THE RELEVANCE OF THE De BROGLIE VELOCITY 
\( V_1 = \frac{h}{2md_1} \) TO SHOCK LOADING INDUCED 
REACTIONS IN LEAD AZIDE

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September 1991

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**Title** (Include Security Classification)

The Relevance of the De Broglie Velocity ($V_1 = \frac{h}{2md_1}$) to Shock Loading Induced Reactions in Lead Azide

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**Type of Report**

Final

**Time Covered**

From Apr 90 to Apr 91

**Date of Report (Year, Month, Day)**

September 1991

**Page Count**

30

**Abstract**

Available experimental shock induced reactive pressure levels for dextrinated and single crystal lead azide are compared to predicted $P_v$ magnitudes. $P_v = \rho_0 C_L V_1$ where $V_1 = \frac{h}{2md_1}$ is the De Broglie velocity. The comparison is favorable and it is suggested that particle motion instability near $V_1$ magnitudes (the "$V_1$ Effect") is responsible for the observed reactions in these marginally stable materials. Similar comparative analyses for other primary energetic materials are needed to further evaluate the "$V_1$ Effect" on these substances.
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I. INTRODUCTION

Reference 1 contained information which indicated that there may be a correlation between experimentally observed Hugoniot Elastic Limit (HEL)/Elastic Plastic Shock Phenomena (EPSP) and the De Broglie velocity, $V_1$ (Section II). Since the publication of Reference 1, the shock physics literature has been searched for additional examples where the De Broglie influence is evident or suspected.

Data have been found which indicate that certain energetic materials can respond to $V_1$ magnitude particle velocities in dramatic manner. That is, particle velocities on the order of $V_1$ produce lattice disturbances sufficient to initiate unstable chemical reactions or atomic rearrangement of a marginally stable substance.

Lead azide ($PbN_6$), both in mixed and Single Crystal (S. C.) forms, exhibits this characteristic. Comparative documentation of this statement for lead azide is contained in Section IV of this report.

The importance of $V_1$ magnitude particle velocities with regard to initiating detonation in primary or sensitive explosives is not a new idea. It was suggested by Fitzgerald [21 in 1969. He showed that $V_1$ and the explosive material critical particle velocities from drop tests compared reasonably well. The present report compares $V_1$ effect predictions with experimental data in cases where the dynamic loading was applied by metal plate impact.
II. THE DE BROGLIE PARTICLE VELOCITY, \( V_1 = \frac{h}{2md_1} \)

Fitzgerald [3, Chpts 1 and 3] delineated the importance of the De Broglie momentum: wave–wave length particle velocity, \( V_1 \), with regard to impacted solid material behavior. The De Broglie velocity, \( V_1 \), is:

\[
V_1 = \frac{h}{2md_1} = \frac{h}{m\lambda_1}
\]

Where:

\( V_1 \) = Limiting particle velocity which can occur without permanent lattice distortion (plastic flow); or the limit particle propagation velocity in a stationary lattice. Units are cm/sec or km/sec [1].

\( h \) = Planck’s Constant
\( = 6.6262 \times 10^{-27} \text{(gram)(cm}^2)/\text{sec} \)

\( m \) = Mass of one atom, grams

\( d_1 \) = Closest distance between the atoms in a crystal lattice, or the atomic spacing in a slip direction, units are cm or angstroms, A, \((1 \text{ A} = 10^{-8} \text{cm})\).

\( \lambda_1 \) = \( 2d_1 \) = wave length associated with the momentum, \( mV_1 \). It is the shortest wave length possible in an undistorted lattice or stationary lattice, cm or A.

Table 1 lists longitudinal elastic wave velocity, \( C_L \), information for the materials considered in this report. Also shown in Table 1 is the elastic wave pressure, \( P_{v1} \), corresponding to the wave velocity, \( C_L \), and the particle velocity, \( V_1 \). This is given by:

\[
P_{v1} = \rho_0C_LV_1
\]

where \( \rho_0 \) is the material density (grams/cc).
III. FITZGERALD'S PARTICLE VELOCITY STABILITY CRITERIA

Fitzgerald, utilizing his concept of reversed lattice motion [3, Chapter 3], shows states with particle velocities ranging from approximately 0.50 \( V_1 \) to 0.75 \( V_1 \) are unstable. Velocities can jump to values higher than \( V_1 \). Particle velocities in the immediate region around \( V_1 \) appear to be stable. In addition, Fitzgerald also showed \( 2V_1 \) was an important unstable velocity where excessive distortion would occur.

Thus, there are three important velocity ranges/values:

1. 0.50 \( V_1 \) to 0.75 \( V_1 \); unstable state, velocities may jump to a magnitude greater than \( V_1 \).
2. \( V_1 \) vicinity; apparently a stable state.
3. \( V_1 \) to \( 2V_1 \); unstable, particle velocities in this region will approach \( V_1 \) under “long-term” operating conditions. Ample time is necessary to allow particle momentum sharing with a sufficient number of lattice masses [3, pp. 72 – 74]. This, by definition, is a relaxation time.

Since interest is in characterization of responses of those cases in which the particle velocity, \( U_p \), is of the same magnitude as \( V_1 \), we have examined published experimental shock data for that dynamic regime. We have partitioned responses into four, not necessarily exclusive, categories. They are in order of severity.

1. No permanent change in structure and/or properties.
2. Some alteration of properties.
3. Classic HEL/EPSP behavior.
4. Significant alteration of structure to include detonation.

Some examples of particle velocity effects in categories 1, 2, and 3