>
<td>20.9</td>
</tr>
<tr>
<td>PATO</td>
<td>Liquid</td>
<td>1.70</td>
<td>500</td>
<td>1.51 x 10¹⁰</td>
<td>32.2</td>
</tr>
<tr>
<td>PETN</td>
<td>Liquid</td>
<td>1.74</td>
<td>300</td>
<td>6.3 x 10¹⁹</td>
<td>47.0</td>
</tr>
<tr>
<td>RDX</td>
<td>Liquid</td>
<td>1.72</td>
<td>500</td>
<td>2.02 x 10¹⁸</td>
<td>47.1</td>
</tr>
<tr>
<td></td>
<td>Vapor</td>
<td>---</td>
<td>---</td>
<td>3.14 x 10¹³</td>
<td>34.1</td>
</tr>
<tr>
<td>TATB</td>
<td>Solid</td>
<td>1.84</td>
<td>600</td>
<td>3.18 x 10¹⁹</td>
<td>59.9</td>
</tr>
<tr>
<td>Tetryl</td>
<td>Liquid</td>
<td>1.73</td>
<td>---</td>
<td>2.5 x 10¹⁵</td>
<td>38.4</td>
</tr>
<tr>
<td>TNT</td>
<td>Liquid</td>
<td>1.57</td>
<td>300</td>
<td>2.51 x 10¹¹</td>
<td>34.4</td>
</tr>
<tr>
<td>TPM</td>
<td>Liquid</td>
<td>1.75</td>
<td>---</td>
<td>1.05 x 10¹⁶</td>
<td>48.5</td>
</tr>
</tbody>
</table>

### 2.5 Heats of Combustion and Formation.

Combustion experiments were conducted in a stationary oxygen-bomb calorimeter that had an automatically controlled adiabatic jacket. The calorimeter was calibrated by burning standard benzoic acid to determine its effective energy equivalent.

The standard heat of combustion of the explosive (in kilocalories per mole) was calculated by use of

\[ \Delta H_\text{c}^\circ = \Delta E_\text{c}^\circ + 0.593 \left( \frac{d}{2} - \frac{b}{4} + \frac{c}{2} \right), \]

where b, c, and d are subscripts in the chemical formula \( C_aH_bN_cO_d \),

\[ \Delta H_\text{c}^\circ = \text{standard heat of combustion at 25°C}, \]

and


**THERMAL PROPERTIES**

\[ \Delta E^o_c = \text{standard internal energy of combustion at 25°C.} \]

The standard heat of formation of the explosive (in kilocalories per mole) was calculated by the use of

\[ \Delta H^o_f = a \Delta H^o_f(\text{CO}_2, \text{g}) + \frac{b}{2} \Delta H^o_f(\text{H}_2\text{O}, \text{l}) - \Delta H^o_c \]

where \( \Delta H^o_f \) = the standard heat of formation of sample,

\[ \Delta H^o_f(\text{CO}_2, \text{g}) = -94.051 \text{ kcal/mole}, \]
\[ \Delta H^o_f(\text{H}_2\text{O}, \text{l}) = -68.315 \text{ kcal/mole}, \]

and \( a \) and \( b \) are the same subscripts as above.

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Heat of Combustion, ( \Delta H^o_c ) (kcal/mole)</th>
<th>Heat of Formation, ( \Delta H^o_f ) (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABH</td>
<td>-2578.4</td>
<td>116.3</td>
</tr>
<tr>
<td>BTF</td>
<td>-1086.1</td>
<td>143.8</td>
</tr>
<tr>
<td>BTX</td>
<td>-1336.2</td>
<td>70.9</td>
</tr>
<tr>
<td>DATB</td>
<td>-711.5</td>
<td>-23.6</td>
</tr>
<tr>
<td>DIPAM</td>
<td>-1326.8</td>
<td>-6.8</td>
</tr>
<tr>
<td>DODECA</td>
<td>-2512.8</td>
<td>50.6</td>
</tr>
<tr>
<td>HMX</td>
<td>-660.7</td>
<td>11.3</td>
</tr>
<tr>
<td>HNAB</td>
<td>-1333.2</td>
<td>67.9</td>
</tr>
<tr>
<td>bis-HNAB</td>
<td>-2653.3</td>
<td>191.1</td>
</tr>
<tr>
<td>HNBP</td>
<td>-1279.9</td>
<td>14.6</td>
</tr>
<tr>
<td>HNS</td>
<td>-1540.3</td>
<td>18.7</td>
</tr>
<tr>
<td>NONA</td>
<td>-1891.2</td>
<td>27.4</td>
</tr>
<tr>
<td>NQ</td>
<td>-210.4</td>
<td>-20.29</td>
</tr>
<tr>
<td>ONT</td>
<td>-1917.6</td>
<td>19.7</td>
</tr>
<tr>
<td>PADP</td>
<td>-1917.4</td>
<td>147.7</td>
</tr>
<tr>
<td>PATO</td>
<td>-999.5</td>
<td>36.3</td>
</tr>
<tr>
<td>PENCO</td>
<td>-1366.9</td>
<td>-26.6</td>
</tr>
<tr>
<td>PETN</td>
<td>618.7</td>
<td>110.34</td>
</tr>
<tr>
<td>PYX</td>
<td>-1858.8</td>
<td>20.9</td>
</tr>
<tr>
<td>RDX</td>
<td>-501.8</td>
<td>14.7</td>
</tr>
<tr>
<td>T-TACOT</td>
<td>-1377.7</td>
<td>112.4</td>
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<tr>
<td>Z-TACOT</td>
<td>1375.7</td>
<td>110.5</td>
</tr>
<tr>
<td>TATB</td>
<td>-735.9</td>
<td>-33.4</td>
</tr>
<tr>
<td>Tetryl</td>
<td>-836.8</td>
<td>7.6</td>
</tr>
<tr>
<td>TNN</td>
<td>-1090.0</td>
<td>12.3</td>
</tr>
<tr>
<td>TNT</td>
<td>-817.2</td>
<td>-12.0</td>
</tr>
<tr>
<td>TPB</td>
<td>-2502.6</td>
<td>-62.1</td>
</tr>
</tbody>
</table>
2.6 Differential Thermal Analysis and Pyrolysis Test. Smothers and Chiang give a complete discussion of the differential thermal analysis technique, and its theory and a complete review is given in the Analytical Reviews edition of Analytical Chemistry.

Figure 2.01 shows the DTA cell design. The 0.139-in.-o.d., 1.25-in.-long stainless steel hypodermic tube, A, is reamed to accept the 0.115-in.-o.d. thermocouple insulators, C. The relatively low thermal conductivity of stainless steel allows use of the axial cell arrangement. The plug, B, between the sample and reference sides of the cell is made by impregnating a small wad of quartz wool with Sauereisen cement and packing it into the center of the tube. After the cement is dry, the cell is ignited in a burner flame. The thermocouples, D, made from 2%gauge Chromel/Alumel, are arc-welded against a carbon rod at the clipped end of a single twist of both wires.

Expendable tube furnaces are a 75-ohm helical coil of Nichrome wire distributed on a helically grooved, 3-in.-long, 11/16-in.-i.d. Alundum tube. A 21/32-in.-o.d. by 3/8-in.-i.d. by 3-in.-long graphite tube is used as a furnace liner for thermal ballast. A 1/4-in.-o.d. aluminum tube is inserted into the furnace liner but is isolated from it by asbestos "O" rings at each end. The natural tubing-cutter constrictions at the ends of the aluminum tube support the thermocouple insulators of the DTA cell and keep it from touching the aluminum walls. A 6-in. cube of foamed glass contains and insulates the assembly. The entire assembly is placed in a blast shield box before a run is started.

The reference thermocouple that indicates cell temperature is connected to the abscissa terminal of a Moseley Autograf Model 2 X-Y recorder. A Leeds and Northrup Model 9835-B dc microvolt amplifier amplifies the differential thermocouple output, which is then connected to the ordinate terminal of the X-Y recorder. An F&M Model 40 linear temperature programmer, which provides a constant heating rate to the cell, is controlled by a thermocouple placed between the Alundum furnace shell and the graphite liner.

Five- to twenty-milligram samples give the best results, but samples as small as 3 mg can be tested. The differential temperature scale normally used is ± 5°C, but the sensitivity can be increased to record differential temperatures of ± 0.5°C.

A deflagration usually does not damage the DTA cell beyond repair. A low-order explosion will destroy the sample thermocouple, but the thermocouple can be replaced without changing the zero-line characteristics of the cell. Detonation of a 10-mg sample will destroy the entire assembly, often including the insulation.

Pyrolysis. Figure 2.02 shows the apparatus used to obtain the pyrolysis curves, and Fig. 2.03 gives details of the pyrolysis block. In this test an ~10-mg sample of
THERMAL PROPERTIES

Fig. 2.02. Pyrolysis apparatus.
A. Carrier gas supply
B. Pressure regulator
C. Flow control needle valve
D. Reference thermal conductivity cell
E. Pyrolysis chamber
F. Combustion tube
G. Active cell
H. Manometer
I. Pressure control needle valve
J. Rotameter

Fig. 2.03. Pyrolysis block.
A. Pyrolysis chamber
B. Nickel plug
C. Carrier gas inlet
D. Carrier gas outlet
E. Cartridge heater wells (2)
F. Helical threads cut in inner body of block
G. Outer shell of block
H. Cooling jacket inlet
I. Cooling jacket outlet

test material is weighed into a small combustion boat and placed in the pyrolysis chamber, initially at room temperature. A 10- to 15-ml/min flow of helium is then started, and when the air has been swept out, the pyrolysis chamber temperature is raised at a constant rate, usually 10°C/min. The helium stream carries gases evolved from the sample through the combustion tube and into the thermal conductivity cell, G. The two cells, D and G, form two arms of a Wheatstone bridge whose output varies with the concentration of impurities (decomposition products, etc.) in the effluent helium stream. The bridge output is fed to one axis of an X-Y recorder, and the pyrolysis chamber temperature is fed to the other. In this manner, the rate of gas evolution from the sample as a function of chamber temperature is determined.

The combustion chamber converts the more complex products, such as undecomposed but vaporized explosive, to simple molecules. This increases the bridge sensitivity and also keeps these products from condensing in the cooler parts of the apparatus.

Data Presentation. All the DTA curves were determined at a heating rate of 11°C/min with granular NaCl as the reference sample. All the pyrolysis curves were determined at a heating rate of 10°C/min. Gas-solid interactions were minimized because gaseous products were swept away from the sample in the pyrolysis apparatus as rapidly as they were formed.

Any possible contribution to the reaction from atmospheric oxygen also was eliminated, because the carrier gas was helium.
THERMAL PROPERTIES

**DATB**

**HMX**

**NQ**
THERMAL PROPERTIES

PETN

RDX

TATB
THERMAL PROPERTIES

Tetryl

TNT

Baratol
THERMAL PROPERTIES

Composition B

Cyclotol 75/25

Octol
THERMAL PROPERTIES

PBX 9501

PBX 9404

PBX 9011
2.7 Time-to-Explosion Test. All explosives decompose exothermally at temperatures above absolute zero. When chemical decomposition produces heat faster than it can be dissipated to the surroundings, the explosive mass self-heats to explosion. In steady-state conditions, the temperature at which a thermal explosion is produced is called the critical temperature, $T_m$. A relatively simple expression for the critical temperature has been derived in terms of the kinetic and physical parameters.

$$T_m = \frac{E}{R \ln \left( \frac{A^2 \rho Q Z E}{T_m^2 \lambda \delta R} \right)},$$

where

- $R$ = gas constant, 1.987 cal/mole,
- $A$ = radius of sphere, cylinder, or half-thickness of a slab,
- $\rho$ = density,
- $Q$ = heat of decomposition reaction,
- $Z$ = pre-exponential factor,
- $E$ = activation energy,
- $\lambda$ = thermal conductivity,
- $\delta$ = shape factor (0.58 for infinite slabs, 2.0 for infinite cylinders, 3.32 for spheres).

The LASL method for determining critical temperatures is based on a time-to-explosion test that Henkin developed. The explosive sample, usually 40 mg, is pressed into a DuPont E-83 aluminum blasting-cap shell and covered with a hollow, skirted plug. A conical punch is used to expand the plug and apply a reproducible 400-lb force. This plug expansion forms a positive seal and confines the sample in a known geometry. The density, which can be calculated from a sample thickness measurement, is usually about 90% of the crystal density.
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This assembly is dropped into a preheated liquid metal bath, and the time to explosion is measured as the time to the sound created by the rupture of the blasting cap or unseating of the plug. The lowest temperature at which a runaway reaction can be obtained is the Tm. Many tests are required to determine Tm with confidence, because it is necessary to raise and lower the bath temperature across the apparent Tm, make many separate tests, and allow enough time for a reaction. A safe failure criterion for 40-mg samples is no explosion in 1000 seconds. We have never obtained an explosion after 10 000 seconds.

Because the reactions can be violent, the metal-bath enclosure shown in Fig. 2.04 is used. The baffles keep most of the hot metal in the chamber, and the test can be made behind a shield in a fume hood.

Fig. 2.04. Time-to-explosion test metal-bath assembly.
A. Cartridge heaters (3 each)
B. Top assembly, bolted to base
C. Sample-cell holder (the sample cell is insulated from the holder by a band of glass tape around its top)
D. Sample cell holder pivot arm, which allows cell and holder to be inserted remotely into the lower assembly
E. Metal-bath container, made from mild steel for stability when containing molten metal
F. Sample cell
G. Sample cell support pedestal, whose length is adjusted to the sample cell length
### THERMAL PROPERTIES

**Table 2.06 TIME-TO-EXPLOSION TEST**

<table>
<thead>
<tr>
<th>Explosive</th>
<th>T&lt;sub&gt;m&lt;/sub&gt; (°C)</th>
<th>a (mm)</th>
<th>Density (g/cm&lt;sup&gt;3&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Explosives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTF</td>
<td>249 ± 1</td>
<td>0.33</td>
<td>1.81</td>
</tr>
<tr>
<td>DATB</td>
<td>321 ± 2</td>
<td>0.35</td>
<td>1.74</td>
</tr>
<tr>
<td>HMX</td>
<td>253 ± 1</td>
<td>0.33</td>
<td>1.81</td>
</tr>
<tr>
<td>HNS</td>
<td>320 ± 1</td>
<td>0.37</td>
<td>1.65</td>
</tr>
<tr>
<td>NQ</td>
<td>202 ± 2</td>
<td>0.39</td>
<td>1.63</td>
</tr>
<tr>
<td>PATO</td>
<td>281 ± 1</td>
<td>0.37</td>
<td>1.70</td>
</tr>
<tr>
<td>PETN</td>
<td>201 ± 2</td>
<td>0.34</td>
<td>1.74</td>
</tr>
<tr>
<td>RDX</td>
<td>216 ± 1</td>
<td>0.35</td>
<td>1.72</td>
</tr>
<tr>
<td>TATB</td>
<td>331 ± P 1</td>
<td>0.331.84</td>
<td></td>
</tr>
<tr>
<td>TNT</td>
<td>288 ± 1</td>
<td>0.38</td>
<td>1.57</td>
</tr>
<tr>
<td>TPM</td>
<td>316 ± 2</td>
<td>0.72</td>
<td>1.66</td>
</tr>
<tr>
<td>Castable Explosives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amatex/20</td>
<td>226 ± 4</td>
<td>0.35</td>
<td>---</td>
</tr>
<tr>
<td>Comp B</td>
<td>214</td>
<td>0.35</td>
<td>---</td>
</tr>
<tr>
<td>Cyclotol 75/24</td>
<td>208</td>
<td>0.36</td>
<td>---</td>
</tr>
<tr>
<td>Plastic-Bonded Explosives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRX 9404</td>
<td>236 + 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**REFERENCES**


3. DETONATION PROPERTIES

3.1 Detonation Velocity and Diameter Effect. The velocity with which a steady detonation travels through an explosive is measured by using a broomstick-shaped piece of the explosive, called a rate stick. A standard rate stick is a right cylinder, usually composed of a number of shorter cylinders that have been cast, pressed, or machined to a predetermined diameter. The stick is detonated at one end, and the progress of the detonation is measured at discrete points along the stick length. The locations of the measurement points are determined with a micrometer. The times at which the detonation front reaches these points are determined by using the high conductivity or pressure at the detonation front to close an electrical switch called a pin. The switch closure allows a capacitor to discharge, and the associated signal is recorded on a fast oscilloscope. The detonation velocity can be calculated from the measured distances and times by using an appropriate numerical procedure.

Sometimes optical records of the detonation trajectory along the stick have been obtained with a smear camera, but this less precise method is used only in special circumstances, as for very small diameter sticks in which pins might perturb the detonation wave significantly.

When a rate stick is detonated initially, there usually are velocity transients for some distance along its length. Therefore, the data from the first part of the run, a distance equal to six rate stick diameters, usually are discarded. Detonation velocities in plastic-bonded explosives pressed to more than 95% of theoretical density commonly are measured to within 0.1% by these techniques.

Liquid-explosive rate sticks must be contained in rigid cylinders. The way in which this container affects the detonation velocity and the explosive diameter at which failure occurs is called the confinement effect. When measuring the detonation velocity of a confined explosive, one should make the container walls thick enough to represent infinitely thick walls, to simplify data interpretation.

Details of these techniques are given in A. W. Campbell and Ray Engelke, Sixth Symposium (International) on Detonation, San Diego, California, August 1976, Office of Naval Research Symposium report ACR-221, and in other works cited therein.

Diameter-Effect Curve

The velocity of a detonation traveling in a cylindrical stick decreases with the stick diameter until a diameter is reached at which detonation no longer propagates. That is called the failure diameter. The steady detonation velocity as a function of the rate stick radius is given by \( D(R) = D(\infty)[1 - A/(R - R_c)] \), where \( D(R) \) and \( D(\infty) \) are the steady detonation velocities at rate stick radius \( R \) and at infinite radius, respectively. \( A \) and \( R_c \) are fitting parameters. Campbell and Engelke discuss this fitting form. Table 3.01 lists nonlinear least squares fits of this function to empirical data. The fits can be used to interpolate the detonation velocity at any diameter that will allow detonation to propagate.
Table 3.01 PARAMETERS OF THE DIAMETER-EFFECT CURVE

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Data, Points/Diameter</th>
<th>Density/TMD(\frac{\text{g}}{\text{cm}^3})</th>
<th>% TMD(%)</th>
<th>(D(\infty) \pm \sigma_D) (mm/µs)</th>
<th>(R_c \pm \sigma_{R_c}) (mm)</th>
<th>(A \pm \sigma_A \times 10^3) (mm)</th>
<th>Experiment Failure Radius (mm)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitromethane</td>
<td>9/5</td>
<td>1.128/1.128</td>
<td>100</td>
<td>6.213 ± 0.001</td>
<td>-0.4 ± 0.1</td>
<td>2.6 ± 0.2</td>
<td>1.42 ± 0.21</td>
<td>The fit shows slight upward concavity. Fired in brass tubes with 3.18-mm-thick walls. Nominally 20/20/40 RDX/TNT/AN. Median AN particle size was 0.5 mm.</td>
</tr>
<tr>
<td>Amatex/20</td>
<td>4/4</td>
<td>1.613/1.710</td>
<td>94.3</td>
<td>7.030 ± 0.010</td>
<td>4.4 ± 0.2</td>
<td>59 + 3</td>
<td>8.5 ± 0.5</td>
<td>24/76 TNT/Ba(NO₃)₂. Interpolating fit. 92/8 RDX/wax. No sticks failed.</td>
</tr>
<tr>
<td>Baratol 76</td>
<td>3/3</td>
<td>2.619/2.63</td>
<td>99.6</td>
<td>4.8/4</td>
<td>4.36</td>
<td>102</td>
<td>21.6 ± 2.5</td>
<td>36/65/1 TNT/RDX/wax 77/23 RDX/TNT</td>
</tr>
<tr>
<td>Comp A</td>
<td>5/5</td>
<td>1.687/1.704</td>
<td>99.0</td>
<td>8.274 ± 0.003</td>
<td>1.2 ± 0.1</td>
<td>1.39 ± 0.17</td>
<td>&lt;1.1</td>
<td>75/19/5/1/1 TNT/Al/wax/carbon black. R = 0.</td>
</tr>
<tr>
<td>Comp B</td>
<td>25/12</td>
<td>1.700/1.742</td>
<td>97.6</td>
<td>7.859 ± 0.010</td>
<td>1.94 ± 0.02</td>
<td>2.84 ± 0.19</td>
<td>2.14 ± 0.03</td>
<td>77/23 HMX/TNT 94/3/5 HMX/NC/CEF 95/2.5/1.25/1.25 HMX/Estane/BDNP/BDNPF</td>
</tr>
<tr>
<td>Cyclotol 77/23</td>
<td>8/8</td>
<td>1.440/1.760</td>
<td>99.1</td>
<td>8.210 ± 0.014</td>
<td>2.44 ± 0.12</td>
<td>4.89 ± 0.82</td>
<td>3.0 ± 0.6</td>
<td>90/10 TATB/Kel-F 800 95/5 TATB/Kel-F 800</td>
</tr>
<tr>
<td>Destex</td>
<td>7/4</td>
<td>1.666/1.722</td>
<td>98.5</td>
<td>6.816 ± 0.009</td>
<td>0.0*</td>
<td>59.4 ± 0.035</td>
<td>14.3 ± 1.6</td>
<td>80/20 PETN/silicone rubber Fired as half-cylinder confined in polycarbonate.</td>
</tr>
<tr>
<td>Octol</td>
<td>8/6</td>
<td>1.814/1.843</td>
<td>98.4</td>
<td>8.481 ± 0.007</td>
<td>1.34 ± 0.21</td>
<td>6.9 ± 0.9</td>
<td>&lt;3.2</td>
<td>77/23 HMX/TNT 94/3/5 HMX/NC/CEF 95/2.5/1.25/1.25 HMX/Estane/BDNP/BDNPF</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>15/13</td>
<td>1.846/1.865</td>
<td>99.0</td>
<td>8.773 ± 0.012</td>
<td>0.553 ± 0.005</td>
<td>0.89 ± 0.08</td>
<td>0.59 ± 0.01</td>
<td>90/10 TATB/Kel-F 800 95/5 TATB/Kel-F 800</td>
</tr>
<tr>
<td>PBX 9501</td>
<td>7/6</td>
<td>1.832/1.836</td>
<td>98.8</td>
<td>8.802 ± 0.006</td>
<td>0.48 ± 0.02</td>
<td>1.9 ± 0.1</td>
<td>&lt;0.76</td>
<td>80/20 PETN/silicone rubber Fired as half-cylinder confined in polycarbonate.</td>
</tr>
<tr>
<td>X-0919</td>
<td>8/6</td>
<td>1.915/1.946</td>
<td>98.4</td>
<td>7.627 ± 0.015</td>
<td>0.0*</td>
<td>26.9 ± 2.3</td>
<td>7.5 ± 0.5</td>
<td>90/10 TATB/Kel-F 800 95/5 TATB/Kel-F 800</td>
</tr>
<tr>
<td>X-09290</td>
<td>5/5</td>
<td>1.895/1.942</td>
<td>97.6</td>
<td>7.706 ± 0.009</td>
<td>0.0*</td>
<td>19.4 ± 0.8</td>
<td>4.5 ± 0.5</td>
<td>80/20 PETN/silicone rubber Fired as half-cylinder confined in polycarbonate.</td>
</tr>
<tr>
<td>XTX 8003</td>
<td>.162/4</td>
<td>1.53/1.556</td>
<td>98.3</td>
<td>7.264 ± 0.003</td>
<td>0.113 ± 0.007</td>
<td>0.018 ± 0.002</td>
<td>0.18 ± 0.05</td>
<td>80/20 PETN/silicone rubber Fired as half-cylinder confined in polycarbonate.</td>
</tr>
</tbody>
</table>

*Fired in air confinement, unless otherwise noted.

Number of shots that propagated a steady wave/number of distinct diameters at which observations were made.

TMD = theoretical maximum density.

\(R_c\) is the average of the radii from two go/no-go shots, \(\sigma\) is one-half the difference in the go/no-go radii.

\(R\), fired at 0.0 gives the smallest variance of fit.
Table 3.02 DETONATION VELOCITY
vs COMMERCIAL-GRADE LIQUID NITROMETHANE* 
RATE STICK DIAMETER

<table>
<thead>
<tr>
<th>Rate Stick Diameter (mm)</th>
<th>Average Velocity D (mm/μs)</th>
<th>Length/Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>95.25</td>
<td>6.210</td>
<td>8</td>
</tr>
<tr>
<td>25.40</td>
<td>6.201</td>
<td>30</td>
</tr>
<tr>
<td>25.37</td>
<td>6.200</td>
<td>30</td>
</tr>
<tr>
<td>12.79</td>
<td>6.188</td>
<td>60</td>
</tr>
<tr>
<td>12.70</td>
<td>6.190</td>
<td>60</td>
</tr>
<tr>
<td>6.33</td>
<td>6.169</td>
<td>120</td>
</tr>
<tr>
<td>6.43</td>
<td>6.166</td>
<td>120</td>
</tr>
<tr>
<td>3.00</td>
<td>6.128</td>
<td>254</td>
</tr>
<tr>
<td>3.05</td>
<td>6.125</td>
<td>254</td>
</tr>
<tr>
<td>2.41</td>
<td>Failed</td>
<td>316</td>
</tr>
</tbody>
</table>

*The nitromethane, which had been purified by redistillation, was confined in brass tubes with 3.18-mm-thick walls that were effectively infinite, unless otherwise specified. The firing temperature was 93.0°F and the density was 1.033 g/cm³.

*The nitromethane, which had been purified by redistillation, was confined in brass tubes with 3.18-mm-thick walls that were effectively infinite, unless otherwise specified. The firing temperature was 93.0°F and the density was 1.033 g/cm³.

D is the average velocity through the stick obtained with electrical pins.

*The initiation assembly consisted of an SE-1 detonator, a booster pellet, a P-16, and a cube of Comp B bigger than the tube diameter.
Table 3.03 AMATEX/20a DETONATION VELOCITY vs RATE STICK DIAMETER

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Rate Stick Diameter (mm)</th>
<th>$D \pm \sigma$ (mm/μs)$^b$</th>
<th>Density (g/cm³)</th>
<th>Length/Diameter</th>
<th>Initiation Assembly</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-3823</td>
<td>101.6</td>
<td>6.937 ± 0.008</td>
<td>1.613</td>
<td>16.5</td>
<td>E-23 detonator, P-40, 101.6-mm-diam by 12.7-mm-long Comp B</td>
<td>Two-segment fit; last piece of four segments failed</td>
</tr>
<tr>
<td>E-3819</td>
<td>50.8</td>
<td>6.840 ± 0.013</td>
<td>1.613</td>
<td>19</td>
<td>SE-1 detonator, pellet, P-22, 50.8-mm-diam by 12.7-mm-long Comp B</td>
<td></td>
</tr>
<tr>
<td>E-3817</td>
<td>25.4</td>
<td>6.532 ± 0.033</td>
<td>1.613</td>
<td>16</td>
<td>SE-1 detonator, pellet, P-16 25.4-mm-diam by 22.2-mm-long TNT</td>
<td></td>
</tr>
<tr>
<td>E-3983</td>
<td>17.0</td>
<td>6.029 (Failed)</td>
<td>1.613</td>
<td>5.9</td>
<td>SE-1 detonator, pellet, P-16, 25.4 mm-diam by 25.4-mm-long Amatex/20</td>
<td></td>
</tr>
</tbody>
</table>

$^a$The prill size of the ammonium nitrate (AN) was ≈0.5 mm.
$^b$Unless otherwise noted, D is the average of the segmental velocities and $\sigma$ is their standard deviation about D.
<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Rate Stick Diameter (mm)</th>
<th>D ± σ (mm/μs)(\text{a})</th>
<th>Density (g/cm(^3))</th>
<th>Length/ Diameter</th>
<th>Initiation Assembly</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-4394</td>
<td>101.60</td>
<td>4.767 ± 0.002</td>
<td>2.619</td>
<td>8.2</td>
<td>1E-23 detonator, P-40</td>
<td></td>
</tr>
<tr>
<td>E-4672</td>
<td>65.30</td>
<td>4.700 ± 0.006</td>
<td>2.619</td>
<td>8.1</td>
<td>1E-23 detonator, P-40</td>
<td></td>
</tr>
<tr>
<td>E-4067</td>
<td>48.13</td>
<td>4.625 ± 0.003</td>
<td>2.619</td>
<td>9.3</td>
<td>SE-1 detonator, pellet, 44.5-mm-diam by 51.2-mm-long cyclotol</td>
<td></td>
</tr>
<tr>
<td>E-4066</td>
<td>38.07</td>
<td>Failed</td>
<td>2.619</td>
<td>10.6</td>
<td>SE-1 detonator, pellet, P-16</td>
<td>Failed</td>
</tr>
</tbody>
</table>

\(\text{a}\)Unless otherwise noted, D is the slope of a linear least squares fit to the detonation trajectory as measured by electrical pins, and \(\sigma\) is one standard deviation of the slope of that line.
## Table 3.05 COMPOSITION B DETONATION VELOCITY vs RATE STICK DIAMETER

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Rate Stick Diameter (mm)</th>
<th>D ± σ (mm/μs)*</th>
<th>Density (g/cm³)</th>
<th>Length/Diameter</th>
<th>Initiation Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-727</td>
<td>25.5</td>
<td>7.868</td>
<td>1.706</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>B-728</td>
<td>25.5</td>
<td>7.887</td>
<td>1.706</td>
<td>2</td>
<td>c</td>
</tr>
<tr>
<td>B-785</td>
<td>24.8</td>
<td>7.869</td>
<td>1.704</td>
<td>5.2</td>
<td>c</td>
</tr>
<tr>
<td>B-785</td>
<td>24.8</td>
<td>7.864</td>
<td>1.702</td>
<td>5.2</td>
<td>c</td>
</tr>
<tr>
<td>B-785</td>
<td>24.8</td>
<td>7.847</td>
<td>1.698</td>
<td>5.2</td>
<td>c</td>
</tr>
<tr>
<td>B-757</td>
<td>12.7</td>
<td>7.816</td>
<td>1.704</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>B-758</td>
<td>12.7</td>
<td>7.819</td>
<td>1.703</td>
<td>4</td>
<td>c</td>
</tr>
<tr>
<td>B-790</td>
<td>10.0</td>
<td>7.787</td>
<td>1.703</td>
<td>5</td>
<td>c</td>
</tr>
<tr>
<td>B-790</td>
<td>10.0</td>
<td>7.792</td>
<td>1.701</td>
<td>5</td>
<td>c</td>
</tr>
<tr>
<td>B-790</td>
<td>10.0</td>
<td>7.755</td>
<td>1.701</td>
<td>5</td>
<td>c</td>
</tr>
<tr>
<td>B-749</td>
<td>8.48</td>
<td>7.738</td>
<td>1.704</td>
<td>6.3</td>
<td>c</td>
</tr>
<tr>
<td>B-738</td>
<td>8.47</td>
<td>7.742</td>
<td>1.708</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>R-786</td>
<td>7.95</td>
<td>7.738</td>
<td>1.704</td>
<td>6.4</td>
<td>c</td>
</tr>
<tr>
<td>B-786</td>
<td>7.95</td>
<td>7.725</td>
<td>1.704</td>
<td>6.4</td>
<td>c</td>
</tr>
<tr>
<td>B-786</td>
<td>7.96</td>
<td>7.746</td>
<td>1.704</td>
<td>6.4</td>
<td>c</td>
</tr>
<tr>
<td>B-730</td>
<td>6.36</td>
<td>7.648</td>
<td>1.703</td>
<td>10.4</td>
<td>c</td>
</tr>
<tr>
<td>B-740</td>
<td>6.35</td>
<td>7.650</td>
<td>1.700</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>B-780</td>
<td>5.61</td>
<td>7.572</td>
<td>1.706</td>
<td></td>
<td>c</td>
</tr>
<tr>
<td>B-781</td>
<td>5.61</td>
<td>7.561</td>
<td>1.706</td>
<td></td>
<td>c</td>
</tr>
<tr>
<td>B-748</td>
<td>5.10</td>
<td>7.476</td>
<td>1.705</td>
<td>9.2</td>
<td>c</td>
</tr>
<tr>
<td>B-750</td>
<td>5.08</td>
<td>7.476</td>
<td>1.705</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>B-784</td>
<td>4.64</td>
<td>7.326</td>
<td>1.703</td>
<td>10.9</td>
<td>c</td>
</tr>
<tr>
<td>B-778</td>
<td>4.60</td>
<td>7.308</td>
<td>1.706</td>
<td>11.0</td>
<td>c</td>
</tr>
<tr>
<td>B-782</td>
<td>4.45</td>
<td>7.092</td>
<td>1.701</td>
<td>11.4</td>
<td>c</td>
</tr>
<tr>
<td>B-783</td>
<td>4.43</td>
<td>7.066</td>
<td>1.703</td>
<td>11.5</td>
<td>c</td>
</tr>
<tr>
<td>B-771</td>
<td>4.28</td>
<td>6.709</td>
<td>1.704</td>
<td>7.9</td>
<td>c</td>
</tr>
<tr>
<td>B-770</td>
<td>4.27</td>
<td>Failed</td>
<td>1.700</td>
<td>11.8</td>
<td>c</td>
</tr>
</tbody>
</table>

*Average velocity through the stick.

*SE-1 detonator, pellet, >4-diam Comp B runup.

*P-15.
**DETONATION PROPERTIES**

Table 3.06 CYCLOTOL DETONATION VELOCITY vs RATE STICK DIAMETER

<table>
<thead>
<tr>
<th>Rate Stick Diameter (mm)</th>
<th>D (mm/μs)(^b)</th>
<th>Density (g/cm(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>101.6</td>
<td>8.217</td>
<td>1.740</td>
</tr>
<tr>
<td>50.8</td>
<td>8.204</td>
<td>1.740</td>
</tr>
<tr>
<td>25.4</td>
<td>8.160</td>
<td>1.740</td>
</tr>
<tr>
<td>16.9</td>
<td>8.107</td>
<td>1.740</td>
</tr>
<tr>
<td>12.7</td>
<td>8.116</td>
<td>1.740</td>
</tr>
<tr>
<td>8.5</td>
<td>8.012</td>
<td>1.740</td>
</tr>
<tr>
<td>7.3</td>
<td>7.859</td>
<td>1.740</td>
</tr>
<tr>
<td>6.4</td>
<td>7.664</td>
<td>1.740</td>
</tr>
<tr>
<td>5.6</td>
<td>Failed</td>
<td>1.740</td>
</tr>
</tbody>
</table>

\(^a\)Information on the booster, length-to-diameter ratio, and shot numbers was unavailable.

\(^b\)D is probably the average of a set of segmental velocities.
<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Rate Stick Diameter (mm)</th>
<th>$D \pm \sigma$ (mm/μs)$^a$</th>
<th>Density (g/cm$^3$)</th>
<th>Length/Diameter</th>
<th>Initiation Assembly</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-8199</td>
<td>101.60</td>
<td>6.743 ± 0.001</td>
<td>1.689</td>
<td>7.0</td>
<td>101.6-mm-diam by 946-mm-long Destex$^b$</td>
<td></td>
</tr>
<tr>
<td>B-8208</td>
<td>101.60</td>
<td>6.737 ± 0.002</td>
<td>1.698</td>
<td>7.5</td>
<td>101.6-mm-diam by 584-mm-long Destex$^a$</td>
<td>c</td>
</tr>
<tr>
<td>F-4543</td>
<td>76.20</td>
<td>6.698 ± 0.001</td>
<td>1.698</td>
<td>13.5</td>
<td>101.6-mm-diam by 101.6-mm-long TNT$^b$</td>
<td></td>
</tr>
<tr>
<td>F-4106</td>
<td>50.80</td>
<td>6.653 ± 0.004</td>
<td>1.690</td>
<td>10.3</td>
<td>50-mm-diam by 6.4-mm-long PBX 9404$^d$</td>
<td></td>
</tr>
<tr>
<td>F-4510</td>
<td>50.80</td>
<td>6.654 ± 0.018</td>
<td>1.700</td>
<td>12.0</td>
<td>50.8-mm-diam by 50.8-mm-long Comp B$^d$</td>
<td></td>
</tr>
<tr>
<td>B-8203</td>
<td>50.80</td>
<td>6.671 ± 0.004</td>
<td>1.695</td>
<td>8.1</td>
<td>50.8-mm-diam by 25.4-mm-long PBX 9404$^d$</td>
<td>Cylinder test, 5.08-mm-thick OFHC copper wall</td>
</tr>
<tr>
<td>E-4542</td>
<td>31.75</td>
<td>6.560 ± 0.003</td>
<td>1.698</td>
<td>12.0</td>
<td>50.8-mm-diam by 76.2-mm-long Comp B$^d$</td>
<td></td>
</tr>
<tr>
<td>F-4089</td>
<td>25.37</td>
<td>Failed</td>
<td>1.69</td>
<td>10.0</td>
<td>SE-1 detonator, pellet, 25.4-mm-diam by 28.6-mm-long PBX 9404</td>
<td>Failed</td>
</tr>
</tbody>
</table>

$^a$Unless otherwise noted, $D$ is the slope of the linear least squares fit to the detonation trajectory as measured by electrical pins, and $\sigma$ is one standard deviation of the slope of that line.

$^b$SE-1 detonator and P-22.

$^c$Cylinder Test, 10.16-mm-thick OFHC copper wall.

$^d$SE-1 detonator, pellet, and P-22.
Table 3.08 OCTOL DETONATION VELOCITY vs RATE STICK DIAMETER

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Rate Stick Diameter (mm)</th>
<th>D ± σ (mm/μs)*</th>
<th>Density (g/cm³)b.</th>
<th>Length/Diameter</th>
<th>Initiation Assemblyc</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-3909</td>
<td>50.79</td>
<td>8.452</td>
<td>1.811</td>
<td>12</td>
<td>Pellet, 50.8-mm-diam by 203-mm-long Octol</td>
</tr>
<tr>
<td>B-3913</td>
<td>38.11</td>
<td>8.450</td>
<td>1.810</td>
<td>21.3</td>
<td>38.11-mm-diam Octol</td>
</tr>
<tr>
<td>B-3915</td>
<td>22.89</td>
<td>8.415</td>
<td>1.813</td>
<td>17.8</td>
<td>22.9-mm-diam by 50.8-mm-long Octol</td>
</tr>
<tr>
<td>E-0074</td>
<td>22.89</td>
<td>8.427</td>
<td>1.813</td>
<td>15.6</td>
<td>50.8-mm-long Octol</td>
</tr>
<tr>
<td>B-3914</td>
<td>16.30</td>
<td>8.402</td>
<td>1.816</td>
<td>24.9</td>
<td>Pellet, 22.9-mm-diam by 50.8-mm-long Octol</td>
</tr>
<tr>
<td>B-3912</td>
<td>16.30</td>
<td>8.400</td>
<td>1.817</td>
<td>24.9</td>
<td>16.3-mm-diam by 50.8-mm-long Octol</td>
</tr>
<tr>
<td>B-3919</td>
<td>12.72</td>
<td>8.357</td>
<td>1.816</td>
<td>60</td>
<td>16.3-mm-diam by 50.8-mm-long Octol</td>
</tr>
<tr>
<td>E-0081</td>
<td>6.34</td>
<td>8.161</td>
<td>1.816</td>
<td>80</td>
<td>Pellet, 6.35-mm-diam by 50.8-mm-long Octol</td>
</tr>
</tbody>
</table>

* D is probably an average of a set of segmented velocities.
* All entries are corrected to 1.814-g/cm³ density.
* SE-1 detonators.
Table 3.09  PBX 9404 DETONATION VELOCITY vs RATE STICK DIAMETER

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Rate Stick Diameter (mm)</th>
<th>D ± σ (mm/μs)</th>
<th>Density (g/cm³)</th>
<th>Length/Diameter</th>
<th>Initiation Assembly</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-4339</td>
<td>146.0</td>
<td>8.800</td>
<td>1.844</td>
<td>NA</td>
<td>146-mm-diam Comp Ba</td>
<td>b</td>
</tr>
<tr>
<td>B-0768</td>
<td>146.0</td>
<td>8.803</td>
<td>1.844</td>
<td>NA</td>
<td>146-mm-diam Comp Ba</td>
<td>b</td>
</tr>
<tr>
<td>B-0768</td>
<td>38.1</td>
<td>8.789</td>
<td>1.844</td>
<td>13.3</td>
<td>38.1-mm-diam by 152-mm-long Comp Ba</td>
<td>b</td>
</tr>
<tr>
<td>B-8033</td>
<td>25.4</td>
<td>8.774 ± &lt;0.001</td>
<td>1.846</td>
<td>22</td>
<td>iE23 detonator, P-80, 203-mm by 50.8-mm-thick PBX 9404 203-mm-diam by 0.38-mm-thick polyethylene, 25.4-mm air gap, and 203-mm-diam by 2.54-mm-thick magnesium.</td>
<td>Stick was strongly overdriven with a flying plate.</td>
</tr>
<tr>
<td>B-8034</td>
<td>25.4</td>
<td>8.775 ± &lt;0.001</td>
<td>1.846</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-4370</td>
<td>22.9</td>
<td>8.793</td>
<td>1.844</td>
<td>22</td>
<td>22.9-mm-diam by 9.16-mm-long Comp Ba</td>
<td>b</td>
</tr>
<tr>
<td>B-4369</td>
<td>16.31</td>
<td>8.789</td>
<td>1.844</td>
<td>31</td>
<td>16.3-mm-diam by 65.2-mm-long Comp Ba</td>
<td>b</td>
</tr>
<tr>
<td>E-0769</td>
<td>12.70</td>
<td>8.776</td>
<td>1.844</td>
<td>40</td>
<td>12.7-mm-diam by 50.8-mm-long Comp Ba</td>
<td>b</td>
</tr>
<tr>
<td>E-0746</td>
<td>6.38</td>
<td>8.731</td>
<td>1.844</td>
<td>80</td>
<td>6.38-mm-diam by 25.5-mm-long Comp Ba</td>
<td>b</td>
</tr>
<tr>
<td>Shot No.</td>
<td>Rate Stick Diameter (mm)</td>
<td>D ± σ (mm/μs)*</td>
<td>Density (g/cm³)</td>
<td>Length/Diameter</td>
<td>Initiation Assembly</td>
<td>Comments</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------</td>
<td>----------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>----------</td>
</tr>
<tr>
<td>E-3977</td>
<td>2.88</td>
<td>8.651 ± 0.031</td>
<td>1.843</td>
<td>69</td>
<td>Pellet, 10.2-mm-dia. by 7.6-mm-long PBX 9404a</td>
<td>D is average velocity. σ is the standard deviation of 3 segmental velocities.</td>
</tr>
<tr>
<td>B-8008</td>
<td>2.80</td>
<td>8.668</td>
<td>1.844</td>
<td>10</td>
<td>12.6-mm-diam by 12.6-mm-long tetryl, 6.35-mm-diam by 12-mm-long PBX 9404a</td>
<td></td>
</tr>
<tr>
<td>B-8009</td>
<td>2.00</td>
<td>8.525</td>
<td>1.844</td>
<td>16</td>
<td>Tetryl pellet, 6.35-mm-diam by 12-mm-long PBX 9404a</td>
<td></td>
</tr>
<tr>
<td>B-8010</td>
<td>1.50</td>
<td>8.355</td>
<td>1.844</td>
<td>18</td>
<td>Tetryl pellet, 6.35-mm-diam by 12-mm-long PBX 9404a</td>
<td></td>
</tr>
<tr>
<td>C-4352</td>
<td>1.27</td>
<td>7.874</td>
<td>1.84</td>
<td>8.3</td>
<td>Pellet*</td>
<td></td>
</tr>
<tr>
<td>C-4351</td>
<td>1.21</td>
<td>7.279</td>
<td>1.84</td>
<td>20.8</td>
<td>Pellet*</td>
<td></td>
</tr>
<tr>
<td>F-2989</td>
<td>1.17</td>
<td>Failed</td>
<td>1.84</td>
<td>10.9</td>
<td>Pellet*</td>
<td></td>
</tr>
</tbody>
</table>

*SE-1 detonator.
*D from linear least squares fit to detonation trajectory.
*σ is one standard deviation of slope of the least squares line.
*Pellet, P-16, 25.4-mm-diam by 152-mm-long Amatex/20.
*D from least squares fit to optical record of the detonation trajectory.
### Table 3.10 PBX-9501 DETONATION VELOCITY vs RATE STICK DIAMETER

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Rate Stick Diameter (mm)</th>
<th>D ± σ (mm/μs)*</th>
<th>Density (g/cm³)</th>
<th>Length/Diameter</th>
<th>Booster</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-4431</td>
<td>25.4</td>
<td>8.790 ± 0.004</td>
<td>1.832</td>
<td>14</td>
<td>25.4-mm-diam by 25.4-mm-long PBX 9404b</td>
<td></td>
</tr>
<tr>
<td>C-4521</td>
<td>25.4</td>
<td>8.791 ± 0.001</td>
<td>1.834</td>
<td>12</td>
<td>P-16b</td>
<td>c</td>
</tr>
<tr>
<td>C-4525</td>
<td>25.4</td>
<td>8.792 ± 0.001</td>
<td>1.834</td>
<td>12</td>
<td>P-16b</td>
<td>c</td>
</tr>
<tr>
<td>C-4442</td>
<td>5.01</td>
<td>8.728 ± 0.010</td>
<td>1.832</td>
<td>30</td>
<td>9.5-mm-diam by 9.5-mm-long PBX 9404b</td>
<td></td>
</tr>
<tr>
<td>C-4427</td>
<td>2.83</td>
<td>8.612 ± 0.011</td>
<td>1.832</td>
<td>21</td>
<td>10.2-mm-diam by 7.6-mm-long PBX 9404b</td>
<td></td>
</tr>
<tr>
<td>C-4440</td>
<td>2.01</td>
<td>8.487 ± 0.013</td>
<td>1.832</td>
<td>24</td>
<td>9.5-mm-diam by 9.5-mm-long PBX 9404b</td>
<td></td>
</tr>
<tr>
<td>C-4441</td>
<td>1.58</td>
<td>8.259 ± 0.013</td>
<td>1.832</td>
<td>30</td>
<td>9.5-mm-diam by 9.5-mm-long PBX 9404b</td>
<td></td>
</tr>
</tbody>
</table>

*Unless otherwise noted, D is the slope of a linear least squares fit to the detonation trajectory as measured by electrical pins, and σ is one standard deviation of the slope of that line.

bSE-1 detonator, pellet.

cCylinder test, 2.54-mm-thick OFHC copper wall.

dD and σ from least squares fit to optical record of detonation trajectory.
Table 3.11 COMPOSITION A
DETONATION VELOCITY vs RATE STICK DIAMETER\(^a\)

<table>
<thead>
<tr>
<th>Rate Stick Diameter (mm)</th>
<th>D (mm/µs)(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.37</td>
<td>8.262</td>
</tr>
<tr>
<td>12.70</td>
<td>8.254</td>
</tr>
<tr>
<td>8.46</td>
<td>8.236</td>
</tr>
<tr>
<td>6.35</td>
<td>8.213</td>
</tr>
<tr>
<td>5.08</td>
<td>8.172</td>
</tr>
<tr>
<td>4.24</td>
<td>8.143</td>
</tr>
</tbody>
</table>

\(^{a}\)Density is 1.687 g/cm\(^3\).
\(^{b}\)Information on the booster, length-to-diameter ratio, and shot numbers was unavailable.
\(^{c}\)D is probably the average of a set of segmental velocities.
Table 3.12 PBX-9502 DETONATION VELOCITY vs RATE STICK DIAMETER

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Rate Stick Diameter (mm)</th>
<th>( D \pm \sigma^a ) (mm/µs)</th>
<th>Density (g/cm³)</th>
<th>Length/Diameter</th>
<th>Booster</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-4081</td>
<td>50.00</td>
<td>7.649 ± &lt;0.001</td>
<td>1.894</td>
<td>12.0</td>
<td>50.9-mm-diam by 50.8-mm-long Comp B²</td>
</tr>
<tr>
<td>E-4096</td>
<td>17.98</td>
<td>7.528 ± &lt;0.001</td>
<td>1.895</td>
<td>33.3</td>
<td>25.4-mm-diam by 26.3-mm-long PBX 9404b</td>
</tr>
<tr>
<td>E-4133</td>
<td>14.00</td>
<td>7.483 ± &lt;0.001</td>
<td>1.893</td>
<td>21.4</td>
<td>25.4-mm-diam by 26.3-mm-long PBX 9404b</td>
</tr>
<tr>
<td>E-4133</td>
<td>12.00</td>
<td>7.455 ± 0.001</td>
<td>1.894</td>
<td>25.0</td>
<td>14-mm-diam by 300-mm-long PBX 9502b</td>
</tr>
<tr>
<td>F-3768</td>
<td>10.00</td>
<td>7.407 ± 0.001</td>
<td>1.894</td>
<td>30.0</td>
<td>10.2-mm-diam by 15.2-mm-long PBX 9404b</td>
</tr>
<tr>
<td>F-8074</td>
<td>7.96</td>
<td>Failed</td>
<td>1.894</td>
<td>14.2</td>
<td></td>
</tr>
</tbody>
</table>

*aUnless otherwise noted, \( D \) is the slope of a linear least-squares fit to the detonation trajectory as measured by electrical pins and \( \sigma \) is one standard deviation of the slope of that line.

²SE-1 detonator, pellet.
Table 3.13 X-0219 DETONATION VELOCITY vs RATE STICK DIAMETER

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Rate Stick Diameter (mm)</th>
<th>(D \pm \sigma) (mm/(\mu)s)(^a)</th>
<th>Density (g/cm(^3))</th>
<th>Length/Diameter</th>
<th>Booster</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-4436</td>
<td>50.8</td>
<td>7.555 ± 0.002</td>
<td>1.912</td>
<td>12</td>
<td>P-22, 50.8-mm-diam by 6.4-mm-long PBX 9404(^b)</td>
<td></td>
</tr>
<tr>
<td>E-3621</td>
<td>41.2</td>
<td>7.531 ± 0.018</td>
<td>1.920</td>
<td>6.2</td>
<td>P-22, 38.1-mm-diam by 114-mm-long Comp B(^b)</td>
<td>Velocity is average of segmental values and (\sigma) is standard deviation of same.</td>
</tr>
<tr>
<td>C-4438</td>
<td>25.4</td>
<td>7.462 ± &lt;0.001</td>
<td>1.911</td>
<td>24</td>
<td>P-16, 25.4-mm-diam by 25.4-mm-long PBX 9404(^b)</td>
<td></td>
</tr>
<tr>
<td>E-4118</td>
<td>25.4</td>
<td>7.457 ± &lt;0.001</td>
<td>1.913</td>
<td>12</td>
<td>P-16, 25.4-mm-diam by 26.3-mm-long PBX 9404(^b)</td>
<td>Test of effect of pressing direction</td>
</tr>
<tr>
<td>E-4119</td>
<td>25.4</td>
<td>7.453 ± &lt;0.001</td>
<td>1.916</td>
<td>12</td>
<td>P-16, 25.4-mm-diam by 26.3-mm-long PBX 9404(^b)</td>
<td>Test of effect of pressing direction</td>
</tr>
<tr>
<td>C-4395</td>
<td>18.0</td>
<td>7.397 ± 0.002</td>
<td>1.915</td>
<td>11.1</td>
<td>P-16, 25.4-mm cube Comp B</td>
<td></td>
</tr>
<tr>
<td>E-4095</td>
<td>15.9</td>
<td>7.380 ± &lt;0.001</td>
<td>1.916</td>
<td>18.9</td>
<td>25.4-mm-diam by 26.3-mm-long PBX 9404(^b)</td>
<td></td>
</tr>
<tr>
<td>E-4095</td>
<td>14.0</td>
<td>Failed</td>
<td>1.915</td>
<td>21.4</td>
<td>Shot E-4095 booster plus 300-mm-long by 15.9-mm-diam X-0219(^b)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Unless otherwise noted, \(D\) is the slope of a linear least squares fit to the detonation trajectory as measured by electrical pins, and \(\sigma\) is one standard deviation of the slope of that line.

\(^b\)SE-1 detonator, pellet.
### Table 3.14 XTX-8003 DETONATION VELOCITY vs RATE STICK DIAMETER

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Rate Stick Diameter (mm)</th>
<th>D ± σ (mm/μs)&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Density (g/cm&lt;sup&gt;3&lt;/sup&gt;)</th>
<th>Length/Diameter</th>
<th>Booster</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.02</td>
<td>7.248 ± 0.014</td>
<td>1.53</td>
<td>199</td>
<td>1E30</td>
<td></td>
</tr>
<tr>
<td>0.45</td>
<td>7.244 ± 0.016</td>
<td>1.53</td>
<td>452</td>
<td>1E30</td>
<td></td>
</tr>
<tr>
<td>0.26</td>
<td>7.167 ± 0.015</td>
<td>1.53</td>
<td>782</td>
<td>1E30</td>
<td></td>
</tr>
<tr>
<td>0.19</td>
<td>7.087 ± 0.021</td>
<td>1.53</td>
<td>1069</td>
<td>1E30</td>
<td></td>
</tr>
</tbody>
</table>

*Fired in half-cylinder geometry confined in polycarbonate.

*<sup>b</sup>D is the average of the linear least squares detonation velocities obtained from the 41 shots, and σ is the standard deviation of the D values about the average value.

*<sup>c</sup>Because these values are average results from 41 shots at each diameter, shot numbers are not listed.

### 3.2 Cylinder Test Performance

The cylinder test, developed at the Lawrence Livermore Laboratory, is used to compare directly the dynamic performance of explosives or to derive empirical equations of state for their detonation products.

A 1-in.-i.d. OFHC copper tube is filled with the test explosive. The tube wall thickness is controlled to give a nominal loading of 4.0331 grams of copper per cubic centimeter of explosive. The explosive is detonated at one end of the tube, and a rotating mirror camera records tube wall expansion as a function of time. The camera slit is positioned at a point 9 diameters (228.6 mm) along the tube from the detonated end.

The wall position -vs- time record on the camera film is measured in approximately 500 places, and these data are fitted with a seventh-order polynomial or various splines. Wall velocities are then obtained by differentiating the fits. Fine detail in the wall motion can be resolved by increasing the number of knots in the spline-fitting form from 15 to 30 or 50.

Given test explosive diameters at which detonation velocity varies little, the tube wall trajectory scales linearly with cylinder diameter. Therefore data from tests at nonstandard diameters are commonly scaled to 25.4 mm for comparison. For two common nonstandard diameters, 50.8 and 101.6 mm, the camera split is located at a position only six diameters distance along the tube from its detonated end.

The detonation velocity of each explosive is monitored by 12 probes made of 50-μm-diam enameled copper wire and attached to the outside of the copper tube at 25-mm intervals. The charge temperature is kept at 24 ± 2°C, and the charge is fired in a helium atmosphere to minimize shock refraction effects at early time.

Cylinder wall velocity data at early times should be evaluated carefully, because the early expansion consists of a series of shock-induced accelerations accompanied by a pullback. Also the preferred test in a helium atmosphere may give slightly lower wall expansion values and velocity than similar tests in air.

Wall velocity accuracy is thought to be 0.5% or better for high-quality explosives.
Table 3.15 GENERAL CYLINDER TEST SHOT INFORMATION

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Data Table</th>
<th>Shot Number</th>
<th>Explosive Density (g/cm³)</th>
<th>Detonation Velocity (mm/μs)</th>
<th>Loading² (Nominal is 4.0331 g/cm³)</th>
<th>Fitting Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBX 9404</td>
<td>3.16</td>
<td>C-4309</td>
<td>1.843</td>
<td>8.768 ± 0.002</td>
<td>Nom.</td>
<td>8-knot spline</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>3.16</td>
<td>C-4335</td>
<td>1.848</td>
<td>8.788 ± 0.002</td>
<td>Nom.</td>
<td>8-knot spline</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>3.16</td>
<td>C-4526</td>
<td>1.847</td>
<td>8.787 ± 0.001</td>
<td>Nom.</td>
<td>8-knot spline</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>3.16</td>
<td>C-4527</td>
<td>1.847</td>
<td>8.783 ± 0.001</td>
<td>Nom.</td>
<td>8-knot spline</td>
</tr>
<tr>
<td>PBX 9501</td>
<td>3.17</td>
<td>C-4521</td>
<td>1.834</td>
<td>8.792 ± 0.001</td>
<td>Nom.</td>
<td>8-knot spline</td>
</tr>
<tr>
<td>PBX 9501</td>
<td>3.17</td>
<td>C-4525</td>
<td>1.834</td>
<td>8.792 ± 0.001</td>
<td>Nom.</td>
<td>8-knot spline</td>
</tr>
<tr>
<td>PBX 9502</td>
<td>3.18</td>
<td>C-4454</td>
<td>1.894</td>
<td>---</td>
<td>Nom.</td>
<td>14-knot spline</td>
</tr>
<tr>
<td>PBX 9502</td>
<td>3.18</td>
<td>C-4455</td>
<td>1.894</td>
<td>7.589 ± 0.018</td>
<td>Nom.</td>
<td>14-knot spline</td>
</tr>
<tr>
<td>X-0282</td>
<td>3.19</td>
<td>C-4443</td>
<td>1.812</td>
<td>8.773 ± 0.001</td>
<td>Nom.</td>
<td>9-knot spline</td>
</tr>
<tr>
<td>X-0282</td>
<td>3.19</td>
<td>C-4520</td>
<td>1.819</td>
<td>8.749 ± 0.001</td>
<td>Nom.</td>
<td>7-knot spline</td>
</tr>
<tr>
<td>X-0282</td>
<td>3.19</td>
<td>C-4507</td>
<td>1.827</td>
<td>8.783 ± 0.002</td>
<td>Nom.</td>
<td></td>
</tr>
<tr>
<td>X-0282</td>
<td>3.19</td>
<td>C-4523</td>
<td>1.829</td>
<td>8.792 ± 0.001</td>
<td>Nom.</td>
<td></td>
</tr>
<tr>
<td>X-0284²</td>
<td>3.20</td>
<td>C-4453</td>
<td>1.636</td>
<td>6.728 ± 0.003</td>
<td>4.0282</td>
<td></td>
</tr>
<tr>
<td>X-0285</td>
<td>3.21</td>
<td>C-4502</td>
<td>1.831</td>
<td>8.784 ± 0.013</td>
<td>Nom.</td>
<td></td>
</tr>
<tr>
<td>X-0287</td>
<td>3.22</td>
<td>B-8193</td>
<td>1.822</td>
<td>8.874 ± 0.003</td>
<td>Nom.</td>
<td>b</td>
</tr>
<tr>
<td>X-0298</td>
<td>3.23</td>
<td>B-8310</td>
<td>1.820</td>
<td>8.841 ± 0.001</td>
<td>Nom.</td>
<td>b</td>
</tr>
<tr>
<td>X-0309⁴</td>
<td>3.24</td>
<td>B-8208</td>
<td>1.699</td>
<td>6.737 ± 0.002</td>
<td>4.0284</td>
<td>8-knot spline</td>
</tr>
<tr>
<td>X-0309⁴</td>
<td>3.25</td>
<td>B-8203</td>
<td>1.694</td>
<td>6.671 ± 0.002</td>
<td>4.035</td>
<td>b</td>
</tr>
</tbody>
</table>

¹Expressed in grams of copper per cubic centimeter of high explosive.
²Seventh-order polynomial.
³Fifteen-knot spline.
⁴Also called Pamatex/20 and Amatex-20K; 4-in. cylinder test.
⁵Also called Destex.
⁶4-in. cylinder test.
⁷2 in. cylinder test.
<table>
<thead>
<tr>
<th>Expansion Radius (mm)</th>
<th>Wall Velocity (mm/µs)</th>
<th>Average Wall Velocity (mm/µs)</th>
<th>Average Specific Wall Kinetic Energy (mm/µs)²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C-4309</td>
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### Table 3.17 PBX-9501 WALL VELOCITY vs EXPANSION RADIUS IN 1-in. CYLINDER TEST

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Table 3.18 PBX-9502 WALL VELOCITY vs EXPANSION RADIUS IN 1-in. CYLINDER TESTS

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Table 3.19 X-0282 WALL VELOCITY vs EXPANSION RADIUS
IN 1-in. CYLINDER TEST

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*Shots C-4507 and C-4523.
Table 3.20  X-0284
WALL VELOCITY vs EXPANSION RADIUS
IN 4-in. CYLINDER TEST

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*Also called Pamatex/20 and Amatex-20K.
### Table 3.21 X-0285
WALL VELOCITY vs EXPANSION RADIUS
IN 1-in. CYLINDER TESTS

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<td>3.094</td>
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<td>3.122</td>
</tr>
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<td>1.774</td>
<td>3.147</td>
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<td>3.172</td>
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<td>3.193</td>
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<td>1.793</td>
<td>3.215</td>
</tr>
<tr>
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### Table 3.22 X-0287
WALL VELOCITY vs EXPANSION RADIUS
IN 1-in. CYLINDER TESTS

<table>
<thead>
<tr>
<th>Expansion Radius (mm)</th>
<th>Wall Velocity B-8193 (mm/μs)</th>
<th>Average Specific Wall Kinetic Energy (mm/μs)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
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<td>2.615</td>
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<td>2.699</td>
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<td>2.776</td>
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<td>2.843</td>
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<td>2.952</td>
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<td>3.147</td>
</tr>
<tr>
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### Table 3.23 X-0298
WALL VELOCITY vs EXPANSION RADIUS
IN 1-in. CYLINDER TESTS

<table>
<thead>
<tr>
<th>Expansion Radius (mm)</th>
<th>Wall Velocity B-8310 (mm/μs)</th>
<th>Average Specific Wall Kinetic Energy (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
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</tr>
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<td>5</td>
<td>1.555</td>
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<td>7</td>
<td>1.622</td>
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<td>2.907</td>
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<td>3.233</td>
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### Table 3.24 X-0309*
WALL VELOCITY vs EXPANSION RADIUS
IN 4-in. CYLINDER TESTS

<table>
<thead>
<tr>
<th>Expansion Radius (mm)</th>
<th>Wall Velocity B-8208 (mm/μs)</th>
<th>Average Specific Wall Kinetic Energy (mm/μs)$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.984</td>
<td>0.969</td>
</tr>
<tr>
<td>5</td>
<td>1.022</td>
<td>1.045</td>
</tr>
<tr>
<td>6</td>
<td>1.051</td>
<td>1.104</td>
</tr>
<tr>
<td>7</td>
<td>1.074</td>
<td>1.153</td>
</tr>
<tr>
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<td>1.198</td>
</tr>
<tr>
<td>9</td>
<td>1.112</td>
<td>1.237</td>
</tr>
<tr>
<td>10</td>
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<td>1.272</td>
</tr>
<tr>
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<td>1.141</td>
<td>1.302</td>
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</tr>
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<td>15</td>
<td>1.179</td>
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<tr>
<td>16</td>
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<tr>
<td>17</td>
<td>1.192</td>
<td>1.421</td>
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<td>1.198</td>
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<td>1.499</td>
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<td>25</td>
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<tr>
<td>26</td>
<td>1.231</td>
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<td>27</td>
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</table>

*Also called Destex.
DETONATION PROPERTIES

Table 3.25 X-0309a
WALL VELOCITY vs EXPANSION RADIUS
IN 2-in. CYLINDER TESTS

<table>
<thead>
<tr>
<th>Expansion Radius (mm)</th>
<th>Wall Velocity B-8203 (mm/μs)</th>
<th>Average Specific Wall Kinetic Energy (mm/μs)²</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.985</td>
<td>0.970</td>
</tr>
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</tr>
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<td>6</td>
<td>1.050</td>
<td>1.103</td>
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<td>1.199</td>
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<td>1.145</td>
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<td>1.168</td>
<td>1.364</td>
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<td>1.177</td>
<td>1.385</td>
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<td>1.402</td>
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<td>16</td>
<td>1.190</td>
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<td>17</td>
<td>1.195</td>
<td>1.428</td>
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<tr>
<td>18</td>
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<tr>
<td>22</td>
<td>1.225</td>
<td>1.501</td>
</tr>
</tbody>
</table>

*Also called Destex.

3.3 Detonation Pressure Determined from Initial Free-Surface Velocity. The detonation pressure is important in any design involving explosives, because it drives inert materials and initiates other explosives. Although detonation pressure has been measured "directly," the most commonly used values are from experiments in which it has been inferred from its measured effects in other materials. The following initial free-surface velocity experiment provides inferential measurements of detonation pressure.

In an initial free-surface velocity experiment, one face of a parallelepiped of test explosive is initiated by a plane-wave lens. In intimate contact with the opposite face is a plate of inert material. The initiated detonation wave traverses the test explosive thickness and transmits a shock wave into the inert material. When this shock wave reaches the free surface of the inert material, it accelerates it. The initial velocity of the free surface is measured. By varying the thickness of the inert plate and measuring the free-surface velocity, one can plot free-surface velocity vs plate thickness and then extrapolate to zero plate thickness. By knowing the plate material equation of state, one can find a corresponding shock velocity and shock
DETONATION PROPERTIES

pressure. The "acoustic approximation" is then used to calculate the corresponding explosive pressure from \( P_x = P_m (\rho_{ox} U_x + \rho_{ox} D)/2\rho_{om} U_s \), where \( P_x \) = pressure in the explosive, \( P_m \) = pressure in the inert plate, \( \rho_{om} \) and \( \rho_{ox} \) = initial densities in the inert plate and explosive, respectively, \( U_s \) = shock velocity, and \( D \) = detonation velocity.

Using an assumed \( \gamma \)-law equation of state for the explosive reaction products, one can then calculate \( \gamma = (\rho_{ox} D^2/P_x) - 1 \) and \( U_{px} = D/(\gamma + 1) \).

The flash-gap technique was used to measure the inert plate's initial free-surface velocities. "Step blocks" of polymethylmethacrylate were mounted on the plate, with 0.1-mm-thick steel shim-covered argon flash gaps as shown in Fig. 3.01. The explosive-accelerated inert plate closed the pair of lateral reference gaps when it began moving, and after traversing the known free-run distance, it closed the other identical gap. The length of this free run was selected to avoid shock reverberation effects on the velocity. Closure of the gaps provided a brilliant, brief flash of light. Images of the flashes were recorded by a streaking camera using multiple slits and yielding multiple determinations of the free-run time, hence velocity. The typical width of a flash gap along the slit length was 19 mm. The initial free-surface velocity technique is described in more detail in "Measurement of Chapman-Jouguet Pressure for Explosives" by W. E. Deal.¹

Table 3.26 lists the detonation or Chapman-Jouguet (C-J) pressure, \( P_x \); the explosive's particle velocity, \( U_{px} \); and the parameter of the assumed \( \gamma \)-law equation of state, \( \gamma \), for each explosive.

Subsequent tables give densities, compositions, sample sizes, boosters, and the detailed shock information on each explosive. In the "analysis" section of the tables, \( t \) represents plate thickness; \( \rho \), density; \( P \), pressure; \( U_{fs} \), free surface velocity; \( U_s \), shock velocity; \( U_p \), particle velocity; \( D \), detonation velocity; and \( \gamma \), the parameter of the assumed \( \gamma \)-law equation of state. The subscript "0" refers to initial state, "x" to explosive, and "m" to the plate material. The parameters are given for a linear least squares fit of free-surface velocity vs plate thickness, and the corresponding explosive parameters are derived from the acoustic approximation.

The detonation pressure has been shown to be a function of the charge geometry, and these data are omitted herein.

Fig. 3.01. Plexiglas block assembly for measurement of free-surface velocity of an explosive-driven plate.
<table>
<thead>
<tr>
<th>Explosive</th>
<th>Plate Material</th>
<th>Explosive Density (mg/m$^3$)</th>
<th>Detonation (Chapman-Jouquet) Pressure (GPa)</th>
<th>Explosive Particle Velocity (km/s)</th>
<th>Gamma-Law Equation-of-State Parameter, $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp B</td>
<td>Dural$^a$</td>
<td>1.713</td>
<td>29.35</td>
<td>2.134</td>
<td>2.763</td>
</tr>
<tr>
<td>Comp B</td>
<td>Brass</td>
<td>1.714</td>
<td>28.54</td>
<td>2.081</td>
<td>2.845</td>
</tr>
<tr>
<td>Cyclotol</td>
<td>Dural</td>
<td>1.742</td>
<td>31.24</td>
<td>2.179</td>
<td>2.787</td>
</tr>
<tr>
<td>Cyclotol</td>
<td>Plexiglas</td>
<td>1.200</td>
<td>12.36</td>
<td>1.587</td>
<td>3.089</td>
</tr>
<tr>
<td>Octol</td>
<td>Dural</td>
<td>1.809</td>
<td>33.84</td>
<td>2.213</td>
<td>2.819</td>
</tr>
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<td>Dural</td>
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<td>34.62</td>
<td>2.170</td>
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<td>Dural</td>
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<td>Dural</td>
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<td>28.63</td>
<td>1.982</td>
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<td>35.35</td>
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</table>

$^a$Aluminum-2024 is known by the name Duraluminum, which we indicate by Dural.
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Table 3.27 COMPOSITION B ON DURAL

Explosive

RDX/TNT: 64.0 ± 0.6 wt% RDX, 1.713 ± 0.002 g/cm³. Holston* Grade A Composition B. Two 102- by 254-mm pieces to make 203-mm thickness. P-080 booster. D = 3.127 ρ₀ + 2.673 at 65 wt% RDX and increases 0.0134 km/s per 1 wt% RDX increase.

Plate

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>No. Uₐ Dets</th>
<th>Free-Surface Velocity (km/s)ᵇ</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
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<td>3.320 ± 0.017</td>
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<td>2</td>
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<td>3.240 ± 0.018</td>
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<td>12.82</td>
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<td>3.251 ± 0.024</td>
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<td>2.790</td>
<td>13.06</td>
<td>5</td>
<td>3.210 ± 0.017</td>
</tr>
<tr>
<td>8A 666</td>
<td>2.790</td>
<td>19.04</td>
<td>5</td>
<td>3.195 ± 0.018</td>
</tr>
<tr>
<td>8A 620</td>
<td>2.790</td>
<td>19.19</td>
<td>5</td>
<td>3.145 ± 0.014</td>
</tr>
<tr>
<td>8A 580</td>
<td>2.790</td>
<td>19.20</td>
<td>5</td>
<td>3.207 ± 0.008</td>
</tr>
<tr>
<td>8A 344</td>
<td>2.782</td>
<td>23.98</td>
<td>8</td>
<td>3.137 ± 0.032</td>
</tr>
<tr>
<td>8A 581</td>
<td>2.790</td>
<td>25.58</td>
<td>5</td>
<td>3.085 ± 0.014</td>
</tr>
<tr>
<td>8A 582</td>
<td>2.790</td>
<td>38.33</td>
<td>5</td>
<td>2.961 ± 0.020</td>
</tr>
<tr>
<td>8A 684</td>
<td>2.784</td>
<td>50.80</td>
<td>5</td>
<td>2.889 ± 0.034</td>
</tr>
<tr>
<td>8A 583</td>
<td>2.790</td>
<td>50.95</td>
<td>5</td>
<td>2.831 ± 0.037</td>
</tr>
</tbody>
</table>

*bData for this entry were determined on some or all of the following shots: 8A-225, -229, -273, -285, and -325; each was fired using several plate thicknesses.
DETONATION PROPERTIES

Analysis

Linear least squares fitting gives $U_{fs} = 3.389 \text{ km/s} - 0.01079 \ t (\text{mm})$. At $t = 0$, plate $U_s = 7.611 \ \text{km/s}$ and $P_m = 35.63 \ \text{GPa}$.

Acoustic approximation with $D = 8.030 \ \text{km/s}$, $\rho_{ox} = 1.713 \ \text{g/cm}^3$, and $\rho_{om} = 2.791 \ \text{g/cm}^3$ gives corresponding explosive parameters of $P_x = 29.35 \ \text{GPa}$, $U_{px} = 2.134 \ \text{km/s}$, and $\gamma = 2.763$.

Table 3.28 COMPOSITION B ON DURAL

| Charge Length/Diameter = 1 |

Explosive

RDX/TNT: $65.5 \pm 1.5 \ \text{wt\% RDX}$. Holston Grade A Composition B. $1.713 \pm 0.007 \ \text{g/cm}^3$. Two 76-mm-thick, 152-mm-diam cylinders to make a 152-mm-length. P-080 booster, $D = 3.127 \ \rho_o + 2.673$ at 65 wt\% RDX and increases 0.0134 km/s per 1 wt\% RDX increase.

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm$^3$)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>7C 180</td>
<td>2.774</td>
<td>6.38</td>
<td>3.359 ± 0.027</td>
</tr>
<tr>
<td>8A 1314</td>
<td>2.782</td>
<td>12.73</td>
<td>3.259 ± 0.008</td>
</tr>
<tr>
<td>8A 1313</td>
<td>2.774</td>
<td>19.07</td>
<td>3.189 ± 0.023</td>
</tr>
<tr>
<td>8A 1334</td>
<td>2.782</td>
<td>25.74</td>
<td>3.058 ± 0.016</td>
</tr>
<tr>
<td>8A 1319</td>
<td>2.774</td>
<td>38.11</td>
<td>2.933 ± 0.014</td>
</tr>
<tr>
<td>8A 1315</td>
<td>2.805</td>
<td>50.86</td>
<td>2.800 ± 0.034</td>
</tr>
</tbody>
</table>

*Mean and standard deviation of seven determinations on each shot.

Analysis

Linear least squares fitting gives $U_{fs} = 3.421 \ \text{km/s} - 0.01259 \ t (\text{mm})$. This intercept is only 0.9% higher than that of the data in Table 3.27 for somewhat larger charges. The slope is steeper. The intercept is 1.6% higher than that in Table 3.29 for charges of the same diameter but ten charge diameters long. The slope is again steeper than found from the data in Table 3.27.
DETONATION PROPERTIES

Table 3.29  COMPOSITION B ON DURAL

Charge Length/Diameter = 10

Explosive

RDX/TNT: 65.5 ± 1.5 wt% RDX. Holston Grade A Composition B. 1.713 ± 0.007 g/cm³. Twenty 76-mm-thick, 152-mm-diam cylinders to make a 1524-mm length. P-080 booster, \( D = 3.127 \rho_o + 2.673 \) at 65 wt% RDX and increases 0.0134 km/s per 1 wt% RDX increase.

Plates

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7C 176</td>
<td>2.774</td>
<td>6.35</td>
<td>3.312 ± 0.014</td>
</tr>
<tr>
<td>7C 174</td>
<td>2.782</td>
<td>12.73</td>
<td>3.216 ± 0.010</td>
</tr>
<tr>
<td>7C 172</td>
<td>2.774</td>
<td>19.10</td>
<td>3.189 ± 0.024</td>
</tr>
<tr>
<td>7C 173</td>
<td>2.784</td>
<td>25.39</td>
<td>3.065 ± 0.013</td>
</tr>
<tr>
<td>7C 175</td>
<td>2.774</td>
<td>38.13</td>
<td>2.994 ± 0.017</td>
</tr>
<tr>
<td>7C 177</td>
<td>2.805</td>
<td>60.85</td>
<td>2.823 ± 0.030</td>
</tr>
</tbody>
</table>

*Mean and standard deviation of seven determinations on each shot.

Analysis

Linear least squares fitting gives \( U_{fs} = 3.368 \text{ km/s} - 0.01054 t \text{ (mm)} \). This intercept is only 0.6% below that for Table 3.27 for somewhat larger diameter but shorter charges. The slope for these long charges is more like that of Table 3.27 than the steeper data of Table 3.28.
DETONATION PROPERTIES

Table 3.30 COMPOSITION B ON BRASS

Explosive

RDX/TNT: 64.2 ± 0.4 wt% RDX. 1.714 ± 0.002 g/cm³. Two 102- by 254- by 254-mm pieces to make a 203-mm length. P-080 booster, \( D = 3.127 \rho_o + 2.673 \) at 65 wt% RDX and increases 0.0134 km/s per 1 wt% RDX increase.

Plates

Brass.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>8.402</td>
<td>1.97</td>
<td>2.124 ± 0.004</td>
</tr>
<tr>
<td>a</td>
<td>8.402</td>
<td>3.76</td>
<td>2.068 ± 0.008</td>
</tr>
<tr>
<td>a</td>
<td>8.402</td>
<td>5.76</td>
<td>2.073 ± 0.027</td>
</tr>
<tr>
<td>a</td>
<td>8.402</td>
<td>7.68</td>
<td>2.037 ± 0.019</td>
</tr>
<tr>
<td>a</td>
<td>8.402</td>
<td>9.58</td>
<td>2.033 ± 0.025</td>
</tr>
<tr>
<td>a</td>
<td>8.402</td>
<td>11.49</td>
<td>2.008 ± 0.015</td>
</tr>
<tr>
<td>a</td>
<td>8.402</td>
<td>13.41</td>
<td>1.991 ± 0.014</td>
</tr>
<tr>
<td>a</td>
<td>8.402</td>
<td>15.32</td>
<td>1.969 ± 0.012</td>
</tr>
<tr>
<td>8A 700</td>
<td>8.386</td>
<td>25.43</td>
<td>1.872 ± 0.010</td>
</tr>
<tr>
<td>8A 769</td>
<td>8.386</td>
<td>38.22</td>
<td>1.781 ± 0.008</td>
</tr>
<tr>
<td>8A 699</td>
<td>8.386</td>
<td>48.38</td>
<td>1.717 ± 0.015</td>
</tr>
<tr>
<td>8A 766</td>
<td>8.386</td>
<td>48.93</td>
<td>1.711 ± 0.017</td>
</tr>
</tbody>
</table>

aData for this entry were determined on some or all of the following shots: 7C-3, 8A-373, and 8A 374; each was fired using several plate thicknesses.

bMean and standard deviation of five determinations on last four entries, three on the first six and the eighth, and two on the seventh.

Analysis

Linear least squares fitting gives \( U_{fs} = 2.107 \text{ km/s} - 0.00830 t \) (mm). At \( t = 0 \), plate \( U_s = 5.173 \text{ km/s} \) and \( P_m = 45.36 \text{ GPa} \). Acoustic approximation with \( D = 8.002 \text{ km/s} \), \( \rho_{ox} = 1.714 \text{ g/cm}^3 \), and \( \rho_{om} = 8.395 \text{ g/cm}^3 \) gives corresponding explosive parameters of \( P_x = 28.54 \text{ GPa} \), \( U_{px} = 2.081 \text{ km/s} \), and \( \gamma = 2.845 \).
DETONATION PROPERTIES

Table 3.31 CYCLOTOL ON DURAL

Explosive
RDX/TNT: 77 + 1.2 wt% RDX. 1.742 ± 0.002 g/cm³. Two 102- by 254-mm pieces to make a 203-mm thickness. P-080 booster. D = 3.193 ρ₀ + 2.702 at 78.1 wt% RDX and increases 0.0134 km/s per 1 wt% RDX increase.

Plates

Dural

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>No. Uₐ Dets</th>
<th>Free-Surface Velocity (km/s)ᵇ</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>2.793</td>
<td>1.23</td>
<td>2</td>
<td>3.746 ± 0.056</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>1.90</td>
<td>3</td>
<td>3.545 ± 0.012</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>2.53</td>
<td>4</td>
<td>3.528 ± 0.023</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>3.13</td>
<td>5</td>
<td>3.494 ± 0.052</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>3.80</td>
<td>4</td>
<td>3.494 ± 0.023</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>4.70</td>
<td>2</td>
<td>3.500 ± 0.026</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>5.07</td>
<td>3</td>
<td>3.462 ± 0.012</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>6.32</td>
<td>6</td>
<td>3.445 ± 0.021</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>7.61</td>
<td>3</td>
<td>3.437 ± 0.014</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>7.95</td>
<td>2</td>
<td>3.471 ± 0.001</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>8.88</td>
<td>4</td>
<td>3.431 ± 0.042</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>9.57</td>
<td>2</td>
<td>3.425 ± 0.021</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>10.15</td>
<td>3</td>
<td>3.416 ± 0.026</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>10.88</td>
<td>1</td>
<td>3.434</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>11.05</td>
<td>1</td>
<td>3.427</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>11.42</td>
<td>4</td>
<td>3.424 ± 0.007</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>12.04</td>
<td>1</td>
<td>3.434</td>
</tr>
<tr>
<td>a</td>
<td>2.793</td>
<td>12.56</td>
<td>3</td>
<td>3.378 ± 0.024</td>
</tr>
<tr>
<td>7C 145</td>
<td>2.774</td>
<td>19.05</td>
<td>5</td>
<td>3.987 ± 0.022</td>
</tr>
<tr>
<td>8A 354</td>
<td>2.788</td>
<td>24.41</td>
<td>6</td>
<td>3.280 ± 0.022</td>
</tr>
<tr>
<td>8A 1252</td>
<td>2.805</td>
<td>38.17</td>
<td>5</td>
<td>3.142 ± 0.006</td>
</tr>
<tr>
<td>8A 1253</td>
<td>2.799</td>
<td>50.85</td>
<td>5</td>
<td>3.027 ± 0.024</td>
</tr>
</tbody>
</table>

ᵃData for this entry were determined on some or all of the following shots: 8A-238, -302, -305, -306, and -318; each was fired using several plate thicknesses.
ᵇMean and standard deviation of multiple determinations.

Analysis

Linear least squares fitting gives Uₐ = 3.531 km/s - 0.01029 t (mm). At t = 0, plate Uₐ = 7.704 km/s and Pₘₐₚ = 37.57 GPa. Acoustic approximation of D = 8.252 km/s, ρ₀ = 1.743 g/cm³, and ρₑₘ = 2.793 g/cm³ gives corresponding explosive parameters of Pₑₙ = 31.34 GPa, Uₑₙ = 2.179 km/s, and γ = 2.787.
DETONATION PROPERTIES

Table 3.32 CYCLOTOL ON DURAL

Explosive

RDX/TNT: 76.7 ± 0.8 wt% RDX. 1.756 ± 0.005 g/cm³. 203-mm-diam pieces from 12.7 to 101.6-mm thick in various combinations to give 12.7- to 812.8-mm thicknesses. P-080 booster. \( D = 3.193 \rho_0 + 2.702 \) at 78.1 wt% RDX and increases 0.003 km/s per 1 wt% RDX increase.

Plates

Dural, 36.57 ± 0.02 mm thick.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm²)</th>
<th>Plate Thickness (mm)</th>
<th>Explosive Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>7C 199</td>
<td>2.795</td>
<td>36.59</td>
<td>12.7</td>
<td>1.869 ± 0.025</td>
</tr>
<tr>
<td>7C 200</td>
<td>2.793</td>
<td>36.53</td>
<td>25.4</td>
<td>2.240 ± 0.019</td>
</tr>
<tr>
<td>7C 201</td>
<td>2.786</td>
<td>36.58</td>
<td>38.1</td>
<td>2.540 ± 0.018</td>
</tr>
<tr>
<td>7C 202</td>
<td>2.786</td>
<td>36.58</td>
<td>50.8</td>
<td>2.676 ± 0.010</td>
</tr>
<tr>
<td>7C 203</td>
<td>2.790</td>
<td>36.58</td>
<td>76.2</td>
<td>2.875 ± 0.018</td>
</tr>
<tr>
<td>7C 204</td>
<td>2.786</td>
<td>36.54</td>
<td>101.6</td>
<td>3.006 ± 0.023</td>
</tr>
<tr>
<td>7C 205</td>
<td>2.786</td>
<td>36.57</td>
<td>152.4</td>
<td>3.149 ± 0.018</td>
</tr>
<tr>
<td>7C 206</td>
<td>2.793</td>
<td>36.57</td>
<td>203.2</td>
<td>3.194 ± 0.026</td>
</tr>
<tr>
<td>7C 207</td>
<td>2.793</td>
<td>36.55</td>
<td>406.4</td>
<td>3.289 ± 0.028</td>
</tr>
<tr>
<td>7C 243</td>
<td>2.793</td>
<td>36.58</td>
<td>609.6</td>
<td>3.279 ± 0.030</td>
</tr>
<tr>
<td>7C 218</td>
<td>2.786</td>
<td>36.57</td>
<td>812.8</td>
<td>3.237 ± 0.021</td>
</tr>
</tbody>
</table>

¹Mean and standard deviation of 12 determinations on the first seven entries and on the ninth and tenth, 11 determinations on the eighth, and 3 determinations on the last.

Analysis

As the charge length-to-diameter ratio is increased, the plate free-surface velocity increases continuously and significantly up to an asymptote of 3.29 km/s at about two charge diameters. A small, though possibly significant, decrease is then seen out to four charge diameters. The velocity at one charge diameter is about 3% less than that at two charge diameters.
DETONATION PROPERTIES

Table 3.33 CYCLOTOLE ON PLEXIGLAS

Explosive

RDX/TNT: 74.99 ± 0.01 wt% RDX, 1.200 ± 0.001 g/cm³. Four 152 ± 0.13-mm-long, 141-mm-diam pieces to make a 610-mm-long charge pressed from ball-milled powder of which 86% passed a 44-μm screen and 12% passed a 96-μm screen. Contained in 5-mm-wall brass tubes. P-080 and 13-mm-thick Comp. B booster. D at infinite diameter and 78 wt% RDX is 6.535 km/s.

Plates

Plexiglas (polymethylmethacrylate), nominal 1.18 g/cm³.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7C 239</td>
<td>1.179</td>
<td>6.26</td>
<td>3.613 ± 0.029</td>
</tr>
<tr>
<td>7C 240</td>
<td>1.179</td>
<td>12.61</td>
<td>3.451 ± 0.021</td>
</tr>
<tr>
<td>7C 242</td>
<td>1.179</td>
<td>19.04</td>
<td>3.342 ± 0.024</td>
</tr>
<tr>
<td>7C 241</td>
<td>1.179</td>
<td>24.61</td>
<td>3.322 ± 0.032</td>
</tr>
<tr>
<td>7C 238</td>
<td>1.182</td>
<td>38.05</td>
<td>3.305 ± 0.023</td>
</tr>
<tr>
<td>7C 237</td>
<td>1.182</td>
<td>48.61</td>
<td>3.173 ± 0.035</td>
</tr>
</tbody>
</table>

*Mean and standard deviation of seven determinations on each shot.

Analysis

Linear least squares fitting gives \( U_r = 3.581 \text{ km/s} - 0.00858 t (\text{mm}) \). At \( t = 0 \), plate \( U_s = 5.220 \text{ km/s} \) and \( P_m = 10.92 \text{ GPa} \). Acoustic approximation with \( D = 6.490 \text{ km/s} \), \( \rho_{ox} = 1.200 \text{ g/cm}^3 \), and \( \rho_{om} = 1.180 \text{ g/cm}^3 \) gives corresponding explosive parameters of \( P_x = 12.36 \text{ GPa} \), \( U_{px} = 1.587 \text{ km/s} \), and \( \gamma = 3.089 \).
DETONATION PROPERTIES

Table 3.34 OCTOL ON DURAL

Explosive

HMX/TNT: 76.3 ± 0.8 wt% HMX, 1.809 ± 0.007 g/cm³. 155-mm-thick conical frustum of 279-mm small diameter and 324-mm large diameter with large end toward plate, P-080 and 32-mm-thick Plexiglas booster. D = 8.478 km/s at ρ₀ = 1.814 g/cm³ and 77 wt% HMX. D increases ~0.8031 km/s per 0.001-g/cm³ density increase and ~0.013 km/s per 1 wt% HMX increase.

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>8A 1322</td>
<td>2.774</td>
<td>2.54</td>
<td>3.674 ± 0.035</td>
</tr>
<tr>
<td>7C 151</td>
<td>2.782</td>
<td>6.31</td>
<td>3.644 ± 0.064</td>
</tr>
<tr>
<td>8A 1337</td>
<td>2.774</td>
<td>6.37</td>
<td>3.698 ± 0.039</td>
</tr>
<tr>
<td>7C 117</td>
<td>2.784</td>
<td>12.88</td>
<td>3.476 ± 0.048</td>
</tr>
<tr>
<td>8A 1177</td>
<td>2.790</td>
<td>19.15</td>
<td>3.438 ± 0.025</td>
</tr>
<tr>
<td>8A 1178</td>
<td>2.782</td>
<td>25.51</td>
<td>3.348 ± 0.021</td>
</tr>
<tr>
<td>8A 1189</td>
<td>2.786</td>
<td>38.13</td>
<td>3.232 ± 0.008</td>
</tr>
<tr>
<td>8A 1180</td>
<td>2.783</td>
<td>50.88</td>
<td>3.113 ± 0.012</td>
</tr>
<tr>
<td>7C 166</td>
<td>2.783</td>
<td>76.76</td>
<td>2.859 ± 0.010</td>
</tr>
</tbody>
</table>

*Mean and standard deviation of seven determinations on the first three shots listed, five determinations on the next five, and three determinations on the last.

Analysis

Linear least squares fitting gives \( U_{fs} = 3.695 \text{ km/s} - 0.01160 \text{ t (mm)} \). At \( t = 0 \), plate \( U_s = 7.811 \text{ km/s} \), and \( P_m = 39.72 \text{ GPa} \). Acoustic approximation with \( D = 8.452 \text{ km/s}, \rho_{ox} = 1.809 \text{ g/cm}^3 \), and \( \rho_{cm} = 2.781 \text{ g/cm}^3 \) gives corresponding explosive parameters of \( P_x = 33.84 \text{ GPa}, U_{px} = 2.213 \text{ km/s} \), and \( \gamma = 2.819 \).
DETONATION PROPERTIES

Table 3.35  PBX 9206 (HMX/KEL-F) ON DURAL

Explosive

HMX/Kel-F 3700: 92/8. 1.837 ± 0.001 g/cm³. Two 76-mm-thick, 156-mm-diam pieces to make a 152-mm thickness. P-080 booster. D = 8.725 km/s at 41-mm diam and ρ₀ = 1852 g/cm³.

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>7C 225</td>
<td>2.788</td>
<td>6.34</td>
<td>3.658 ± 0.018</td>
</tr>
<tr>
<td>7C 210</td>
<td>2.774</td>
<td>12.81</td>
<td>3.560 ± 0.032</td>
</tr>
<tr>
<td>7C 211</td>
<td>2.774</td>
<td>19.14</td>
<td>3.487 ± 0.022</td>
</tr>
<tr>
<td>7C 212</td>
<td>2.774</td>
<td>25.10</td>
<td>3.511 ± 0.014</td>
</tr>
<tr>
<td>7C 254</td>
<td>2.782</td>
<td>25.74</td>
<td>3.445 ± 0.017</td>
</tr>
<tr>
<td>7C 214</td>
<td>2.782</td>
<td>38.13</td>
<td>3.307 ± 0.008</td>
</tr>
<tr>
<td>7C 215</td>
<td>2.782</td>
<td>50.79</td>
<td>3.195 ± 0.027</td>
</tr>
</tbody>
</table>

*Mean and standard deviation of seven determinations on each shot.

Analysis

Linear least squares fitting gives \( U_{fs} = 3.710 \text{ km/s} - 0.01016 t (\text{mm}) \). At \( t = 0 \), plate \( U_s = 7.821 \text{ km/s} \) and \( P_m = 39.93 \text{ GPa} \). Acoustic approximation with \( D = 8.685 \text{ km/s} \), \( \rho_{ox} = 1.837 \text{ g/cm}^3 \), and \( \rho_{em} = 2.779 \text{ g/cm}^3 \) gives corresponding explosive parameters of \( P_x = 34.62 \text{ GPa} \), \( U_{px} = 2.170 \text{ km/s} \), and \( \gamma = 3.002 \).
DETONATION PROPERTIES

Table 3.36  PBX 9207 (HMX/EXON/CEF) ON DURAL

Explosive

HMX/Exon 461/CEF: 92/6/2. 1.837 ± 0.002 g/cm³. Two 76-mm-thick, 156-mm-diam pieces to make a 152-mm thickness. P-080 booster. \( D = 8.677 \text{ km/s at } 41\text{-mm diam} \) and \( \rho_o = 1.843 \text{ g/cm}^3 \).

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>8A 1449</td>
<td>2.784</td>
<td>5.13</td>
<td>3.599 ± 0.025</td>
</tr>
<tr>
<td>7C 231</td>
<td>2.788</td>
<td>6.17</td>
<td>3.728 ± 0.030</td>
</tr>
<tr>
<td>7C 226</td>
<td>2.782</td>
<td>12.71</td>
<td>3.553 ± 0.013</td>
</tr>
<tr>
<td>7C 227</td>
<td>2.782</td>
<td>19.08</td>
<td>3.499 ± 0.016</td>
</tr>
<tr>
<td>7C 228</td>
<td>2.789</td>
<td>24.20</td>
<td>3.439 ± 0.025</td>
</tr>
<tr>
<td>7C 229</td>
<td>2.788</td>
<td>38.12</td>
<td>3.334 ± 0.027</td>
</tr>
<tr>
<td>7C 244</td>
<td>2.789</td>
<td>50.83</td>
<td>3.215 ± 0.013</td>
</tr>
</tbody>
</table>

*aMean and standard deviation of seven determinations on six shots and six determinations on the third one listed.

Analysis

Linear least squares fitting gives \( U_{ts} = 3.692 \text{ km/s} - 0.00954 t (\text{mm}) \). At \( t = 0 \), plate \( U_s = 7.809 \text{ km/s} \) and \( P_m = 39.68 \text{ GPa} \). Acoustic approximation with \( D = 8.665 \text{ km/s}, \rho_{ox} = 1.837 \text{ g/cm}^3 \), and \( \rho_{om} = 2.786 \text{ g/cm}^3 \) gives corresponding parameters of \( P_x = 34.35 \text{ GPa}, U_{px} = 2.158 \text{ km/s}, \) and \( \gamma = 3.015 \).
DETONATION PROPERTIES

Table 3.37 PBX 9401 (RDX/PS) ON DURAL

Explosive

RDX/PS/TOF: 94.2/3.6/2.2. 1.713 ± 0.002 g/cm³. A 203-mm-thick conical frustum of 229-mm small diameter and 324-mm large diameter with its small end toward the plate. P-080 booster. D = 8.426 km/s at \( \rho_0 = 1.711 \) g/cm³.

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>8A 1191</td>
<td>2.784</td>
<td>6.28</td>
<td>3.229 ± 0.019</td>
</tr>
<tr>
<td>7C 92</td>
<td>2.771</td>
<td>12.77</td>
<td>3.171 ± 0.050</td>
</tr>
<tr>
<td>7C 91</td>
<td>2.790</td>
<td>19.13</td>
<td>3.183 ± 0.010</td>
</tr>
<tr>
<td>7C 94</td>
<td>2.782</td>
<td>25.49</td>
<td>3.156 ± 0.019</td>
</tr>
<tr>
<td>7C 95</td>
<td>2.786</td>
<td>38.15</td>
<td>3.095 ± 0.012</td>
</tr>
<tr>
<td>7C 96</td>
<td>2.783</td>
<td>50.88</td>
<td>2.990 ± 0.021</td>
</tr>
</tbody>
</table>

*Mean and standard deviation of five determinations on each shot.

Analysis

Linear least squares fitting gives \( U_{fs} = 3.263 \) km/s \(- 0.00492 \) t (mm). At \( t = 0 \), plate \( U_s = 7.529 \) km/s and \( P_m = 33.89 \) GPa. Acoustic approximation with \( D = 8.432 \) km/s, \( \rho_{ox} = 1.713 \) g/cm³, and \( \rho_{om} = 2.783 \) g/cm³ gives corresponding explosive parameters of \( P_s = 28.63 \) GPa, \( U_{ps} = 1.982 \) km/s, and \( \gamma = 3.254 \).
DETONATION PROPERTIES

Table 3.38  PBX 9402 (HMX/NC/CEF) ON DURAL

Explosive

HMX/NC/CEF: 94/3/3. 1.831 ± 0.011 g/cm³. Three 64-mm-thick conical frusta of 279-mm small diameter and 324-mm large diameter with small ends toward plate. P-080 booster. \( D = 8.732 \text{ km/s} - 0.037/\text{diam (cm)} \), at \( \rho_o = 1.822 \text{ g/cm}^3 \) and increases approximately 0.003 km/s per 0.001-g/cm³ increase.

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>7C 124</td>
<td>2.782</td>
<td>6.36</td>
<td>3.717 ± 0.013</td>
</tr>
<tr>
<td>7C 75</td>
<td>2.771</td>
<td>12.75</td>
<td>3.653 ± 0.021</td>
</tr>
<tr>
<td>7C 79</td>
<td>2.790</td>
<td>19.10</td>
<td>3.620 ± 0.009</td>
</tr>
<tr>
<td>7C 149</td>
<td>2.805</td>
<td>25.45</td>
<td>3.534 ± 0.022</td>
</tr>
<tr>
<td>7C 76</td>
<td>2.782</td>
<td>26.21</td>
<td>3.503 ± 0.042</td>
</tr>
<tr>
<td>7C 90</td>
<td>2.786</td>
<td>38.20</td>
<td>3.475 ± 0.038</td>
</tr>
<tr>
<td>7C 86</td>
<td>2.783</td>
<td>51.37</td>
<td>3.308 ± 0.005</td>
</tr>
</tbody>
</table>

*Mean and standard deviation of five determinations on six shots and three determinations on the second one listed.

Analysis

Linear least squares fitting gives \( U_{rs} = 3.767 \text{ km/s} - 0.00870 t(\text{mm}) \). At \( t = 0 \), plate \( U_s = 7.858 \text{ km/s} \) and \( P_m = 40.73 \text{ GPa} \). Acoustic approximation with \( D = 8.773 \text{ km/s} \), \( \rho_{ox} = 1.836 \text{ g/cm}^3 \), and \( \rho_{om} = 2.786 \text{ g/cm}^3 \) gives corresponding explosive parameters of \( P_x = 35.35 \text{ GPa} \), \( U_{px} = 2.195 \text{ km/s} \), and \( \gamma = 2.997 \).
DETONATION PROPERTIES

Table 3.39  PBX 9404 (HMX/NC/CEF) ON DURAL

Explosive

HMX/NC/CEF: 94/3/3. 1.827 ± 0.001 g/cm³. Two 76-mm-thick, 156-mm-diam pieces to make a 152-mm thickness. P-080 booster. \( D = 8.732 \text{ km/s} - 0.037/\text{diam (cm)} \) at \( \rho_0 = 1.822 \text{ g/cm}^3 \) and increases approximately 0.003 km/s per 0.001-g/cm³ increase.

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm²)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>7C 235</td>
<td>2.788</td>
<td>6.37</td>
<td>3.757 ± 0.024</td>
</tr>
<tr>
<td>7C 246</td>
<td>2.782</td>
<td>12.74</td>
<td>3.661 ± 0.019</td>
</tr>
<tr>
<td>7C 247</td>
<td>2.789</td>
<td>19.13</td>
<td>3.596 ± 0.029</td>
</tr>
<tr>
<td>7C 232</td>
<td>2.782</td>
<td>25.35</td>
<td>3.547 ± 0.025</td>
</tr>
<tr>
<td>7C 233</td>
<td>2.788</td>
<td>38.12</td>
<td>3.426 ± 0.003</td>
</tr>
<tr>
<td>7C 234</td>
<td>2.789</td>
<td>50.85</td>
<td>3.360 ± 0.022</td>
</tr>
</tbody>
</table>

*Mean and standard deviation of seven determinations on each shot.

Analysis

Linear least squares fitting gives \( U_{rs} = 3.812 \text{ km/s} - 0.01065 t \) (mm). At \( t = 0 \), plate \( U_s = 7.88 \text{ km/s} \) and \( P_m = 41.36 \text{ GPa} \). Acoustic approximation with \( D = 8.745 \text{ km/s} \), \( \rho_{ox} = 1.827 \text{ g/cm}^3 \), and \( \rho_{cm} = 2.786 \text{ g/cm}^3 \) gives corresponding explosive parameters of \( P_x = 35.72 \text{ GPa} \), \( U_{px} = 2.235 \text{ km/s} \), and \( \gamma = 2.912 \).
DETONATION PROPERTIES

Table 3.40  PBX-9405 (RDX/NC/CEF) ON DURAL

Explosive

RDX/NC/CEF: 93.7/3.15/3.15, 1.757 ± 0.001 g/cm³. A 203-mm-thick conical frustum of 229-mm small diameter and 326-mm large diameter with its small end toward the plate. P-080 booster, \( D = 8.489 - 0.157 \text{diam (cm)} \) at \( \rho_0 = 1.755 \text{ g/cm}^3 \).

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)a</th>
</tr>
</thead>
<tbody>
<tr>
<td>8A 1325</td>
<td>2.774</td>
<td>2.54</td>
<td>3.643 ± 0.076</td>
</tr>
<tr>
<td>7C 152</td>
<td>2.782</td>
<td>6.35</td>
<td>3.690 ± 0.066</td>
</tr>
<tr>
<td>8A 1230</td>
<td>2.782</td>
<td>12.76</td>
<td>3.594 ± 0.013</td>
</tr>
<tr>
<td>8A 1231</td>
<td>2.774</td>
<td>19.03</td>
<td>3.517 ± 0.004</td>
</tr>
<tr>
<td>8A 1236</td>
<td>2.805</td>
<td>25.41</td>
<td>3.385 ± 0.032</td>
</tr>
<tr>
<td>7C 148</td>
<td>2.805</td>
<td>25.53</td>
<td>3.378 ± 0.015</td>
</tr>
<tr>
<td>8A 1237</td>
<td>2.805</td>
<td>38.16</td>
<td>3.283 ± 0.019</td>
</tr>
<tr>
<td>8A 1238</td>
<td>2.799</td>
<td>50.88</td>
<td>3.129 ± 0.013</td>
</tr>
</tbody>
</table>

*Mean and standard deviation of seven determinations on the first two shots listed and five determinations on the other six.

Analysis

Linear least squares fitting gives \( U_{fs} = 3.718 \text{ km/s} - 0.01173 \text{ t (mm)} \). At \( t = 0 \), plate \( U_x = 7.826 \text{ km/s} \) and \( P_m = 40.04 \text{ GPa} \). Acoustic approximation with \( D = 8.494 \text{ km/s} \), \( \rho_{ox} = 1.757 \text{ g/cm}^3 \) and \( \rho_{om} = 2.791 \text{ g/cm}^3 \) gives corresponding explosive parameters of \( P_x = 33.70 \text{ GPa} \), \( U_{px} = 2.258 \text{ km/s} \), and \( \gamma = 2.762 \).
DETONATION PROPERTIES

Table 3.41  RDX PRESSED ON DURAL

Explosive

100% RDX pressed without binder. 1.768 ± 0.014 g/cm³. Two 76-mm-thick, 152-mm-diam pieces to make 152-mm thickness. P-080 booster. D = 3.466 ρo + 2.515.

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a 2.790</td>
<td>2.56</td>
<td>3.589 ± 0.019</td>
<td></td>
</tr>
<tr>
<td>a 2.790</td>
<td>5.11</td>
<td>3.484 ± 0.010</td>
<td></td>
</tr>
<tr>
<td>7C 153</td>
<td>2.782</td>
<td>6.31</td>
<td>3.695 ± 0.033</td>
</tr>
<tr>
<td>a 2.790</td>
<td>7.63</td>
<td>3.470 ± 0.012</td>
<td></td>
</tr>
<tr>
<td>a 2.790</td>
<td>10.17</td>
<td>3.471 ± 0.015</td>
<td></td>
</tr>
<tr>
<td>b 2.790</td>
<td>12.61</td>
<td>3.468 ± 0.019</td>
<td></td>
</tr>
<tr>
<td>7C 84</td>
<td>2.782</td>
<td>12.69</td>
<td>3.476 ± 0.011</td>
</tr>
<tr>
<td>7C 144</td>
<td>2.774</td>
<td>19.09</td>
<td>3.434 ± 0.045</td>
</tr>
<tr>
<td>8A 350</td>
<td>2.790</td>
<td>25.37</td>
<td>3.286 ± 0.021</td>
</tr>
<tr>
<td>7C 146</td>
<td>2.805</td>
<td>38.13</td>
<td>3.212 ± 0.049</td>
</tr>
<tr>
<td>7C 85</td>
<td>2.782</td>
<td>50.80</td>
<td>3.027 ± 0.079</td>
</tr>
</tbody>
</table>

*Data for this entry were determined on some or all of the following shots: 8A-326, -331, -332, and -333; each was fired using several plate thicknesses.

**Shots 8A-331, -332, and -333.

*Mean and standard deviation of seven determinations on the third entry, five each on the last five, four each on the four single-asterisk entries marked a, and three determinations on the entry marked by b.

Analysis

The data at 6.31 mm seem anomalous, but no good reason for discard was found. Linear least squares fitting of all the data gives Uᵣᵣ = 3.633 km/s – 0.01184 t (mm). At t = 0, plate Uᵣᵣ = 7.770 km/s and Pᵣᵣ = 38.88 GPa. Acoustic approximation with D = 8.642 ρᵣᵣ = 1.768 g/cm³, and ρᵣᵣ = 2.787 g/cm³ gives corresponding explosive parameters of Pᵣᵢ = 33.16 GPa, Uᵣᵣᵣ = 2.169 km/s, and γ = 2.984.
DETONATION PROPERTIES

Table 3.42 RDX AND DNPA ON DURAL

Explosive

RDX/DNPA: 90/10. $1.745 \pm 0.001 \text{g/cm}^3$. Two 76-mm-thick, 150-mm-diam pieces to make 152-mm thickness. P-080 booster. $D = 3.233 \rho_0 + 2.785$.

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm$^3$)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>2.790</td>
<td>2.49</td>
<td>3.578 ± 0.016</td>
</tr>
<tr>
<td>a</td>
<td>2.790</td>
<td>5.04</td>
<td>3.491 ± 0.024</td>
</tr>
<tr>
<td>a</td>
<td>2.790</td>
<td>6.36</td>
<td>3.466</td>
</tr>
<tr>
<td>a</td>
<td>2.790</td>
<td>7.58</td>
<td>3.426 ± 0.009</td>
</tr>
<tr>
<td>a</td>
<td>2.790</td>
<td>10.12</td>
<td>3.421 ± 0.009</td>
</tr>
<tr>
<td>8A 365</td>
<td>2.793</td>
<td>12.71</td>
<td>3.376</td>
</tr>
<tr>
<td>8A 352</td>
<td>2.790</td>
<td>25.35</td>
<td>3.274 ± 0.015</td>
</tr>
<tr>
<td>7C 150</td>
<td>2.805</td>
<td>37.97</td>
<td>3.087 ± 0.056</td>
</tr>
<tr>
<td>C 147</td>
<td>2.799</td>
<td>50.87</td>
<td>2.966 ± 0.083</td>
</tr>
</tbody>
</table>

$^a$Data for this entry were determined on some or all of the following shots: 8A-315, -334, -335, and -345; each was fired using several plate thicknesses.

$^b$Mean and standard deviation of five determinations on the last three entries, four on the second through sixth, three on the first, and one on the third and seventh.

Analysis

Linear least squares fitting gives $U_{ts} = 3.552 \text{ km/s} - 0.01171 t$ (mm). At $t = 0$, plate $U_s = 7.719 \text{ km/s}$ and $P_m = 37.86 \text{ GPa}$. Acoustic approximation with $D = 8.427 \text{ km/s}$, $\rho_{ox} = 1.745 \text{ g/cm}^3$, and $\rho_{om} = 2.793 \text{ g/cm}^3$ gives corresponding explosive parameters of $P_x = 31.66 \text{ GPa}$, $U_{px} = 2.153 \text{ km/s}$, and $\gamma = 2.915$. 

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Table 3.43 RDX AND KEL-F ON DURAL

Explosive

RDX/Kel-F 150: 85/15. 1.809 ± 0.004 g/cm³. Two 76-mm-thick, 150-mm-diam pieces to make a 152-mm thickness. P-080 booster. D = 8.280 km/s at ρ₀ = 1.807 g/cm³.

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm³)</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>2.790</td>
<td>5.08</td>
<td>3.683 ± 0.020</td>
</tr>
<tr>
<td>a</td>
<td>2.790</td>
<td>6.35</td>
<td>3.639 ± 0.017</td>
</tr>
<tr>
<td>a</td>
<td>2.790</td>
<td>7.62</td>
<td>3.616 ± 0.032</td>
</tr>
<tr>
<td>a</td>
<td>2.790</td>
<td>8.89</td>
<td>3.623 ± 0.008</td>
</tr>
<tr>
<td>a</td>
<td>2.790</td>
<td>10.16</td>
<td>3.567 ± 0.018</td>
</tr>
<tr>
<td>a</td>
<td>2.790</td>
<td>12.70</td>
<td>3.517 ± 0.035</td>
</tr>
<tr>
<td>8A 404</td>
<td>2.790</td>
<td>13.16</td>
<td>3.505 ± 0.026</td>
</tr>
<tr>
<td>8A 403</td>
<td>2.790</td>
<td>25.40</td>
<td>3.388 ± 0.014</td>
</tr>
</tbody>
</table>

*a Data for this entry were determined on some or all of the following shots: 8A-347, 348, 349, -384, -387, -411, and -412; each was fired using multiple plate thicknesses.

*bMean and standard deviation of seven determinations each on the second and sixth entry, six each on the third and fifth, five each on the first and seventh, four on the last, and two on the fourth.

Analysis

Linear least squares fitting gives $U_{ts} = 3.725 \text{ km/s} - 0.01449 \ t \ (\text{mm})$. At $t = 0$, plate $U_s = 7.831 \text{ km/s}$ and $P_m = 40.21 \text{ GPa}$. Acoustic approximation with $D = 8.287 \text{ km/s}$, $\rho_{ox} = 1.809 \text{ g/cm³}$, and $\rho_{em} = 2.790 \text{ g/cm³}$ gives corresponding explosive parameters of $P_s = 33.71 \text{ GPa}$, $U_{px} = 2.248 \text{ km/s}$, and $\gamma = 2.686$. 

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DETONATION PROPERTIES

Table 3.44 TNT PRESSED ON DURAL

Explosive

Granular 400-\(\mu\)m particle-size TNT pressed to a density of 1.635 ± 0.006 g/cm\(^3\). Conical 203-mm-thick frusta of 213-mm minimum and 235-mm maximum diameter. Small end toward plate. \(D = 2.799 \rho_0 + 2.360\).

Plates

Dural.

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm(^3))</th>
<th>Plate Thickness (mm)</th>
<th>No. U(_{fs}) Dets</th>
<th>Free-Surface Velocity (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>2.793</td>
<td>1.79</td>
<td>3</td>
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</tr>
<tr>
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<tr>
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<td>2.409 ± 0.010</td>
</tr>
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<td>2.397 ± 0.026</td>
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<td>7</td>
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<td>2.363 ± 0.019</td>
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<td>2.322 ± 0.026</td>
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<td>2.309 ± 0.001</td>
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<td>2.322 ± 0.004</td>
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<td>2.193 ± 0.005</td>
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<td>3</td>
<td>2.144 ± 0.003</td>
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<td>8A 703</td>
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<td>50.92</td>
<td>5</td>
<td>2.165 ± 0.021</td>
</tr>
</tbody>
</table>

*Data for this entry were determined on some or all of the following shots: 8A-251, -255, -311, -312, and -313; each was fired using multiple plate thicknesses.

Analysis

Linear least squares fitting to the data on 6-mm plate thickness gives \(U_{fs} = 2.510\) km/s − 0.02535 t (mm). At t = 0, plate \(U_s = 7.033\) km/s and \(P_m = 24.49\) GPa. Acoustic approximation with \(D = 6.948\) km/s, \(\rho_{ox} = 1.639\) g/cm\(^3\), and \(\rho_{om} = 2.792\) g/cm\(^3\) gives corresponding explosive pressure of \(P_x = 19.35\) GPa. Linear least
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squares fitting to the data above 6-mm plate thickness gives \( U_{fs} = 2.373 \text{ km/s} - 0.00425 \ t \ (\text{mm}) \). The intersection of these two lines at 6.5-mm plate thickness corresponds to a plate \( U_{fs} = 2.345 \text{ km/s} \), \( U_s = 6.924 \text{ km/s} \), and \( P_m = 22.52 \text{ GPa} \). Acoustic approximation with \( D = 6.942 \text{ km/s} \), \( \rho_\infty = 1.637 \text{ g/cm}^3 \), and \( \rho_\text{om} = 2.789 \text{ g/cm}^3 \) gives corresponding explosive parameters of \( P_x = 17.89 \text{ GPa} \), \( U_{px} = 1.572 \text{ km/s} \), and \( \gamma = 3.415 \).

### Table 3.45 TNT AND DNT ON BRASS

<table>
<thead>
<tr>
<th>Explosive</th>
<th>TNT/DNT: 60.8/39.2. 1.579 ± 0.002 \text{ g/cm}^3. Six 102-mm-high, 150-mm-diam cylinders. P-080 and 13-mm-thick Composition B booster. ( D = 3.235 \rho_\infty + 1.647 ).</th>
</tr>
</thead>
</table>

**Plates**

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Plate Density (g/cm(^3))</th>
<th>Plate Thickness (mm)</th>
<th>Free-Surface Velocity (km/s)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8A 1323</td>
<td>8.426</td>
<td>2.54</td>
<td>1.441 ± 0.006</td>
</tr>
<tr>
<td>8A 1306</td>
<td>8.426</td>
<td>6.29</td>
<td>1.391 ± 0.007</td>
</tr>
<tr>
<td>8A 1179</td>
<td>8.426</td>
<td>12.82</td>
<td>1.313 ± 0.006</td>
</tr>
<tr>
<td>8A 1304</td>
<td>8.426</td>
<td>19.04</td>
<td>1.293 ± 0.007</td>
</tr>
<tr>
<td>8A 1186</td>
<td>8.426</td>
<td>25.49</td>
<td>1.266 ± 0.006</td>
</tr>
<tr>
<td>8A 1303</td>
<td>8.426</td>
<td>38.19</td>
<td>1.202 ± 0.007</td>
</tr>
<tr>
<td>7C 109</td>
<td>8.426</td>
<td>51.64</td>
<td>1.085 ± 0.009</td>
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</table>

\( \rho_\infty = 1.637 \text{ g/cm}^3 \), \( \rho_\text{om} = 2.789 \text{ g/cm}^3 \) gives corresponding explosive parameters of \( P_x = 17.89 \text{ GPa} \), \( U_{px} = 1.572 \text{ km/s} \), and \( \gamma = 3.055 \).

**Analysis**

Linear least squares fitting gives \( U_{fs} = 1.433 \text{ km/s} - 0.00666 \ t \ (\text{mm}) \). At \( t = 0 \), plate \( U_s = 4.649 \text{ km/s} \) and \( P_m = 27.94 \text{ GPa} \). Acoustic approximation with \( D = 6.755 \text{ km/s} \), \( \rho_\infty = 1.579 \text{ g/cm}^3 \), and \( \rho_\text{om} = 8.426 \text{ g/cm}^3 \) gives corresponding explosive parameters of \( P_x = 17.77 \text{ GPa} \), \( U_{px} = 1.666 \text{ km/s} \), and \( \gamma = 3.055 \).
3.4 Plate Dent Test. The plate dent test was developed during World War II at the Explosives Research Laboratory at Bruceton, Pennsylvania. It was designed to provide a relative estimate of explosive power. The test involves detonating an unconfined cylindrical charge of high explosive in contact with a heavy steel plate and measuring the depth of the dent produced in the plate. The explosive charges are of a diameter and length that ensure establishment of a steady-state detonation wave of almost infinite-diameter velocity in most explosives. The steel witness plates are massive and strong enough to limit the damage to the area of interest.

The explosive to be tested is prepared in the form of 1 5/8-in.-diam cylinders of varying lengths (see Table 3.46). The test plates are 6-in.-square by 2-in.-thick pieces of 1018 cold-rolled steel, cut from 2- by 6-in. bar stock having a Rockwell hardness of B-74 to B-76.

To eliminate spalling from the rear surface, several test plates are stacked vertically, and the upper surface of the top plate is greased lightly to ensure good coupling with the charge. The test charge is centered on the plate, a booster of adequate size is placed on the charge, and the detonator is put in place. If necessary, a piece of tape may be used to hold the assembly together and maintain good contact among its various components. The assembly ready for firing is shown in Fig. 3.02.
### Table 3.46 PLATE DENT TEST RESULTS

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm²)</th>
<th>Explosive Length (mm)</th>
<th>Dent Depth (mm)</th>
<th>Remarks</th>
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<td>BTF</td>
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<td>HMX</td>
<td>1.730</td>
<td>203</td>
<td>10.07</td>
<td>b</td>
</tr>
<tr>
<td>Nitromethane</td>
<td>1.133</td>
<td>203</td>
<td>10.07</td>
<td>b</td>
</tr>
<tr>
<td>NQ</td>
<td>0.25</td>
<td>76.2</td>
<td>0.56</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>0.40</td>
<td>76.2</td>
<td>0.79</td>
<td>c</td>
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<tr>
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<td>1.744</td>
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<tr>
<td></td>
<td>1.754</td>
<td>203</td>
<td>10.35</td>
<td>b</td>
</tr>
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<td>TATB</td>
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<td>TNT - pressed at 65°C</td>
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<td>12.7</td>
<td>1.57</td>
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<tr>
<td></td>
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<td>16.9</td>
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<tr>
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<td>25.4</td>
<td>1.93</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>1.629</td>
<td>31.7</td>
<td>1.93</td>
<td>a</td>
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<td>a</td>
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*12.7-mm explosive diameter.
*bTest explosive diameter 41.3 mm.
*c1100 aluminum plate.
*d25.4-mm explosive diameter.
<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>Explosive Length (mm)</th>
<th>Dent Depth (mm)</th>
<th>Remarks</th>
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</thead>
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**Castable Explosives**

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</tr>
<tr>
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<td>813</td>
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<td>b</td>
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**Plastic-Bonded Explosives**

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Table 3.46 (continued)

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85 RDX/15 Kel-F
88 RDX/12 Kel-F
94 RDX/3 NC/3 CEF

Remarks: b
### Lead-Filled

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### Silicon-Filled

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### Titanium-Hydride-Filled

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### Zirconium-Hydride-Filled

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Table 3.47 LEAD-LOADED EXPLOSIVE WAFER TEST

A series of plate dent tests were performed in which a wafer of a lead-loaded explosive was placed between the donor explosive and the witness plate. The test results are given below.

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*22.2 HMX/36 Exon/74.2 Pb.

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*34.2 RDX/4.6 Exon/61.2 Pb.
*23.3 RDX/3.7 Exon/73.0 Pb.
DETONATION PROPERTIES

Table 3.47 (continued)

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<td>6.37</td>
<td>10.72</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>5.004</td>
<td>9.52</td>
<td>11.18</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>5.025</td>
<td>12.70</td>
<td>11.04</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>5.007</td>
<td>203</td>
<td>8.13</td>
<td>No donor HE</td>
</tr>
<tr>
<td>d</td>
<td>5.526</td>
<td>6.37</td>
<td>10.86</td>
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<td>d</td>
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<td>9.62</td>
<td>11.98</td>
<td></td>
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<tr>
<td>d</td>
<td>5.522</td>
<td>9.52</td>
<td>11.68</td>
<td></td>
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<tr>
<td>d</td>
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<td>11.73</td>
<td></td>
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<td>d</td>
<td>5.537</td>
<td>203</td>
<td>9.75</td>
<td>No donor HE</td>
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</tbody>
</table>

*16.1 RDX/3.0 Exon/80.6 Pb

3.5 Detonation Failure Thickness. The wedge-shaped explosive sample is confined on the bottom by a 1-in.-thick brass plate and on the sides by 1/4-in.-thick steel bars. The test assembly is shown in Fig. 3.03. The wedge is usually 1 in. wide and, with side confinement, adequately represents a wedge of infinite width. High-density solid explosive samples are prepared most conveniently by gluing a rectangular explosive prism to the brass plate and then forming the wedge by milling. The wedge thickness is measured at various distances from the end of the brass, the side plates are then glued on, and the charge is ready for firing. To minimize damage to the brass, it is backed by a heavy steel plate when the charge is fired. A step in the brass plate indicates the location and thus the thickness of the explosive at the point where detonation fails.

The booster explosive may cause an artificially energetic and rapid detonation, called overdrive, in the sample. To correct for overdrive, wedges with apex angles of 1, 2, 3, 4, and 5° are fired, and the resulting failure thicknesses are plotted vs angle.

Fig. 3.03. Minimum failure thickness test assembly.
# DETONATION PROPERTIES

## Table 3.48 DETONATION FAILURE THICKNESS

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>Failure Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pure Explosives</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium picrate</td>
<td>1.64</td>
<td>3.29</td>
</tr>
<tr>
<td>TNT</td>
<td>1.61</td>
<td>1.91*</td>
</tr>
<tr>
<td><strong>Castable Mixtures</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp A-3</td>
<td>1.63</td>
<td>0.57</td>
</tr>
<tr>
<td>Comp B-3</td>
<td>1.72</td>
<td>0.94</td>
</tr>
<tr>
<td>Cyclotol 75/25</td>
<td>1.75</td>
<td>1.51</td>
</tr>
<tr>
<td>Octol 75/25</td>
<td>1.79</td>
<td>1.43</td>
</tr>
<tr>
<td>Pentolite</td>
<td>1.70</td>
<td>1.39b</td>
</tr>
<tr>
<td><strong>Plastic-Bonded Explosives</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>HMX-Based</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBX 9011</td>
<td>1.77</td>
<td>0.61</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.83</td>
<td>0.46</td>
</tr>
<tr>
<td>X-0204</td>
<td>1.922</td>
<td>0.41</td>
</tr>
<tr>
<td><em>RDX-Based</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBX 9010</td>
<td>1.78</td>
<td>0.52</td>
</tr>
<tr>
<td>PBX 9205</td>
<td>1.69</td>
<td>0.57</td>
</tr>
<tr>
<td>PBX 9407</td>
<td>1.77</td>
<td>0.30</td>
</tr>
</tbody>
</table>

*Pressed at 65°C.
*bCast 50-mm wedge.

A linear curve is fitted through the data and extrapolated to 0°, and the failure thickness at 0° is designated the detonation failure thickness.

If the brass plate were completely incompressible, the failure thickness so determined would be half that of an unconfined infinite sheet. The failure thickness of an unconfined sheet is less than the failure diameter of a cylinder because rarefactions in a cylinder enter from all sides of the charge and influence the detonation. Thus, the failure diameter may be several times the failure thickness and may vary from one explosive to another.

More complete details are given in a LASL report.

## REFERENCES

SHOCK INITIATION PROPERTIES

4. SHOCK INITIATION PROPERTIES

ORDER OF WEDGE TEST RESULTS

Pure Explosives

HMX
HMX (single crystal)
Nitromethane (NM)
Nitroguanidine (NQ)
PETN (pressed)
PETN (single-crystal)
TATB (purified)
TATB (micronized)
TATB (superfine)
Tetryl
TNT (cast)
TNT (single-crystal)

Castable Mixtures

Baratol (76 barium nitrate, 24 TNT)
Comp B (60 RDX, 40 TNT)
X-0809 (Destex)

Plastic-Bonded Explosives

DATB Base
X-0300 (95 DATB, 5 Estane)

HMX Base
PBX 9501 (95 HMX, 2.5 Estane, 2.5 BDNPFA)
PBX 9404 (94 HMX, 3 NC, 3 chloroethylphosphate)
PBX 9011 (90 HMX, 10 Estane)
LX-04 (85 HMX, 15 Viton)
X-0219-50-14-10 (50 HMX, 40 TATB, 10 Kel-F 800)

NQ Base
X-0241 (96 NQ, 2 wax, 2 Elvax)
95 NQ, 5 Estane
X-0228 (90 NQ, 10 Estane)
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*PETN Base*
  XTX-8003 (Extex) (80 PETN, 20 Sylgard)

*RDX Base*
  95 RDX, 2.5 wax, 2.5 Elvax
  PBX 9407 (94 RDX, 6 Exon)
  PBX 9405 (93.7 RDX, 3.15 NC, 3.15 chloroethylphosphate)
  X-0224 (74 RDX, 20 Al, 5.4 Elvax, 0.6 wax)
  X-0250-40-19 (40.4 RDX, 40.4 cyanuric acid, 19.4 Sylgard)

*TATB Base*
  PBX 9502 (95 TATB, 5 Kel-F 800 (X-0290)
  95 TATB, 2.5 Kel-F 800, 2.5 Kel-F 827
  94 TATB (coarse), 6 Estane
  94 TATB (bimodal), 6 Estane
  94 TATB, 3 Elvax, 3 wax
  94 TATB, 4.5 polystyrene, 1.5 dioctylphthalate
  92 TATB, 6 polystyrene, 2 dioctylphthalate
  90 TATB, 10 Estane
  X-0219 (90 TATB, 10 Kel-F 800)
  90 TATB, 5 Elvax, 5 wax
  90 TATB, 5 Kel-F 800, 5 Kel-F 820
  85 TATB, 15 Kel-F 800
  85 TATB, 7.5 Kel-F 800, 7.5 Kel-F 827

*Propellants*

FKM Class VII
SPIS-44 Class VII
SPIS-45 Class II
TP-N1028 Class VII
UTP-20930 Class VII
VOP-7 Class VII
VRO Class VII
VRP Class VII
VTG-5A Class VII
VTQ-2 Class VII
VTQ-3 Class VII
VWC-2 Class VII

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4.1 Wedge-Test Data. Majowicz and Jacobs,1 and Campbell, Davis, Ramsay, and Travie2 first used the wedge test to study shock initiation of solid explosives. The test is named for the wedge-shaped explosive sample that is shocked by a booster-and-attenuator system as shown in Fig. 4.01. The explosive is wedge-shaped so that the shock or detonation wave moving through it is visible along the slant face. The slant face and flat of the sample are covered with a thin aluminized plastic and are illuminated by an intense light source. A smear camera is aligned so as to record the light reflecting from the aluminized plastic. As the shock wave proceeds through the explosive, the motion of the explosive mass tilts the reflecting surface on the slant face so that the light is no longer reflected into the camera. This sharp cutoff of light gives a well-defined record of the shock or detonation location vs time. Usually, the shock wave appears to travel through the explosive sample at a slightly increasing velocity and then to travel at a significantly higher velocity when detonation occurs. The point of interest is the distance into the sample, x*, or time, t*, at which detonation occurs.

The booster-and-attenuator system is selected to provide about the desired shock pressure in the sample wedge. In all but a few of the experiments on which data are presented here, the booster-and-attenuator systems consisted of a plane-wave lens, a booster explosive, and an inert metal or plastic shock attenuator. In some instances, the attenuator is composed of several materials. The pressure and particle velocity are assumed to be the same on both sides of the attenuator-and-sample interface. However, because initiation is not a steady state, this boundary condition is not precisely correct. The free-surface velocity of the attenuator is measured, and the particle velocity is assumed to be about half that. The shock Hugoniot of the attenuator is assumed to be known, so the shock pressure and particle velocity in the attenuator can be evaluated using the free-surface velocity measurement. Then, the pressure (P) and particle velocity (U_p) in the explosive sample are found by determining graphically the intersection of the attenuator rarefaction locus and the

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Fig. 4.01. Experimental arrangement for most wedge test shots.
explosives-state locus given by the conservation-of-momentum relation for the explosive, $P = \rho_0 U_p U_s$, where $U_s$ = shock velocity and $\rho_0$ = initial density. The attenuator rarefaction locus is approximated by reflecting the attenuator Hugoniot line about a line where the attenuator particle velocity is a constant. Because initiation is not a steady state, the conservation-of-momentum relation does not hold precisely; however, near the sample and attenuator interface, the reaction is slight enough that the accuracy is sufficient. Values of the initial shock parameters, $P_0$, $U_{p0}$, and $U_{s0}$, are given in the tables that follow.

Figure 4.02 shows a typical smear camera wedge record. Characteristically, these traces show the initial shock, the point of transition to high-order detonation, and the high-order detonation. The space and time dimensions are shown. Although the shock and detonation velocities in the explosive can be determined from these records, only the coordinates for the high-order detonation, $x^*$ and $t^*$, are normally found. Historically, many analysis techniques have been used, including those used here for data analysis.

THE TECHNIQUES

Technique 1. In Technique 1, the early average shock velocity is determined from the angle generated on the camera record by the shock-wave progress along the wedge surface, the optical magnification, the wedge angle, the viewing angle, and the camera writing speed. The distance over which this measurement is made is kept as short as is practical. The distance and time of transition to high-order detonation are determined from the film measurements, knowledge of the viewing angle, etc. In all the techniques described here, it is assumed that the shock wave is plane and parallel to the wedge-and-attenuator interface. The initial shock and particle velocity vs pressure in the wedge are obtained from a graphical solution involving the wedge density, early average shock velocity, and pressure in the last attenuator plate.
Technique 2. All wedges analyzed using Technique 2 had a flat portion extending beyond the end of the normal wedge face. The shock position was determined from ratios of disturbed vs undisturbed positions measured on the film image and wedge face. Times were obtained from the known writing speed of the camera and from film measurements. A film trace is obtained when the shock arrives at the free surface of the attenuator plate. Another is obtained when the detonation arrives at the free surface of the flat part of the sample. This latter trace is especially informative about the uniformity of initiation and helps to explain an occasional apparent overshoot. Phase velocities are measured at various positions on the wedge, depending on the specific record, and are analyzed by Technique 1. Each velocity is assigned to a midpoint of the interval over which the measurement is made, and the initial velocity is found by extrapolating the velocity vs thickness curve to zero thickness. The initial pressure and particle velocity are found from a graphical solution as in Technique 1.

Technique 3. In Technique 3, the shock position in the sample, x, is determined from 20-40 points using the same method of proportions as in Technique 2 and considering the wedge thickness and the length of the slant face image. The corresponding times, t, are determined from the known writing speed of the camera and from film measurements. When this technique was used, various equations were tested against the x-t data obtained from the wedge section of the sample. The equation \( x = c(e^{kt} + t - 1) \) was chosen to fit the data from the partially reacting run. A plot of \( t \) vs \( \ln(x - ct + c) \) produced a straight line of slope \( k \) if the proper \( c \) value was selected. Sensitivity of the fit to a chosen \( c \) was such that a poor choice was usually recognized, and a questionable choice had only a relatively minor effect on the first derivative evaluated at \( t = 0 \).

\[
\frac{dx}{dt} \bigg|_{t=0} = c(k + 1) = U_{s0}
\]

The \( c \) is chosen best from a plot of the data for a shot with a long run to high-order detonation. The data used to evaluate \( c \) can come from an experiment in which the shock was accelerating, and high-order detonation need not be observed. The value of \( c \) is treated as a constant for that particular explosive formulation and density. This procedure typically gives a lower initial shock velocity value than does Technique 1.

Technique 4. When Technique 4 is used, the lighting of the flat face is adjusted to show particle paths after a shock front has passed. As in Technique 3, the smear camera record is measured and the measurements are converted to real times, t, and distances, x, for the shock traversing the wedge. Average velocities, \( x/t \), are calculated for points before high-order detonation and are plotted against t. (Any inconsistent data near the beginning and end are rejected.) The data are then fitted with \( x - U_{s0}t \pm 1/2 bt^2 \) by the least squares method. The derivative evaluated at \( t = 0 \) is taken as the initial shock velocity. Thereafter, the analysis is like that in Techniques 2 and 3. The single-curve buildup hypothesis is checked by plotting, for
SHOCK INITIATION PROPERTIES

each shot, the shock wave trajectory measured back from the transition to high-order detonation and superimposing the plots using the transition as a fiducial. Detonation velocities are obtained from x-t data measured in the high-order region.

Technique 5. In Technique 5, the driving plate free-surface velocity always is measured with electrical pin contactors. Buildup data from all experiments on a given density of explosive are pooled on the assumption of a single curve buildup and are fitted by the least squares method to the empirical function,

\[ D = A_1 T^{(1-A_3)} \left[ 1 - \exp \left(-A_2 T^{A_3}\right) \right] + (A_4 - A_1 A_2) T \]

where \( D \) is the distance to detonation, \( T \) is the time to detonation at any point on the buildup curve, \( A_1 \) is the detonation velocity, and \( A_1, A_2, \) and \( A_3 \) are arbitrary constants. The shock velocities are evaluated from the derivative of the above function,

\[ u_{s0} = A_1 (1 - A_3) T^{-A_3} \left[ 1 - \exp \left(-A_2 T^{A_3}\right) \right] + A_1 A_2 A_3 \exp \left(-A_2 T^{A_3}\right) + A_4 - A_1 A_2 \]

using the coefficients fitted to the pooled data and the time to detonation, \( T = t^* \), observed in the individual experiments. This shock velocity value is then used with the driving plate free-surface velocity determined as before.

Technique 6. In Technique 6, a flash gap consisting of grooved Lucite blocks is used to measure the driving plate free-surface velocity. Also, shock velocities are determined by reading the average slopes from the streak records. Samples thus analyzed had two phase-velocity regions, the normal high-order detonation and an intermediate velocity region. The two abrupt changes in phase velocity are read from the streak records to give the distance to the intermediate region and the distance to detonation. All other analysis is done using Technique 5.

Technique 7. In Technique 7, the x-t data are digitized into 70 discrete points. A linear fit is made to three adjacent x-t points, and the slope is taken as the velocity at the midpoint of the line. Then one x-t end point is dropped, a new one is added on the other end, a new linear fit is made, and the velocity is found. This running linear least squares process is repeated until all 70 x-t points have been used. The u-x data are then extrapolated to zero thickness (x = 0) to find the initial shock velocity, \( U_{s0} \). All other analysis is done as in Technique 1.
THE DATA TABLES

The data tables indicate the driver-and-attenuator systems used for each experiment. Also given are the LASL shot number; the initial shock pressure, particle velocity, and shock velocity; a fitting parameter, $1/2 b$, used in the data reduction where appropriate; the sample density; the distance to detonation, $x^*$, and time to detonation, $t^*$.

Usually the $U_s - U_p$ data are plotted. Also given are equations for these data fitted to one of two functional forms, the most common of which is linear. These equations are given with their coefficients and the standard errors of the coefficients. If the sound speed has been used as a data point in determining the fit, it also is given. For a few explosives, a hyperbolic function is fitted to the data and coefficients without standard errors are given.

For some explosives, a logarithmic function fit to the initiation data, $x^*$ or $t^*$ vs $P_0$, is given. Generally, this is done only for the distance to detonation, $x^*$. Usually, if these fits are given, a "Pop" plot also is included. The "Pop" plot functional form traditionally has been a power function with $x^*$ or $t^*$ as dependent variables and $P_0$ as the independent variable. However, recent work suggests that the appropriate fitting plane should be log-log, because the measurement errors in $x^*$ have been shown to be lognormal, and the $t^*$ and $P_0$ errors may also be lognormal. Since $x^*$ and $t^*$ are measured quantities and $P_0$ is based on measurements, all are stochastic variables, and a statistically valid regression analysis cannot be used to estimate a functional relationship. Nevertheless, $x^*$ and $t^*$ physically occur after the imposition of $P_0$, and thus it has been argued that they result from (or are dependent on) $P_0$. Since the error in $P_0$ data is generally greater than $x^*$ and $t^*$ error, in finding an "average relationship" between them, it is more appropriate to assume that the variable with the least error is the independent variable. For these reasons, the "Pop" plot functions are given in log form, with log $P_0$ being the dependent variable.
Table 4.01 WEDGE TEST LENS AND BOOSTER SYSTEMS

The lens and booster explosive systems used for most of the wedge tests are listed below, generally in order of increasing pressure output. All lenses, designated by P-xxx, have plane-wave output. The output face diameter is indicated by the designation number; for instance, P-040 and P-081 and 4 are 8.1 inches in diameter, respectively. The booster explosive thickness also is given.

<table>
<thead>
<tr>
<th>System</th>
<th>Lens</th>
<th>Booster Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.25-g/cm² NQ PL-38</td>
<td>---</td>
</tr>
<tr>
<td>B</td>
<td>P-081</td>
<td>25.4 Baratol</td>
</tr>
<tr>
<td>C</td>
<td>P-120</td>
<td>25.4 Baratol</td>
</tr>
<tr>
<td>C-1</td>
<td>P-081</td>
<td>50.8 Baratol</td>
</tr>
<tr>
<td>D</td>
<td>P-081</td>
<td>6.3 Comp B and 25.4 Baratol</td>
</tr>
<tr>
<td>E</td>
<td>P-081</td>
<td>50.8 Baratol</td>
</tr>
<tr>
<td>F</td>
<td>P-081</td>
<td>12.7 TNT</td>
</tr>
<tr>
<td>G</td>
<td>P-081</td>
<td>25.4 TNT</td>
</tr>
<tr>
<td>H</td>
<td>P-081</td>
<td>50.8 TNT</td>
</tr>
<tr>
<td>I</td>
<td>P-040</td>
<td>25.4 Comp B</td>
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<td>J</td>
<td>P-081</td>
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<td>K</td>
<td>P-081</td>
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<td>P-081</td>
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<td>O</td>
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<td>P</td>
<td>P-061</td>
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<td>35.5 PBX 9404</td>
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<tr>
<td>R</td>
<td>P-061</td>
<td>38.1 PBX 9404</td>
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<td>S</td>
<td>P-061</td>
<td>50.8 PBX 9404</td>
</tr>
<tr>
<td>T</td>
<td>P-081</td>
<td>12.7 Plex*, 16-mesh screen, and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50.8 PBX 9404</td>
</tr>
<tr>
<td>U</td>
<td>P-081</td>
<td>101.6 PBX 9404</td>
</tr>
</tbody>
</table>

*The following abbreviations are used in describing wedge-test boosters. Plex = Plexiglas; Foam = 0.19-g/cm² polyurethane foam; SS = 304 stainless steel; PC = Lexan polycarbonate; PMMA = any of several polymethylmethacrylates, and PE = polyethylene.
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Table 4.02  HMX

Composition
100 wt% HMX

Theoretical Maximum Density
1.905 g/cm³

Preparation Method
Solvent pressing

Data Summary
ρ₀ = 1.891 g/cm³, T₀ = 25°C, Technique 1

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P₀ (GPa)</td>
<td>Uₚ₀ (mm/µs)</td>
<td>Uₚ₀ (mm/µs)</td>
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<tr>
<td>E-2106</td>
<td>4.41</td>
<td>0.592</td>
<td>3.943</td>
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<td>E-2108</td>
<td>4.89</td>
<td>0.593</td>
<td>4.359</td>
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<td>E-2117</td>
<td>4.93</td>
<td>0.632</td>
<td>4.126</td>
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<td>E-2125</td>
<td>7.54</td>
<td>0.884</td>
<td>4.511</td>
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<td>E-2116</td>
<td>8.02</td>
<td>0.912</td>
<td>4.651</td>
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<td>E-2099</td>
<td>8.40</td>
<td>0.902</td>
<td>4.924</td>
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<td>9.35</td>
<td>0.952</td>
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<tr>
<td>E-2118</td>
<td>9.55</td>
<td>1.036</td>
<td>4.877</td>
</tr>
</tbody>
</table>

*Measured over the first millimeter of run.

Reduced Data

Uₚ₀ = (2.901 ± 0.407) + (2.058 ± 0.490) Uₚ₀.

log P = (1.18 ± 0.02) − (0.59 ± 0.03) log x* for 4.41 < P < 9.55.
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![Graph of pressure vs. distance to detonation for HMX.](image)

![Graph of initial shock velocity vs. initial particle velocity for HMX.](image)
Table 4.03  HMX (SINGLE CRYSTAL)

Composition
100 wt% HMX

Theoretical Maximum Density
1.905 g/cm³

Preparation Method
Controlled solvent evaporation

Data Summary
\[ \rho_o = 1.90 \text{ g/cm}^3, \quad T_o = 24°C. \quad \text{Technique 4} \]

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Flyer Plate Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_o ) (GPa)</td>
<td>( U_{po} ) (mm/µs)</td>
<td>( U_{oo} ) (mm/µs)</td>
</tr>
<tr>
<td>E-3794</td>
<td>43.5</td>
<td>2.93</td>
<td>7.812</td>
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<td>E-3792</td>
<td>36.6</td>
<td>2.61</td>
<td>7.177</td>
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<tr>
<td>E-3796</td>
<td>34.8</td>
<td>2.49</td>
<td>7.357</td>
</tr>
</tbody>
</table>

\( \bar{U}_o \) is an estimated initial shock velocity based on the average velocity of the shock in the crystal, the assumption that the shock advanced at a constant velocity, and allowance for experimental complications.

\( x_{OT} \) is the average level at which detonation overtook the shock front in the crystal.

\( t_{OT} \) is the average time at which detonation overtook the shock front in the crystal.

\( P \)-081, 50-mm PBX 9404, 0.25-mm PE, magnesium flyer, 25.4-mm air, 5-mm magnesium.

Overtake occurred after the initial shock had crossed the 7.4-mm-thick crystal. \( t_{OT} \) includes the time needed to overtake the crystal's moving free surface.
Table 4.04  NITROMETHANE

Composition
100 wt% NM

Theoretical Maximum Density
1.125 g/cm³

Data Summary
\( \rho_s = 1.125 \text{ g/cm}^3 \). Technique 2

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( T_o ) (°C)</th>
<th>( P_s ) from Driver (GPa)</th>
<th>( U_p ) from Driver (mm/μs)</th>
<th>( U_p ) from Driven (mm/μs)</th>
<th>( \Delta U_p ) Driven-Driver</th>
<th>Driving System Thickness (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-1412</td>
<td>20.4</td>
<td>2.50</td>
<td>2.918</td>
<td>0.762</td>
<td>0.730</td>
<td>+0.032</td>
</tr>
<tr>
<td>E-1395</td>
<td>19.2</td>
<td>3.10</td>
<td>3.080</td>
<td>0.896</td>
<td>0.928</td>
<td>+0.032</td>
</tr>
<tr>
<td>E-1397</td>
<td>17.8</td>
<td>5.38</td>
<td>3.670</td>
<td>1.304</td>
<td>1.235</td>
<td>+0.079</td>
</tr>
<tr>
<td>E-1381</td>
<td>22.0</td>
<td>5.65</td>
<td>3.819</td>
<td>1.315</td>
<td>1.373</td>
<td>+0.058</td>
</tr>
<tr>
<td>E-1382</td>
<td>22.0</td>
<td>5.58</td>
<td>3.761</td>
<td>1.319</td>
<td>1.315</td>
<td>-0.004</td>
</tr>
<tr>
<td>E-1402</td>
<td>18.0</td>
<td>5.86</td>
<td>3.885</td>
<td>1.340</td>
<td>1.299</td>
<td>-0.041</td>
</tr>
<tr>
<td>E-1411</td>
<td>17.2</td>
<td>6.28</td>
<td>4.025</td>
<td>1.387</td>
<td>1.373</td>
<td>-0.014</td>
</tr>
<tr>
<td>E-1396</td>
<td>19.6</td>
<td>6.07</td>
<td>3.882</td>
<td>1.390</td>
<td>1.338</td>
<td>+0.052</td>
</tr>
<tr>
<td>E-1383</td>
<td>22.0</td>
<td>6.60</td>
<td>4.016</td>
<td>1.460</td>
<td>1.492</td>
<td>+0.032</td>
</tr>
<tr>
<td>E-1384</td>
<td>21.6</td>
<td>6.72</td>
<td>4.077</td>
<td>1.465</td>
<td>1.475</td>
<td>+0.010</td>
</tr>
<tr>
<td>E-1413</td>
<td>17.3</td>
<td>7.35</td>
<td>4.243</td>
<td>1.540</td>
<td>1.446</td>
<td>-0.094</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>E-1386</td>
<td>22.1</td>
<td>9.60</td>
<td>4.639</td>
<td>1.839</td>
<td>Detonation between plates</td>
<td></td>
</tr>
<tr>
<td>E-1385</td>
<td>22.0</td>
<td>9.59</td>
<td>4.629</td>
<td>1.841</td>
<td>Detonation between plates</td>
<td></td>
</tr>
</tbody>
</table>

\[ U_p \] was deduced from the initial \[ U_{in} \] of a Dural plate on a flat of the nitromethane wedge.

K, 13.4 Micarta, 6.4 brass, 6.4 Dural

---
**SHOCK INITIATION PROPERTIES**

### Table 4.05 NITROGUANIDINE (NQ)

**Composition**

100 wt% NQ

**Theoretical Maximum Density**

1.774 g/cm³

**Particle Size Distribution**

Large grain and Commercial grain

**Preparation Method**

Pressing and machining to shape

**Data Summary**

\( T_0 = 23°C \). Technique 3 or as noted

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 ) (GPa)</td>
<td>( U_{p0} ) (mm/µs)</td>
<td>( U_{s0} ) (mm/µs)</td>
</tr>
<tr>
<td>E-2838</td>
<td>14.08</td>
<td>1.601</td>
<td>5.300</td>
</tr>
<tr>
<td>E-2840</td>
<td>15.72</td>
<td>1.683</td>
<td>5.630</td>
</tr>
<tr>
<td>E-2864</td>
<td>20.78</td>
<td>2.003</td>
<td>6.251</td>
</tr>
<tr>
<td>E-2892</td>
<td>24.07</td>
<td>2.184</td>
<td>6.640</td>
</tr>
</tbody>
</table>

**Large Grain, \( \rho_0 = 1.659 \text{ g/cm}^3 \)**

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 ) (GPa)</td>
<td>( U_{p0} ) (mm/µs)</td>
<td>( U_{s0} ) (mm/µs)</td>
</tr>
<tr>
<td>E-2865</td>
<td>13.35</td>
<td>1.368</td>
<td>5.692b</td>
</tr>
<tr>
<td>E-2866</td>
<td>21.30</td>
<td>1.920</td>
<td>6.469</td>
</tr>
<tr>
<td>E-2867</td>
<td>24.63</td>
<td>2.072</td>
<td>6.932</td>
</tr>
</tbody>
</table>

**Commercial-Grain (needle), \( \rho_0 = 1.688 \text{ g/cm}^3 \), Technique 2**

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 ) (GPa)</td>
<td>( U_{p0} ) (mm/µs)</td>
<td>( U_{s0} ) (mm/µs)</td>
</tr>
<tr>
<td>E-1890</td>
<td>10.15</td>
<td>1.172</td>
<td>5.131</td>
</tr>
<tr>
<td>E-1987</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>E-1989</td>
<td>11.71</td>
<td>1.320</td>
<td>5.257</td>
</tr>
<tr>
<td>E-1996</td>
<td>16.4</td>
<td>1.650</td>
<td>5.880</td>
</tr>
<tr>
<td>E-1891</td>
<td>21.34</td>
<td>1.962</td>
<td>6.445</td>
</tr>
<tr>
<td>E-1939</td>
<td>24.25</td>
<td>2.128</td>
<td>6.751</td>
</tr>
</tbody>
</table>
SHOCK INITIATION PROPERTIES

Table 4.05 (continued)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 )</td>
<td>( U_{p0} )</td>
<td>( U_{so} )</td>
</tr>
<tr>
<td>E-1897</td>
<td>25.85</td>
<td>2.167</td>
<td>7.067</td>
</tr>
<tr>
<td>E-1908</td>
<td>27.28</td>
<td>2.336</td>
<td>6.918</td>
</tr>
</tbody>
</table>

Data from the 10-mm Level\(^a\)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P )</th>
<th>( U_p )</th>
<th>( U_s )</th>
<th>( x^* )</th>
<th>( t^* )</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-1890</td>
<td>10.1</td>
<td>1.207</td>
<td>4.962</td>
<td></td>
<td></td>
<td>B, 6.3 Plex</td>
</tr>
<tr>
<td>E-1987</td>
<td>16.3</td>
<td>1.667</td>
<td>5.800</td>
<td></td>
<td></td>
<td>I, 1.0 D-38</td>
</tr>
<tr>
<td>E-1898</td>
<td>21.7</td>
<td>2.045</td>
<td>6.278</td>
<td></td>
<td></td>
<td>M, 1.02 D-38</td>
</tr>
<tr>
<td>E-1896</td>
<td>21.2</td>
<td>1.979</td>
<td>6.359</td>
<td></td>
<td></td>
<td>G, 6.3 Plex</td>
</tr>
<tr>
<td>E-1897</td>
<td>detonated</td>
<td>8.387</td>
<td></td>
<td></td>
<td></td>
<td>U, 25 Plex</td>
</tr>
<tr>
<td>E-1891</td>
<td>detonated</td>
<td>8.232</td>
<td></td>
<td></td>
<td></td>
<td>J, 6 Plex</td>
</tr>
<tr>
<td>E-1898</td>
<td>detonated</td>
<td>8.268</td>
<td></td>
<td></td>
<td></td>
<td>L, 6 Plex</td>
</tr>
<tr>
<td>E-1897</td>
<td>detonated</td>
<td>8.379</td>
<td></td>
<td></td>
<td></td>
<td>N, 6 Plex</td>
</tr>
<tr>
<td>E-1908</td>
<td>detonated</td>
<td>8.384</td>
<td></td>
<td></td>
<td></td>
<td>T, 6 Plex</td>
</tr>
</tbody>
</table>

\(^a\)Distributed about 250 \( \mu \)m.
\(^b\)Almost constant.
\(^c\)Decelerates.
\(^d\)Nonuniform initiation produced unrealistically large \( x^* \).
\(^e\)\( P \) and \( U_s \) were deduced from the initial \( U_{so} \) of a 2.26-mm-thick 2024T-4 Dural plate placed on a flat at the 10-mm level of the NQ wedge.

Reduced Data

Large grain, all densities
\[
U_{so} = (3.544 \pm 0.524) + (1.459 \pm 0.276) U_{p0}.
\]
\[
\log P = (1.44 \pm 0.07) - (0.15 \pm 0.08) \log x^* \text{ for } 13.35 < P < 26.28.
\]
\[
\log P = (1.32 \pm 0.03) - (0.15 \pm 0.07) \log t^*.
\]

Commercial grain
\[
U_{so} = (3.048 \pm 0.254) + (1.725 \pm 0.135) U_{p0}.
\]
\[
\log P = (1.51 \pm 0.02) - (0.26 \pm 0.03) \log x^* \text{ for } 21.2 < P < 27.1.
\]
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm) / Time to Detonation (μs)

Pressure (GPa) vs. Distance to Detonation (mm)

Pressure (GPa) vs. Time to Detonation (μs)
SHOCK INITIATION PROPERTIES

![Graph showing the relationship between initial particle velocity and shock velocity for large grain NQ.]
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

NQ
(commercial grain)

Initial Particle Velocity, \( U_{p0} \) (mm/\( \mu \)s)

Initial Shock Velocity, \( U_s \) (mm/\( \mu \)s)
### Table 4.06 PETN (PRESSED)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Pure detonator-grade pentaerythritol tetranitrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Maximum Density</td>
<td>1.778 g/cm³</td>
</tr>
<tr>
<td>Particle Size Distribution</td>
<td>The elongated, prismatic crystals are 130-160 μm long and 10-20 μm across. Air permeation determinations on 1.0-g/cm³ specimens gave a specific surface of 3300 cm²/g.</td>
</tr>
<tr>
<td>Preparation Method</td>
<td>Cold pressing into pellets and machining into wedges, except for the 1.0-g/cm³ wedges, which were formed by cutting.</td>
</tr>
<tr>
<td>Comments</td>
<td>The experiments and analyses differed from all previous ones as follows. (a) The Hugoniot relations for 1.72- and 1.6-g/cm³ PETN were fitted by constraining the intercept of the fitted shock-velocity vs particle-velocity curve to be the bulk sound speed measured in the explosive. This Hugoniot was used to calculate the relations between input shock strength and time and distance to detonation. (See Los Alamos Scientific Laboratory report LA-5131.) (b) The gas-gun experiment shown in Fig. 4.03 was used to obtain data on 1.4- and 1.75-g/cm³ PETN. Listed are both the input shock parameters, from the observed shock velocities and impedance match solution with the projectile, and &quot;calculated pressures&quot; obtained from an explosive Hugoniot obtained separately using quartz-gauge experiments and the measured particle velocities. These calculated pressures are used in fitting relations between initial pressure and distance and time to detonation.</td>
</tr>
</tbody>
</table>
Table 4.06 (continued)

Coordinates for
High-Order
Detonation

<table>
<thead>
<tr>
<th>$P_0$ (GPa)</th>
<th>$U_{p0}$ (mm/μs)</th>
<th>$U_{so}$ (mm/μs)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
<th>No. of Elements</th>
<th>Attenuator System</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.72</td>
<td>0.22</td>
<td>2.05</td>
<td>&gt;9.5</td>
<td>...</td>
<td>4</td>
<td>Brass, ethyl ether</td>
</tr>
<tr>
<td>0.95</td>
<td>0.28</td>
<td>2.13</td>
<td>&gt;9.5</td>
<td>...</td>
<td>4</td>
<td>Brass, water</td>
</tr>
<tr>
<td>1.2</td>
<td>0.35</td>
<td>2.15</td>
<td>4.03</td>
<td>1.65</td>
<td>4</td>
<td>Brass, carbon tetrachloride</td>
</tr>
<tr>
<td>1.3</td>
<td>0.37</td>
<td>2.12</td>
<td>3.79</td>
<td>1.54</td>
<td>4</td>
<td>Brass, carbon tetrachloride</td>
</tr>
<tr>
<td>1.4</td>
<td>0.41</td>
<td>2.21</td>
<td>2.30</td>
<td>0.84</td>
<td>3</td>
<td>Brass, carbon tetrachloride</td>
</tr>
<tr>
<td>1.8</td>
<td>0.44</td>
<td>2.50</td>
<td>1.94</td>
<td>0.74</td>
<td>4</td>
<td>Brass, mixture 1</td>
</tr>
<tr>
<td>1.8</td>
<td>0.42</td>
<td>2.65</td>
<td>2.08</td>
<td>0.78</td>
<td>4</td>
<td>Brass, mixture 1</td>
</tr>
<tr>
<td>2.0</td>
<td>0.48</td>
<td>2.58</td>
<td>1.47</td>
<td>0.55</td>
<td>4</td>
<td>Brass, tetrabromoethane</td>
</tr>
</tbody>
</table>

Reduced Data

\[ \rho_0 = 1.60 \text{ g/cm}^3, \text{ where } 1.2 < P < 2.0. \]

\[ \log P = (0.40 \pm 0.03) - (0.54 \pm 0.05) \log x^*. \]

\[ \log P = (0.18 \pm 0.02) - (0.44 \pm 0.09) \log t^*. \]
Table 4.06 (continued)

<table>
<thead>
<tr>
<th>$P_0$ (GPa)</th>
<th>$U_{p0}$ (mm/μs)</th>
<th>$U_{so}$ (mm/μs)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
<th>No. of Elements</th>
<th>Attenuator System</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.89</td>
<td>0.20</td>
<td>2.59</td>
<td>&gt;9.5</td>
<td>---</td>
<td>4</td>
<td>Brass, ethyl alcohol</td>
</tr>
<tr>
<td>1.5</td>
<td>0.29</td>
<td>2.92</td>
<td>&gt;9.5</td>
<td>---</td>
<td>4</td>
<td>Brass, carbon tetrachloride</td>
</tr>
<tr>
<td>1.6</td>
<td>0.34</td>
<td>2.79</td>
<td>4.44</td>
<td>1.50</td>
<td>4</td>
<td>Dural, ethyl ether</td>
</tr>
<tr>
<td>2.0</td>
<td>0.37</td>
<td>3.10</td>
<td>4.16</td>
<td>1.60</td>
<td>4</td>
<td>Brass, Mixture 1</td>
</tr>
<tr>
<td>2.1</td>
<td>0.42</td>
<td>2.83</td>
<td>2.90</td>
<td>0.88</td>
<td>4</td>
<td>Brass, tetrabromoethane</td>
</tr>
<tr>
<td>2.2</td>
<td>0.38</td>
<td>3.40</td>
<td>3.69</td>
<td>1.14</td>
<td>4</td>
<td>Brass, tetrabromoethane</td>
</tr>
<tr>
<td>2.3</td>
<td>0.42</td>
<td>3.17</td>
<td>3.20</td>
<td>0.96</td>
<td>4</td>
<td>Dural, ethyl alcohol</td>
</tr>
<tr>
<td>2.4</td>
<td>0.44</td>
<td>3.18</td>
<td>2.47</td>
<td>0.95</td>
<td>4</td>
<td>Dural, water</td>
</tr>
<tr>
<td>2.6</td>
<td>0.46</td>
<td>3.33</td>
<td>2.31</td>
<td>0.69</td>
<td>4</td>
<td>Dural, dichloroethyl ether</td>
</tr>
<tr>
<td>2.6</td>
<td>0.42</td>
<td>3.55</td>
<td>2.05</td>
<td>0.61</td>
<td>3</td>
<td>Dural, ethyl alcohol</td>
</tr>
<tr>
<td>2.7</td>
<td>0.47</td>
<td>3.39</td>
<td>3.17</td>
<td>1.02</td>
<td>4</td>
<td>Dural, water</td>
</tr>
<tr>
<td>3.4</td>
<td>0.49</td>
<td>3.99</td>
<td>1.74</td>
<td>0.49</td>
<td>4</td>
<td>Dural, trichloroethylene</td>
</tr>
<tr>
<td>3.5</td>
<td>0.54</td>
<td>3.72</td>
<td>1.46</td>
<td>0.44</td>
<td>3</td>
<td>Dural, water</td>
</tr>
<tr>
<td>3.9</td>
<td>0.59</td>
<td>3.83</td>
<td>1.29</td>
<td>0.33</td>
<td>4</td>
<td>Dural, tetrabromoethane</td>
</tr>
<tr>
<td>6.8</td>
<td>---</td>
<td>---</td>
<td>&lt;3.6</td>
<td>---</td>
<td>2</td>
<td>Dural, polymethylmethacrylate</td>
</tr>
</tbody>
</table>

$\rho_0 = 1.72 \text{ g/cm}^3$, 96.7% $\rho_T$

*Booster system was a P-080 plane-wave lens and 5 cm of Baratol. In three- and four-element attenuators, the third layer was brass and the fourth was one of the polymethylmethacrylates. Mixture 1 consisted of tetrabromoethane and carbon tetrachloride, 2 to 1 by volume.

Reduced Data

$U_{so} = 2.326 + 2.342 U_{p0}$

$log P = (0.61 \pm 0.03) - (0.49 \pm 0.05) log x^*$

$log P = (0.34 \pm 0.02) - (0.50 \pm 0.09) log t^*$
SHOCK INITIATION PROPERTIES

PETN ($\rho=160$)

Distance to Detonation (mm)

Time to Detonation (us)

Pressure (GPa)
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

PETN
($\mu=1.76$)

Time to Detonation (\(\mu\)s)

Pressure (GPa)

PETN
($\rho=1.72$)

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SHOCK INITIATION PROPERTIES

PETN ($\rho=1.75$)

Initial Shock Velocity, $U_p$ (mm/µs)

Initial Particle Velocity, $U_{ip}$ (mm/µs)

Pressure (GPa)

Distance to Detonation (mm)
SHOCK INITIATION PROPERTIES

Table 4.06 (continued) PETN (PRESSED), DRIVEN BY A GAS GUN

<table>
<thead>
<tr>
<th>$v_o^*$ (mm/$\mu$s)</th>
<th>$P_o$(calc) (GPa)</th>
<th>$P_o$ (GPa)</th>
<th>$U_{po}$ (mm/$\mu$s)</th>
<th>$U_{so}$ (mm/$\mu$s)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ ($\mu$s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.418</td>
<td>1.66</td>
<td>1.82</td>
<td>0.300</td>
<td>3.47</td>
<td>&gt;6.4</td>
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</tr>
<tr>
<td>0.426</td>
<td>1.70</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>6.24</td>
<td>---</td>
</tr>
<tr>
<td>0.439</td>
<td>1.76</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>5.85</td>
<td>---</td>
</tr>
<tr>
<td>0.452</td>
<td>1.83</td>
<td>1.47</td>
<td>0.352</td>
<td>2.39</td>
<td>5.83</td>
<td>1.85</td>
</tr>
<tr>
<td>0.460</td>
<td>1.85</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>4.48</td>
<td>---</td>
</tr>
<tr>
<td>0.508</td>
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<td>2.15</td>
<td>0.363</td>
<td>3.39</td>
<td>5.08</td>
<td>1.55</td>
</tr>
<tr>
<td>0.518</td>
<td>2.13</td>
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<td>---</td>
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<td>4.28</td>
<td>---</td>
</tr>
<tr>
<td>0.526</td>
<td>2.16</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>3.29</td>
<td>---</td>
</tr>
<tr>
<td>0.540</td>
<td>2.24</td>
<td>2.13</td>
<td>0.397</td>
<td>3.06</td>
<td>2.97</td>
<td>0.95</td>
</tr>
<tr>
<td>0.571</td>
<td>2.38</td>
<td>2.52</td>
<td>0.408</td>
<td>3.53</td>
<td>3.78</td>
<td>1.05</td>
</tr>
<tr>
<td>0.602</td>
<td>2.54</td>
<td>2.49</td>
<td>0.435</td>
<td>3.27</td>
<td>2.62</td>
<td>0.84</td>
</tr>
</tbody>
</table>

| $\rho_o = 1.4$ g/cm$^3$ | |
|-------------------------||
| 0.313                   | 0.66              | 0.42        | 0.284                 | 1.05                  | 7.26       | 5.2         |
| 0.294                   | 0.57              | 0.37        | 0.268                 | 1.00                  | 7.84       | 5.7         |
| 0.317                   | 0.67              | 0.41        | 0.290                 | 1.02                  | 6.98       | 4.9         |
| 0.357                   | 0.78              | 0.58        | 0.318                 | 1.31                  | 4.06       | 2.7         |
| 0.407                   | 0.99              | 0.79        | 0.354                 | 1.60                  | 2.35       | 1.3         |
| 0.305                   | 0.62              | 0.42        | 0.278                 | 1.07                  | 7.39       | 5.4         |

*Velocity is that of 7075 aluminum alloy projectile.

Reduced Data

$U_{so} = 2.26 + 2.32 U_{po}$ (mm/$\mu$s).

$\rho_o = 1.75$ g/cm$^3$.

For $1.7 < P < 2.54$,

$\log P = (0.57 \pm 0.04) - (0.41 \pm 0.06) \log x^*$, and

$\log P = (0.33 \pm 0.02) - (0.22 \pm 0.16) \log t^*$,

$\rho_o = 1.4$ g/cm$^3$.

For $0.66 < P < 0.99$,

$\log P = (0.14 \pm 0.03) - (0.1 \pm 0.05) \log x^*$, and

$\log P = (0.04 \pm 0.02) - (0.33 \pm 0.04) \log t^*$.
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

PETN
($\rho=1.40$)

Time to Detonation (µs)

Pressure (GPa)
Fig. 4.03. The gas-gun assembly used in PETN testing.
Table 4.07  PETN (SINGLE CRYSTAL)

**Composition**
100 wt% PETN

**Theoretical Maximum Density**
1.775 g/cm³

**Particle Size Distribution**
Single crystal

**Preparation Method**
Controlled solvent evaporation

**Data Summary**
\( \rho_0 = 1.775 \text{ g/cm}^3, T_0 = 24^\circ \text{C}, \text{ Technique 4} \)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{p0} ) (mm/μs)</th>
<th>( U_{so} ) (mm/μs)</th>
<th>( 1/2 , b ) (mm/μs²)</th>
<th>( t_{tt} ) (μs)</th>
<th>( t_i ) (μs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-3799</td>
<td>11.23</td>
<td>1.246</td>
<td>5.078</td>
<td>0.029</td>
<td>1.06</td>
<td>0.28</td>
<td>H, 40.6 Plex</td>
</tr>
<tr>
<td>E-3800</td>
<td>10.98</td>
<td>1.240</td>
<td>4.990</td>
<td>0.005</td>
<td>1.03</td>
<td>0.32</td>
<td>-0.40</td>
</tr>
<tr>
<td>E-3788</td>
<td>11.05</td>
<td>1.221</td>
<td>5.100</td>
<td>0.063</td>
<td>0.94</td>
<td>0.34</td>
<td>-0.51</td>
</tr>
<tr>
<td>E-3787</td>
<td>10.10</td>
<td>1.212</td>
<td>4.696</td>
<td>0.020</td>
<td>1.15</td>
<td>0.61</td>
<td>-</td>
</tr>
<tr>
<td>E-3809</td>
<td>8.78</td>
<td>1.068</td>
<td>4.630</td>
<td>0.103</td>
<td>1.58</td>
<td>0.81</td>
<td>B, 9.1 Plex</td>
</tr>
<tr>
<td>E-3808</td>
<td>7.19</td>
<td>0.914</td>
<td>4.432</td>
<td>0.020</td>
<td>---</td>
<td>---</td>
<td>B, 48.3 Plex</td>
</tr>
<tr>
<td>E-3870</td>
<td>3.95</td>
<td>0.543</td>
<td>4.099</td>
<td>-0.039</td>
<td>---</td>
<td>---</td>
<td>B, 24.1 SS, 8.9 Plex</td>
</tr>
</tbody>
</table>

*\( t_{tr} \) is the time at which detonation overtook the shock front in the crystal.

\[ t_i \] is the induction time.

**Reduced Data**
\[ U_{so} = (3.311 \pm 0.26) + (1.323 \pm 0.238) \, U_{p0}. \]
Table 4.08 TATB (PURIFIED)

<table>
<thead>
<tr>
<th>Composition</th>
<th>100 wt% TATB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Maximum Density</td>
<td>1.938 g/cm³</td>
</tr>
</tbody>
</table>

**Particle Size Distribution**
- Wt%: below 10 μm = 4.51; below 25 μm = 41.10; below 30 μm = 53.3; below 45 μm = 77.8.
- Surface area over range = 22.62 cm²/g.

**Preparation Method**
- Pressing, and machining to shape

**Data Summary**
- Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>T₀ (°C)</th>
<th>P₀ (GPa)</th>
<th>Uₚ₀ (mm/μs)</th>
<th>U₀₀ (mm/μs)</th>
<th>l/2 b (mm/μs²)</th>
<th>x* (mm)</th>
<th>t* (μs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-3646</td>
<td>~23</td>
<td>0.57</td>
<td>0.152</td>
<td>1.999</td>
<td>-0.0126</td>
<td>&gt;&gt;12.72</td>
<td>&gt;&gt;5.80</td>
<td>A, 11.4 SS, 10.9 Plex</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.67</td>
<td>0.179</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-3672</td>
<td>~23</td>
<td>2.89</td>
<td>0.489</td>
<td>3.151</td>
<td>0.0503</td>
<td>&gt;&gt;12.47</td>
<td>&gt;&gt;3.77</td>
<td>B, 17.8 polyethylene, 11.4 SS, 9.7 Acrylite</td>
</tr>
<tr>
<td>E-3587</td>
<td>~23</td>
<td>3.02</td>
<td>0.480</td>
<td>3.356</td>
<td>0.0113</td>
<td>&gt;&gt;12.71</td>
<td>&gt;&gt;3.69</td>
<td>B, 17.8 polyethylene, 11.4 SS, 9.7 Acrylite</td>
</tr>
<tr>
<td>E-3569</td>
<td>~23</td>
<td>6.74</td>
<td>0.858</td>
<td>4.186</td>
<td>0.049</td>
<td>&gt;&gt;12.65</td>
<td>&gt;&gt;2.92</td>
<td>B, 48.5 Plex</td>
</tr>
<tr>
<td>E-3568</td>
<td>~23</td>
<td>9.42</td>
<td>1.063</td>
<td>4.723</td>
<td>0.111</td>
<td>&gt;12.74</td>
<td>&gt;2.44</td>
<td>G, 38.1 Plex</td>
</tr>
<tr>
<td>E-3558</td>
<td>~23</td>
<td>11.40</td>
<td>1.208</td>
<td>5.030</td>
<td>0.319</td>
<td>7.66</td>
<td>1.38</td>
<td>G, 18.0 Acrylite</td>
</tr>
<tr>
<td>E-3549</td>
<td>~23</td>
<td>13.03</td>
<td>1.340</td>
<td>5.184</td>
<td>0.425</td>
<td>5.80</td>
<td>1.02</td>
<td>G, 12.2 Everkleer</td>
</tr>
<tr>
<td>E-3559</td>
<td>~23</td>
<td>16.22</td>
<td>1.471</td>
<td>5.879</td>
<td>0.684</td>
<td>3.23</td>
<td>0.52</td>
<td>G, 6.4 Plex</td>
</tr>
</tbody>
</table>

\( \rho₀ = 1.876 \text{ g/cm}^³ \)
Table 4.08 (continued)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>T₀ (°C)</th>
<th>P₀ (GPa)</th>
<th>Uᵥ₀ (mm/μs)</th>
<th>Uᵥ₀ (mm/μs)</th>
<th>1/2 b (mm/μs²)</th>
<th>x* (mm)</th>
<th>t* (μs)</th>
<th>Driving System Thickness (mm)</th>
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</thead>
<tbody>
<tr>
<td>E-4630</td>
<td>~49</td>
<td>4.47</td>
<td>0.784</td>
<td>3.33</td>
<td>---</td>
<td>16.6</td>
<td>4.32</td>
<td>R, 24.1 SS, 12.2 PC, 6.2 air, 6.1 PC</td>
</tr>
<tr>
<td>E-4544</td>
<td>~0</td>
<td>5.36</td>
<td>0.806</td>
<td>3.88</td>
<td>---</td>
<td>6.7</td>
<td>1.37</td>
<td>C, 38.1 PC, 6.2 air, 6.1 PC</td>
</tr>
<tr>
<td>E-4535</td>
<td>~8</td>
<td>2.68</td>
<td>0.551</td>
<td>2.84</td>
<td>---</td>
<td>&gt;25.5</td>
<td>&gt;9.5</td>
<td>B, 24.1 SS, 8.9 PC, 6.2 air, 6.1 PC</td>
</tr>
<tr>
<td>E-4556</td>
<td>18</td>
<td>3.72</td>
<td>0.657</td>
<td>3.31</td>
<td>---</td>
<td>14.6</td>
<td>3.93</td>
<td>R, 24.1 SS, 12.2 PC, 6.2 air, 6.1 PC</td>
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<tr>
<td>E-4566</td>
<td>23</td>
<td>3.10</td>
<td>0.588</td>
<td>3.08</td>
<td>---</td>
<td>18.7</td>
<td>5.32</td>
<td>N, 24.1 SS, 11.9 PC, 6.2 air, 6.1 PC</td>
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<td>65</td>
<td>3.86</td>
<td>0.686</td>
<td>3.28</td>
<td>---</td>
<td>12.7</td>
<td>3.18</td>
<td>R, 24.1 SS, 12.2 PC, 6.2 air, 6.1 PC</td>
</tr>
</tbody>
</table>

\( \rho₀ = 1.714 \text{ g/cm}^3 \)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>T₀ (°C)</th>
<th>P₀ (GPa)</th>
<th>Uᵥ₀ (mm/μs)</th>
<th>Uᵥ₀ (mm/μs)</th>
<th>1/2 b (mm/μs²)</th>
<th>x* (mm)</th>
<th>t* (μs)</th>
<th>Driving System Thickness (mm)</th>
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<tbody>
<tr>
<td>E-4628</td>
<td>~56</td>
<td>6.44</td>
<td>0.845</td>
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<td>---</td>
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<td>C, 38.1 PC, 6.2 air, 6.1 PC</td>
</tr>
<tr>
<td>E-4538</td>
<td>~4</td>
<td>6.05</td>
<td>0.786</td>
<td>4.18</td>
<td>---</td>
<td>12.6</td>
<td>2.72</td>
<td>C, 38.1 PC, 6.2 air, 6.1 PC</td>
</tr>
<tr>
<td>E-4567</td>
<td>7</td>
<td>5.34</td>
<td>0.716</td>
<td>4.05</td>
<td>---</td>
<td>~29</td>
<td>~7.0</td>
<td>S, 24.1 SS, 11.9 PC, 6.2 air, 6.1 PC</td>
</tr>
<tr>
<td>E-4536</td>
<td>~8</td>
<td>16.80</td>
<td>1.590</td>
<td>5.74</td>
<td>---</td>
<td>2.33</td>
<td>0.38</td>
<td>S, 19.0 PC, 6.2 air, 6.1 PC</td>
</tr>
<tr>
<td>E-4562</td>
<td>~11</td>
<td>7.96</td>
<td>0.992</td>
<td>4.36</td>
<td>---</td>
<td>7.71</td>
<td>1.54</td>
<td>G, 31.8 PC, 6.2 air, 6.1 PC</td>
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<tr>
<td>E-4595</td>
<td>65</td>
<td>6.99</td>
<td>0.883</td>
<td>4.3</td>
<td>---</td>
<td>11.5</td>
<td>2.49</td>
<td>C, 38.1 PC, 6.2 air, 6.1 PC</td>
</tr>
</tbody>
</table>

Reduced Data

\( \frac{C_{\text{Longitudinal}}}{= 1.98 \pm 0.03 \text{ mm/μs, } C_{\text{Shear}} = 1.16 \pm 0.02 \text{ mm/μs, and } C_0 = 1.46 \pm 0.005 \text{ mm/μs at } \rho = 1.87 \text{ g/cm}^3.} \)

\( U_{\text{vo}} = (1.663 \pm 0.123) + (2.827 + 0.132) U_{\text{vo}}. \)
\[ \rho = 1.876 \text{ g/cm}^3. \]

For \(11.4 < P < 16.22\),
\[ \log P = (1.42 \pm 0.02) - (0.40 \pm 0.03) \log x^*, \text{ and} \]
\[ \log P = (1.11 \pm 0.01) - (0.36 \pm 0.03) \log t^*. \]
\[ \rho_o = 1.714 \text{ g/cm}^3. \]

For \(3.27 < P < 5.64\),
\[ \log P = (1.09 \pm 0.2) - (0.41 \pm 0.17) \log x^*, \text{ and} \]
\[ \log P = (0.8 \pm 0.07) - (0.32 \pm 0.12) \log t^*. \]
\[ \rho_o = 1.841 \text{ g/cm}^3. \]

For \(5.93 < P < 16.5\),
\[ \log P = (1.39 \pm 0.07) - (0.52 \pm 0.07) \log x^*, \text{ and} \]
\[ \log P = (1.01 \pm 0.02) - (0.46 \pm 0.05) \log t^*. \]
SHOCK INITIATION PROPERTIES

![Graph 1: Pressure vs. Distance to Detonation (mm)]

![Graph 2: Pressure vs. Time to Detonation (μs)]

TATB
(pure, ρ=1.876)
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

Time to Detonation (μs)

TATB
(pure, ρ=1.841)

TNT
(pure, ρ=1.841)
SHOCK INITIATION PROPERTIES

Table 4.09 TATB (MICRONIZED)

| Composition | 100 wt% TATB |
| Theoretical Maximum Density | 1.938 g/cm³ |

Particle Size Distribution

The micronized TATB was prepared by grinding dry aminated superfine TATB, suspended in water. Screen tests showed 89.2% <10-μm and 99.1% <20-μm particles.

Preparation Method

Pellets were dry pressed to a density of 1.808 g/cm³. Wedges were made by abrading the pellets under water.

Data Summary

ρ₀ = 1.808 g/cm³. Technique 6

<table>
<thead>
<tr>
<th>Initial Shock Parameters</th>
<th>Coordinates for Intermediate Regions</th>
<th>Coordinates for High-Order Detonation</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₀ (GPa)</td>
<td>Uₚ₀ (mm/μs)</td>
<td>Uₜ₀ (mm/μs)</td>
</tr>
<tr>
<td>14.27</td>
<td>1.4</td>
<td>5.64</td>
</tr>
<tr>
<td>18.01</td>
<td>1.7</td>
<td>5.86</td>
</tr>
<tr>
<td>17.79</td>
<td>1.6</td>
<td>6.15</td>
</tr>
<tr>
<td>22.40</td>
<td>1.9</td>
<td>6.52</td>
</tr>
<tr>
<td>23.19</td>
<td>1.9</td>
<td>6.75</td>
</tr>
<tr>
<td>23.02</td>
<td>1.9</td>
<td>6.70</td>
</tr>
<tr>
<td>25.55</td>
<td>2.1</td>
<td>6.73</td>
</tr>
<tr>
<td>27.84</td>
<td>2.2</td>
<td>7.00</td>
</tr>
</tbody>
</table>

Driving Systems consisted of a plane-wave lens (usually P-081), 50.8 mm of explosive as listed, and 12.7 mm of 6061 aluminum.

Reduced Data

Uₙ₀ = 2.156 + 2.302 Uₚ₀.
For 14.3 < P < 27.8,

\[ \log P = 1.42 - 0.38 \log x^*, \] 

\[ \log P = 0.92 - 0.36 \log t^*. \]
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

Time to Detonation (μs)

Pressure (GPa)

TATB (micronized, ρ=1.808)

TATB (micronized, ρ=1.808)
SHOCK INITIATION PROPERTIES

Initial Particle Velocity, $U_p$ (mm/μs)

TATB (micronized, $\rho = 1.808$)

Initial Shock Velocity, $U_s$ (mm/μs)

13 15 17 19 21 23

5 5.5 6 6.5 7 7.5 8
SHOCK INITIATION PROPERTIES

Table 4.10  TATB (SUPERFINE)

Composition
100 wt% TATB

Theoretical Maximum Density
1.938 g/cm³

Particle Size Distribution
This superfine TATB was dry-aminated, irregular, layer-shaped crystals with many holes and imperfections. A screen test showed 78.7% <20-μm and 99.8% <45-μm particles.

Preparation Method
Pellets were dry pressed to a density of 1.806 g/cm³. Wedges were made by abrading the pellets under water.

Data Summary
$\rho_0 = 1.806$ g/cm³, Technique 6

<table>
<thead>
<tr>
<th>Initial Shock Parameters</th>
<th>Coordinates for Intermediate Regions</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving² System</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_o$        (GPa)</td>
<td>$U_{po}$ (mm/μs)</td>
<td>$U_{so}$ (mm/μs)</td>
<td>$x_1^*$ (mm)</td>
</tr>
<tr>
<td>10.1</td>
<td>1.2</td>
<td>4.65</td>
<td>2.00</td>
</tr>
<tr>
<td>16.0</td>
<td>1.6</td>
<td>5.56</td>
<td>0.80</td>
</tr>
<tr>
<td>16.7</td>
<td>1.5</td>
<td>6.18</td>
<td>0.87</td>
</tr>
<tr>
<td>20.4</td>
<td>2.0</td>
<td>5.64</td>
<td>0.33</td>
</tr>
<tr>
<td>21.2</td>
<td>1.8</td>
<td>6.52</td>
<td>0.48</td>
</tr>
<tr>
<td>21.8</td>
<td>1.8</td>
<td>6.70</td>
<td>0.31</td>
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²Driving systems consisted of a plane-wave lens (usually P-081), 50.8 mm of explosive as listed, and 12.7 mm of 6061 aluminum.

Reduced Data
$U_{so} = 2.156 + 2.302 U_{po}$.
For 10.1 < $P < 28.1$ (mm/μs),
$log P = (1.31 \pm 0.01) - (0.43 \pm 0.03) log x^*$, and
$log P = (1.00 \pm 0.02) - (0.38 \pm 0.03) log t^*$.
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Time to Detonation (ps)

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SHOCK INITIATION PROPERTIES

Table 4.11 TETRYL

Composition

100 wt% tetryl

Theoretical Maximum Density

1.73 g/cm³

Particle Size Distribution

Particles were mostly shapeless, multicrystalline agglomerates, about 0.6 mm in diameter, with a small fraction of 0.1- to 0.2-mm particles.

Preparation Method

Pellets were dry pressed. 1.70-g/cm³ wedges were formed by machining, and the lower density wedges were made by abrading the pellets under water.

Data Summary

Technique 5

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<tr>
<th>$p_0$ (GPa)</th>
<th>$U_{p0}$ (mm/μs)</th>
<th>$U_{w0}$ (mm/μs)</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System$^a$</th>
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$\rho_0 = 1.6$ g/cm³

| $p_0 = 1.6$ g/cm³ |
| 8.02 | 1.232 | 4.07 | 0.52 | 0.13 | 1 |
| 5.82 | 1.004 | 3.62 | 0.87 | 0.22 | 2 |
| 5.15 | 0.935 | 3.44 | 1.08 | 0.27 | 3 |
| 4.72 | 0.867 | 3.40 | 1.46 | 0.36 | 4 |
| 3.52 | 0.699 | 3.15 | 1.89 | 0.49 | 6 |
| 2.64 | 0.580 | 2.85 | 2.58 | 0.75 | 7 |
| 2.38 | 0.548 | 2.71 | 3.23 | 0.99 | 8 |
| 1.98 | 0.482 | 2.57 | 4.61 | 1.49 | 9 |
| 1.77 | 0.451 | 2.45 | 5.44 | 1.87 | 10 |
| 1.58 | 0.414 | 2.39 | 6.38 | 2.21 | 11 |
| 1.49 | 0.400 | 2.33 | 6.82 | 2.39 | 13 |

$^a$See "Notes" at end of table.
SHOCK INITIATION PROPERTIES

Table 4.11 (continued)

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$\rho_0 = 1.5 \text{ g/cm}^3$

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$\rho_0 = 1.4 \text{ g/cm}^3$

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SHOCK INITIATION PROPERTIES

Table 4.11 (continued)

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<th>U₀/₀ (mm/μs)</th>
<th>U₀/₀ (mm/μs)</th>
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Reduced Data

Buildup Function Coefficients

ρ₀ = 1.7 g/cm³.

A₁ = 0.9532, A₂ = 5.1388, A₃ = 0.4179, and A₄ = 7.65.

U₀/₀ = 2.4763 + 1.4160 U₀/₀.  
For 2.22 < P < 8.53,

log P = (0.79 ± 0.01) - (0.42 ± 0.01) log x*, and

log P = (0.55 ± 0.01) - (0.39 ± 0.01) log t*.

ρ₀ = 1.6 g/cm³.

A₁ = 1.7738, A₂ = 3.2707, A₃ = 0.4182, and A₄ = 7.35.

U₀/₀ = 2.3621 + 1.5285 U₀/₀ - 0.2549/U₀/₀.  
For 1.08 < P < 8.02,

log P = (0.73 ± 0.01) - (0.65 ± 0.01) log x*, and

log P = (0.4 ± 0.01) - (0.55 ± 0.01) log t*.

ρ₀ = 1.5 g/cm³.

A₁ = 2.8078, A₂ = 2.2508, A₃ = 0.4027, and A₄ = 7.05.

U₀/₀ = 2.1674 + 1.6225 U₀/₀ - 0.3411/U₀/₀.  
For 0.62 < P < 7.09,

log P = (0.75 ± 0.01) - (0.81 ± 0.01) log x*, and

log P = (0.35 ± 0.01) - (0.64 ± 0.01) log t*.

ρ₀ = 1.4 g/cm³.

A₁ = 3.3485, A₂ = 1.8668, A₃ = 0.4564, and A₄ = 6.75.

U₀/₀ = 1.6111 + 1.9658 U₀/₀ - 0.2784/U₀/₀.  
For 0.51 < P < 6.84,

log P = (0.84 ± 0.01) - (0.99 ± 0.02) log x*, and

log P = (0.35 ± 0.01) - (0.75 ± 0.01) log t*.
SHOCK INITIATION PROPERTIES

\( \rho_0 = 1.3 \text{ g/cm}^3 \).
\( A_1 = 6.0649, A_2 = 1.2364, A_3 = 0.3587, \text{ and } A_4 = 6.45. \)
\( U_{so} = 2.1620 + 1.4271 U_{p0} - 0.4993/U_{p0}. \)

For \( 0.37 < P < 6.91 \),
\[ \log P = (0.87 \pm 0.05) - (1.11 \pm 0.07) \log x^*, \text{ and} \]
\[ \log P = (0.33 \pm 0.02) - (0.83 \pm 0.03) \log t^*. \]

Notes on Driving System

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<th>Second-Layer Liquid</th>
<th>Free-Surface Velocity (mm/\mu s)</th>
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<td>16</td>
<td>Brass</td>
<td>Ethyl alcohol-water mixture</td>
<td>0.35-0.39c</td>
</tr>
<tr>
<td>20</td>
<td>16</td>
<td>Brass</td>
<td>Toluene</td>
<td>0.36</td>
</tr>
<tr>
<td>21</td>
<td>16</td>
<td>Brass</td>
<td>Ethyl alcohol</td>
<td>0.35</td>
</tr>
<tr>
<td>22</td>
<td>16</td>
<td>Brass</td>
<td>Diethyl ether-ethyl alcohol mixture</td>
<td>0.31-0.35c</td>
</tr>
<tr>
<td>23</td>
<td>16</td>
<td>Brass</td>
<td>Diethyl ether</td>
<td>0.31</td>
</tr>
</tbody>
</table>

*All experiments were performed with a P-120, 30-cm-diameter plane-wave lens and a 10-cm thickness of Baratol. Attenuators were made with either one layer or three layers; the third layer was always brass.

'This attenuator was a single plate of the "first layer metal."

The value depends on the proportions of the two liquids.

The original solution density was 1.77 g/cm³. The density may have been different at the time of use owing to water evaporation.
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

Time to Detonation (μs)

Pressure (GPa)

TETRYL
(ρ=1.7)
SHOCK INITIATION PROPERTIES

**TETRYL**

(p=16)

Distance to Detonation (mm)

Pressure (GPa)

**TETRYL**

(p=16)

Time to Detonation (µs)

Pressure (GPa)
SHOCK INITIATION PROPERTIES

![Graph 1: Pressure vs. Distance to Detonation (mm)]

- **TETRYL**
  - Density $\rho = 1.5$

![Graph 2: Pressure vs. Time to Detonation ($\mu$s)]
SHOCK INITIATION PROPERTIES

**Graph 1:**
- **Title:** Tetryl (\(\rho = 1.4\))
- **Axes:**
  - X-axis: Distance to Detonation (mm)
  - Y-axis: Pressure (GPa)

**Graph 2:**
- **Title:** Tetryl (\(\rho = 1.4\))
- **Axes:**
  - X-axis: Time to Detonation (\(\mu s\))
  - Y-axis: Pressure (GPa)
SHOCK INITIATION PROPERTIES

TETRYL ($\rho=1.3$)

Distance to Detonation (mm)

Pressure (GPa)

TETRYL ($\rho=13$)

Time to Detonation (μs)

Pressure (GPa)
Table 4.12  TNT (CAST)

**Composition**
100 % TNT

**Theoretical Maximum Density**
1.654 g/cm³

**Preparation Method**
Casting

**Data Summary**
Technique 7

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Temp. (°C)</th>
<th>( \rho_0 ) (g/cm³)</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{po} ) (mm/µs)</th>
<th>( U_{so} ) (mm/µs)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (µs)</th>
<th>( U_{ts} ) (mm/µs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-4451</td>
<td>25</td>
<td>1.634</td>
<td>7.43</td>
<td>1.03</td>
<td>4.43</td>
<td>&gt;25.4</td>
<td>&gt;5.22</td>
<td>2.407</td>
<td>G, 32 PC, 63 air, 63 PC</td>
</tr>
<tr>
<td>E-4373</td>
<td>25</td>
<td>1.634</td>
<td>9.17</td>
<td>1.16</td>
<td>4.85</td>
<td>22.2</td>
<td>4.30</td>
<td>2.746</td>
<td>N, 32 PC, 63 air, 63 PC</td>
</tr>
<tr>
<td>E-4377</td>
<td>73</td>
<td>1.62</td>
<td>8.80</td>
<td>1.16</td>
<td>4.69</td>
<td>18.9</td>
<td>3.80</td>
<td>2.705</td>
<td>N, 32 PC, 63 air, 63 PC</td>
</tr>
<tr>
<td>E-4393</td>
<td>25</td>
<td>1.634</td>
<td>10.4</td>
<td>1.26</td>
<td>5.05</td>
<td>20.2</td>
<td>3.84</td>
<td>2.992</td>
<td>N, 19 PC, 63 air, 63 PC</td>
</tr>
<tr>
<td>E-4399</td>
<td>73</td>
<td>1.62</td>
<td>10.4</td>
<td>1.34</td>
<td>4.80</td>
<td>14.3</td>
<td>2.77</td>
<td>3.069</td>
<td>N, 19 PC, 63 air, 63 PC</td>
</tr>
<tr>
<td>E-4412</td>
<td>25</td>
<td>1.634</td>
<td>15.1</td>
<td>1.69</td>
<td>5.49</td>
<td>6.96</td>
<td>1.24</td>
<td>3.877</td>
<td>S, 19 PC, 63 air, 63 PC</td>
</tr>
<tr>
<td>E-4414</td>
<td>73</td>
<td>1.62</td>
<td>14.9</td>
<td>1.69</td>
<td>5.44</td>
<td>4.42</td>
<td>0.76</td>
<td>3.867</td>
<td>S, 19 PC, 63 air, 63 PC</td>
</tr>
</tbody>
</table>

\( \rho_0 = 1.62-1.634 \text{ g/cm}^3, T_o = 25-73^\circ \text{C} \)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Temp. (°C)</th>
<th>( \rho_0 ) (g/cm³)</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{po} ) (mm/µs)</th>
<th>( U_{so} ) (mm/µs)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (µs)</th>
<th>( U_{ts} ) (mm/µs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2187</td>
<td>30</td>
<td>1.624</td>
<td>1.35</td>
<td>0.298</td>
<td>2.80</td>
<td>&gt;10</td>
<td>---</td>
<td>0.661</td>
<td>C, 25.1 brass, 24.5 Plex, 12.7 brass, 11.8 Plex</td>
</tr>
<tr>
<td>E-2184</td>
<td>27</td>
<td>1.624</td>
<td>3.31</td>
<td>0.604</td>
<td>3.38</td>
<td>&gt;10</td>
<td>---</td>
<td>1.353</td>
<td>C, 24.4 Plex, 12.6 brass, 11.6 Plex</td>
</tr>
<tr>
<td>E-2164</td>
<td>22</td>
<td>1.624</td>
<td>4.36</td>
<td>0.688</td>
<td>3.90</td>
<td>&gt;10</td>
<td>---</td>
<td>1.608</td>
<td>B, 6.35 brass, 6.63 Plex</td>
</tr>
</tbody>
</table>

\( \rho_0 = 1.624 \text{ g/cm}^3, T_o = 5-30^\circ \text{C} \)
Table 4.12 (continued)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Temp. (°C)</th>
<th>$\rho_0$ (g/cm$^3$)</th>
<th>$P_0$ (GPa)</th>
<th>$U_{p0}$ (mm/μs)</th>
<th>$U_{so}$ (mm/μs)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
<th>$U_{is}$ (mm/μs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2100</td>
<td>14</td>
<td>1.624</td>
<td>7.63</td>
<td>1.04</td>
<td>4.50</td>
<td>&gt;10</td>
<td>---</td>
<td>2.418</td>
<td>B, 24.8 Plex</td>
</tr>
<tr>
<td>E-2097</td>
<td>14</td>
<td>1.624</td>
<td>8.93</td>
<td>1.15</td>
<td>4.77</td>
<td>&gt;10</td>
<td>---</td>
<td>2.684</td>
<td>B, 6.38 Lucite</td>
</tr>
<tr>
<td>E-2101</td>
<td>16</td>
<td>1.624</td>
<td>13.4</td>
<td>1.54</td>
<td>5.38</td>
<td>&gt;10</td>
<td>---</td>
<td>3.543</td>
<td>J, 24.8 Plex</td>
</tr>
<tr>
<td>E-2102</td>
<td>16</td>
<td>1.624</td>
<td>15.6</td>
<td>1.75</td>
<td>5.50</td>
<td>6.0</td>
<td>---</td>
<td>3.965</td>
<td>G, 5.90 Lucite</td>
</tr>
<tr>
<td>E-2114</td>
<td>17</td>
<td>1.624</td>
<td>15.1</td>
<td>1.65</td>
<td>5.65</td>
<td>4.9</td>
<td>---</td>
<td>3.810</td>
<td>J, 18.2 Plex</td>
</tr>
<tr>
<td>E-2109</td>
<td>5</td>
<td>1.624</td>
<td>17.0</td>
<td>1.79</td>
<td>5.85</td>
<td>3.6</td>
<td>---</td>
<td>4.121</td>
<td>H, 6.29 Plex</td>
</tr>
<tr>
<td>E-2115</td>
<td>14</td>
<td>1.624</td>
<td>17.1</td>
<td>1.81</td>
<td>5.83</td>
<td>2.7</td>
<td>---</td>
<td>4.155</td>
<td>L, 24.6 Plex</td>
</tr>
</tbody>
</table>

**Reduced Data**

$C_0 = 2.08 \pm 0.13$ mm/μs

at $\rho = 1.635$ g/cm$^3$.

**Low pressure**

$U_{so} = (2.109 \pm 0.222) + (2.337 \pm 0.313) U_{p0}$.

**High pressure**

$U_{so} = (2.974 \pm 0.199) + (1.555 \pm 0.132) U_{p0}$.

For both densities, $9.17 < P < 17.1$,

$\log P = (1.40 \pm 0.03) - (0.32 \pm 0.03) \log x^*$, and

$\log P = (1.16 \pm 0.03) - (0.31 \pm 0.05) \log t^*$. 
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

Time to Detonation (μs)

Pressure (GPa)
SHOCK INITIATION PROPERTIES

Initial Particle Velocity, $U_{p0}$ (mm/μs)

Initial Shock Velocity, $U_{sh0}$ (mm/μs)

TNT (cast: low pressure)

Initial Particle Velocity, $U_{p0}$ (mm/μs)

Initial Shock Velocity, $U_{sh0}$ (mm/μs)

TNT (cast: high pressure)
SHOCK INITIATION PROPERTIES

Fig. 4.04. Shock Hugoniot for cast TNT at two temperatures.

Fig. 4.05. Relationship between initial pressure and distance-to-detonation for cast TNT at 25 and 73°C and liquid TNT at 85 and 150°C.


SHOCK INITIATION PROPERTIES

Table 4.13 TNT (α) (SINGLE CRYSTAL)

<table>
<thead>
<tr>
<th>Composition</th>
<th>100 wt% TNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Maximum Density</td>
<td>1.654 g/cm³</td>
</tr>
<tr>
<td>Particle Size Distribution</td>
<td>Single crystal</td>
</tr>
<tr>
<td>Preparation Method</td>
<td>Controlled solvent evaporation</td>
</tr>
</tbody>
</table>

**Data Summary**

\[ \rho_0 = 1.654 \text{ g/cm}^3, \quad T_0 = 24°C. \text{ Technique 4} \]

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 ) (GPa)</td>
<td>( U_{p0} ) (mm/μs)</td>
</tr>
<tr>
<td>E-2257</td>
<td>1.45</td>
<td>0.295</td>
</tr>
<tr>
<td>E-2252</td>
<td>4.35</td>
<td>0.672</td>
</tr>
<tr>
<td>E-2255</td>
<td>7.80</td>
<td>1.059</td>
</tr>
<tr>
<td>E-2262</td>
<td>8.38</td>
<td>1.118</td>
</tr>
<tr>
<td>E-2236</td>
<td>8.42</td>
<td>1.107</td>
</tr>
<tr>
<td>E-2267</td>
<td>8.67</td>
<td>1.083</td>
</tr>
<tr>
<td>E-2267</td>
<td>10.07</td>
<td>1.324</td>
</tr>
<tr>
<td>E-2261</td>
<td>11.8</td>
<td>1.453</td>
</tr>
<tr>
<td>E-2256</td>
<td>13.7</td>
<td>1.536</td>
</tr>
<tr>
<td>E-2254</td>
<td>13.9</td>
<td>1.516</td>
</tr>
<tr>
<td>E-2253</td>
<td>14.3</td>
<td>1.588</td>
</tr>
<tr>
<td>E-2302</td>
<td>18.1</td>
<td>1.932</td>
</tr>
<tr>
<td>E-2237</td>
<td>18.0</td>
<td>1.745</td>
</tr>
<tr>
<td>E-2254</td>
<td>23.3</td>
<td>2.146</td>
</tr>
</tbody>
</table>

*The first \( U_{s0} \) given is that uncorrected for wave tilt as indicated by the large value of \( 1/2 b \); the second \( U_{s0} \) given was obtained by forcing \( 1/2 b \) to equal zero.

**Reduced Data**

When the data are corrected for wave tilt,

\[ U_{s0} = (2.576 \pm 0.229) + (1.822 \pm 0.161) U_{p0}. \]
### Table 4.14 BARATOL

**Composition**
24 wt% TNT, 76 wt% barium nitrate

**Theoretical Maximum Density**
2.634 g/cm³

**Preparation Method**
Casting

**Data Summary**
T₀ ≈ 23°C. Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>(\rho_0) (g/cm³)</th>
<th>(P_0) (GPa)</th>
<th>(U_{v0}) (mm/µs)</th>
<th>(U_{w0}) (mm/µs)</th>
<th>(1/2 b) (mm/µs²)</th>
<th>(x^*) (mm)</th>
<th>(t^*) (µs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-3714</td>
<td>2.608</td>
<td>3.31</td>
<td>0.424</td>
<td>3.011</td>
<td>+0.002</td>
<td>≥25.4</td>
<td>≥8.40</td>
<td>B, 17.7 polyethylene 11.4 SS, 10.9 Plex</td>
</tr>
<tr>
<td>E-3645</td>
<td>2.612</td>
<td>5.71</td>
<td>0.627</td>
<td>3.485</td>
<td>+0.008</td>
<td>≥25.4</td>
<td>≥7.10</td>
<td>J, 20.3 SS, 1.09 Plex</td>
</tr>
<tr>
<td>E-3660</td>
<td>2.615</td>
<td>6.86</td>
<td>0.714</td>
<td>3.675</td>
<td>+2.615</td>
<td>16.82</td>
<td>4.39</td>
<td>K, 24.1 SS, 1.09 Plex</td>
</tr>
<tr>
<td>E-3643</td>
<td>2.616</td>
<td>8.12</td>
<td>0.836</td>
<td>3.714</td>
<td>+0.081</td>
<td>8.05</td>
<td>2.05</td>
<td>B, 38.1 Plex</td>
</tr>
<tr>
<td>E-3674</td>
<td>2.616</td>
<td>9.01</td>
<td>0.959</td>
<td>3.594</td>
<td>+0.311</td>
<td>6.79</td>
<td>1.63</td>
<td>B, 18.7 Plex</td>
</tr>
<tr>
<td>E-3712</td>
<td>2.610</td>
<td>9.16</td>
<td>0.983</td>
<td>3.569</td>
<td>+0.389</td>
<td>5.46</td>
<td>1.33</td>
<td>B, 12.7 Plex</td>
</tr>
<tr>
<td>E-3713</td>
<td>2.606</td>
<td>11.82</td>
<td>1.140</td>
<td>3.977</td>
<td>+0.780</td>
<td>3.604</td>
<td>0.79</td>
<td>G, 24.5 Plex</td>
</tr>
</tbody>
</table>

**Reduced Data**
\(C_L = 2.95 \pm 0.05\) mm/µs,
\(C_S = 1.48 \pm 0.01\) mm/µs, and
\(C_0 = 2.40 \pm 0.06\) mm/µs,
all at \(\rho = 2.538\) g/cm³.
Table 4.14 (continued)

\[ U_{\infty} = (2.360 \pm 0.08) + (1.773 \pm 0.154) U_{\infty}. \]
\[ C_0 \leq U_{\infty} \leq 3.675 \]
for \( 6.86 < P < 11.82 \),
\[ \log P = (1.2 \pm 0.03) - (0.30 \pm 0.03) \log x^* , \text{ and} \]
\[ \log P = (1.01 \pm 0.01) - (0.27 \pm 0.02) \log t^* . \]
Table 4.15 X-0309 (DESTEX)

**Composition**
74.6 wt% TNT, 18.7 wt% aluminum, 4.8 wt% wax, 1.9 wt% acetylene black

**Preparation Method**
Casting and machining to shape

**Data Summary**
\[ \rho_0 = 1.69 \text{ g/cm}^3, T_0 = 23^\circ\text{C}, \text{ Technique 4} \]

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{p0} ) (mm/( \mu )s)</th>
<th>( U_{s0} ) (mm/( \mu )s)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (( \mu )s)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-4454</td>
<td>5.79</td>
<td>0.801</td>
<td>4.280</td>
<td>23.48</td>
<td>5.30</td>
<td>R, 24.1 SS, 11:5 Plex</td>
</tr>
<tr>
<td>E-4383</td>
<td>6.80</td>
<td>0.930</td>
<td>4.328</td>
<td>12.93</td>
<td>2.74</td>
<td>B, 38.1 Plex</td>
</tr>
<tr>
<td>E-4435</td>
<td>7.45</td>
<td>1.014</td>
<td>4.348</td>
<td>11.91</td>
<td>2.45</td>
<td>B, 24.1 Plex</td>
</tr>
<tr>
<td>E-4436</td>
<td>9.57</td>
<td>1.198</td>
<td>4.725</td>
<td>6.96</td>
<td>1.33</td>
<td>G, 31.7 Plex</td>
</tr>
<tr>
<td>E-4382</td>
<td>10.40</td>
<td>1.224</td>
<td>5.028</td>
<td>5.57</td>
<td>1.05</td>
<td>G, 25.0 Plex</td>
</tr>
<tr>
<td>E-4434</td>
<td>11.46</td>
<td>1.370</td>
<td>4.948</td>
<td>3.93</td>
<td>0.72</td>
<td>B, 24.1 Plex</td>
</tr>
<tr>
<td>E-4379</td>
<td>13.74</td>
<td>1.537</td>
<td>5.290</td>
<td>2.2</td>
<td>0.39</td>
<td>H, 20.4 Plex</td>
</tr>
</tbody>
</table>

**Reduced Data**
\[ U_{so} = (2.998 \pm 0.252) + (1.481 \pm 0.214) U_{p0} \]
For \( 5.80 < P < 13.73 \),
\[ \log P = (1.28 \pm 0.02) - (0.38 \pm 0.02) \log x^*, \text{ and} \]
\[ \log P = (1.01 \pm 0.01) - (0.35 \pm 0.02) \log t^*. \]
SHOCK INITIATION PROPERTIES

![Graph showing the relationship between distance to detonation and pressure.](image1)

![Graph showing the relationship between time to detonation and pressure.](image2)
SHOCK INITIATION PROPERTIES

Initial Particle Velocity, $U_p$ (mm/μs)

Initial Shock Velocity, $U_{sh}$ (mm/μs)

DESTEX (X-0309)
Table 4.16 95 DATB/5 ESTANE

**Composition**
95 wt% DATB, 5 wt% Estane

**Theoretical Maximum Density**
1.835 g/cm³

**Particle Size Distribution**

<table>
<thead>
<tr>
<th>Particle Size (μm)</th>
<th>Wt% Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>0.3</td>
</tr>
<tr>
<td>90</td>
<td>0.3</td>
</tr>
<tr>
<td>60</td>
<td>1.7</td>
</tr>
<tr>
<td>45</td>
<td>1.9</td>
</tr>
<tr>
<td>30</td>
<td>16.0</td>
</tr>
<tr>
<td>20</td>
<td>19.4</td>
</tr>
<tr>
<td>20</td>
<td>50.4</td>
</tr>
</tbody>
</table>

**Preparation Method**
Pressing

**Data Summary**
\[ \rho_0 = 1.61-1.64 \text{ g/cm}^3, \quad T_0 = 25-150^\circ\text{C}. \text{ Technique 7} \]
### Initial Shock Parameters

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Temp. (°C)</th>
<th>( \rho_0 ) (g/cm(^2))</th>
<th>( P_s ) (GPa)</th>
<th>( U_{p0} ) (mm/μs)</th>
<th>( U_{s0} ) (mm/μs)</th>
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<th>( t^* ) (μs)</th>
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### Coordinates for High-Order Detonation

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### Driving System Thickness (mm)

- B, 18 foam, 19 SS, 5.1 PC, 6.3 air, 6.3 PC
- N, 24 SS, 26 PC, 6.3 air, 6.3 PC
- N, 24 SS, 19 PC, 6.3 air, 6.3 PC
- N, 24 SS, 19 PC, 6.3 air, 6.3 PC
- N, 24 SS, 19 PC, 6.3 air, 6.3 PC
- N, 24 SS, 19 PC, 6.3 air, 6.3 PC
- L, 24 SS, 19 PC, 6.3 air, 6.3 PC
- L, 24 SS, 19 PC, 6.3 air, 6.3 PC
- L, 24 SS, 19 PC, 6.3 air, 6.3 PC

### Reduced Data

Combined data for all temperatures

\[ U_{so} = (1.296 \pm 0.575) + (2.536 \pm 0.897)U_{pn} \]
SHOCK INITIATION PROPERTIES

Fig. 4.06. Shock Hugoniot for 95 DATB/5 Estane at three temperatures.

Fig. 4.07. Relationship between initial pressure and distance-to-detonation for DATB at three temperatures. The arrows indicate that the transition was not observed up to the distance where the point is plotted.
Table 4.17  PBX 9501

Composition
95 wt% HMX, 2.5 wt% Estane, 2.5 wt% BDNPF/A

Theoretical Maximum Density
1.855 g/cm³

Particle Size Distribution
HMX: 75%; 90% through USS-50, 50% through USS-100, 20%
through USS-200, and 13% through USS-325 sieves. 25%; 100%
through USS-50, 98% through USS-120, and 75% min. through
USS-325 sieves.

Preparation Method
Slurry mixing, steel die pressing, and machining to shape

Data Summary
Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Temp (°C)</th>
<th>$\rho_0$ (g/cm³)</th>
<th>$P_o$ (GPa)</th>
<th>$U_{p0}$ (mm/μs)</th>
<th>$U_{s0}$ (mm/μs)</th>
<th>$1/2 b$ (mm/μs²)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
<th>$U_{tr}$ (mm/μs)</th>
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$\rho_0 = 1.833$ g/cm³, 98.8% $\rho_T$, $T = 23°C$

$\rho_0 = 1.844$ g/cm³, 99.4% $\rho_T$, $T = 23°C$
Table 4.17 (continued)

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<th>$U_{ao}$ (mm/$\mu$s)</th>
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<th>$x^*$ (mm)</th>
<th>$t^*$ ($\mu$s)</th>
<th>$U_{oa}$ (mm/$\mu$s)</th>
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Reduced Data

$\rho_0 = 1.833$ g/cm$^3$.

$U_{so} = (2.501 \pm 0.131) + (2.261 \pm 0.233) U_{vo}$.

For $2.38 < P < 7.32$,

$log P = (1.15 \pm 0.05) - (0.64 \pm 0.06) \log x^*$, and

$log P = (0.73 \pm 0.01) - (0.53 \pm 0.03) \log t^*$.

$\rho_0 = 1.844$ g/cm$^3$.

$U_{so} = (2.953 \pm 0.098) + (1.507 \pm 0.179) U_{vo}$.

For $2.47 < P < 7.21$,

$log P = (1.10 \pm 0.04) - (0.51 \pm 0.03) \log x^*$, and

$log P = (0.76 \pm 0.01) - (0.45 \pm 0.03) \log t^*$.
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

Initial Particle Velocity, $U_{pe}$ (mm/μs)

Initial Shock Velocity, $U_{sh}$ (mm/μs)

PRX 9501
($\rho = 1.833$)

PBX 9501
($\rho = 1.833$)
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

Time to Detonation (μs)

Pressure (GPa)

ρBX 9501
(ρ=1.844)
SHOCK INITIATION PROPERTIES

PBX 9501
($\rho=1.844$)

Initial Shock Velocity, $U_s$ (mm/µs)

Initial Particle Velocity, $U_p$ (mm/µs)
SHOCK INITIATION PROPERTIES

Fig. 4.08. Relationship between initial pressure and distance-to-detonation for PBX 9501 at four temperatures.

Fig. 4.09. Shock Hugoniot for PBX 9501 at four temperatures.
Table 4.18  PBX 9404

**Composition**  
94 wt% HMX, 3 wt% nitrocellulose, 3 wt% chloroethylphosphate

**Theoretical Maximum Density**  
1.866 g/cm³

**Preparation Method**  
Hydrostatic pressing to 1.839 g/cm³ or ram-pressing to 1.840 ± 0.003 g/cm³

**Data Summary**  
T₀ ≈ 23°C. Technique 4

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<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
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PBX-9404 hydrostatically pressed to $p_0 = 1.839 \text{ g/cm}^3$

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<th>$P_0$ (GPa)</th>
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<th>$U_{\text{so}}$ (mm/μs)</th>
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<th>$t^*$ (μs)</th>
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Table 4.18 (continued)

<table>
<thead>
<tr>
<th>Coordinates for High-Order Detonation</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
</table>

B, 17.78 polyethylene, 11.43 SS, 10.92 H2O
NQ lens, 11.176 Acrylic
B, 17.78 polyethylene, 11.43 SS, 10.92 Acrylic
B, 17.78 polyethylene, 11.43 SS, 10.92 Acrylic
B, 17.78 polyethylene, 11.43 SS, 10.92 Acrylic
B, 17.78 Acrylic, 11.43 SS, 10.92 Acrylic
B, 25.4 SS, 14.986 Plex
B, 11.43 SS, 10.92 Acrylic
B, 25.4 brass, 24.638 Plex
B, 25.4 brass, 14.986 Plex
A, 25.4 Acrylic
A, 17.78 Acrylic
A, 12.7 Acrylic
R, 0.8636 D-38
N, 12.7 Everkleer
N, 6.35 Acrylic

Like E-3104
Like E-2984
<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\rho_0$ (g/cm$^3$)</td>
<td>$P_0$ (GPa)</td>
<td>$U_{ps}$ (mm/μs)</td>
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<tr>
<td>E-3185</td>
<td>3.51</td>
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<td>3.564</td>
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<td>E-3198</td>
<td>7.18</td>
<td>0.897</td>
<td>4.351</td>
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PBX 9404 ram-pressed to $\rho_0 = 1.845 \pm 0.002$ g/cm$^3$

<table>
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<tr>
<th>Shot Number</th>
<th>$\rho_0$ (g/cm$^3$)</th>
<th>$P_0$ (GPa)</th>
<th>$U_{ps}$ (mm/μs)</th>
<th>$U_{se}$ (mm/μs$^2$)</th>
<th>$1/2 b$</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
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<td>0.417</td>
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<td>4.49</td>
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<tr>
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<td>3.16</td>
<td>0.497</td>
<td>3.447</td>
<td>0.076</td>
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<td>2.78</td>
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<tr>
<td>E-3273</td>
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<td>6.59</td>
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<td>1.097</td>
<td>2.30</td>
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PBX-9404 pressed to $\rho_0 = 1.721$ g/cm$^3$

<table>
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<th>$P_0$ (GPa)</th>
<th>$U_{ps}$ (mm/μs)</th>
<th>$U_{se}$ (mm/μs$^2$)</th>
<th>$1/2 b$</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
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</thead>
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<td>1.724</td>
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<td>0.033</td>
<td>6.80</td>
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<td>E-3547</td>
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<td>2.782</td>
<td>0.124</td>
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<td>1.83</td>
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<td>E-3537</td>
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$D \approx 8.3$ mm/μs

SHOCK INITIATION PROPERTIES
Table 4.18 (continued)

<table>
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<tr>
<th>Shot Number</th>
<th>$\rho_0$ (g/cm$^3$)</th>
<th>$P_0$ (GPa)</th>
<th>$U_{pa}$ (mm/μs)</th>
<th>$U_{sa}$ (mm/μs)</th>
<th>$1/2 b$ (mm/μs$^2$)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
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<tbody>
<tr>
<td>E-663</td>
<td>1.82</td>
<td>6.8</td>
<td>0.81</td>
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<td>2.56</td>
<td>0.44</td>
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<tr>
<td>E-707</td>
<td>1.83</td>
<td>1.7</td>
<td>0.28</td>
<td>3.27</td>
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<td>&gt;17</td>
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<tr>
<td>E-711</td>
<td>1.83</td>
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Additional Data
PBX-9404

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<th>$P_0$ (GPa)</th>
<th>$U_{pa}$ (mm/μs)</th>
<th>$U_{sa}$ (mm/μs)</th>
<th>$1/2 b$ (mm/μs$^2$)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
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<td>13.9</td>
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PBX-9404-00

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<th>Shot Number</th>
<th>$\rho_0$ (g/cm$^3$)</th>
<th>$P_0$ (GPa)</th>
<th>$U_{pa}$ (mm/μs)</th>
<th>$U_{sa}$ (mm/μs)</th>
<th>$1/2 b$ (mm/μs$^2$)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
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<tbody>
<tr>
<td>E-663</td>
<td>1.82</td>
<td>6.8</td>
<td>0.81</td>
<td>4.65</td>
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<td>0.44</td>
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<td>E-707</td>
<td>1.83</td>
<td>1.7</td>
<td>0.28</td>
<td>3.27</td>
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<td>&gt;17</td>
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<tr>
<td>E-711</td>
<td>1.83</td>
<td>2.2</td>
<td>0.38</td>
<td>3.27</td>
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<td>4.51</td>
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<td>E-743</td>
<td>1.83</td>
<td>3.6</td>
<td>0.53</td>
<td>3.67</td>
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<td>8.2</td>
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</tr>
<tr>
<td>B-4317</td>
<td>1.82</td>
<td>5.7</td>
<td>0.71</td>
<td>4.38</td>
<td>---</td>
<td>3.47</td>
<td>0.66</td>
</tr>
</tbody>
</table>
Very poor record.

Five replicate shots were fired without simultaneously measuring the driver pressure. However, the driver free-surface velocity had been measured in eight shots. Data for the driver and the reported $U_{in}$ were used to deduce $P_0$ and $U_{in}$.

**Reduced Data**

For $\rho_0 = 1.84$ g/cm$^3$.

$U_{x0} = (2.494 \pm 0.039) + (2.093 \pm 0.045)U_{D0}$.

For $2.27 < P < 25.72$,

$\log P = (1.11 \pm 0.01) - (0.65 \pm 0.02) \log x^*$, and

$\log P = (0.69 \pm 0.01) - (0.54 \pm 0.01) \log t^*$.

$D = 8.81$ mm/$\mu$s.

For $\rho_0 = 1.72$ g/cm$^3$.

$U_{x0} = (1.890 \pm 0.197) + (1.565 \pm 0.353)U_{D0}$.

For $1.19 < P < 6.34$,

$\log P = (0.96 \pm 0.03) - (0.71 \pm 0.04) \log x^*$, and

$\log P = (0.54 \pm 0.01) - (0.57 \pm 0.02) \log t^*$. 
SHOCK INITIATION PROPERTIES

Pressure (GPa) vs. Distance to Detonation (mm)

Pressure (GPa) vs. Time to Detonation (μs)
SHOCK INITIATION PROPERTIES

PBX 9404
($\rho=1.84$)

Initial Shock Velocity, $U_I$ (mm/μs)

PBX 9404
($\rho=1.72$)

Initial Shock Velocity, $U_I$ (mm/μs)
Table 4.19 PBX 9011

Composition
90 wt% HMX, 10 wt% Estane

Theoretical Maximum Density
1.795 g/cm³

Particle Size Distribution
HMX: 100% through USS-50 sieve, 98% min. through USS-120 sieve, and 75% min. through USS-325 sieve

Preparation Method
Slurring mixing, hydrostatic pressing, and machining to shape

Data Summary
$\rho = 1.790 \text{ g/cm}^3$, $T_0 \approx 23^\circ \text{C}$, Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>$P_0$ (GPa)</th>
<th>$U_{\nu 0}$ (mm/μs)</th>
<th>$U_{\phi 0}$ (mm/μs)</th>
<th>1/2 b (mm/μs²)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
<th>Driving System Thickness (mm)</th>
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<td>E-2415</td>
<td>15.65</td>
<td>1.427</td>
<td>6.126</td>
<td>+2.320</td>
<td>0.995</td>
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<tr>
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<td>9.81</td>
<td>1.096</td>
<td>5.001</td>
<td>+1.029</td>
<td>1.893</td>
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</tr>
<tr>
<td>E-2399</td>
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<td>0.932</td>
<td>4.528</td>
<td>+0.738</td>
<td>2.930</td>
<td>0.578</td>
<td>H, 25.4 Plex, 11.176 brass</td>
</tr>
<tr>
<td>E-2396</td>
<td>6.24</td>
<td>0.803</td>
<td>4.340</td>
<td>+0.483</td>
<td>3.719</td>
<td>0.769</td>
<td>B, 6.096 brass</td>
</tr>
<tr>
<td>E-2416</td>
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<td>0.654</td>
<td>4.115</td>
<td>+0.191</td>
<td>6.043</td>
<td>1.342</td>
<td>B, 13.208 Plex, 6.096 brass</td>
</tr>
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</table>

Reduced Data
$C_L = 2.89 \pm 0.03 \text{ mm/μs}$,
$C_S = 1.38 \pm 0.02 \text{ mm/μs}$, and
$C_\phi = 2.41 \pm 0.04 \text{ mm/μs}$.
$\rho = 1.77 \text{ g/cm}^3$.
$U_{\phi 0} = (2.363 \pm 0.131) + (2.513 \pm 0.141)U_{\nu 0}$.
For $4.82 < P < 15.65$,
$log P = (1.18 \pm 0.01) - (0.66 \pm 0.02) log x^*$, and
$log P = (0.74 \pm 0.01) - (0.55 \pm 0.01) log t^*$. 
SHOCK INITIATION PROPERTIES

\[
\text{Distance to Detonation (mm)}
\]

\[
\text{Time to Detonation (us)}
\]
SHOCK INITIATION PROPERTIES

Initial Particle Velocity, \( U_0 \) (mm/\( \mu \)s)

Initial Shock Velocity, \( U_m \) (mm/\( \mu \)s)

PBX 9011
(\( \rho = 1790 \))
SHOCK INITIATION PROPERTIES

Table 4.20  LX-04

**Composition**  
85 wt% HMX, 15 wt% Viton

**Particle Size Distribution**  
"Fine-grain" HMX

**Preparation Method**  
Pressing and machining to shape

**Data Summary**  
\( \rho_0 = 1.859 \text{ g/cm}^3 \). Technique 1

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
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<tr>
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<td>( P_0 ) (GPa)</td>
<td>( U_{p_0} ) (mm/μs)</td>
<td>( U_{s_0} ) (mm/μs)</td>
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<td>E-1894</td>
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<td>0.577</td>
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</table>

**Reduced Data**  
\( U_{s_0} = (2.546 \pm 0.089) + (2.176 \pm 0.131)U_{p_0} \).

For \( 4.06 < P < 6.74 \),  
\( \log P = (1.01 \pm 0.06) - (0.47 \pm 0.08) \log x^* \).
### Composition
50 wt% HMX, 40 wt% TATB, 10 wt% Kel-F 800

### Theoretical Maximum Density
1.927 g/cm³

### Preparation Method
Slurry mixing, pressing, and machining to shape

### Data Summary
\( \rho_0 = 1.912 \text{ g/cm}^3, T_0 \approx 23^\circ\text{C}. \) Technique 4

### Initial Shock Parameters

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{\phi_0} ) (mm/μs)</th>
<th>( U_{\phi_2} ) mm/μs</th>
<th>( 1/2 b ) (mm/μs²)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (μs)</th>
<th>( B, 25.4 ) brass, 18.542 Plex</th>
<th>( B, 49.53 ) Plex</th>
<th>( L, 24.13 ) SS, 10.92 Plex</th>
<th>( H, 24.13 ) SS, 10.92 Plex</th>
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<td>B, 25.4 brass, 18.542 Plex</td>
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<td>E-3596</td>
<td>7.15</td>
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</tbody>
</table>

### Coordinates for High-Order Detonation
\( U_{\phi_0} = (2.674 \pm 0.387) + (1.826 \pm 0.497) U_{\phi_0}. \)
For \( 3.9 < P < 7.15 \).
\[ \log P = (0.92 \pm 0.05) + (0.12 \pm 0.06) \log x^*, \] and
\[ \log P = (0.83 \pm 0.01) - (0.11 \pm 0.05) \log t^*. \]
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm) vs. Pressure (GPa)

Time to Detonation (µs) vs. Pressure (GPa)
SHOCK INITIATION PROPERTIES

![Graph showing the relationship between initial shock velocity (mm/μs) and initial particle velocity (mm/μs). The graph plots data points and shows a linear trend.]

X-0219-50-14-10

Initial Shock Velocity, $u_s$ (mm/μs)

Initial Particle Velocity, $u_p$ (mm/μs)
Table 4.22 X-0241-96

**Composition**
96 wt% NQ, 2 wt% wax, 2 wt% Elvax

**Theoretical Maximum Density**
1.720 g/cm³

**Preparation Method**
Slurry mixing, pressing, and machining to shape

**Data Summary**
ρ₀ = 1.676 g/cm³, T₀ ≈ 23°C, Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>P₀ (GPa)</th>
<th>U₀ (mm/µs)</th>
<th>U₀ (mm/µs)</th>
<th>1/2 b (mm/µs²)</th>
<th>x* (mm)</th>
<th>t* (µs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-3284</td>
<td>24.29</td>
<td>2.216</td>
<td>6.539</td>
<td>+0.742</td>
<td>4.23</td>
<td>0.60</td>
<td>N, 6.096 Everkleer</td>
</tr>
<tr>
<td>E-3279</td>
<td>20.30</td>
<td>1.898</td>
<td>6.380</td>
<td>+0.058</td>
<td>15.14</td>
<td>2.29</td>
<td>N, 14.986 Plex</td>
</tr>
<tr>
<td>E-3285</td>
<td>18.66</td>
<td>1.794</td>
<td>6.206</td>
<td>+0.056</td>
<td>24.52</td>
<td>3.80</td>
<td>N, 16.51 Plex</td>
</tr>
<tr>
<td>E-3352</td>
<td>9.05</td>
<td>1.136</td>
<td>4.753</td>
<td>+0.019</td>
<td>&gt;25.40</td>
<td>&gt;5.24</td>
<td>B, 17.78 Acrylite</td>
</tr>
</tbody>
</table>

**Reduced Data**

Uₘ₀ = (2.88 ± 0.58) + (1.755 ± 0.321)U₀

For 9.05 < P < 24.29,

log P = (1.48 ± 0.01) - (0.15 ± 0.01) log x*, and

log P = (1.35 ± 0.003) - (0.14 ± 0.01) log t*.
Table 4.23 95 NQ/5 ESTANE

**Composition**
95 wt% NQ, 5 wt% Estane

**Theoretical Maximum Density**
1.738 g/cm³

**Particle Size Distribution**
Standard

**Preparation Method**
Pressing and machining to shape

**Data Summary**
T = 23°C. Technique 3

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P₀ (GPa)</td>
<td>U₀ (mm/μs)</td>
<td>U₀₀ (mm/μs)</td>
</tr>
<tr>
<td>E-2977</td>
<td>8.59</td>
<td>1.041</td>
<td>4.859³</td>
</tr>
<tr>
<td>E-2936</td>
<td>15.87</td>
<td>1.603</td>
<td>5.828</td>
</tr>
<tr>
<td>E-3050</td>
<td>18.70</td>
<td>1.746</td>
<td>6.303</td>
</tr>
<tr>
<td>E-2939</td>
<td>18.75</td>
<td>1.778</td>
<td>6.208</td>
</tr>
<tr>
<td>E-2938</td>
<td>21.00</td>
<td>1.920</td>
<td>6.438</td>
</tr>
<tr>
<td>E-2927</td>
<td>14.24</td>
<td>1.571</td>
<td>5.449</td>
</tr>
<tr>
<td>E-2925</td>
<td>15.50</td>
<td>1.672</td>
<td>5.576</td>
</tr>
<tr>
<td>E-2910</td>
<td>26.32</td>
<td>2.302</td>
<td>6.874</td>
</tr>
</tbody>
</table>

³ \( \rho_0 = 1.699 \text{ g/cm}^3 \)

\( \rho_0 = 1.663 \text{ g/cm}^3 \)
$\rho_s = 1.653 \text{ g/cm}^3$

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>$P_o$ (GPa)</th>
<th>$U_{vo}$ (mm/μs)</th>
<th>$U_{vo}$ (mm/μs)</th>
<th>$1/2b$ (mm/μs²)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2930$^b$</td>
<td>14.73</td>
<td>1.565</td>
<td>5.695</td>
<td>12.23</td>
<td>1.99</td>
<td>J, 18.1 Plex</td>
<td></td>
</tr>
<tr>
<td>E-2932$^c$</td>
<td>14.50</td>
<td>---</td>
<td>---</td>
<td>&gt;9.42</td>
<td>---</td>
<td>J, 18.5 Plex</td>
<td></td>
</tr>
</tbody>
</table>

$^a$Decelerates.

$^b$This wedge had a tight butt joint in the direction of propagation.

$^c$The butt joint for this shot was spaced open by 0.005 in. A multi-slit technique was used to show that high-order detonation first occurred about 7.5 mm on each side of the joint.
Table 4.23 (continued)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_i ) (GPa)</th>
<th>( U_{si} ) (mm/( \mu )s)</th>
<th>( 1/2 h_i ) (mm/( \mu )s(^2))</th>
<th>( x_{ot} ) (mm)</th>
<th>( t_{ot} ) (( \mu )s)</th>
<th>( P_r^* ) (GPa)</th>
<th>( U_{r2} ) (mm/( \mu )s)</th>
<th>( x^* ) (mm)</th>
<th>Driving System Thickness (mm)</th>
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</thead>
<tbody>
<tr>
<td>E-3245</td>
<td>16.2</td>
<td>5.904</td>
<td>-0.013</td>
<td>15.24</td>
<td>2.62</td>
<td>18.8</td>
<td>6.256</td>
<td>&gt;25.4</td>
<td>R, 3.0 SS</td>
</tr>
<tr>
<td>E-3220</td>
<td>15.7</td>
<td>5.787</td>
<td>+0.025</td>
<td>8.45</td>
<td>1.46</td>
<td>18.9</td>
<td>6.215</td>
<td>&gt;25.4</td>
<td>N, 1.73 SS</td>
</tr>
<tr>
<td>E-3423</td>
<td>16.9</td>
<td>5.988</td>
<td>-0.106</td>
<td>19.88</td>
<td>3.54</td>
<td>11.4b</td>
<td>5.276</td>
<td>&gt;25.4</td>
<td>F, 2.96 Plex</td>
</tr>
<tr>
<td>E-3442</td>
<td>19.1</td>
<td>6.232</td>
<td>-0.042</td>
<td>17.56</td>
<td>2.88</td>
<td>20.7</td>
<td>6.399</td>
<td>&gt;25.4</td>
<td>R, 1.91 Pb</td>
</tr>
<tr>
<td>E-2960</td>
<td>15.7</td>
<td>5.89</td>
<td>-0.162</td>
<td>15.45</td>
<td>2.80</td>
<td>16.6</td>
<td>6.19</td>
<td>&gt;29.2</td>
<td>P, 2.87 Ni</td>
</tr>
<tr>
<td>E-2961</td>
<td>13.5</td>
<td>5.54</td>
<td>-0.01</td>
<td>15.89</td>
<td>2.94</td>
<td>---</td>
<td>5.75</td>
<td>&gt;29.2</td>
<td>Q, 1.93 U</td>
</tr>
<tr>
<td>E-2962</td>
<td>12.6</td>
<td>5.43</td>
<td>-0.01</td>
<td>6.5/13.8/ 1.2/2.4/17.9</td>
<td>6.09</td>
<td>23.3d</td>
<td>P, 0.89 U</td>
<td>&gt;29.2</td>
<td>Q, 2.89 Ni</td>
</tr>
<tr>
<td>E-2963</td>
<td>---</td>
<td>5.85</td>
<td>-0.05</td>
<td>15.15</td>
<td>2.63</td>
<td>---</td>
<td>6.03</td>
<td>&gt;29.2</td>
<td>Q, 2.89 Ni</td>
</tr>
</tbody>
</table>

*From \( P \) vs \( U_s \) data for a single shock and observed \( U_{si} \).

*Probably low owing to edge effect.

*Three overtakes.

*Total distance including overtakes.

**Reduced Data**

Standard NQ only.

\[
U_{so} = (3.022 \pm 0.376) + (1.713 \pm 0.219)U_{po}.
\]

For \( 14.24 < P < 18.75 \),

\[
\log P = (1.42 \pm 0.07) - (0.19 \pm 0.07) \log x^*, \text{ and}
\]

\[
\log P = (1.27 \pm 0.03) - (0.19 \pm 0.02) \log t^*.
\]
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

Time to Detonation (μs)

Pressure (GPa)
SHOCK INITIATION PROPERTIES

Initial Particle Velocity, $U_{in}$ (mm/μs)

Initial Shock Velocity, $U_{sh}$ (mm/μs)

95 NQ/5 ESTANE
Table 4.24 X-0228-90

Composition
90 wt% NQ, 10 wt% Estane

Theoretical Maximum Density
1.698 g/cm³

Preparation Method
Slurry mixing, pressing, and machining to shape

Data Summary
$T_0 \approx 23°C$, Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>$P_0$ (GPa)</th>
<th>$U_{p0}$ (mm/μs)</th>
<th>$U_{o0}$ (mm/μs)</th>
<th>$1/2 b$ (mm/μs²)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
<th>System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-3278</td>
<td>27.24</td>
<td>2.274</td>
<td>7.186</td>
<td>+0.659</td>
<td>2.07</td>
<td>0.28</td>
<td>S, 6.35 Everkleer</td>
</tr>
<tr>
<td>E-3275</td>
<td>24.58</td>
<td>2.181</td>
<td>6.761</td>
<td>+0.283</td>
<td>5.05</td>
<td>0.72</td>
<td>N, 6.096 Everkleer</td>
</tr>
<tr>
<td>E-3276</td>
<td>22.61</td>
<td>2.068</td>
<td>6.558</td>
<td>+0.117</td>
<td>13.39</td>
<td>1.91</td>
<td>N, 9.652 Plex</td>
</tr>
<tr>
<td>E-3277</td>
<td>20.90</td>
<td>2.001</td>
<td>6.266</td>
<td>-0.000</td>
<td>&gt;25.42</td>
<td>&gt;4.04</td>
<td>N, 12.954 Everkleer</td>
</tr>
<tr>
<td>E-3353</td>
<td>8.15</td>
<td>1.018</td>
<td>4.804</td>
<td>+0.003</td>
<td>&gt;25.42</td>
<td>&gt;5.274</td>
<td>B, 18.78 Acrylite</td>
</tr>
</tbody>
</table>

$\rho_0 = 1.667$ g/cm³ "Large" Grain

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>$P_0$ (GPa)</th>
<th>$U_{p0}$ (mm/μs)</th>
<th>$U_{o0}$ (mm/μs)</th>
<th>$1/2 b$ (mm/μs²)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
<th>System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2941</td>
<td>20.27</td>
<td>1.924</td>
<td>6.325</td>
<td>---</td>
<td>14.35</td>
<td>2.20</td>
<td>N, 12.192 Acrylite</td>
</tr>
</tbody>
</table>

$\rho_0 = 1.666$ g/cm³ "Commercial" Grain

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>$P_0$ (GPa)</th>
<th>$U_{p0}$ (mm/μs)</th>
<th>$U_{o0}$ (mm/μs)</th>
<th>$1/2 b$ (mm/μs²)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
<th>System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2909</td>
<td>24.83</td>
<td>2.083</td>
<td>7.238</td>
<td>---</td>
<td>2.21</td>
<td>0.30</td>
<td>N, 6.096 Plex</td>
</tr>
<tr>
<td>E-2926</td>
<td>17.32</td>
<td>1.766</td>
<td>5.954</td>
<td>---</td>
<td>12.09</td>
<td>1.90</td>
<td>N, 19.05 Plex</td>
</tr>
<tr>
<td>E-2916</td>
<td>15.03</td>
<td>1.628</td>
<td>5.606</td>
<td>---</td>
<td>&gt;24.93</td>
<td>&gt;4.08</td>
<td>N, 25.4 Plex</td>
</tr>
<tr>
<td>E-2929</td>
<td>~13.1</td>
<td>---</td>
<td>~5.5</td>
<td>---</td>
<td>&gt;31.42</td>
<td>&gt;4.94</td>
<td>J, 19.05 Plex</td>
</tr>
</tbody>
</table>

$\rho_0 = 1.647$ g/cm³ "Commercial" Grain
**Reduced Data**

Combined densities.

\[ U_\infty = (2.68 \pm 0.477) + (1.923 \pm 0.249)U_\rho. \]

For \( 17.32 < P < 27.24 \),

\[ \log P = (1.35 \pm 0.02) - (0.14 \pm 0.05) \log t^*, \]

and

\[ \log P = (1.47 \pm 0.05) - (0.15 \pm 0.05) \log x^*. \]
SHOCK INITIATION PROPERTIES

![Graph showing shock initiation properties with distance to detonation (mm) on the x-axis and pressure (GPa) on the y-axis for 90 NQ/10 ESTANE (X-022B).]

![Graph showing shock initiation properties with time to detonation (μs) on the x-axis and pressure (GPa) on the y-axis for 90 NQ/10 ESTANE (X-022B).]
Table 4.25 XTX-8003 (EXTEX)

Composition
80 wt% PETN, 20 wt% Sylgard silicone rubber

Theoretical Maximum Density
1.556 g/cm³

Particle Size Distribution
Prepared with irregular 10- to 30-μm PETN crystals.

Preparation Method
Pellets were made by extruding the explosive into evacuated forms, and wedges were cut with a razor blade.

Data Summary
$\rho_0 = 1.53 \text{ g/cm}^3$. Technique 5

<table>
<thead>
<tr>
<th>No. of</th>
<th>Attenuator System</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Brass, methylene iodide</td>
</tr>
<tr>
<td>4</td>
<td>Brass, mixture 2</td>
</tr>
<tr>
<td>4</td>
<td>Dural, carbon tetrachloride</td>
</tr>
<tr>
<td>3</td>
<td>Dural, carbon tetrachloride</td>
</tr>
<tr>
<td>4</td>
<td>Dural, carbon tetrachloride</td>
</tr>
<tr>
<td>3</td>
<td>Dural, methylene iodide</td>
</tr>
<tr>
<td>2</td>
<td>Zinc, PMMA</td>
</tr>
<tr>
<td>2</td>
<td>Magnesium, PMMA</td>
</tr>
</tbody>
</table>

*Booster system was a P 80 plane-wave lens and 5 cm of Baratol. In three- and four-element attenuators, the third layer was brass and the fourth was PMMA. Mixture 2 consisted of equal volumes of methylene iodide and tetrabromoethane.
Reduced Data

\[ U_{\infty} = (1.59 \pm 0.39) + (3.24 \pm 0.63)U_{p0}. \]

For \( 2.5 < P < 8.2 \),

\[ \log P = (0.74 \pm 0.01) - (0.37 \pm 0.02) \log x^*, \]

and

\[ \log P = (0.53 \pm 0.008) - (0.33 \pm 0.02) \log t^*. \]
Table 4.26  RDX/2.5 WAX/2.5 ELVAX

**Composition**  
95 wt% RDX, 2.5 wt% wax, 2.5 wt% Elvax

**Theoretical Maximum Density**  
1.726 g/cm³

**Particle Size Distribution**  
98% 62 to 350 µm

**Preparation Method**  
Slurry mixing, pressing, and machining to shape

**Data Summary**  
\( \rho_0 = 1.711, T_0 \approx 23°C, \) Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{1o} ) (mm/µs)</th>
<th>( U_{2o} ) (mm/µs)</th>
<th>( 1/2 b ) (mm/µs²)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (µs)</th>
<th>System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-3239</td>
<td>2.96</td>
<td>0.473</td>
<td>3.662</td>
<td>0.014</td>
<td>21.5</td>
<td>5.56</td>
<td>B, 11.43 SS, 12.7 Plex</td>
</tr>
<tr>
<td>E-3234</td>
<td>7.00</td>
<td>0.899</td>
<td>4.599</td>
<td>0.167</td>
<td>5.18</td>
<td>1.06</td>
<td>B, 25.4 Plex</td>
</tr>
<tr>
<td>E-3249</td>
<td>11.64</td>
<td>1.371</td>
<td>4.963</td>
<td>0.137</td>
<td>3.71</td>
<td>0.72</td>
<td>C-1, 12.7 Plex</td>
</tr>
</tbody>
</table>

**Reduced Data**  
\( U_{10} = (3.094 \pm 0.405) + (1.437 \pm 0.411)U_{p0}. \)  
\( 2.96 < P < 11.71. \)  
\( \log P = (1.43 \pm 0.14) - (0.73 \pm 0.15) \log x^*, \) and  
\( \log P = (0.93 \pm 0.06) - (0.63 \pm 0.13) \log t^*. \)
Table 4.27 PBX 9407

**Compositon**
94 wt% RDX, 6 wt% Exon

**Theoretical Maximum Density**
1.81 g/cm³

**Particle Size Distribution**
Roughly spherical RDX particles, 10-50 μm in diameter

**Preparation Method**
RDX fines were coated with Exon and cold pressed to the 1.6-g/cm³ specimen density. Wedges were machined.

**Data Summary**
\( \rho_0 = 1.60 \text{ g/cm}^3 \). Technique 5

<table>
<thead>
<tr>
<th>( P_0 ) (GPa)</th>
<th>( U_{p0} ) (mm/μs)</th>
<th>( U_{so} ) (mm/μs)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (μs)</th>
<th>System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.14</td>
<td>0.349</td>
<td>2.033</td>
<td>15.519</td>
<td>7.022</td>
<td>16 brass, 16 water</td>
</tr>
<tr>
<td>1.18</td>
<td>0.359</td>
<td>2.046</td>
<td>11.091</td>
<td>4.8473</td>
<td>16 brass, 16 water</td>
</tr>
<tr>
<td>1.37</td>
<td>0.406</td>
<td>2.110</td>
<td>6.873</td>
<td>2.8099</td>
<td>12 brass, 12 diethanolamine</td>
</tr>
<tr>
<td>1.47</td>
<td>0.426</td>
<td>2.153</td>
<td>5.634</td>
<td>2.2283</td>
<td>12 brass, 12 β</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>β'-dichloerythyl ether</td>
</tr>
<tr>
<td>1.50</td>
<td>0.433</td>
<td>2.171</td>
<td>5.216</td>
<td>2.0305</td>
<td>12 brass, 12 trichlorethylene</td>
</tr>
<tr>
<td>1.80</td>
<td>0.487</td>
<td>2.310</td>
<td>3.346</td>
<td>1.1964</td>
<td>12 brass, 12 aqueous solution</td>
</tr>
<tr>
<td>2.21</td>
<td>0.558</td>
<td>2.475</td>
<td>2.278</td>
<td>0.7480</td>
<td>12 brass, 12 organic mixture</td>
</tr>
<tr>
<td>2.44</td>
<td>0.597</td>
<td>2.557</td>
<td>1.943</td>
<td>0.6148</td>
<td>12 brass, 12 methylene iodide</td>
</tr>
<tr>
<td>3.49</td>
<td>0.783</td>
<td>2.783</td>
<td>1.334</td>
<td>0.3858</td>
<td>12 Dural, 12 carbon tetrachloride</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>------</td>
<td>----------------------</td>
</tr>
<tr>
<td>4.17</td>
<td>0.860</td>
<td>3.032</td>
<td>0.943</td>
<td>0.2508</td>
<td>12 Dural, twelve</td>
</tr>
<tr>
<td>4.69</td>
<td>0.928</td>
<td>3.163</td>
<td>0.801</td>
<td>0.2047</td>
<td>12 brass</td>
</tr>
</tbody>
</table>

"Explosives for all experiments were a 30-cm-diam plane-wave lens and 10 cm of Baratol. All except the high pressure shot used three-layer attenuator systems. The final attenuator element was a 12-mm-thick brass layer in all cases.

**Reduced Data**

Buildup function coefficients

\[
A_1 = 1.404, \quad A_2 = 4.713, \quad A_3 = 0.398, \quad \text{and} \quad A_4 = 0.011.
\]

\[
U_{a0} = 1.328 + 1.993 U_{po}.
\]

For \(1.4 < P < 4.69\),

\[
\log P = (0.57 \pm 0.02) - (0.49 \pm 0.03) \log x^*, \quad \text{and}
\]

\[
\log P = (0.33 \pm 0.13) - (0.41 \pm 0.09) \log t^*.
\]
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm)

Pressure (GPa)

Time to Detonation (μs)

PBX 9407
\( p = 16 \)
SHOCK INITIATION PROPERTIES

![Graph showing initial shock velocity vs initial particle velocity for PBX 9407 (ρ=1.6)]
### Composition
93.7 wt% RDX, 3.15 wt% nitrocellulose, 3.15 wt% chloroethylphosphate

### Theoretical Maximum Density
1.789 g/cm³

### Particle Size Distribution
- RDX: 25%, less than 44 μm (average 25 μm);
- 75%, of which 98% pass through USS-50 sieves, 90% pass through USS-100 sieves, and 46% pass through USS-200 sieves.

### Preparation Method
Slurry mixing, steel die pressing, and machining to shape

### Data Summary
\[ \rho_0 = 1.761 \text{ g/cm}^3, \quad T_0 \approx 23{}^\circ\text{C}, \quad \text{Technique 4} \]

### Table 4.28 PBX 9405

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 ) (GPa)</td>
<td>( U_{\infty} ) (mm/μs)</td>
<td>( U_{\infty} ) (mm/μs)</td>
</tr>
<tr>
<td>E-3709</td>
<td>0.5</td>
<td>0.087</td>
<td>3.276</td>
</tr>
<tr>
<td>E-3700</td>
<td>2.19</td>
<td>0.394</td>
<td>3.152</td>
</tr>
<tr>
<td>E-3708</td>
<td>2.27</td>
<td>0.404</td>
<td>3.195</td>
</tr>
<tr>
<td>E-3704</td>
<td>2.84</td>
<td>0.496</td>
<td>3.255</td>
</tr>
<tr>
<td>E-3723</td>
<td>2.92</td>
<td>0.488</td>
<td>3.400</td>
</tr>
</tbody>
</table>

- A, 11.4 SS, 10.9 Acrylite
- B, 17.8 foam, 11.4 SS, 10.9 Acrylite
- B, 17.8 Polyethylene, 11.4 SS, 10.9 Acrylite
- A, (0.4 g/cm³)
- 10.9 Acrylite
Reduced Data (without Shot E-3709)

\[ U_a = (2.433 \pm 0.092) + (1.88 \pm 0.153) U_p. \]
For \( 2.19 < P < 6.81 \).

\[ \log P = (1.16 \pm 0.06) - (0.70 \pm 0.06) \log x^*, \text{ and} \]
\[ \log P = (0.71 \pm 0.02) - (0.59 \pm 0.05) \log t^*. \]
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm) vs Pressure (GPa)

Time to Detonation (μs) vs Pressure (GPa)

PBX 9405
(p = 1.761)

394
Table 4.29  X-0224

Composition
74 wt% RDX, 20 wt% aluminum, 5.4 wt% Elvax, 0.6 wt% wax

Theoretical Maximum Density
1.818 g/cm³

Particle Size Distribution
Mean aluminum particle size ~30 μm; 96.1 wt% passed through 90-μm screen; 33 wt% passed through 20-μm screen

Preparation Method
Slurry mixing, pressing, and machining to shape

Data Summary
\[ \rho_0 = 1.812 \text{ g/cm}^3, \quad T_o \approx 23^\circ \text{C}, \quad \text{Technique 4} \]

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{ps} ) (mm/μs)</th>
<th>( U_{sa} ) (mm/μs)</th>
<th>( 1/2 , b ) (mm/μs²)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (μs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-3570</td>
<td>7.25</td>
<td>0.997</td>
<td>4.016</td>
<td>0.910</td>
<td>3.242</td>
<td>0.676</td>
<td>B, 23.62 Plex</td>
</tr>
<tr>
<td>E-3573</td>
<td>3.71</td>
<td>0.565</td>
<td>3.627</td>
<td>0.093</td>
<td>11.150</td>
<td>2.799</td>
<td>B, 25.4 brass, 17.78 Plex</td>
</tr>
<tr>
<td>E-3574</td>
<td>2.41</td>
<td>0.394</td>
<td>3.377</td>
<td>0.018</td>
<td>&gt;25.52</td>
<td>&gt;7.20</td>
<td>B, 17.78 foam, 11.43 SS, 10.92 Plex</td>
</tr>
<tr>
<td>E-3580</td>
<td>3.02</td>
<td>0.468</td>
<td>3.564</td>
<td>0.010</td>
<td>19.262</td>
<td>5.139</td>
<td>B, 17.78 Polyethylene, 11.43 SS, 10.82 Plex</td>
</tr>
<tr>
<td>E-3608</td>
<td>~8.0</td>
<td>~1.05</td>
<td>~4.2</td>
<td>---</td>
<td>1.923</td>
<td>0.344</td>
<td>A, (1.0 g/cm³), 0.729 Plex</td>
</tr>
</tbody>
</table>

Reduced Data
\[ U_{sa} = (2.999 \pm 0.083) + (1.091 \pm 0.111)U_{ps}. \]
For 2.41 < \( P < 8.0 \),
\[ \log P = (1.05 \pm 0.03) - (0.45 \pm 0.04) \log x^*, \text{ and} \]
\[ \log P = (0.75 \pm 0.02) - (0.38 \pm 0.04) \log t^*. \]
Table 4.30  X-0250-40-19

Composition
40.2 wt% RDX, 40.4 wt% cyanuric acid, 19.4 wt% Sylgard

Theoretical Maximum Density
1.573 g/cm³

Particle Size Distribution
Avg. 25 µm, all less than 44 µm

Material Preparation
Extrusion

Data Summary
ρ₀ = 1.45 g/cm³, T₀ ≈ 23°C. Technique 4
D = 5.37 mm/µs

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>ρ₀ (g/cm³)</th>
<th>P₀ (GPa)</th>
<th>Uₚ₀ (mm/µs)</th>
<th>Uₛ₀ (mm/µs)</th>
<th>1/2 b (mm/µs²)</th>
<th>x* (mm)</th>
<th>t* (µs)</th>
<th>System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-3548</td>
<td>1.433</td>
<td>6.48</td>
<td>1.228</td>
<td>3.682</td>
<td>0.538</td>
<td>2.73</td>
<td>0.66</td>
<td>B, 24.38 PMMA</td>
</tr>
<tr>
<td>E-3560</td>
<td>1.442</td>
<td>3.06</td>
<td>0.710</td>
<td>2.990</td>
<td>0.066</td>
<td>18.36</td>
<td>5.20</td>
<td>B, 24.13 SS, 13.208 Plex</td>
</tr>
<tr>
<td>E-3576</td>
<td>1.453</td>
<td>2.82</td>
<td>0.711</td>
<td>2.731</td>
<td>0.062</td>
<td>18.43</td>
<td>5.83</td>
<td>B, 24.13 SS, 17.78 Plex</td>
</tr>
<tr>
<td>E-3546</td>
<td>1.447</td>
<td>5.08</td>
<td>1.126</td>
<td>3.117</td>
<td>0.403</td>
<td>~2.85</td>
<td>~0.82</td>
<td>B, 48.514 Plex</td>
</tr>
</tbody>
</table>

Multiple Shock

E-3553  1.473  2.18  0.592  2.502  0.040 >24.25  8.39  B, 0.7 polyethylene, 0.45 SS, 0.45 Acrylate

Reduced Data
Single shock
Uₛ₀ = (1.944 ± 0.528) + (1.257 ± 0.543)Uₚ₀.
For 2.82 < P < 6.48,
log P = (0.92 ± 0.06) - (0.36 ± 0.06) log x*, and
log P = (0.72 ± 0.02) - (0.34 ± 0.04) log t*.
Table 4.31  PBX 9502 (X-0290)

Composition
95 wt% TATB, 5 wt% Kel-F 800

Theoretical Maximum Density
1.942 g/cm³

Particle Size Distribution
Pantex standard

Preparation Method
Slurry mixing, pressing, and machining to shape

Data Summary
ρ₀ = 1.896 g/cm³. Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P₀ (GPa)</td>
<td>Uₚ₀ (mm/μs)</td>
<td>Uₚₒ (mm/μs³)</td>
</tr>
<tr>
<td>E-4122</td>
<td>10.05</td>
<td>1.083</td>
<td>4.894</td>
</tr>
<tr>
<td>E-4106</td>
<td>11.76</td>
<td>1.148</td>
<td>5.401</td>
</tr>
<tr>
<td>E-4121</td>
<td>14.31</td>
<td>1.349</td>
<td>5.595</td>
</tr>
<tr>
<td>E-4105</td>
<td>14.96</td>
<td>1.421</td>
<td>5.552</td>
</tr>
</tbody>
</table>

Reduced Data
Uₚₒ = (3.263 ± 0.977) + (1.678 ± 0.777)Uₚ₀.
For 10.05 < P < 14.95,
\[ \log P = (1.39 ± 0.05) - (0.31 ± 0.05) \log x^*, \text{ and} \]
\[ \log P = (1.15 ± 0.01) - (0.28 ± 0.04) \log t^*. \]
SHOCK INITIATION PROPERTIES

Distance to Detonation (mm) vs Pressure (GPa) for PBX 9502 (X-0290, ρ=1.996):

Time to Detonation (μs) vs Pressure (GPa) for PBX 9502 (X-0290, ρ=1.996):
Table 4.32 95 TATB/2.5 Kel-F 800/2.5 Kel-F 827

<table>
<thead>
<tr>
<th>Composition</th>
<th>95 wt% TATB, 2.5 wt% Kel-F 800, 2.5 wt% Kel-F 827</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Maximum Density</td>
<td>1.941 g/cm³</td>
</tr>
<tr>
<td>Particle Size Distribution</td>
<td>Standard</td>
</tr>
<tr>
<td>Preparation Method</td>
<td>Hot pressing and machining to shape</td>
</tr>
<tr>
<td>Data Summary</td>
<td>$\rho_0 = 1.883$ g/cm³, $T_o \approx 23^\circ$C, Technique 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_o$ (GPa)</td>
<td>$U_{po}$ (mm/µs)</td>
<td>$U_{so}$ (mm/µs)</td>
</tr>
<tr>
<td>E-2897</td>
<td>8.77</td>
<td>1.030</td>
<td>4.524</td>
</tr>
<tr>
<td>E-2815</td>
<td>13.70</td>
<td>1.339</td>
<td>5.434</td>
</tr>
<tr>
<td>E-2813</td>
<td>15.64</td>
<td>1.462</td>
<td>5.683</td>
</tr>
<tr>
<td>E-2814</td>
<td>17.50</td>
<td>1.545</td>
<td>6.014</td>
</tr>
</tbody>
</table>

Reduced Data

$U_{so} = (1.620 \pm 0.195) + (2.823 \pm 0.144)U_{po}$.

For $13.7 < P < 17.49$,

$\log P = (1.41 \pm 0.03) - (0.35 \pm 0.05) \log x^*$, and

$\log P = (1.14 \pm 0.01) - (0.31 \pm 0.05) \log t^*$.
Table 4.33 94 TATB (COARSE)/6 ESTANE

**Composition**
94 wt% TATB (coarse), 6 wt% Estane

**Theoretical Maximum Density**
1.868 g/cm³

**Particle Size Distribution**
Coarse, 65-μm median particle diameter

**Preparation Method**
Hot pressing and machining to shape

**Data Summary**
ρ₀ = 1.846 g/cm³, T₀ ≈ 23°C. Technique 3

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>P₀ (GPa)</th>
<th>U₀ (mm/μs)</th>
<th>U₀₀ (mm/μs)</th>
<th>x* (mm)</th>
<th>t* (μs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2891</td>
<td>15.33</td>
<td>1.506</td>
<td>5.515</td>
<td>13.82</td>
<td>2.33</td>
<td>H, 11.8 Plex</td>
</tr>
<tr>
<td>E-2912</td>
<td>17.94</td>
<td>1.652</td>
<td>5.882</td>
<td>8.15</td>
<td>1.31</td>
<td>J, 11.8 PMMA</td>
</tr>
<tr>
<td>E-2893</td>
<td>25.86</td>
<td>2.040</td>
<td>6.867</td>
<td>1.93</td>
<td>0.28</td>
<td>N, 6.3 Plex</td>
</tr>
</tbody>
</table>

**Reduced Data**

U₀₀ = (1.699 ± 0.009) + (2.533 ± 0.005)U₀₀.

log P = (1.49 ± 0.01) - (0.27 ± 0.01) log x*.

log P = (1.28 ± 0.003) - (0.25 ± 0.01) log t*.
SHOCK INITIATION PROPERTIES

Table 4.34  94 TATB (BIMODAL)/6 ESTANE

Composition
94 wt% TATB (bimodal), 6 wt% Estane

Theoretical Maximum Density
1.869 g/cm³

Particle Size Distribution
Bimodal

Preparation Method
Hot pressing and machining to shape

Data Summary
ρ₀ = 1.833 g/cm³. T₀ ≈ 23°C. Technique 3

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P₀ (GPa)</td>
<td>U₀ (mm/µs)</td>
<td>U₀ (mm/µs)</td>
</tr>
<tr>
<td>E-2915</td>
<td>12.00</td>
<td>1.299</td>
<td>5.040</td>
</tr>
<tr>
<td>E-2889</td>
<td>13.40</td>
<td>1.350</td>
<td>5.414</td>
</tr>
<tr>
<td>E-2913</td>
<td>17.82</td>
<td>1.677</td>
<td>5.796</td>
</tr>
<tr>
<td>E-2890</td>
<td>25.72</td>
<td>2.139</td>
<td>6.560</td>
</tr>
</tbody>
</table>

Reduced Data
U₀ = (3.032 ± 0.358) + (1.652 ± 0.217)U₀₀.
log P = (1.47 ± 0.02) − (0.32 ± 0.02) log x*.
log P = (1.21 ± 0.81) − (0.29 ± 0.02) log t*. 
Table 4.35 94 TATB/3 ELVAX/3 WAX

**Composition**
94 wt% TATB, 3 wt% Elvax, 3 wt% wax

**Theoretical Maximum Density**
1.822 g/cm³

**Particle Size Distribution**
Standard

**Preparation Method**
Hot pressing and machining to shape

**Data Summary**
ρ₀ = 1.802 g/cm³, T₀ ≈ 23°C. Technique 3

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>P₀ (GPa)</th>
<th>U₀ₚ (mm/μs)</th>
<th>U₀ₑ (mm/μs)</th>
<th>x* (mm)</th>
<th>t* (μs)</th>
<th>System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2899</td>
<td>14.98</td>
<td>1.482</td>
<td>5.610</td>
<td>&gt;19.09</td>
<td>&gt;3.312</td>
<td>H, 13.4 PMMA</td>
</tr>
<tr>
<td>E-2904</td>
<td>17.13</td>
<td>1.660</td>
<td>5.725</td>
<td>17.59</td>
<td>2.951</td>
<td>J, 13.2 PMMA</td>
</tr>
<tr>
<td>E-2905</td>
<td>21.22</td>
<td>1.847</td>
<td>6.375</td>
<td>5.32</td>
<td>0.80</td>
<td>G, 6.3 Plex</td>
</tr>
<tr>
<td>E-2898</td>
<td>26.17</td>
<td>2.105</td>
<td>6.908</td>
<td>1.92</td>
<td>0.28</td>
<td>N, 6.1 Plex</td>
</tr>
</tbody>
</table>

**Reduced Data**
U₀ₑ = (2.215 ± 0.585) + (2.221 ± 0.327)U₀ₚ.
log P = (1.47 ± 0.01) - (0.19 ± 0.01) log x*.
log P = (1.32 ± 0.004) - (0.18 ± 0.01) log t*.
SHOCK INITIATION PROPERTIES

Table 4.36  94 TATB/4.5 PS/1.5 DOP

Composition
94 wt% TATB, 4.5 wt% polystyrene, 1.5 wt% dioctylphthalate (DOP)

Theoretical Maximum Density
1.841 g/cm³

Particle Size Distribution
Standard

Preparation Method
Hot pressing and machining to shape

Data Summary
\( T_0 \approx 23°C \). Technique 3

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{p0} ) (mm/μs)</th>
<th>( U_{s0} ) (mm/μs)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (μs)</th>
<th>System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2906</td>
<td>12.88</td>
<td>1.403</td>
<td>5.054</td>
<td>16.84</td>
<td>2.97</td>
<td>F, 12.3 Plex</td>
</tr>
<tr>
<td>E-2851</td>
<td>15.24</td>
<td>1.523</td>
<td>5.508</td>
<td>9.06</td>
<td>1.49</td>
<td>H, 6.2 Plex</td>
</tr>
<tr>
<td>E-2914</td>
<td>17.40</td>
<td>1.674</td>
<td>5.719</td>
<td>7.22</td>
<td>1.15</td>
<td>J, 12.1 PMMA</td>
</tr>
<tr>
<td>E-2887</td>
<td>25.62</td>
<td>2.083</td>
<td>6.768</td>
<td>1.60</td>
<td>0.22</td>
<td>N, 6.0 Plex</td>
</tr>
<tr>
<td>E-2903</td>
<td>15.32</td>
<td>1.526</td>
<td>5.498</td>
<td>14.43</td>
<td>2.45</td>
<td>H, 12.2 Plex</td>
</tr>
<tr>
<td>E-2850</td>
<td>17.01</td>
<td>1.642</td>
<td>5.675</td>
<td>10.72</td>
<td>1.77</td>
<td>H, 6.1 Plex</td>
</tr>
<tr>
<td>E-2888</td>
<td>25.86</td>
<td>2.080</td>
<td>6.813</td>
<td>1.78</td>
<td>0.23</td>
<td>N, 6.0 Plex</td>
</tr>
</tbody>
</table>

Reduced Data
\[ U_{s0} = (1.69 \pm 0.185) + (2.448 \pm 0.107)U_{p0}. \]
\[ \log P = (1.47 \pm 0.03) - (0.27 \pm 0.03) \log x^*. \]
\[ \log P = (1.25 \pm 0.01) - (0.24 \pm 0.02) \log t^*. \]
SHOCK INITIATION PROPERTIES

Table 4.37  92 TATB/6 PS/2 DOP

Composition
92 wt% TATB, 6 wt% polystyrene, 2 wt% dioctylphthalate

Theoretical Maximum Density
1.811 g/cm³

Particle Size Distribution
Standard

Preparation Method
Hot pressing and machining to shape

Data Summary
\( \rho_0 = 1.797 \text{ g/cm}^3, T_o \approx 23^\circ \text{C}. \) Technique 3

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{50} ) (mm/μs)</th>
<th>( U_{90} ) (mm/μs)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (μs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2920</td>
<td>13.35</td>
<td>1.420</td>
<td>5.231</td>
<td>&gt;25.46</td>
<td>&gt;4.64</td>
<td>G, 11.8 PMMA</td>
</tr>
<tr>
<td>E-2945</td>
<td>13.75</td>
<td>1.452</td>
<td>5.270</td>
<td>19.25</td>
<td>3.38</td>
<td>H, 18.1 PMMA</td>
</tr>
<tr>
<td>E-2954</td>
<td>15.25</td>
<td>1.529</td>
<td>5.549</td>
<td>14.37</td>
<td>2.44</td>
<td>H, 12.0 PMMA</td>
</tr>
<tr>
<td>E-2917</td>
<td>17.93</td>
<td>1.693</td>
<td>5.895</td>
<td>7.98</td>
<td>1.29</td>
<td>L, 24.8 Plex</td>
</tr>
</tbody>
</table>

Reduced Data
\( U_{90} = (1.676 \pm 0.325) + (2.501 \pm 0.213)U_{50}. \)
## SHOCK INITIATION PROPERTIES

### Table 4.38 90 TATB/10 ESTANE

**Composition**  
90 wt% TATB, 10 wt% Estane

**Theoretical Maximum Density**  
1.827 g/cm³

**Particle Size Distribution**  
Standard

**Preparation Method**  
Hot pressing and machining to shape

**Data Summary**  
\( \rho_0 = 1.805 \text{ g/cm}^3, T_0 \approx 23^\circ \text{C}, \text{ Technique 3} \)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_o ) (GPa)</td>
<td>( U_{p0} ) (mm/( \mu \text{s} ))</td>
<td>( U_{so} ) (mm/( \mu \text{s} ))</td>
</tr>
<tr>
<td>E-2911</td>
<td>17.04</td>
<td>1.646</td>
<td>5.734</td>
</tr>
<tr>
<td>E-2908</td>
<td>24.48</td>
<td>2.049</td>
<td>6.620</td>
</tr>
</tbody>
</table>
Composition
90 wt% TATB, 10 wt% Kel-F 800

Theoretical Maximum Density
1.943 g/cm³

Particle Size Distribution
See table captions below

Preparation Method
Hot pressing and machining to shape

Data Summary
T₀ ≈ 23°C, Technique 3

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P₀ ) ((\text{GPa}))</th>
<th>( U₀ ) ((\text{mm/μs}))</th>
<th>( U₀₀ ) ((\text{mm/μs}))</th>
<th>( \frac{1}{2} b ) ((\text{mm/μs}²))</th>
<th>( x^* ) ((\text{mm}))</th>
<th>( t^* ) ((\text{μs}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-4122</td>
<td>10.05</td>
<td>1.083</td>
<td>4.894</td>
<td>0.101</td>
<td>15.38</td>
<td>2.89</td>
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<tr>
<td>E-4106</td>
<td>11.76</td>
<td>1.148</td>
<td>5.401</td>
<td>0.034</td>
<td>12.78</td>
<td>2.24</td>
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<td>E-4121</td>
<td>14.31</td>
<td>1.349</td>
<td>5.595</td>
<td>0.278</td>
<td>5.88</td>
<td>0.99</td>
</tr>
<tr>
<td>E-4105</td>
<td>14.96</td>
<td>1.421</td>
<td>5.552</td>
<td>0.697</td>
<td>4.64</td>
<td>0.76</td>
</tr>
</tbody>
</table>

\( \rho₀ = 1.896 \text{ g/cm}³, \text{ Pantex standard} \)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P₀ ) ((\text{GPa}))</th>
<th>( U₀ ) ((\text{mm/μs}))</th>
<th>( U₀₀ ) ((\text{mm/μs}))</th>
<th>( \frac{1}{2} b ) ((\text{mm/μs}²))</th>
<th>( x^* ) ((\text{mm}))</th>
<th>( t^* ) ((\text{μs}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-4073</td>
<td>7.80</td>
<td>0.942</td>
<td>4.363</td>
<td>0.063</td>
<td>&gt;25.5</td>
<td>&gt;5.32</td>
</tr>
<tr>
<td>E-4068</td>
<td>9.80</td>
<td>1.125</td>
<td>4.590</td>
<td>0.163</td>
<td>18.50</td>
<td>3.53</td>
</tr>
<tr>
<td>E-4047</td>
<td>11.40</td>
<td>1.218</td>
<td>4.931</td>
<td>0.225</td>
<td>11.72</td>
<td>2.12</td>
</tr>
<tr>
<td>E-4069</td>
<td>14.40</td>
<td>1.369</td>
<td>5.543</td>
<td>0.325</td>
<td>6.20</td>
<td>1.04</td>
</tr>
<tr>
<td>E-4048</td>
<td>15.15</td>
<td>1.468</td>
<td>5.473</td>
<td>0.429</td>
<td>5.21</td>
<td>0.87</td>
</tr>
</tbody>
</table>

\( \rho₀ = 1.898 \text{ g/cm}³, \text{ Pantex standard} \)
Table 4.39 (continued)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for ( \frac{1}{2} b )</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 ) (GPa)</td>
<td>( U_{\rho_0} ) (mm/μs)</td>
<td>( U_{\infty} ) (mm/μs)</td>
</tr>
<tr>
<td>E-4068</td>
<td>9.80</td>
<td>1.125</td>
<td>4.590</td>
</tr>
<tr>
<td>E-4043</td>
<td>9.68</td>
<td>1.110</td>
<td>4.579</td>
</tr>
<tr>
<td>E-4027</td>
<td>11.21</td>
<td>1.213</td>
<td>4.850</td>
</tr>
<tr>
<td>E-4024</td>
<td>13.95</td>
<td>1.395</td>
<td>5.250</td>
</tr>
<tr>
<td>E-4023</td>
<td>15.69</td>
<td>1.447</td>
<td>5.692</td>
</tr>
<tr>
<td>E-4044</td>
<td>9.71</td>
<td>1.074</td>
<td>4.728</td>
</tr>
<tr>
<td>E-4025</td>
<td>11.62</td>
<td>1.239</td>
<td>4.905</td>
</tr>
<tr>
<td>E-4019</td>
<td>13.80</td>
<td>1.449</td>
<td>4.982</td>
</tr>
<tr>
<td>E-4018</td>
<td>15.30</td>
<td>1.522</td>
<td>5.259</td>
</tr>
<tr>
<td>E-4049</td>
<td>9.80</td>
<td>1.114</td>
<td>4.596</td>
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<tr>
<td>E-4026</td>
<td>11.43</td>
<td>1.256</td>
<td>4.755</td>
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<tr>
<td>E-4022</td>
<td>14.21</td>
<td>1.390</td>
<td>5.340</td>
</tr>
<tr>
<td>E-4020</td>
<td>15.77</td>
<td>1.455</td>
<td>5.664</td>
</tr>
</tbody>
</table>
$\rho_0 = 1.920 \text{ g/cm}^3$, standard

<table>
<thead>
<tr>
<th></th>
<th>E-2896</th>
<th>E-2849</th>
<th>E-2863</th>
<th>E-2845</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P$</td>
<td>13.07</td>
<td>15.80</td>
<td>16.58</td>
<td>18.72</td>
</tr>
<tr>
<td>$x_0$</td>
<td>1.360</td>
<td>1.545</td>
<td>1.582</td>
<td>1.776</td>
</tr>
<tr>
<td>$U_0$</td>
<td>5.005</td>
<td>5.328</td>
<td>5.460</td>
<td>5.491</td>
</tr>
<tr>
<td>$W$</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>$E_0$</td>
<td>16.48</td>
<td>9.99</td>
<td>9.42</td>
<td>5.47</td>
</tr>
<tr>
<td>$T_0$</td>
<td>2.92</td>
<td>1.71</td>
<td>1.55</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>H, 25.4 Plex</td>
<td>H, 7.4 Plex</td>
<td>G, 6.3 Plex</td>
<td>H, 6.0 Plex</td>
</tr>
</tbody>
</table>

$\rho_0 = 1.929 \text{ g/cm}^3$, Pantex standard

<table>
<thead>
<tr>
<th></th>
<th>E-4091</th>
<th>E-4088</th>
<th>E-4089</th>
<th>E-4090</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P$</td>
<td>13.50</td>
<td>14.20</td>
<td>15.35</td>
<td>16.10</td>
</tr>
<tr>
<td>$x_0$</td>
<td>1.302</td>
<td>1.388</td>
<td>1.470</td>
<td>1.532</td>
</tr>
<tr>
<td>$U_0$</td>
<td>5.375</td>
<td>5.302</td>
<td>5.413</td>
<td>5.448</td>
</tr>
<tr>
<td>$T_0$</td>
<td>0.070</td>
<td>0.175</td>
<td>0.186</td>
<td>0.442</td>
</tr>
<tr>
<td>$E_0$</td>
<td>20.17</td>
<td>16.10</td>
<td>15.13</td>
<td>8.374</td>
</tr>
<tr>
<td>$T_0$</td>
<td>3.545</td>
<td>2.763</td>
<td>2.543</td>
<td>1.358</td>
</tr>
<tr>
<td></td>
<td>H, 23.5 Plex</td>
<td>H, 18.59 Plex</td>
<td>H, 12.80 Plex</td>
<td>H, 6.38 Plex</td>
</tr>
</tbody>
</table>

**Reduced Data**

$U_{so} = (3.178 \pm 0.340) + (1.483 \pm 0.253) U_{p0}$.

For $9.68 < P < 18.72$,

$\log P = (1.40 \pm 0.05) - (0.28 \pm 0.05) \log x^*$, and

$\log P = (1.19 \pm 0.01) - (0.27 \pm 0.04) \log t^*$. 

SHOCK INITIATION PROPERTIES
Table 4.40 90 TATB/5 KEL-F 800/5 KEL-F 820

**Composition**
90 wt% TATB, 5 wt% Kel-F 800, 5 wt% Kel-F 820

**Theoretical Maximum Density**
1.944 g/cm³

**Particle Size Distribution**
Standard

**Preparation Method**
Hot pressing and machining to shape

**Data Summary**
\( \rho_0 = 1.917 \text{ g/cm}^3, T_0 \approx 23^\circ \text{C. Technique 2} \)

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{p0} ) (mm/μs)</th>
<th>( U_{s0} ) (mm/μs)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2260</td>
<td>10.16</td>
<td>1.105</td>
<td>4.796</td>
<td>&gt;20.73</td>
<td>---</td>
</tr>
<tr>
<td>E-2263</td>
<td>13.86</td>
<td>1.342</td>
<td>5.387</td>
<td>&gt;20.82</td>
<td>---</td>
</tr>
<tr>
<td>E-2266</td>
<td>16.19</td>
<td>1.499</td>
<td>5.635</td>
<td>9.60</td>
<td>---</td>
</tr>
<tr>
<td>E-2258</td>
<td>18.99</td>
<td>1.625</td>
<td>6.096</td>
<td>3.7</td>
<td>---</td>
</tr>
</tbody>
</table>

**Multiple Shock**

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_1 ) (GPa)</th>
<th>( U_{p1} ) (mm/μs)</th>
<th>( U_{s1} ) (mm/μs)</th>
<th>( x_{OT} ) (mm)</th>
<th>( P_2 ) (GPa)</th>
<th>( U_{s2} ) (mm/μs)</th>
<th>( x^* ) (mm)</th>
<th>( \text{Driving System Thickness (mm)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2265</td>
<td>12.2</td>
<td>~1.22</td>
<td>5.058</td>
<td>6.65</td>
<td>~18.2</td>
<td>5.985</td>
<td>10.7</td>
<td>P, 1.05 D-38</td>
</tr>
</tbody>
</table>

*Decelerates.

*Poor record.

*4.05 mm downstream from overtake.
Table 4.41  90 TATB/5 ELVAX/5 WAX

Composition
90 wt% TATB, 5 wt% Elvax, 5 wt% wax

Theoretical Maximum Density
1.751 g/cm³

Particle Size Distribution
Standard

Preparation Method
Hot pressing and machining to shape

Data Summary
ρ₀ = 1.739 g/cm³. T₀ ≈ 23°C. Technique 3

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P₀ (GPa)</td>
<td>Uₚ₀ (mm/µs)</td>
<td>Uₛ₀ (mm/µs)</td>
</tr>
<tr>
<td>E-2918</td>
<td>18.32</td>
<td>1.672</td>
<td>6.302</td>
</tr>
<tr>
<td>E-2931</td>
<td>19.85</td>
<td>1.834</td>
<td>6.224*</td>
</tr>
<tr>
<td>E-2928</td>
<td>21.38</td>
<td>1.909</td>
<td>6.441</td>
</tr>
</tbody>
</table>

*The input wave was tilted significantly in a direction that caused low initial shock velocity.

Reduced Data
Fit not made owing to nature of the data.
SHOCK INITIATION PROPERTIES

Table 4.42  85 TATB/15KEL-F 800

<table>
<thead>
<tr>
<th>Composition</th>
<th>85 wt% TATB, 15 wt% Kel-F 800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Maximum Density</td>
<td>1.948 g/cm³</td>
</tr>
<tr>
<td>Particle Size Distribution</td>
<td>Standard</td>
</tr>
<tr>
<td>Preparation Method</td>
<td>Hot pressing and machining to shape</td>
</tr>
<tr>
<td>Data Summary</td>
<td>( \rho_0 = 1.930 \text{ g/cm}^3, T_0 = 23^\circ\text{C}, \text{Technique 3} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{p0} ) (mm/( \mu )s)</th>
<th>( U_{s0} ) (mm/( \mu )s)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (( \mu )s)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-2900</td>
<td>14.31</td>
<td>1.380</td>
<td>5.371</td>
<td>16.60</td>
<td>2.88</td>
<td>H, 18.8 PMMA</td>
</tr>
<tr>
<td>E-2848</td>
<td>15.60</td>
<td>1.476</td>
<td>5.477</td>
<td>12.35</td>
<td>2.12</td>
<td>H, 13.1 Plex</td>
</tr>
<tr>
<td>E-2852</td>
<td>17.14</td>
<td>1.575</td>
<td>5.638</td>
<td>8.72</td>
<td>1.46</td>
<td>H, 6.3 Plex</td>
</tr>
<tr>
<td>E-2846</td>
<td>18.68</td>
<td>1.684</td>
<td>5.749</td>
<td>6.73</td>
<td>1.11</td>
<td>H, 6.0 PMMA</td>
</tr>
</tbody>
</table>

Reduced Data
\[ U_{s0} = (3.603 \pm 0.125) + (1.279 \pm 0.082)U_{p0}. \]
SHOCK INITIATION PROPERTIES

Table 4.43  85 TATB/7.5 KEL-F 800/7.5 KEL-F 827

Composition
85 wt% TATB, 7.5 wt% Kel-F 800, 7.5 wt% Kel-F 827

Theoretical Maximum Density
1.947 g/cm³

Particle Size Distribution
Standard

Preparation Method
Hot pressing and machining to shape

Data Summary
$\rho_0 = 1.912 \text{ g/cm}^3$. $T_o \approx 23^\circ \text{C}$. Technique 3

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_o$ (GPa)</td>
<td>$U_{po}$ (mm/μs)</td>
<td>$U_{so}$ (mm/μs)</td>
</tr>
<tr>
<td>E-2895</td>
<td>13.18</td>
<td>1.341</td>
<td>5.141</td>
</tr>
<tr>
<td>E-2818*</td>
<td>~13.6</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>E-2819</td>
<td>14.42</td>
<td>1.381</td>
<td>5.462</td>
</tr>
<tr>
<td>E-2820</td>
<td>18.67</td>
<td>1.707</td>
<td>5.722</td>
</tr>
</tbody>
</table>

*Very poor record.

Reduced Data
$U_{so} = (0.944 \pm 0.828) + (3.179 \pm 0.632)U_{po}$. 

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### Table 4.44 FKM CLASS VII PROPELLANT

#### Theoretical Maximum Density

1.814 g/cm³

#### Preparation Method

Vacuum casting and pressure curing

#### Data Summary

\( \rho_o = 1.814 \text{ g/cm}^3 \), \( T_o = 25^\circ \text{C} \), Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_o ) (GPa)</td>
<td>( U_{p0} ) (mm/\mu s)</td>
<td>( U_{x0} ) (mm/\mu s²)</td>
<td>( x^* ) (mm)</td>
</tr>
<tr>
<td>E-4289</td>
<td>1.30</td>
<td>0.263</td>
<td>2.726</td>
<td>+0.0003</td>
</tr>
<tr>
<td>E-4276</td>
<td>2.29</td>
<td>0.427</td>
<td>2.956</td>
<td>+0.003</td>
</tr>
<tr>
<td>E-4279</td>
<td>3.30</td>
<td>0.568</td>
<td>3.205</td>
<td>+0.061</td>
</tr>
<tr>
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<td>2.86</td>
<td>0.484</td>
<td>3.256</td>
<td>+0.001</td>
</tr>
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<td>E-4287</td>
<td>3.57</td>
<td>0.586</td>
<td>3.355</td>
<td>+0.050</td>
</tr>
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<td>E-4285</td>
<td>3.30</td>
<td>0.535</td>
<td>3.398</td>
<td>-0.003</td>
</tr>
<tr>
<td>E-4286</td>
<td>4.79</td>
<td>0.689</td>
<td>3.831</td>
<td>+0.009</td>
</tr>
</tbody>
</table>

Almost transited to high order within 25.4-mm-thick sample

Second shock overtook shock wave thereby invalidating measurement

Nonsimultaneous arrival caused larger than usual errors
<table>
<thead>
<tr>
<th></th>
<th>E-4291</th>
<th>6.73</th>
<th>0.902</th>
<th>4.111</th>
<th>±0.095</th>
<th>3.51</th>
<th>0.81</th>
<th>B, 48.2 Plex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E-4280</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>≈3.8</td>
<td>≈0.8</td>
<td>B, 49.1 Plex</td>
</tr>
</tbody>
</table>

No decomposition signal observed, miniwedge x* too short for accurate measurement of parameters with standard wedge

**Reduced Data**

\[ U_{n0} = (2.079 + 0.146) + 2.292 \pm 0.249)U_{dn} \]

\[ \log P = 1.06 - 0.47 \log x^* \]
SHOCK INITIATION PROPERTIES

Table 4.45  SPIS-44 CLASS II PROPELLANT

Composition
49 wt% AP, 20 wt% HMX, 21 wt% Al, 7.27 wt% R45M, 2 wt% INDOPOL, 0.51 wt% IPDI, 0.15 wt% Tepanol, 0.07 wt% CAO-14

Theoretical Maximum Density
1.831 g/cm³

Particle Size Distribution
9-μm HMX, 200-μm AP (28%), 6-μm AP (21%), 6-μm Al

Preparation Method
Casting, curing, and machining to shape

Data Summary
$\rho_o = 1.830 \text{ g/cm}^3$, $T_o = 24^\circ\text{C}$, Technique 7

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>$P_0$ (GPa)</th>
<th>$U_{p0}$ (mm/μs)</th>
<th>$U_{p0}$ (mm/μs)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ (μs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-4527</td>
<td>3.63</td>
<td>0.536</td>
<td>3.70</td>
<td></td>
<td></td>
<td>C, 24.1 SS, 18.3 Plex</td>
</tr>
<tr>
<td>E-4554</td>
<td>7.05</td>
<td>0.864</td>
<td>4.46</td>
<td></td>
<td></td>
<td>L, 24.1 SS, 10.9 Plex</td>
</tr>
<tr>
<td>E-4563</td>
<td>22.3</td>
<td>1.92</td>
<td>6.36</td>
<td></td>
<td></td>
<td>L, 17.8 Plex</td>
</tr>
<tr>
<td>E-4561</td>
<td>25.7</td>
<td>2.11</td>
<td>6.65</td>
<td></td>
<td></td>
<td>S, 10.9 Plex</td>
</tr>
</tbody>
</table>

*aNo transition to detonation was observed within 25.4 mm, but a violent reaction trailed the shock wave at a time that depended on the shock pressure.

Reduced Data
$U_{a0} = (2.774 \pm 0.093) + (1.855 \pm 0.062)U_{p0}$.
Table 4.46 SPIS-45 CLASS II PROPELLANT

**Composition**

72.7 wt% R45M, 0.07 wt% CAO-14, 2.00 wt% INDOPOL, 0.15 wt% Tepanol, 0.51 wt% IPDI, 21 wt% Al, 12 wt% HMX, 57 wt% AP

**Theoretical Maximum Density**

1.832 g/cm³

**Particle Size Distribution**

9-μm HMX, 200-μm AP (36%), 6-μm AP (21%), 6-μm Al

**Preparation Method**

Casting and curing

**Data Summary**

$\rho_0 = 1.831$ g/cm³, $T_0 \approx 24^\circ$C. Technique 7

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_0$ (GPa)</td>
<td>$U_{p0}$ (mm/μs)</td>
<td>$U_{so}$ (mm/μs)</td>
</tr>
<tr>
<td>E-4553</td>
<td>5.47</td>
<td>0.723</td>
<td>4.13</td>
</tr>
<tr>
<td>E-4559</td>
<td>18.7</td>
<td>1.69</td>
<td>6.05</td>
</tr>
</tbody>
</table>

*No transition to detonation was observed within 25.4 mm, but a violent reaction trailed the shock wave at a time that depended on the shock pressure.*
SHOCK INITIATION PROPERTIES

Table 4.47  TP-N1028 CLASS VII PROPELLANT

Data Summary
\( \rho_0 = 1.846 \, \text{g/cm}^3 \). \( T_0 = 24^\circ \text{C} \). Technique 7

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 ) (GPa)</td>
<td>( U_{p0} ) (mm/\mu s)</td>
<td>( U_{so} ) (mm/\mu s)</td>
</tr>
<tr>
<td>E-4609</td>
<td>3.20</td>
<td>0.501</td>
<td>3.46</td>
</tr>
<tr>
<td>E-4597</td>
<td>3.76</td>
<td>0.604</td>
<td>3.37</td>
</tr>
<tr>
<td>E-4606</td>
<td>3.97</td>
<td>0.601</td>
<td>3.58</td>
</tr>
<tr>
<td>E-4593</td>
<td>4.66</td>
<td>0.632</td>
<td>4.00</td>
</tr>
<tr>
<td>E-4588</td>
<td>5.38</td>
<td>0.678</td>
<td>4.30</td>
</tr>
<tr>
<td>E-4607</td>
<td>5.26</td>
<td>0.723</td>
<td>3.94</td>
</tr>
<tr>
<td>E-4599</td>
<td>6.70</td>
<td>0.794</td>
<td>4.57</td>
</tr>
<tr>
<td>E-4604</td>
<td>7.60</td>
<td>0.879</td>
<td>4.68</td>
</tr>
<tr>
<td>E-4610</td>
<td>7.86</td>
<td>0.906</td>
<td>4.70</td>
</tr>
<tr>
<td>E-4612</td>
<td>8.85</td>
<td>1.008</td>
<td>4.76</td>
</tr>
</tbody>
</table>

Reduced Data
\( \rho = 1.846 \, \text{g/cm}^3 \).
\( U_{so} = (2.20 \pm 0.199) + (2.659 \pm 0.279)U_{p0} \).
\( C_L = 2.36 \, \text{mm/\mu s}, \ C_S = 0.35 \, \text{mm/\mu s}, \) and \( C_o = 2.33 \, \text{mm/\mu s} \).
SHOCK INITIATION PROPERTIES

Table 4.48 UTP-20930 CLASS VII PROPELLANT

Data Summary
$p_0 = 1.838 \text{ g/cm}^3, T_0 = 24^\circ\text{C}$. Technique 7

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>$P_0$ (GPa)</th>
<th>$U_{p0}$ (mm/$\mu$s)</th>
<th>$U_{s0}$ (mm/$\mu$s)</th>
<th>$x^*$ (mm)</th>
<th>$t^*$ ($\mu$s)</th>
<th>Driving System Thickness (mm)</th>
</tr>
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<tbody>
<tr>
<td>E-4608</td>
<td>3.13</td>
<td>0.494</td>
<td>3.45</td>
<td>&gt;26</td>
<td>---</td>
<td>B, 17.8 PC, 12.7 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>E-4603</td>
<td>4.46</td>
<td>0.613</td>
<td>3.96</td>
<td>24.3</td>
<td>5.73</td>
<td>H, 24.1 SS, 18.0 PMMA</td>
</tr>
<tr>
<td>E-4598</td>
<td>4.58</td>
<td>0.635</td>
<td>3.92</td>
<td>26.5</td>
<td>6.2</td>
<td>D, 19 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>E-4594</td>
<td>5.18</td>
<td>0.705</td>
<td>4.00</td>
<td>17.3</td>
<td>4.05</td>
<td>H, 19 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>E-4602</td>
<td>5.39</td>
<td>0.714</td>
<td>4.11</td>
<td>18.3</td>
<td>4.18</td>
<td>H, 19 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>E-4600</td>
<td>6.50</td>
<td>0.830</td>
<td>4.26</td>
<td>10.9</td>
<td>2.33</td>
<td>K, 19 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>E-4605</td>
<td>7.41</td>
<td>0.892</td>
<td>4.52</td>
<td>6.5</td>
<td>1.37</td>
<td>L, 19 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>E-4601</td>
<td>7.41</td>
<td>0.942</td>
<td>4.28</td>
<td>7.0</td>
<td>1.53</td>
<td>L, 19 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>E-4611</td>
<td>8.8</td>
<td>0.98</td>
<td>4.9 ± 0.1</td>
<td>4.6</td>
<td>0.91</td>
<td>B, 20.3, PMMA</td>
</tr>
</tbody>
</table>

Reduced Data
$p = 1.838 \text{ g/cm}^3$.
$U_{s0} - (2.529 \pm 0.133) + (2.157 \pm 0.181)U_{p0}$.
$C_L = 2.61 \text{ mm/} \mu \text{s}, C_S = 0.41 \text{ mm/} \mu \text{s}, \text{ and } C_o = 2.57 \text{ mm/} \mu \text{s}$.
Table 4.49  VOP-7 CLASS VII PROPELLANT

Theoretical Maximum Density
>1.910 g/cm³

Preparation Method
Vacuum casting and pressure curing

Data Summary
\( \rho_0 = 1.910 \, \text{g/cm}^3. \, T_0 = 25^\circ \text{C}. \) Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{p0} ) (mm/µs)</th>
<th>( U_{w0} ) (mm/µs)</th>
<th>( 1/2 , b ) (mm/µs²)</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (µs)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-4213</td>
<td>0.5</td>
<td>0.093</td>
<td>2.811</td>
<td>-0.030</td>
<td>&gt;=25.3</td>
<td>&gt;=9.93</td>
<td>A, 11.4 SS, 10.9 Plex</td>
</tr>
<tr>
<td>E-4209</td>
<td>2.40</td>
<td>0.394</td>
<td>3.186</td>
<td>0.015</td>
<td>&gt;25.2</td>
<td>&gt;8.13</td>
<td>A, 25.4 Plex</td>
</tr>
<tr>
<td>E-4193</td>
<td>2.49</td>
<td>0.392</td>
<td>3.323</td>
<td>0.032</td>
<td>21.49</td>
<td>5.90</td>
<td>B, 10.9 Plex</td>
</tr>
<tr>
<td>E-4207</td>
<td>2.35</td>
<td>0.385</td>
<td>3.105</td>
<td>0.054</td>
<td>21.04</td>
<td>5.84</td>
<td>B, 10.9 Plex</td>
</tr>
<tr>
<td>E-4194</td>
<td>4.44</td>
<td>0.643</td>
<td>3.615</td>
<td>0.070</td>
<td>11.64</td>
<td>2.90</td>
<td>B, 12.7 Plex</td>
</tr>
<tr>
<td>E-4208</td>
<td>5.20</td>
<td>0.710</td>
<td>3.835</td>
<td>0.292</td>
<td>6.17</td>
<td>1.43</td>
<td>J, 11.4 Plex</td>
</tr>
<tr>
<td>E-4202</td>
<td>6.75</td>
<td>0.858</td>
<td>4.121</td>
<td>1.077</td>
<td>3.95</td>
<td>0.78</td>
<td>B, 24.7 Plex</td>
</tr>
<tr>
<td>E-4203</td>
<td>4.80</td>
<td>0.706</td>
<td>3.561</td>
<td>0.515</td>
<td>6.06</td>
<td>1.41</td>
<td>J, 11.4 Plex</td>
</tr>
<tr>
<td>E-4225</td>
<td>12.2</td>
<td>1.081</td>
<td>5.911</td>
<td>-0.395</td>
<td>1.914</td>
<td>0.33</td>
<td>J, 48.6 Plex</td>
</tr>
<tr>
<td>E-4221</td>
<td>10.20</td>
<td>1.157</td>
<td>4.614</td>
<td>1.578</td>
<td>1.49</td>
<td>0.29</td>
<td>J, 50.7 Plex</td>
</tr>
</tbody>
</table>

E-4218 ≈15 GPa expected, but results are not consistent with those of other experiments. It is not clear whether the inconsistency is caused by the poor records obtained or by the unusually large change in slope of the \( U_x-U_p \) curve.

E-4219 J, 24.2 Plex

Reduced Data
\( U_{w0} = (2.571 \pm 0.080) + (1.708 \pm 0.1211)U_{p0}. \)
Table 4.50 VRO CLASS VII PROPELLANT

Preparation Method
Vacuum casting, pressure curing, and machining to shape

Data Summary
\( \rho_0 = 1.833 \text{ g/cm}^3, T_0 = 25°C. \) Technique 4

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>( P_0 ) (GPa)</th>
<th>( U_{iso} ) (mm/( \mu )s)</th>
<th>( U_{ano} ) (mm/( \mu )s)</th>
<th>1/2 ( b ) (mm/( \mu )s(^2))</th>
<th>( x^* ) (mm)</th>
<th>( t^* ) (( \mu )s)</th>
<th>Driving System Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-4473</td>
<td>7.26</td>
<td>0.903</td>
<td>4.385</td>
<td>0.109</td>
<td>4.21</td>
<td>0.92</td>
<td>L, 24.1 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>E-4461</td>
<td>6.45</td>
<td>0.844</td>
<td>4.170</td>
<td>0.104</td>
<td>6.10</td>
<td>1.36</td>
<td>K, 24.1 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>E-4472</td>
<td>4.93</td>
<td>0.703</td>
<td>3.823</td>
<td>0.084</td>
<td>10.74</td>
<td>2.59</td>
<td>H, 24.2 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>E-4450</td>
<td>4.70</td>
<td>0.677</td>
<td>3.790</td>
<td>0.098</td>
<td>10.59</td>
<td>2.58</td>
<td>H, 24.2 SS, 10.9 PMMA</td>
</tr>
<tr>
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<td>3.75</td>
<td>0.583</td>
<td>3.508</td>
<td>0.040</td>
<td>20.26</td>
<td>5.32</td>
<td>B, 15.3 SS, 15.2 PMMA</td>
</tr>
<tr>
<td>E-4442</td>
<td>3.75</td>
<td>0.584</td>
<td>3.506</td>
<td>0.033</td>
<td>23.31</td>
<td>6.11</td>
<td>D, 24.2 SS, 17.8 PMMA</td>
</tr>
<tr>
<td>E-4441</td>
<td>3.25</td>
<td>0.522</td>
<td>3.395</td>
<td>0.039</td>
<td>&gt;25.50</td>
<td>&gt;6.82</td>
<td>B, 23.9 SS, 25.5 PMMA</td>
</tr>
<tr>
<td>E-4471</td>
<td>2.54</td>
<td>0.446</td>
<td>3.109</td>
<td>0.013</td>
<td>&gt;25.47</td>
<td>&gt;7.85</td>
<td>B, 17.8 foam, 11.5 SS, 10.9 PMMA</td>
</tr>
<tr>
<td>Shot Number</td>
<td>Initial Shock Parameters</td>
<td>Coordinates for High-Order Detonation</td>
<td>Driving System Thickness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
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<td>--------------------------</td>
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</tr>
<tr>
<td></td>
<td>$P_0$ (GPa)</td>
<td>$U_{p_0}$ (mm/µs)</td>
<td>$U_{u_0}$ (mm/µs)</td>
<td>$x^*$ (mm)</td>
<td>$t^*$ (µs)</td>
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</tr>
<tr>
<td>E-4513</td>
<td>3.42</td>
<td>0.548</td>
<td>3.40</td>
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<td>&gt;7.15</td>
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</tr>
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<td>H, 19 SS, 19.0 PMMA</td>
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<td>22.6</td>
<td>5.81</td>
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<td></td>
</tr>
<tr>
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</tr>
<tr>
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<td>5.42</td>
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<td>9.40</td>
<td>2.21</td>
<td>G, 19 SS, 10.9 PMMA</td>
<td></td>
</tr>
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<td>E-4534</td>
<td>4.35</td>
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<td>3.63</td>
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<td>0.784</td>
<td>4.35</td>
<td>5.75</td>
<td>1.27</td>
<td>K, 24.1 SS, 10.9 PMMA</td>
<td></td>
</tr>
<tr>
<td>E-4545</td>
<td>7.20</td>
<td>0.872</td>
<td>4.5</td>
<td>5.21</td>
<td>1.03</td>
<td>L, 24.1 SS, 10.9 PMMA</td>
<td></td>
</tr>
</tbody>
</table>

Reduced Data

$U_{p_0} = (1.992 \pm 0.365) + (2.761 \pm 0.507)U_{p_0}$.

---

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_0$ (GPa)</td>
<td>$U_{p_0}$ (mm/µs)</td>
<td>$U_{u_0}$ (mm/µs)</td>
</tr>
<tr>
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<td>6.01</td>
<td>0.760</td>
<td>4.3</td>
</tr>
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<td>E-4515</td>
<td>5.52</td>
<td>0.728</td>
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<td>E-4516</td>
<td>5.79</td>
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<td>4.20</td>
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<td>E-4518</td>
<td>3.53</td>
<td>0.545</td>
<td>3.52</td>
</tr>
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<td>3.68</td>
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<td>3.50</td>
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<tr>
<td>E-4537</td>
<td>7.25</td>
<td>0.876</td>
<td>4.5</td>
</tr>
<tr>
<td>E-4546</td>
<td>4.45</td>
<td>0.637</td>
<td>3.80</td>
</tr>
</tbody>
</table>

Reduced Data

$U_{p_0} = (1.703 \pm 0.177) + (3.292 \pm 0.251)U_{p_0}$.


## SHOCK INITIATION PROPERTIES

### Table 4.53 VTQ-2 CLASS VII PROPELLANT

**Preparation Method**
Vacuum casting, pressure curing, and machining to shape

**Data Summary**
\( \rho_0 = 1.852 \text{ g/cm}^3, T_0 = 24^\circ\text{C} \). Technique 7

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 ) (GPa)</td>
<td>( U_{po} ) (mm/( \mu )s)</td>
<td>( U_{so} ) (mm/( \mu )s)</td>
</tr>
<tr>
<td>Lot 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-4470</td>
<td>2.50</td>
<td>0.43</td>
<td>3.14</td>
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<td>0.42</td>
<td>3.19</td>
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<td>E-4480</td>
<td>2.99</td>
<td>0.47</td>
<td>3.44</td>
</tr>
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<td>E-4462</td>
<td>2.85</td>
<td>0.46</td>
<td>3.35</td>
</tr>
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<td>E-4440</td>
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<td>11.4</td>
<td>1.07</td>
<td>5.73</td>
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<td>Lot 2</td>
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<td>E-4522</td>
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<td>0.48</td>
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<td>E-4502</td>
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<td>0.67</td>
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<tr>
<td>E-4503</td>
<td>5.89</td>
<td>0.77</td>
<td>4.13</td>
</tr>
</tbody>
</table>

**Reduced Data**
\[ U_{so} = (1.514 \pm 0.192) + (3.887 + 0.303)U_{po}. \]
SHOCK INITIATION PROPERTIES

Table 4.54 VTQ-3 CLASS VII PROPELLANT

Preparation Method
Vacuum casting and pressure curing

Data Summary
\( \rho_0 = 1.857 \text{ g/cm}^3, \ T_0 \approx 24^\circ\text{C}. \) Technique 7

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 ) (GPa)</td>
<td>( U_{po} ) (mm/\mu s)</td>
<td>( U_{so} ) (mm/\mu s)</td>
</tr>
<tr>
<td>E-4555</td>
<td>3.21</td>
<td>0.590</td>
<td>3.46</td>
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<td>E-4560</td>
<td>3.88</td>
<td>0.571</td>
<td>3.66</td>
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<td>E-4551</td>
<td>4.21</td>
<td>0.625</td>
<td>3.63</td>
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<td>E-4550</td>
<td>5.12</td>
<td>0.673</td>
<td>4.1</td>
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<td>E-4540</td>
<td>5.74</td>
<td>0.773</td>
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<td>E-4558</td>
<td>7.15</td>
<td>0.877</td>
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Reduced Data

\( U_{so} = (2.287 \pm 0.318) + (2.368 \pm 0.466)U_{po}. \)
\( C_0 = 2.20 \text{ mm/\mu s}. \)

Table 4.55 VWC-2 CLASS VII PROPELLANT

Preparation Method
Vacuum casting, pressure curing, and machining to shape

Data Summary
\( \rho_0 = 1.835 \text{ g/cm}^3, \ T_0 = 24^\circ\text{C}. \) Technique 7

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Initial Shock Parameters</th>
<th>Coordinates for High-Order Detonation</th>
<th>Driving System Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 ) (GPa)</td>
<td>( U_{po} ) (mm/\mu s)</td>
<td>( U_{so} ) (mm/\mu s)</td>
</tr>
<tr>
<td>E-4564</td>
<td>3.87</td>
<td>0.596</td>
<td>3.54</td>
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<tr>
<td>E-4552</td>
<td>3.92</td>
<td>0.597</td>
<td>3.58</td>
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<tr>
<td>E-4548</td>
<td>4.47</td>
<td>0.640</td>
<td>3.81</td>
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<td>E-4547</td>
<td>4.79</td>
<td>0.706</td>
<td>3.7 \pm 0.2</td>
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<td>E-4565</td>
<td>5.13</td>
<td>0.718</td>
<td>3.89</td>
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<td>E-4539</td>
<td>5.19</td>
<td>0.702</td>
<td>4.03</td>
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<td>E-4557</td>
<td>6.44</td>
<td>0.811</td>
<td>4.33</td>
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<td>E-4549</td>
<td>7.30</td>
<td>0.878</td>
<td>4.53</td>
</tr>
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</table>

Reduced Data

\( \rho = 1.835 \text{ g/cm}^3. \)
\( U_{so} = (1.989 \pm 0.121) + (2.754 \pm 0.180)U_{po}. \)
\( C_L = 2.13 \text{ mm/\mu s}, \ C_S = 0.49 \text{ mm/\mu s}, \) and \( C_0 = 2.05 \text{ mm/\mu s}. \)
4.2 Small- and Large-Scale Gap Thicknesses. Gap tests are explosive shock tests. A standard donor explosive produces a shock pressure of uniform magnitude which is transmitted to the test explosive through an attenuating inert barrier or gap. By varying the thickness of the barrier between the donor and test (acceptor) explosives, one can determine the barrier thickness required to inhibit detonation in the test explosive half the time ($G_{50}$).

A variety of gap tests have been used to qualitatively measure the shock wave amplitude required to initiate detonation in explosives. LASL has used two test configurations that differ only in scale. The diameter of the cylindrical acceptor charge in the small-scale test is 12.7 mm; that in the large-scale test is 41.3 mm. An explosive whose detonation failure diameter is near to or greater than the diameter of the acceptor charge cannot be tested in the small-scale test so the large-scale test is used. Figures 4.10 and 4.11 show the configuration of both gap tests. The test procedure is to fire a few preliminary shots to determine the spacer thickness that allows detonation in the test explosive. Shots are fired with the spacer thickness alternately increased and decreased until the spacer thickness that allows detonation in the acceptor explosive in half of the trials is determined. A deep, sharply defined dent in the steel witness plate indicates that the test explosive detonated.

![Fig. 4.10. Large-scale gap test assembly.](image1)

![Fig. 4.11. Small-scale gap test assembly.](image2)
### Table 4.56 SMALL- AND LARGE-SCALE GAP TEST RESULTS

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm²)</th>
<th>Small $G_{50}$ (mm)</th>
<th>Large $G_{50}$ (mm)</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td><strong>Pure Explosives</strong></td>
<td></td>
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<tr>
<td>Ammonium picrate</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>1.0</td>
<td>No go</td>
<td>35.7</td>
<td>Pressed</td>
</tr>
<tr>
<td></td>
<td>1.604</td>
<td>0.13</td>
<td>43.0</td>
<td>Pressed</td>
</tr>
<tr>
<td></td>
<td>1.635</td>
<td>0.36</td>
<td>43.0</td>
<td>Pressed</td>
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<td>0.33</td>
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<td>Pressed</td>
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<td>Baratol (76/24) mixture</td>
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<td>22.2</td>
<td>Cast</td>
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<td>0.75</td>
<td>41.7</td>
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<tr>
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<td>0.72</td>
<td>6.32</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.07</td>
<td>---</td>
<td>70.7</td>
<td>Pressed</td>
</tr>
<tr>
<td></td>
<td>1.18</td>
<td>2.46</td>
<td>38.7</td>
<td>Water-filled voids</td>
</tr>
<tr>
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<td>1.18</td>
<td>2.77</td>
<td>---</td>
<td>Saturated ZnCl solution-filled voids</td>
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<td>1.02</td>
<td>2.11</td>
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<td>Ball-milled to $d_m$ 15 $\mu$m</td>
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<td>1.63</td>
<td>No go</td>
<td>5.0</td>
<td>Pressed</td>
</tr>
<tr>
<td>PETN</td>
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<td>See Figs. 4.12-4.18</td>
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<td>Water-filled voids</td>
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<td>See Figs. 4.19 and 4.20</td>
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<td>$S_t$ 3300 cm²/g</td>
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<td>17.02 $\pm$ 0.05*</td>
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</tr>
<tr>
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</tr>
<tr>
<td>-------------</td>
<td>---</td>
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<td>---</td>
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<tr>
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<td>15.53</td>
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<td>47.9</td>
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<td>3.04</td>
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<td>(S_g = 2300 \text{ cm}^2/\text{g})</td>
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<td>(S_g = 2900 \text{ cm}^2/\text{g})</td>
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<td>2.79</td>
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### Castable Mixtures

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*Tested at 25.4-mm diam.
Table 4.56 (continued)

<table>
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<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>Small G₅₀ (mm)</th>
<th>Large G₅₀ (mm)</th>
<th>Remarks</th>
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<tr>
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<td>1.700</td>
<td>10.69 ± 0.08*</td>
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<tr>
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<tr>
<td>1.913</td>
<td>1.73 ± 0.08*</td>
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</tr>
<tr>
<td>1.914</td>
<td>1.63 ± 0.05*</td>
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<tr>
<td>1.914</td>
<td>1.65 ± 0.05*</td>
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<tr>
<td>1.349</td>
<td>11.76 ± 0.18*</td>
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<tr>
<td>1.498</td>
<td>13.46 ± 0.05*</td>
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<tr>
<td>1.700</td>
<td>13.54 ± 0.05*</td>
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<tr>
<td>1.803</td>
<td>11.50 ± 0.08*</td>
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<tr>
<td>1.845</td>
<td>9.22 ± 0.08*</td>
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<tr>
<td>1.846</td>
<td>8.89 ± 0.25*</td>
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</tr>
<tr>
<td>1.895</td>
<td>3.38 ± 0.15*</td>
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</tr>
<tr>
<td>1.908</td>
<td>1.93 ± 0.23*</td>
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<td></td>
</tr>
</tbody>
</table>

X-0291

| 1.501   | 11.10 ± 0.36* |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 1.700   | 12.65         |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 1.701   | 12.14 ± 0.18* |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 1.905   | 2.06 ± 0.64*  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

Reworked TATB
Fig. 4.12. Small-scale gap test sensitivity of PETN vs loading density.

Fig. 4.13. Small-scale gap test sensitivity of 0.95-g/cm³ PETN vs specific surface.

Fig. 4.14. Small-scale gap test sensitivity of 0.95-g/cm³ PETN vs specific surface.
Fig. 4.15. Small-scale gap test sensitivity of PETN vs oxygen concentration.

Fig. 4.16. Small-scale gap test sensitivity of PETN vs oxygen concentration.
SHOCK INITIATION PROPERTIES

Fig. 4.17. Small-scale gap test sensitivity of PETN vs interstitial gas pressure.

Fig. 4.18. Small-scale gap test sensitivity of PETN vs interstitial gas pressure.
4.3. Minimum Priming Charge. The minimum priming charge test determines the quantity of some initiator or booster explosive that will cause high-order detonation in the test explosive in half the trials. This test has been used to determine both the relative effectiveness of various initiator explosives and the relative sensitivities of various test explosives. The basic property of the test explosive is its ability to build up to a high-order detonation after a short, intense, geometrically small, and usually highly divergent shock wave is induced from the priming charge.

Figure 4.21 shows the LASL version of this test. The test charge is a 2-in.-diam by 2-in.-high cylinder. A hemispherical cavity milled into one face is filled with a putty-like explosive, XTX 8003, prepared by roll-milling 80 parts of a specially recrystallized PETN with 20 parts of an uncatalyzed silicone resin (Dow Corning 433..."
Resin 93-022, Sylgard 182). This material was chosen because it can be loaded readily into the cavity, and it propagates a detonation in quite small diameters of test explosives. The 1/2-in.-thick brass plate that covers the assembly partly confines the explosive reaction and also serves as a locating ring for the 2-grain/ft mild detonating fuse (MDF) that carries the detonation from the detonator to the XTX 8003.

The quantity varied is the diameter of the hemispherical cavity, and hence the volume and weight of the XTX 8003 booster. This is done by using a set of end mills whose tips have been ground so that they form cavities of the desired sizes. The cavity is filled by weighing out the required quantity of XTX 8003 (1.53-g/cm³ loading density), rolling it into a ball, and pressing it into place.

The weight of XTX 8003 is increased and decreased in logarithmic steps of 0.1 log units, starting with 1.53 mg, until the quantity of XTX 8003 required to detonate the test charge in half the trials is found.

4.4 Rifle Bullet Test. Three tests have been used at LASL to determine the response of explosives to attack by rifle bullets.

In the first test, a bare, 2-in.-diam by 3-in.-long cylinder is placed in the V-notch of a plastic holder that rests on a steel plate. The projectile, a 90-grain steel cylinder, roughly 0.3 in. in diameter and 0.5 in. long, is fired at the end of the charge by a .30 caliber rifle. The approximate bullet velocity is measured with velocity screens. A microphone or pressure transducer that measures the overpressure created by an event usually indicates either no overpressure or a pressure characteristic of a detonation. Results are expressed in terms of a critical velocity, \( V_{\text{cri}} \); the minimum velocity at which detonations were observed, \( V_{\text{det min}} \); and the maximum velocity at which no reactions were observed, \( V_{\text{inert max}} \). This test is another shock sensitivity test. The bullet velocity is an indirect indicator of the shock pressure required to initiate detonation.

In the second and third tests, the explosive is confined in a 1- by 1.5-in. pipe nipple or a 1-pint cardboard carton, respectively. Standard .30 and .50 caliber bullets weighing 153 and 700 grains are fired at velocities of 2755 and 2840 ft/s to attack the explosive. (In these tests the pipe nipple confinement is used for explosives cast or pressed to more than 95% of their crystal densities. The cardboard carton confine-
SHOCK INITIATION PROPERTIES

ment is used to test explosives at their bulk densities.) In each case the bullet is
fired at the cylindrical surface of the confinement vessel with the bullet velocity and
caliber held constant.

The results are expressed as follows: no explosion (NE), in which there is no ex-

plosive reaction; partial explosion (PE), in which some unconsumed explosive is
recovered; explosion (E), in which no explosive is recovered; and complete explosion
(CE), in which no explosive is recovered and the steel pipe nipple is recovered in
small fragments. The difference between an explosion and complete explosion is
subjective in that it depends upon the amplitude of the sound produced by the

event and recovery of the debris.

A test series usually consists of 10 to 20 shots, and the results are given as the
probability of no explosion, $P_{NE}$, and the probability of a complete explosion, $P_{CE}$.

Table 4.57  MINIMUM PRIMING CHARGE

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm$^3$)</th>
<th>Minimum Priming Weight, $W_{40}$ (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pure Explosives</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium picrate</td>
<td>1.646</td>
<td>1790</td>
</tr>
<tr>
<td>DATB</td>
<td>1.707</td>
<td>26</td>
</tr>
<tr>
<td>TNT$^{a}$</td>
<td>1.59</td>
<td>394</td>
</tr>
<tr>
<td></td>
<td>1.63</td>
<td>1260</td>
</tr>
<tr>
<td>Tetryl</td>
<td>1.692</td>
<td>&lt;5</td>
</tr>
<tr>
<td><strong>Castable Mixtures</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp A-3</td>
<td>1.63</td>
<td>51</td>
</tr>
<tr>
<td>Comp B-3</td>
<td>1.725</td>
<td>623</td>
</tr>
<tr>
<td>Cyclotol (70/30)</td>
<td>1.739</td>
<td>898</td>
</tr>
<tr>
<td>Cyclotol (75/25)</td>
<td>1.749</td>
<td>785</td>
</tr>
<tr>
<td>Octol</td>
<td>1.818</td>
<td>292</td>
</tr>
<tr>
<td><strong>Plastic-Bonded Explosives</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>HMX-Based</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBX 9011</td>
<td>1.77</td>
<td>88.8</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.830</td>
<td>22.8</td>
</tr>
<tr>
<td>X-0234</td>
<td>1.847</td>
<td>24.0</td>
</tr>
<tr>
<td><em>RDX-Based</em></td>
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<tr>
<td>PBX 9007</td>
<td>1.649</td>
<td>14.4</td>
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<td>PBX 9010</td>
<td>1.782</td>
<td>58.1</td>
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<td>PBX 9205</td>
<td>1.690</td>
<td>78.5</td>
</tr>
<tr>
<td>PBX 9407</td>
<td>1.764</td>
<td>6.3</td>
</tr>
<tr>
<td><em>TATB-Based</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBX 9502</td>
<td>1.915</td>
<td>&gt;4835</td>
</tr>
</tbody>
</table>

$^{a}$Pressed at 65°C.
## SHOCK INITIATION PROPERTIES

### Table 4.58 UNCONFINED EXPLOSIVES (except as noted)

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density * (g/cm³)</th>
<th>$V_{det , min}$ (ft/s)</th>
<th>$V_{inert , max}$ (ft/s)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pure Explosives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetryl</td>
<td>1.677</td>
<td>2077</td>
<td>2116</td>
<td>---</td>
</tr>
<tr>
<td><strong>Castable Mixtures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp B-3</td>
<td>1.728</td>
<td>3410</td>
<td>3395</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>1.728</td>
<td>3420</td>
<td>3390</td>
<td>Confined in 1/8-in.-thick brass tube</td>
</tr>
<tr>
<td></td>
<td>1.728</td>
<td>3405</td>
<td>3433</td>
<td>Confined in 1/4-in.-thick brass tube</td>
</tr>
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<td></td>
<td>1.728</td>
<td>3364</td>
<td>3395</td>
<td>Confined in 3/8-in.-thick brass tube</td>
</tr>
<tr>
<td>Octol 75/25</td>
<td>1.807</td>
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<td>3842</td>
<td>---</td>
</tr>
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<td><strong>Plastic-Bonded Explosives</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>HMX-Based</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.826</td>
<td>3058</td>
<td>3085</td>
<td>Unimodal HMX 25-μm median diameter</td>
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<td>1.825</td>
<td>3028</td>
<td>3098</td>
<td></td>
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<tr>
<td></td>
<td>1.824</td>
<td>3129</td>
<td>3178</td>
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<td>1.843</td>
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<td>2970</td>
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</tr>
<tr>
<td></td>
<td>1.830</td>
<td>2830</td>
<td>2976</td>
<td>88 wt% HMX/12 wt% Elvax</td>
</tr>
<tr>
<td></td>
<td>1.837</td>
<td>2738</td>
<td>2878</td>
<td>88 wt% HMX/6 wt% Elvax/6 wt% wax</td>
</tr>
<tr>
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<td>1.836</td>
<td>2896</td>
<td>2991</td>
<td>88 wt% HMX/12 wt%</td>
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<tr>
<td></td>
<td>1.837</td>
<td>2640</td>
<td>2830</td>
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</tr>
<tr>
<td>HMX and wax</td>
<td>1.767</td>
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<td>3102</td>
<td>88 wt% HMX/12 wt%</td>
</tr>
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<td></td>
<td>1.763</td>
<td>3267</td>
<td>3190</td>
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<td>PBX 9010</td>
<td>1.786</td>
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<td>3070</td>
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<tr>
<td>RDX and wax</td>
<td>1.696</td>
<td>2900</td>
<td>2890</td>
<td>96 wt% RDX/3.7 wt% wax/0.3 wt% rubber</td>
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<tr>
<td></td>
<td>1.680</td>
<td>2400</td>
<td>2340</td>
<td>98 wt% RDX/1.7 wt% wax/0.3 wt% rubber</td>
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</tbody>
</table>

*Unimodal HMX 125-μm median diameter.

*Standard HMX particle size distribution.
SHOCK INITIATION PROPERTIES

Table 4.59 CONFINED EXPLOSIVES

Confinement: 1- by 1.5-in. pipe nipple
Bullet Type: .30 Caliber
Bullet Weight: 153 grains
Bullet Velocity: 2755 ft/s

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>NE</th>
<th>PE</th>
<th>E</th>
<th>CE</th>
<th>P_ne</th>
<th>P_cr</th>
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<td></td>
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<tr>
<td>Comp B</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Cyclotol 75/25</td>
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<td>0</td>
<td>0</td>
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<td>0</td>
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<td>Octol 25/25</td>
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<td>100</td>
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Plastic-Bonded Explosives

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<th>Density (g/cm³)</th>
<th>NE</th>
<th>PE</th>
<th>E</th>
<th>CE</th>
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<td></td>
<td></td>
</tr>
<tr>
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<td>0</td>
<td>1</td>
<td>18</td>
<td>1</td>
<td>0</td>
<td>5</td>
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<td>7</td>
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<td>1.827</td>
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<td>15</td>
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<td>15</td>
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<tr>
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<td>7</td>
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<td>1</td>
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<td>5</td>
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<tr>
<td>97 wt% HMX/3 wt% wax</td>
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<td>1</td>
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<td>PBX 9407</td>
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Confinement: 1- by 1.5-in. pipe nipple
Bullet Type: .50 Caliber
Bullet Weight: 153 grains
Bullet Velocity: 2840 ft/s

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<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>NE</th>
<th>PE</th>
<th>E</th>
<th>CE</th>
<th>P_ne</th>
<th>P_cr</th>
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<tbody>
<tr>
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<td>Tetryl</td>
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<td>8</td>
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<table>
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<th>Density (g/cm³)</th>
<th>NE</th>
<th>PE</th>
<th>E</th>
<th>CE</th>
<th>P_ne</th>
<th>P_cr</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Castable Mixture</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Comp B</td>
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<td>18</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>90</td>
<td>0</td>
</tr>
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<td>Cyclotol 75/25</td>
<td>1.74</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>NE</th>
<th>PE</th>
<th>E</th>
<th>CE</th>
<th>P_ne</th>
<th>P_cr</th>
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<tbody>
<tr>
<td>HMX-Based</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.844</td>
<td>10</td>
<td>6</td>
<td>4</td>
<td>0</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>RDX-Based</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBX 9010</td>
<td>1.783</td>
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<td>20</td>
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</table>
SHOCK INITIATION PROPERTIES

Table 4.59 (continued)

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>NE</th>
<th>PE</th>
<th>E</th>
<th>CE</th>
<th>P_{NE}</th>
<th>P_{CE}</th>
</tr>
</thead>
</table>

Confinement: Cardboard Carton, 3-5/16-in. i.d. by 3-3/16-in.-high by 1/32-in.-wall
Bullet Type: .30 Caliber
Bullet Weight: 153 grains
Bullet Velocity: 2755 ft/s

**Pure Explosives**

| Tetryl       | 0.85 | 0   | 0   | --- | 20 | 0      | 100     |

**Plastic-Bonded Explosives**

**HMX-Based**

<table>
<thead>
<tr>
<th>PBX 9404</th>
<th>1.00</th>
<th>0</th>
<th>2</th>
<th>---</th>
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<tr>
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<td>0.63</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>10</td>
<td>90</td>
</tr>
</tbody>
</table>

Confinement: Cardboard, 3.312-in.-i.d. by 3.187-in.-high by .30-in.-wall
Bullet Type: .30 Caliber
Bullet Weight: 153 grains
Bullet Velocity: 2000 ft/s

**Pure Explosives**

| Tetryl       | 0.89 | 18  | 0   | --- | 2  | 90     | 10      |

**Plastic-Bonded Explosives**

**HMX-Based**

<table>
<thead>
<tr>
<th>PBX 9404</th>
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<th>12</th>
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<tr>
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<td>0</td>
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**RDX-Based**

| PBX 9010     | 0.89 | 18  | 0   | --- | 2  | 90     | 10      |

438
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<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>NE</th>
<th>PE</th>
<th>E</th>
<th>CE</th>
<th>P_NE</th>
<th>P_CE</th>
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<tr>
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<td>0</td>
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<td>5</td>
<td>95</td>
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<td>0</td>
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<tr>
<td>PBX 9010</td>
<td>---</td>
<td>10</td>
<td>0</td>
<td>---</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

Confinement: Cardboard, 3.312-in.-i.d. by 3.187-in.-high by 0.030-in.-wall
Bullet Type: .30 Caliber
Bullet Weight: 153 grains
Bullet Velocity: 2250 ft/s
SHOCK INITIATION PROPERTIES

Fig. 4.22. Experimental arrangement for initiation by sustained shocks.

4.5 Miscellaneous Tests.

4.5.1 Initiation of Detonation by a Sustained Shock. A common way to initiate detonation in an explosive is to transmit a shock wave into it. The shock enters at a velocity less than the explosive’s detonation velocity and travels for a time, \( t_s \), before detonation occurs. The detonation would require a different time, \( t_D \), to travel the same distance. The difference between the detonation and shock travel time is \( t_s - t_D \), the excess transit time is \( t_e \). It is related inversely to the strength of the input shock. If the shock is produced by hitting the explosive with a flying plate, the shock pressure induced in the explosive is proportional to the plate velocity, and the shock duration is proportional to the plate weight, and hence, thickness. Thus, production of a "sustained" shock requires a "thick" flying plate or flyer.

In the test used to produce the data that follow, a plane, square wave-shaped shock was transmitted to the various explosives by an explosive-propelled flyer whose thickness was selected so that the induced shock always lasted longer than the time required to initiate a steady-state detonation. The flyer was propelled by an explosive driver consisting of a 305-mm-diam plane-wave generator, a 50- or 100-mm explosive charge, and an attenuator. After traversing a methane-filled space, the flyer collided with the 25.4-mm-diam by 6.35-mm-high right circular cylinder of explosive. Figure 4.22 shows the experimental setup.

The flyer velocity was adjusted by varying the explosive and attenuator. The free-surface velocity of the flyer and the shock transit time through the explosive sample were measured with ionization switches. Premature, ionization-caused, switch discharge was prevented by the methane atmosphere. The explosive detonation velocity and thus the detonation transit time, \( t_D \), is known from other experiments. The difference between the measured time and \( t_D \) is the excess transit time \( t_e \). The free-surface velocity of the flyer has been correlated with \( t_e \), \( t_e \) has been correlated with the free-surface velocity of the flyer, and functions have been found.

4.5.2 Initiation of Detonation by Short-Duration Shocks. Short-duration shocks in the test explosives were produced by striking them with a thin flying foil. The thin foils were driven from the surface of a material of higher impedance by shocking it with an explosive driver. Figure 4.23 shows the experimental setup. The shock duration was adjusted by varying the foil thickness, and the free-surface velocity was adjusted by varying the explosive driver. The thin foils flew through vacuum (10-mm Hg) and struck the 25.4-mm-diam by 6.35-mm-thick test explosives. Transit times through the test explosives and free-surface velocities of the foils were determined using ionization switches.

The unreduced data from all of the experiments are given in Table 4.61.
Table 4.60  INITIATION OF DETONATION BY A SUSTAINED SHOCK

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>Detonation Assumed Velocity (mm/μs)</th>
<th>Flyer</th>
<th>Number of Observations</th>
<th>Least Squares Fit Experimental Data</th>
<th>Valid U₉ₐ Range (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pure Explosives</td>
<td></td>
<td></td>
<td></td>
<td>Log tₑ =</td>
<td></td>
</tr>
<tr>
<td>Tetryl</td>
<td>...</td>
<td>7.453</td>
<td>2024 Al</td>
<td>21</td>
<td>(2.30 ± 0.07) - (3.30 ± 0.24) log U₉ₐ</td>
<td>1.00-3.34</td>
</tr>
<tr>
<td>Comp B</td>
<td>1.715 ± 0.003</td>
<td>8.00</td>
<td>2024 Al</td>
<td>32</td>
<td>(3.14 ± 0.03) - (3.08 ± 0.09) log U₉ₐ</td>
<td>1.06-3.31</td>
</tr>
<tr>
<td>Cyclotol 75/25</td>
<td>1.726 ± 0.002</td>
<td>7.95</td>
<td>2024 Al</td>
<td>32</td>
<td>(2.99 ± 0.02) - (3.33 ± 0.07) log U₉ₐ</td>
<td>1.07-2.85</td>
</tr>
<tr>
<td>Cyclotol 75/25</td>
<td>1.755 ± 0.003</td>
<td>8.3</td>
<td>2024 Al</td>
<td>117</td>
<td>(3.20 ± 0.02) - (2.98 ± 0.07) log U₉ₐ</td>
<td>1.17-3.37</td>
</tr>
<tr>
<td>Octol</td>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td>Log tₑ =</td>
<td></td>
</tr>
<tr>
<td>Octol 75/25</td>
<td>1.815 ± 0.001</td>
<td>8.475</td>
<td>2024 Al</td>
<td>17</td>
<td>(3.00 ± 0.01) - (2.80 ± 0.04) log U₉ₐ</td>
<td>1.17-2.82</td>
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<tr>
<td>EDC-1</td>
<td>1.770 ± 0.010</td>
<td>8.310</td>
<td>2024 Al</td>
<td>15</td>
<td>(2.71 ± 0.01) - (2.64 ± 0.06) log U₉ₐ</td>
<td>1.02-2.03</td>
</tr>
<tr>
<td>EDC-1</td>
<td>1.790 ± 0.005</td>
<td>8.380</td>
<td>2024 Al</td>
<td>15</td>
<td>(3.02 ± 0.02) - (2.69 ± 0.06) log U₉ₐ</td>
<td>1.19-2.86</td>
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<tr>
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<td>Castable Explosives</td>
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<td>Log tₑ =</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plastic-Bonded Explosives</td>
<td></td>
<td></td>
<td></td>
<td>Log tₑ =</td>
<td></td>
</tr>
<tr>
<td>PBX 9010</td>
<td>1.781 ± 0.004</td>
<td>8.33</td>
<td>2024 Al</td>
<td>33</td>
<td>(2.82 ± 0.02) - (3.38 ± 0.09) log U₉ₐ</td>
<td>1.01-3.06</td>
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<tr>
<td>PBX 9011*</td>
<td>1.764 ± 0.001</td>
<td>8.50</td>
<td>2024 Al</td>
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<td>(2.89 ± 0.01) - (3.09 ± 0.04) log U₉ₐ</td>
<td>1.13-2.29</td>
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<tr>
<td>PBX 9404</td>
<td>1.789 ± 0.002</td>
<td>8.650</td>
<td>2024 Al</td>
<td>9</td>
<td>(2.63 ± 0.01) - (2.68 ± 0.03) log U₉ₐ</td>
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<tr>
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<td>2024 Al</td>
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<td>1.844</td>
<td>8.80</td>
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<td>0.68-3.10</td>
</tr>
<tr>
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<td>1.843 ± 0.001</td>
<td>8.80</td>
<td>Magnesium</td>
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<td>(3.00 ± 0.01) - (2.92 ± 0.03) log U₉ₐ</td>
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<tr>
<td>PBX 9404</td>
<td>1.843 ± 0.001</td>
<td>8.80</td>
<td>Mild steel</td>
<td>21</td>
<td>(2.43 ± 0.02) - (3.27 ± 0.12) log U₉ₐ</td>
<td>0.65-1.90</td>
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<td>PBX 9404*</td>
<td>Variable</td>
<td>Variable</td>
<td>Mild steel</td>
<td>12</td>
<td>(2.06 ± 0.09) + (1.70 ± 0.37) log ρ₀</td>
<td>1.584-1.837</td>
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</table>

*The effect shown is that of the explosive initial density on the excess transit time, where the steel flyer U₉ₐ = 1.23 mm/μs.
SHOCK INITIATION PROPERTIES

Fig. 4.23. Experimental arrangement for producing short-duration shocks.

Table 4.61 INITIATION OF DETONATION BY SHORT-DURATION SHOCKS

Explosive: PBX 9404
Density: 1.842 ± 0.003 g/cm³
Assumed Detonation Velocity: 8.80 mm/µs
Flyer Material: 2024 Aluminum

<table>
<thead>
<tr>
<th>Foil Thickness (mm)</th>
<th>Foil Velocity (mm/µs)</th>
<th>Observed Transit Time (ns)</th>
<th>Excess Transit Time (ns)</th>
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<td>1.26</td>
<td>0.75</td>
<td>4585*</td>
<td>2845</td>
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<td>1.26</td>
<td>0.75</td>
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<td>1.58</td>
<td>0.78</td>
<td>2868</td>
<td>1137</td>
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<td>0.78</td>
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<td>1122</td>
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<td>130</td>
</tr>
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<td>0.31</td>
<td>1.76</td>
<td>847</td>
<td>122</td>
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</table>

*A slowly rising pulse indicated marginal initiation.
4.5.3 **Partial Reaction in Shocked Explosives.** As a shock wave passes through an explosive, some reaction usually occurs behind the wave front. If the shock wave is strong enough, the decomposition can build up to a detonation. There are few experimental data or theories that describe this process, but the following data give evidence of its effect in one configuration.

Figure 4.24 shows the experimental arrangement. A plane-wave shock of known amplitude was transmitted into one side of the test explosive, and the free-surface velocity of a witness plate on the opposite side was measured. The explosive thickness was varied for each input shock amplitude. If the explosive were totally inert, the witness plate free-surface velocity would be expected to decrease slightly with increasing explosive thickness and constant input shock. Instead, as the data show, the velocity increases, indicating that energy is added to the transmitted shock from shock-induced reaction in the explosive. Unfortunately, there are no similar data with the explosive as an inert. They would allow the reaction to be characterized quantitatively as a free-surface velocity increase for a particular shock pressure and run distance in the explosive. These data were included with the hope that they can be useful and perhaps encourage further study of shock-induced reaction.

![Experimental arrangement for producing partial reaction in shocked explosives.](image-url)
### Table 4.62 DATA ON PARTIAL REACTION IN SHOCKED EXPLOSIVES

**Explosive: PBX 9404**  
Density: $1.847 \pm 0.001 \text{ g/cm}^3$  
Shock Transmitter: 2024 Aluminum  
Witness Plate: Lucite

<table>
<thead>
<tr>
<th>Transmitter Free-Surface Velocity (mm/μs)</th>
<th>Test Explosive Thickness (mm)</th>
<th>Witness Plate Thickness (mm)</th>
<th>Free-Surface Velocity (mm/μs)</th>
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</thead>
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<tr>
<td>1.108</td>
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<td>1.96</td>
<td>5.05</td>
<td>2.964</td>
</tr>
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<td>1.108</td>
<td>2.56</td>
<td>5.06</td>
<td>3.251</td>
</tr>
<tr>
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<td>4.01</td>
<td>5.09</td>
<td>3.574</td>
</tr>
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<td>1.103</td>
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<td>4.121</td>
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<td>1.124</td>
<td>2.53</td>
<td>6.35</td>
<td>3.075</td>
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</table>

**Explosive: PBX 9404**  
Density: $1.843 \pm 0.001 \text{ g/cm}^3$  
Shock Transmitter: 2024 Aluminum  
Witness Plate: Magnesium

<table>
<thead>
<tr>
<th>Transmitter Free-Surface Velocity (mm/μs)</th>
<th>Test Explosive Thickness (mm)</th>
<th>Witness Plate Thickness (mm)</th>
<th>Free-Surface Velocity (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.048</td>
<td>1.92</td>
<td>2.54</td>
<td>2.393</td>
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<tr>
<td>1.063</td>
<td>7.62</td>
<td>2.55</td>
<td>3.800</td>
</tr>
<tr>
<td>---</td>
<td>7.62</td>
<td>2.53</td>
<td>3.838</td>
</tr>
</tbody>
</table>

**Explosive: Nitroguanidine**  
Density: $1.700 \pm 0.001 \text{ g/cm}^3$  
Shock Transmitter: Polymethylmethacrylate  
Witness Plate: Plexiglas

<table>
<thead>
<tr>
<th>Transmitter Free-Surface Velocity (mm/μs)</th>
<th>Test Explosive Thickness (mm)</th>
<th>Witness Plate Thickness (mm)</th>
<th>Free-Surface Velocity (mm/μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.450</td>
<td>0.00</td>
<td>5.09</td>
<td>4.229</td>
</tr>
<tr>
<td>4.475</td>
<td>5.02</td>
<td>5.07</td>
<td>4.356</td>
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<td>4.450</td>
<td>10.02</td>
<td>5.09</td>
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</tr>
<tr>
<td>4.475</td>
<td>14.01</td>
<td>5.08</td>
<td>5.408</td>
</tr>
</tbody>
</table>
SHOCK INITIATION PROPERTIES

Table 4.62 (continued)
Explosive: Comp B
Density: 1.700 ± 0.003 g/cm³
Shock Transmitter: 2024 Aluminum
Witness Plate: 2024 Aluminum
Witness Plate Thickness: 4.75 ± 0.05 mm

<table>
<thead>
<tr>
<th>Transmitter Free-Surface Velocity (mm/μs)</th>
<th>Test Explosive Thickness (mm)</th>
<th>Witness Plate Thickness (mm)</th>
<th>Free-Surface Velocity (mm/μs)</th>
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<td>5.08</td>
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<td>3.85</td>
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<td>3.12</td>
<td>5.11</td>
<td>4.74</td>
<td>2.99</td>
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REFERENCES

SENSITIVITY TESTS

5. SENSITIVITY TESTS

5.1 Drop Weight Impact Text. The drop weight impact machine used at LASL is based on the design that the Explosive Research Laboratory at Bruceton, Pennsylvania developed during World War II. It consists of a free-falling weight, tooling to hold the explosive sample, and a supporting frame (Fig. 5.01).

An electronic monitoring circuit is used to distinguish between events and failures. The noise that the event creates is picked up by a microphone or pressure transducer whose output is fed to a triggering circuit. The threshold of this circuit is adjusted to place one of the standard explosives, usually TNT, at a fixed point on the drop weight impact scale.

The sample to be tested is dried, usually under vacuum, and loaded into a dimple in the center of a 6.5-cm² sheet of 5/0 garnet paper. That is the Type 12 sample configuration. A variation, the Type 12B without garnet paper, also is used.

In it the striker and anvil surfaces are roughened by sandblasting with No. 40 carborundum, and the explosive is placed on the roughened surface of the anvil. Depending on the bulk density, the sample weight varies from 30 to 40 mg. Explosives that are normally received in granular form, such as PETN, RDX, and the plastic-bonded molding powders, are tested as received. Cast explosives, such as Comp B, are ground, and the test sample is a 50/50 mixture of material that passes through a USS 16 but is retained on a USS 30 sieve and that passes through a USS 30 but is retained on a USS 50 sieve. A third sample configuration, called Type 13, is used to test liquids. A drop of liquid is placed on the anvil surface, and the lower surface of the striker is positioned approximately 3 mm above the sample. A wooden shear pin is used to locate the striker.

A standard test consists of 25 shots performed by following the 'up-and-down' testing techniques normally used in sensitivity testing, and results are reported in terms of the height at which an event is obtained 50% of the time (H₀). The intervals between drop heights used at LASL are 0.05 times the logarithm (base 10) of the preceding drop height. The logarithmic scale is used on the assumption that the heights at which events occur follow a lognormal distribution. The interval size in this method of testing is based on the standard deviation of the mean, or 50%, point.
Fig. 5.01. Drop weight impact machine, based on Explosives Research Laboratory model with Type 12 tooling.
### Table 5.01 DROP WEIGHT IMPACT RESULTS

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Result</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 12</td>
<td>Type 12B</td>
</tr>
<tr>
<td></td>
<td>$H_{50}$</td>
<td>$\sigma$</td>
</tr>
<tr>
<td>Pure Explosives</td>
<td>(cm)</td>
<td>(log)</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>2 go's at 320</td>
<td>&gt;320</td>
</tr>
<tr>
<td>Ammonium picrate</td>
<td>136 ± 0.05</td>
<td>220 ± 0.05</td>
</tr>
<tr>
<td></td>
<td>137 to &gt;320$^a$</td>
<td>220 to &gt;320$^a$</td>
</tr>
<tr>
<td>BTF</td>
<td>22.7 ± 0.17</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>45.2 ± 0.09</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>13.8 ± 0.05</td>
<td>---</td>
</tr>
<tr>
<td>DATB</td>
<td>&gt;320</td>
<td>&gt;320</td>
</tr>
<tr>
<td>DINA</td>
<td>41.1 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>DIPAM</td>
<td>85.1 ± 0.06</td>
<td>95.5 ± 0.04</td>
</tr>
<tr>
<td>DIREHAN</td>
<td>25.8 ± 0.11</td>
<td>32.8 ± 0.06</td>
</tr>
<tr>
<td>EDNA</td>
<td>42.7 ± 0.04</td>
<td>---</td>
</tr>
<tr>
<td>HMX</td>
<td>26.1 ± 0.03$^a$</td>
<td>36.0 ± 0.04$^a$</td>
</tr>
<tr>
<td></td>
<td>31.7 ± 0.05$^a$</td>
<td>29.9 ± 0.05$^a$</td>
</tr>
<tr>
<td>HNAB</td>
<td>36.6 ± 0.07</td>
<td>32.3 ± 0.11</td>
</tr>
<tr>
<td>HNB</td>
<td>15.6 ± 0.03</td>
<td>16.8 ± 0.04</td>
</tr>
<tr>
<td>HNS</td>
<td>53.7 ± 0.07</td>
<td>66.3 ± 0.04</td>
</tr>
<tr>
<td>MAN</td>
<td>64.2 ± 0.03</td>
<td>242</td>
</tr>
<tr>
<td>NC</td>
<td>49.8 ± 0.02</td>
<td>56.6 ± 0.04</td>
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<tr>
<td>NM</td>
<td>&gt;320$^b$</td>
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</tr>
<tr>
<td>NP</td>
<td>284 ± 0.01$^b$</td>
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<tr>
<td>NQ</td>
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<td>&gt;320</td>
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<tr>
<td>PETN</td>
<td>12.5 ± 0.02$^a$</td>
<td>13.9 ± 0.08$^a$</td>
</tr>
<tr>
<td></td>
<td>16.2 ± 0.05$^a$</td>
<td>20.1 ± 0.05$^a$</td>
</tr>
<tr>
<td>PNA</td>
<td>19.3 ± 0.08</td>
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## Piercates

<table>
<thead>
<tr>
<th>Material</th>
<th>Value 1 ± Error</th>
<th>Value 2 ± Error</th>
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<tbody>
<tr>
<td>Cesium</td>
<td>29.0 ± 0.12</td>
<td>30.2 ± 0.23</td>
</tr>
<tr>
<td>Lithium</td>
<td>36.3 ± 0.05</td>
<td>110.0 ± 0.06</td>
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<tr>
<td>Potassium</td>
<td>37.3 ± 0.05</td>
<td>55.9 ± 0.04</td>
</tr>
<tr>
<td>Rubidium</td>
<td>27.2 ± 0.01</td>
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</tr>
<tr>
<td>Sodium</td>
<td>58.0 ± 0.06</td>
<td>180 ± 0.01</td>
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<tr>
<td>Picric acid</td>
<td>73.0 ± 0.03</td>
<td>191 ± 0.11</td>
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<tr>
<td>Picryl azide</td>
<td>12.1 ± 0.04</td>
<td>52.6 ± 0.13</td>
</tr>
<tr>
<td>PYX</td>
<td>122 ± 0.07</td>
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</tr>
<tr>
<td>QMAN</td>
<td>&gt;320</td>
<td>&gt;320</td>
</tr>
<tr>
<td>RDX</td>
<td>23.3 ± 0.08*a</td>
<td>66 ± 0.05*a</td>
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<td>&gt;320</td>
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<td>Tetryl</td>
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<td>TNT</td>
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<tr>
<td>TPM</td>
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### Castable Mixtures

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<td>132 ± 0.07</td>
<td>40 AN/40 TNT/20 RDX wt%</td>
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<td>98 ± 0.02*a</td>
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<td></td>
<td>140 ± 0.13*a</td>
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<td></td>
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<td>Boracitol</td>
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<td>&gt;320</td>
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</tr>
<tr>
<td>Comp B</td>
<td>48.7 ± 0.01*a</td>
<td>72 ± 0.04*a</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>85 ± 0.08*a</td>
<td>300 ± 0.18*a</td>
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<tr>
<td>Comp B-3</td>
<td>45.6 ± 0.02*a</td>
<td>68.9 ± 0.02*a</td>
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<tr>
<td></td>
<td>80.4 ± 0.10*a</td>
<td>123 ± 0.10*a</td>
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</table>

*aRange of values obtained for various lots of explosive manufactured to the same material specification.

*bType 13 tool used for liquid.
<table>
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<tr>
<th>Explosive</th>
<th>Result</th>
<th>Remarks</th>
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<tr>
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<td>Type 12</td>
<td>Type 12B</td>
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<tr>
<td></td>
<td>(H_{50}) (\sigma)</td>
<td>(H_{50}) (\sigma)</td>
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<td>(cm) (log)</td>
<td>(cm) (log)</td>
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<td>Cyclotol 75/25</td>
<td>41.9 ± 0.02(^a)</td>
<td>98.6 ± 0.02(^a)</td>
</tr>
<tr>
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<td>52.0 ± 0.13(^a)</td>
<td>129 ± 0.11(^a)</td>
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<tr>
<td>Cyclotol 70/30</td>
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<td>52.7 ± 0.05</td>
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<tr>
<td>Destex</td>
<td>299 ± 0.05</td>
<td>&gt;320</td>
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<tr>
<td>Octol 75/25</td>
<td>35.0 ± 0.01(^a)</td>
<td>48.9 ± 0.01(^a)</td>
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<td>52.2 ± 0.08(^a)</td>
<td>274. ± 0.17(^a)</td>
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- **Plastic-Bonded Explosives**

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<td>95 DATB/2.5 PS/2.5 DOP</td>
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<tr>
<td>95 DATB/5 Estane</td>
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<td>&gt;320</td>
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<tr>
<td>95 DATB/5 Kel-F</td>
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<tr>
<th>HMX-Based</th>
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<tr>
<td>PBX 9011(^a)</td>
<td>44.8 ± 0.01</td>
<td>53.2 ± 0.01</td>
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<tr>
<td>PBX 9404(^a)</td>
<td>88.8 ± 0.08</td>
<td>97.5 ± 0.11</td>
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<td>PBX 9501(^a)</td>
<td>33.0 ± 0.02</td>
<td>35.0 ± 0.02</td>
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<td>PBX 9501(^a)</td>
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<td>57.0 ± 0.10</td>
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<tr>
<td>86.4 HMX/13.6 Estane(^a)</td>
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<td>57.4 ± 0.10</td>
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</tr>
<tr>
<td>93.4 HMX/6.6 Estane(^a)</td>
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</tr>
<tr>
<td>Composition</td>
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<td>DNPA Weight %</td>
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<tr>
<td>-------------</td>
<td>--------------</td>
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<tr>
<td>83 HMX/17 Teflon</td>
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<td>55.3 ± 0.01</td>
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<td>94 HMX/3.6 DNPA/2.4 NP</td>
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<td>39.8 ± 0.05</td>
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<tr>
<td>94 HMX/3 DNPA/3 CEF</td>
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<td>45.2 ± 0.05</td>
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<tr>
<td>94 HMX/3.6 DNPA/2.4 CEF</td>
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<td>62.9 ± 0.06</td>
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<td>94 HMX/4.2 DNPA/1.8 CEF</td>
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<td>48.2 ± 0.10</td>
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<td>94 HMX/4.8 DNPA/1.2 CEF</td>
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<td>46.2 ± 0.12</td>
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<tr>
<td>97 HMX/1.35 Kraton/1.65 oil</td>
<td>49.7 ± 0.05</td>
<td>59.1 ± 0.05</td>
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<tr>
<td>97 IIIMX/1.9 Kraton/1.1 wax</td>
<td>48.3 ± 0.07</td>
<td>66.0 ± 0.05</td>
</tr>
<tr>
<td>75 HMX/25 Nitroso rubber</td>
<td>49.7 ± 0.03</td>
<td>101 ± 0.04</td>
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<td>80 HMX/20 Nitroso rubber</td>
<td>53.7 ± 0.04</td>
<td>42.7 ± 0.03</td>
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<tr>
<td>85 HMX/15 Nitroso rubber</td>
<td>41.0 ± 0.04</td>
<td>39.7 ± 0.05</td>
</tr>
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<td>90 HMX/10 Nitroso rubber</td>
<td>38.2 ± 0.03</td>
<td>87 ± 0.04</td>
</tr>
<tr>
<td>95 HMX/5 Nitroso rubber</td>
<td>36.2 ± 0.02</td>
<td>46 ± 0.04</td>
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</tbody>
</table>

**HMX-Based with Metal Fill**

<table>
<thead>
<tr>
<th>Composition</th>
<th>HMX Weight %</th>
<th>Metal Weight %</th>
<th>Epoxy Weight %</th>
</tr>
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<tbody>
<tr>
<td>77.5 HMX/20 Al/2.5 Kraton oil</td>
<td>41.5 ± 0.03</td>
<td>48.3 ± 0.04</td>
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</tr>
<tr>
<td>77.6 HMX/20.4 Pb/2.0 Exon</td>
<td>40.3 ± 0.06</td>
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<tr>
<td>13.2 HMX/85.3 W/1.5 Estane</td>
<td>74.2 ± 0.05 a</td>
<td>134 ± 0.03 a</td>
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</tr>
<tr>
<td>&gt;320*</td>
<td>&gt;320*</td>
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**RDX-Based**

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<tr>
<th>Composition</th>
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<th>UO2 Weight %</th>
<th>Teflon Weight %</th>
</tr>
</thead>
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<td>87 HMX/5 UO2/8 Teflon</td>
<td>39.1 ± 0.05</td>
<td>43.9 ± 0.03</td>
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<tr>
<td>PBX 9001</td>
<td>39.1 ± 0.05</td>
<td>43.9 ± 0.03</td>
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<tr>
<td>PBX 9007</td>
<td>39.1 ± 0.05</td>
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</tr>
<tr>
<td>PBX 9010</td>
<td>30.8 ± 0.03 a</td>
<td>30.8 ± 0.03 a</td>
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<tr>
<td>Comp C</td>
<td>41.7 ± 0.06</td>
<td>36.3 ± 0.06</td>
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</tr>
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<td>PBX 9205</td>
<td>44.3 ± 0.04 a</td>
<td>47.9 ± 0.05 a</td>
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<td>PBX 9401</td>
<td>59.6 ± 0.18 a</td>
<td>55.8 ± 0.15 a</td>
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<tr>
<td>PBX 9407</td>
<td>43.5 ± 0.04</td>
<td>56.6 ± 0.09</td>
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</tr>
<tr>
<td>XTX 8004</td>
<td>37. ± 0.03 a</td>
<td>49 ± 0.05 a</td>
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</tr>
<tr>
<td>95 RDX/5 Viton wt%</td>
<td>45.6 ± 0.06 a</td>
<td>46 ± 0.08 a</td>
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</tr>
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<td>88 RDX/12 wax</td>
<td>80.4 ± 0.13</td>
<td>180 ± 0.25</td>
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<tr>
<td>92 RDX/6 PS/2 DOP</td>
<td>80.4 ± 0.13</td>
<td>180 ± 0.25</td>
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</tr>
<tr>
<td>94.2 RDX/3.2 PS/2.2 TOF</td>
<td>80.4 ± 0.13</td>
<td>180 ± 0.25</td>
<td></td>
</tr>
</tbody>
</table>
### Table 5.01 (continued)

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Result</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Type 12</td>
<td>Type 12A</td>
</tr>
<tr>
<td></td>
<td>$H_{so}$ (cm)</td>
<td>$\sigma$ (log)</td>
</tr>
<tr>
<td>RDX-Based with Metal Fill</td>
<td></td>
<td></td>
</tr>
<tr>
<td>81.8 RDX/9.1 Kel-F/0.1 Al</td>
<td>39.1 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>85.5 RDX/5.4 Exon/9.1 Al</td>
<td>19.4 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>74 RDX/20 Al/5.4 Wax/0.6 Elvax</td>
<td>50.3 ± 0.04</td>
<td>83.8 ± 0.05</td>
</tr>
<tr>
<td>74 RDX/20 Al/6 Wax</td>
<td>44.8 ± 0.04</td>
<td>80.0 ± 0.04</td>
</tr>
<tr>
<td>74 RDX/20 Al/6 Wax</td>
<td>54.8 ± 0.17</td>
<td>81.1 ± 0.14</td>
</tr>
<tr>
<td>0.5 Stearic Acid/16.2 RDX/81.5 Pb/1.4 PS/0.5 DOP</td>
<td>&gt;320</td>
<td>&gt;320</td>
</tr>
<tr>
<td>10.3 RDX/88.1 W/1.3 PS/0.3 DOP</td>
<td>&gt;320</td>
<td>&gt;320</td>
</tr>
<tr>
<td>15.4 RDX/82.6 W/1.6 PS/0.4 DOP</td>
<td>305 ± 0.06</td>
<td>---</td>
</tr>
<tr>
<td>23.9 RDX/73.4 W/2.2 PS/0.5 DOP</td>
<td>170 ± 0.08</td>
<td></td>
</tr>
<tr>
<td>HMX-TATB Mixtures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 TATB/95 HMX/2 Estane</td>
<td>39 ± 0.04</td>
<td>61 ± 0.04</td>
</tr>
<tr>
<td>3 TATB/92 HMX/5 Kel-F</td>
<td>39.9 ± 0.02</td>
<td>65 ± 0.06</td>
</tr>
<tr>
<td>38 TATB/57 HMX/5 Kel-F</td>
<td>58 ± 0.05</td>
<td>82 ± 0.06</td>
</tr>
<tr>
<td>18 TATB/72 HMX/10 Kel-F</td>
<td>52.7 ± 0.04</td>
<td>62 ± 0.15</td>
</tr>
<tr>
<td>20 TATB/70 HMX/10 Kel-F</td>
<td>74 ± 0.04</td>
<td>58 ± 0.05</td>
</tr>
<tr>
<td>36 TATB/54 HMX/10 Kel-F</td>
<td>67 ± 0.06</td>
<td>80 ± 0.08</td>
</tr>
<tr>
<td>45 TATB/45 HMX/10 Kel-F</td>
<td>156 ± 0.04</td>
<td>145 ± 0.05</td>
</tr>
<tr>
<td>45 TATB/40 HMX/10 Kel-F</td>
<td>74 ± 0.10</td>
<td>87 ± 0.05</td>
</tr>
<tr>
<td>63 TATB/27 HMX/10 Kel-F</td>
<td>&gt;320</td>
<td>185 ± 0.12</td>
</tr>
<tr>
<td>70 TATB/20 HMX/10 Kel-F</td>
<td>&gt;320</td>
<td>254 ± 0.04</td>
</tr>
<tr>
<td>RDX-Oxidizer Mixtures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 RDX/60 AN</td>
<td>45.6 ± 0.04</td>
<td>71.2 ± 0.12</td>
</tr>
<tr>
<td>40 RDX/60 MAN</td>
<td>60.3 ± 0.04</td>
<td>71.0 ± 0.09</td>
</tr>
<tr>
<td>20 RDX/80 MAN</td>
<td>68.9 ± 0.07</td>
<td>125 ± 0.17</td>
</tr>
<tr>
<td>40 RDX/45 AN/15 MAN</td>
<td>51 ± 0.04</td>
<td>125 ± 0.05</td>
</tr>
</tbody>
</table>

Aluminized PBX 9010

Aluminized PBX 9407
<table>
<thead>
<tr>
<th>Oxidizer Mixtures</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>40 RDX/48 AN/12 QMAN</td>
<td>56.8 ± 0.07</td>
<td>56.6 ± 0.08</td>
</tr>
<tr>
<td>40 RDX/40 AN/20 QMAN</td>
<td>73.7 ± 0.05</td>
<td>92.8 ± 0.07</td>
</tr>
<tr>
<td>40 RDX/30 AN/30 MAN</td>
<td>60 ± 0.03</td>
<td>114 ± 0.04</td>
</tr>
<tr>
<td>40 RDX/30 AN/30 QMAN</td>
<td>78.8 ± 0.05</td>
<td>82 ± 0.07</td>
</tr>
<tr>
<td>40 RDX/15 AN/45 MAN</td>
<td>58.4 ± 0.06</td>
<td>117 ± 0.06</td>
</tr>
<tr>
<td>50 AN/50 MAN</td>
<td>81.9 ± 0.06</td>
<td>180 ± 0.01</td>
</tr>
<tr>
<td>75 AN/25 MAN</td>
<td>104 ± 0.05</td>
<td>~225</td>
</tr>
<tr>
<td>ANFO</td>
<td>1 go at 320</td>
<td>1 go at 320</td>
</tr>
</tbody>
</table>
5.2 Skid Test. The skid test used at LASL is a modification of one designed by the Atomic Weapons Research Establishment in cooperation with the Explosives Research and Development Establishment, both of the United Kingdom. The intent of this test, sometimes called the oblique impact test, is to simulate a bare explosive charge accidentally hitting a rigid surface at an oblique angle during handling. In these circumstances, combined impact, friction, and shearing forces generate thermal energy.

In the most common version of this test, an uncased hemispherical charge, 254 mm in diameter, is dropped vertically in free fall onto a rigid target inclined at a 45° angle. In a second version, the hemispherical charge swings down in a harness on the end of a cable and strikes a rigid horizontal target at a predetermined angle.

In either version, the variables are the drop height, the angle of impact between target and explosive, and the target surface.

Two target surfaces have been used. The first is a thin (10-gauge) steel pad painted with epoxy resin sprinkled with sea sand. After curing, this surface resembles coarse sandpaper. Closekote, 80D-grit garnet paper bonded with epoxy resin to the surface of a 6.3-mm-thick Dural plate has also been used. The steel or aluminum target is placed on a rigid steel pad, 114.3 mm thick.

A standard test consists of 10 to 15 drops performed by following the up and down techniques normally used in sensitivity testing. The overpressure at a distance of 10 ft is measured with an Atlantic Research Model LC-13 pressure gauge. Results reported are the drop height that produces events in 50% of the trials and the average overpressure. This test measures each of initiation (drop height) and ease of detonation growth (overpressure).
Table 5.02 SKID TEST RESULTS

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>Impact Angle (°)</th>
<th>Target Surface</th>
<th>$H_{so}$ (ft)</th>
<th>Over-pressure (psi)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castable Explosives</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp A-3</td>
<td>---</td>
<td>45</td>
<td>Sand + epoxy</td>
<td>&gt;150</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Comp B-3</td>
<td>1.727</td>
<td>16</td>
<td>Sand + epoxy</td>
<td>9.8</td>
<td>&lt;0.5</td>
<td></td>
</tr>
<tr>
<td>Cyclotol 75/25</td>
<td>1.758</td>
<td>15</td>
<td>Sand + epoxy</td>
<td>4</td>
<td>&lt;1.0</td>
<td></td>
</tr>
<tr>
<td>Octol</td>
<td>1.810</td>
<td>45</td>
<td>Sand + epoxy</td>
<td>~75</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Octol + 1 wt% wax</td>
<td>1.805</td>
<td>45</td>
<td>Sand + epoxy</td>
<td>&gt;150</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>HMX-Based Plastic-Bonded Explosives</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LX 09</td>
<td>1.840</td>
<td>45</td>
<td>Garnet paper</td>
<td>5.7</td>
<td>~9</td>
<td>75 Class A/25 Class B HMX</td>
</tr>
<tr>
<td>PBX 9011</td>
<td>1.773</td>
<td>45</td>
<td>Garnet paper</td>
<td>78</td>
<td>&lt;0.5</td>
<td>HE cooled to -20°F</td>
</tr>
<tr>
<td>PBX 9011</td>
<td>1.773</td>
<td>45</td>
<td>Garnet paper</td>
<td>4</td>
<td>&lt;0.5</td>
<td>HMX particle-size study - 75 Class B/25 Class A HMX</td>
</tr>
<tr>
<td>PBX 9011-03</td>
<td>1.773</td>
<td>45</td>
<td>Garnet paper</td>
<td>11</td>
<td>&lt;0.5</td>
<td>25 Class B/75 Class C HMX</td>
</tr>
<tr>
<td>PBX 9011-04</td>
<td>1.773</td>
<td>45</td>
<td>Garnet paper</td>
<td>4</td>
<td>&lt;0.5</td>
<td>50 Class B/50 Class C HMX</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.847</td>
<td>45</td>
<td>Sand + epoxy</td>
<td>~4.5</td>
<td>&gt;20</td>
<td></td>
</tr>
<tr>
<td>PBX 9404 + 10 wt% wax</td>
<td>1.820</td>
<td>45</td>
<td>Sand + epoxy</td>
<td>23.1</td>
<td>---</td>
<td>93 HMX/3 NC/3 CEF/1 wax</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.837</td>
<td>45</td>
<td>Garnet paper</td>
<td>4</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.866</td>
<td>45</td>
<td>Garnet paper</td>
<td>3</td>
<td>11</td>
<td>High density</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.828</td>
<td>45</td>
<td>Garnet paper</td>
<td>4.8</td>
<td>8</td>
<td>Low density</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.837</td>
<td>45</td>
<td>Garnet paper</td>
<td>3.0</td>
<td>~15</td>
<td>Nominal density</td>
</tr>
<tr>
<td>PBX 9501</td>
<td>1.830</td>
<td>45</td>
<td>Garnet paper</td>
<td>26</td>
<td>~1.0</td>
<td>PBX 9501 with 0.5 wt% calcium stearate</td>
</tr>
</tbody>
</table>
### Table 5.02 (continued)

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>Impact Angle (°)</th>
<th>Target Surface</th>
<th>H₂₀ (ft)</th>
<th>Over-pressure (psi)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp A-3</td>
<td>1.638</td>
<td>45</td>
<td>Sand + epoxy</td>
<td>&gt;150</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>PBX 9010</td>
<td>1.786</td>
<td>45</td>
<td>Garnet paper</td>
<td>2.5</td>
<td>~15</td>
<td></td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.838</td>
<td>15</td>
<td>Quartz</td>
<td>1.8</td>
<td>~15</td>
<td>Target surface finish 1.2-2.0 μm</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.838</td>
<td>15</td>
<td>Alumina</td>
<td>~11</td>
<td>~15</td>
<td>Target surface finish 1.2-2.0 μm</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.838</td>
<td>15</td>
<td>Alumina</td>
<td>~19</td>
<td>~15</td>
<td>Target surface finish 0.5-0.9 μm</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.838</td>
<td>45</td>
<td>Gold</td>
<td>&gt;150</td>
<td>---</td>
<td>Smooth target surface</td>
</tr>
<tr>
<td>PBX 9501</td>
<td>1.830</td>
<td>45</td>
<td>Garnet</td>
<td>26</td>
<td>~1.0</td>
<td></td>
</tr>
<tr>
<td>PBX 9501</td>
<td>1.830</td>
<td>15</td>
<td>Quartz</td>
<td>~14</td>
<td>---</td>
<td>Target surface finish 200 μm</td>
</tr>
</tbody>
</table>

#### Effect of Target Surface

- Sand + epoxy: >150 ---
- Garnet paper: 2.5 ~13
- Quartz: 1.8 ~15
- Alumina: ~11 ~15
- Alumina: ~19 ~15
- Gold: >150 ---
- Garnet: 26 ~1.0
- Quartz: ~14 ---

#### Experimental Formulations

**HMX-Estane Systems**
- X-0009: --- 45 Sand + epoxy 19.7 --- 93.4 HMX/6.6 Estane
- LX-14: --- 45 Garnet 4 1.5 95.5 HMX/4.5 Estane
- X-0282: --- 45 Garnet 7.1 0.9 95.5 HMX/4.5 Estane
- X-0242: --- 45 Garnet 6.1 1.45 95.0 HMX/5 Estane

**HMX-Teflon Systems**
- X-0204: --- 45 Garnet 4.9 --- 83 HMX/17 Teflon

**HMX-Viton Systems**
- X-0215: 1.829 45 Garnet 11 2.5 90 HMX/8.5 Viton/1.5 wax/

**HMX-Kraton Formulations**
- X-0298: 1.820 45 Garnet 12.5 1.0 97.5 HMX/1.12 Kraton/1.38 high-vacuum oil
- X-0287: 1.820 45 Garnet 9.2 1.0 97.4 HMX/1.43 Kraton/1.17 wax
<table>
<thead>
<tr>
<th>HMX-DNPA-NP Formulations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X-0217-90-04-60</td>
<td>1.832</td>
</tr>
<tr>
<td>X-0217-93-01-60</td>
<td>1.835</td>
</tr>
<tr>
<td>X-0217-93-01-60</td>
<td>1.837</td>
</tr>
<tr>
<td>X-0217-94-01-75</td>
<td>1.839</td>
</tr>
<tr>
<td>X-0217-94-01-75</td>
<td>1.824</td>
</tr>
<tr>
<td>X-0217-94-01-63</td>
<td>1.818</td>
</tr>
<tr>
<td>X-0127-94-04-50</td>
<td>1.821</td>
</tr>
<tr>
<td>X-0217-94-04-60</td>
<td>1.834</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HMX-DNPA-CEF Formulations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X-0234-94-01-80</td>
<td>1.841</td>
</tr>
<tr>
<td>X-0234-94-01-70</td>
<td>1.842</td>
</tr>
<tr>
<td>X-0234-94-01-70</td>
<td>1.841</td>
</tr>
<tr>
<td>X-0234-94-01-60</td>
<td>1.844</td>
</tr>
<tr>
<td>X-0234-94-01-60</td>
<td>1.845</td>
</tr>
<tr>
<td>X-0234-94-01-50</td>
<td>1.847</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HMX-TATB-Kel-F 800 Systems</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X-0219-90</td>
<td>1.869</td>
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<tr>
<td>X-0219-70</td>
<td>1.873</td>
</tr>
<tr>
<td>X-0219-50</td>
<td>1.878</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>HMX-TATB-Estane Systems</th>
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</tr>
</thead>
<tbody>
<tr>
<td>X-0272</td>
<td>1.844</td>
</tr>
</tbody>
</table>
5.3 Large-Scale Drop Test or Spigot Test. This test, developed by LASL, is used to help assess the safety of large explosive charges subjected to combined mechanical impact and shearing and, possibly, adiabatic heating. A 6-in.-diam, 4-in.-high right circular cylinder of high explosive weighing 7-9 lb, and usually at its working density, is glued into the counterbore of an inert plastic-bonded material that has about the same shock impedance characteristics. The inert material is an 8-3/4-in.-high truncated cone with diameters of 12-3/4 in. at the top and 8-3/4 in. at the bottom. A 1/2-in.-thick Micarta plate is glued to its top surface to hold a wire sling that is used to raise the assembly. A 1/2-in.-thick steel plate glued to the bottom surface has a 3/4-in.-diam hole in its center and a 1-3/16-in.-diam, 1/4-in.-deep counterbore cut from the surface facing the HE. A steel pin with a 1-1/8-in.-diam, 1/4-in.-thick head and a 1-1/4-in.-long, 3/4-in.-diam shaft is placed through this hole so that its shaft protrudes from the bottom of the HE. As assembled, the head of the steel pin is separated from the bottom surface of the explosive by a 0.35- to 0.50-mm gap and the shaft extends 25 mm beyond the bottom surface of the steel plate.

A test normally consists of 20 drops performed by following the up-and-down technique. The results are reported in terms of the drop height that produces events in half of the trials and of the magnitude of the event.

![Drop test assembly diagram](image-url)
<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density (g/cm³)</th>
<th>H₉₀ (ft)</th>
<th>Type of Event</th>
<th>Over-pressure (psi)</th>
<th>Average Air Gap (mils)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Castable Explosives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp B-3</td>
<td>1.726</td>
<td>85</td>
<td>P</td>
<td>---</td>
<td>---</td>
<td>U.K. Octol with 1 wt% wax</td>
</tr>
<tr>
<td>EDC-1</td>
<td>1.766</td>
<td>110</td>
<td>P</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Octol</td>
<td>1.810</td>
<td>45</td>
<td>P</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Octol + 1 wt% wax</td>
<td>1.805</td>
<td>~150</td>
<td>P</td>
<td>---</td>
<td>---</td>
<td>Very low order, partial</td>
</tr>
<tr>
<td><strong>Plastic-Bonded HMX</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBX 9011</td>
<td>1.773</td>
<td>96</td>
<td>P</td>
<td>~0.2</td>
<td>0.040</td>
<td></td>
</tr>
<tr>
<td>PBX 9404</td>
<td>1.835</td>
<td>49</td>
<td>E</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>PBX 9404 + 1 wt% wax</td>
<td>1.820</td>
<td>~110</td>
<td>D</td>
<td>---</td>
<td>0.030</td>
<td>Detonation</td>
</tr>
<tr>
<td>PBX 9501</td>
<td>1.830</td>
<td>&gt;150</td>
<td>P</td>
<td>---</td>
<td>0.030</td>
<td>1 partial in 8 drops from 150 ft</td>
</tr>
<tr>
<td>LX-10</td>
<td>1.863</td>
<td>75</td>
<td>D</td>
<td>30.0</td>
<td>0.030</td>
<td>Events were detonation</td>
</tr>
<tr>
<td>LX-09</td>
<td>1.842</td>
<td>~90</td>
<td>D</td>
<td>27.0</td>
<td>0.040</td>
<td>Events were detonation</td>
</tr>
<tr>
<td><strong>Plastic-Bonded RDX</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp A-3</td>
<td>1.638</td>
<td>&gt;150</td>
<td>P</td>
<td>---</td>
<td>---</td>
<td>2 events in 18 trials from 150 ft</td>
</tr>
<tr>
<td>PBX 9010</td>
<td>1.786</td>
<td>66</td>
<td>E</td>
<td>---</td>
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<td>HMX-DATB Systems</td>
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<tr>
<td>X-0143</td>
<td>---</td>
<td>~106</td>
<td>D</td>
<td>---</td>
<td>0.020</td>
<td>85.6 HMX/9.2 DATB/5.2 Estane</td>
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<tr>
<td>HMX-DATB-Viton</td>
<td>1.839</td>
<td>~130</td>
<td>E</td>
<td>5.0</td>
<td>---</td>
<td>70 HMX/20 DATB/10 Viton</td>
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<tr>
<td>HMX-NP-DNPA Systems</td>
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<tr>
<td>X-0217-94-04-60</td>
<td>---</td>
<td>~150</td>
<td>E</td>
<td>---</td>
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<td>94 HMX/3.6 NP/2.4 DNPA</td>
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<td>HMX-Teflon Systems</td>
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<td>X-0204</td>
<td>---</td>
<td>~53</td>
<td>P</td>
<td>---</td>
<td>---</td>
<td>85 HMX/15 Teflon</td>
</tr>
</tbody>
</table>

---

*a* Partial explosion with most of the explosive unreacted. *E* = explosion with some of the explosive unreacted. *D* = detonation with all of the explosive reacted.

*b* Air gap between the head of the pin and the explosive.
5.4 Spark Sensitivity. The spark sensitivity of an explosive is determined by subjecting the explosive to a high-voltage discharge from a capacitor. The discharge energy is increased and decreased until the spark energy that produces initiation in half, and only half, of the explosive samples is found.

The explosive sample is placed in a holder like that shown in Fig. 5.03. A polystyrene sleeve is cemented around a steel dowel leaving a 3/16-in.-diam by 1/4-in.-high space to contain the sample. The sample is placed in the sleeve and covered with a lead-foil disk. A polystyrene ring is then clamped over the polystyrene sleeve to hold the foil and sample in place.

The steel dowel provides the ground plane for the electrical circuit. To induce a spark, a needle, charged at high voltage, moves toward and penetrates the lead disk and then is retracted. The discharge takes place when the needle has penetrated the disk and a spark passes through the explosive to the grounded steel dowel. Spark initiation of the explosive is evidenced by a ruptured lead disk; otherwise, the disk is intact except for a single puncture.

The charged needle is moved in and out by a sewing-machine-like mechanism with a stroke duration of about 0.04 seconds. The needle is electrically connected to a variable-capacitance capacitor bank that is, in turn, connected to a variable power supply. Various combinations of voltage and capacitance can be selected to produce the variable spark energy required for the test. The energies given in the tables are found using $E = \frac{1}{2} CV^2$, where $C =$ capacitance in farads, $V =$ potential in volts, and $E =$ spark energy in joules.

![Exploded view of sample holder.](image)
## SENSITIVITY TESTS

### Table 5.04 SPARK SENSITIVITY

<table>
<thead>
<tr>
<th>Explosive</th>
<th>0.076-mm Foil</th>
<th>0.254-mm Foil</th>
<th>Comments</th>
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<tr>
<td>Pure Explosives</td>
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<tr>
<td>ABH</td>
<td>0.82</td>
<td>2.92</td>
<td>23% explosions</td>
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<tr>
<td>HMX</td>
<td>0.23</td>
<td>1.42</td>
<td>Brass electrode</td>
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<tr>
<td>ICMP</td>
<td>1.93</td>
<td>4.04</td>
<td></td>
</tr>
<tr>
<td>Lead chromate</td>
<td>1.03</td>
<td>6.50</td>
<td>Tested at 125°C</td>
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<tr>
<td>PADP</td>
<td>0.42</td>
<td>1.90</td>
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<tr>
<td>HNAB</td>
<td>0.37</td>
<td>1.38</td>
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<tr>
<td>PETN</td>
<td>0.19</td>
<td>0.75</td>
<td>8% explosions</td>
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<tr>
<td>Potassium picrate</td>
<td>0.73</td>
<td>0.54</td>
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<tr>
<td>PYX</td>
<td>1.17</td>
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</tr>
<tr>
<td>RDX</td>
<td>0.22</td>
<td>0.55</td>
<td>Brass electrode</td>
</tr>
<tr>
<td>TACOT</td>
<td>--</td>
<td>16.83</td>
<td></td>
</tr>
<tr>
<td>TCTNB</td>
<td>0.38</td>
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<td>3.83</td>
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<td>4.00</td>
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<tr>
<td>Composition A</td>
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<td>4.38</td>
<td>0% explosions</td>
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<td>Detasheet</td>
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<tr>
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<td>2.77</td>
<td>33% explosions</td>
</tr>
<tr>
<td>PBX 9404</td>
<td>0.42</td>
<td>3.13</td>
<td>0% explosions</td>
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<tr>
<td>X-0298</td>
<td>0.5</td>
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<tr>
<td>LX-04</td>
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<td>2.58</td>
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<tr>
<td>PBX 9010</td>
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<td>PBX 9205</td>
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</tr>
<tr>
<td>PBX 9407</td>
<td>0.42</td>
<td>3.13</td>
<td>0% explosions</td>
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GLOSSARY

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ABH</td>
<td>Azo-bis (2,2',4,4',6,6'-hexanitrobenzene), C_{26}H_{14}N_{24}O_{24}</td>
</tr>
<tr>
<td>Amatex-20</td>
<td>X-0284</td>
</tr>
<tr>
<td>ATNI</td>
<td>Ammonium 2,4,5-trinitroimidazole, C_{6}H_{4}N_{6}O_{6}</td>
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<tr>
<td>BDNPA</td>
<td>Bis-dinitropropyl acetal</td>
</tr>
<tr>
<td>BDNPF</td>
<td>Bis-dinitropropyl formal</td>
</tr>
<tr>
<td>BTF</td>
<td>Benzotrioxane (Benzotris-1,2,5-oxadiazole-1-oxide), C_{6}N_{6}O_{6}</td>
</tr>
<tr>
<td>CEF</td>
<td>Tris-beta chloroethylphosphate</td>
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</tbody>
</table>
| Cell parameters | a, b, c Lengths of unit cell edges along x, y, z axis  
|              | α, β, γ Interaxial angles α(b,c), β(a,c), γ(a,b) |
| Destex       | 74.8 wt% TNT, 18.7 wt% aluminum 4.7 wt% wax, and 1.9 wt% graphite; also called X-0309 |
| DINA         | Di(nitroethyl) nitramine, C_{6}H_{4}N_{4}O_{4} |
| DNPA         | 2,2'-Dinitropropyl acrylate, C_{16}H_{12}N_{2}O_{6} |
| DNT          | Dinitrotoluene |
| DODECA       | 2,2',2'',4,4',4'',6,6',6'',6'''-Dodeca-nitro-m-m'-quaraphenyle, C_{64}H_{36}N_{4}O_{24} |
| DOP          | Di-2-ethylhexyl phthalate, C_{24}H_{36}O_{4} |
| EDC-1        | Another name for octol |
| EDNA         | Ethylene dinitramine, C_{6}H_{4}N_{4}O_{4} |
| Elvax        | A copolymer of ethylene and vinyl acetate |
Estane
A polyester polyurethane

EXON-461
A fluorinated thermoplastic resin

FEFO
Bis(1-fluoro-2,2-dinitroethyl) formal, $C_9H_4N_4O_{10}F_2$

HNAB
$2,2',4,4',6,6'-$Hexanitroazobenzene, $C_{12}H_4N_6O_{12}$

Bis-HNAB
$2,2',4,4',6,6',6'^{-}$-Dodecanitro-$3,3'$-bis(phenylazo) biphenyl, $C_{26}H_{26}N_6O_{24}$

HNB
Hexanitrobenzene, $C_9N_6O_{12}$

HNBP
$2,2',4,4',6,6'$-Hexanitrophenyl, $C_{12}H_4N_6O_{12}$

Indices of refraction
The ratio of the velocity of light in two contrasting substances is a constant and is called the refractive index. The absolute refractive index of a substance is its index with respect to a vacuum; this has practically the same value as the index against air. Solid crystalline materials are either isotropic or anisotropic. Isotropic materials have a single index of refraction. Anisotropic crystals of hexagonal or tetragonal systems exhibit, for monochromatic light vibrating parallel to the 'c' axis, a unique index of refraction customarily symbolized as epsilon. For all vibrations directed at 90° to the 'c' axis the refractive indices all equal a common value symbolized as omega. Anisotropic biaxial crystals belong to the orthorhombic, monoclinic, or triclinic system and possess three significant indices of refraction symbolized as alpha, beta, and gamma.

Kel-F 800
Chlorofluoroethylene polymers

Kel-F 827

LX-09
A high-explosive formulation developed by the Lawrence Livermore Laboratory consisting of 93 wt% HMX, 2.4 wt% FEFO, and 4.6 wt% DNPA

LX-14
A high-explosive formulation developed by the Lawrence Livermore Laboratory consisting of 95.5 wt% HMX and 4.5 wt% Estane

MAN
Methyl amine nitrate, $CH_4N_2O_3$

NC
Nitrocellulose

NONA
$2,2',2'',4,4',4'',6,6'',6'''^{-}$-Nonanitroterphenyl, $C_{18}H_4N_6O_{12}$
NP  Nitroplasticizer
OFHC  Oxygen-free high conductivity
ONT  2,2',4,4',4'',6,6',6''- Octanitro-m-terphenyl, C₁₈H₆N₄O₁₆
P-16  A conical explosive lens with a base of 1.6 inches, designed to generate a plane detonation
P-22  A conical explosive lens with a base of 2.2 inches, designed to generate a plane detonation
P-40  A conical explosive lens with a base of 4.0 inches, designed to generate a plane detonation
P-80  A conical explosive lens with a base of 8.0 inches, designed to generate a plane detonation
P-120 A conical explosive lens with a base of 12.0 inches, designed to generate a plane detonation
PADP  2,6-Bis(picrylazo)-3,5-dinitropyridine, C₁₇H₁₂N₁₂O₁₆
PATO  3-Picrylamino-1,2,4-triazole, C₅H₅N₇O₆
PC  A thermoplastic polycarbonate
PENCO  2,2',4,4',6-Pentanitrobenzophenone, C₁₃H₅N₅O₁₁
PMMA  Any of several polymethylmethacrylates
PS  Polystyrene
PYX  2,6-Bis(picrylamo)-3,5-dinitropyridine, C₁₇H₁₇N₁₅O₁₆
QMAN  Tetramethylammonium nitrate, C₄H₁₂N₂O₃
Sauereisen  A brand name of an acid-proof cement
Susan Test  This projectile impact sensitivity test was developed by the Lawrence Livermore Laboratory. The high-explosive test sample configured in the form of a right circular cylinder and weighing about 0.45 kg is loaded into an aluminum cap, which becomes the head of a steel-bodied projectile. Projectiles containing the test explosive in the nose cap are fired from a gun at progressively increasing velocities against a rigid steel target. The overpressure resulting from the impact or from subsequent events such as explosions or detonations are determined. Results are generally reported as a single sensitivity curve with overpressure, normalized...
to a point source detonation, plotted as a function of the projectile velocity. A more complete description of the test may be obtained in a paper by L. G. Green and G. D. Dorough published in the *Fourth Symposium (International) on Detonation* (Office of Naval Research, ACR-126, October 1965).

<table>
<thead>
<tr>
<th>Symbol</th>
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<tr>
<td>Sylgard</td>
<td>Low-temperature vulcanizing silicone resin</td>
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<tr>
<td>T-TACOT</td>
<td>1,3,8,10-Tetranitrobenzotriazolo-1,2a-benzotriazole, C_{18}H_{16}N_{6}O_{6}</td>
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<td>Z-TACOT'</td>
<td>1,3,7,9-Tetranitrobenzotriazolo-2,1a-benzotriazole, C_{18}H_{16}N_{6}O_{6}</td>
</tr>
<tr>
<td>TCTNB</td>
<td>Trichlorotrinitrobenzene, C_{6}N_{3}O_{6}Cl_{3}</td>
</tr>
<tr>
<td>TNN</td>
<td>1,4,5,8-Tetranitronaphthalene, C_{16}H_{14}N_{4}O_{6}</td>
</tr>
<tr>
<td>TNS</td>
<td>Trinitrostilbene, C_{14}H_{12}N_{2}O_{6}</td>
</tr>
<tr>
<td>TOF</td>
<td>Trioctylphosphate, a plasticizer</td>
</tr>
<tr>
<td>TPB</td>
<td>1,3,5-Tripicrylbenzene, C_{22}H_{26}N_{3}O_{18}</td>
</tr>
<tr>
<td>TPM</td>
<td>Tripicrylmelamine, C_{21}H_{25}N_{18}O_{18}</td>
</tr>
<tr>
<td>TPT</td>
<td>2,4,6-Tripicryl-s-triazine, C_{21}H_{18}N_{12}O_{18}</td>
</tr>
<tr>
<td>Viton</td>
<td>A fluoroelastomer</td>
</tr>
<tr>
<td>Wax</td>
<td>Any of a series of petroleum-based paraffins</td>
</tr>
<tr>
<td>XTX</td>
<td>EXTrudable eXplosive</td>
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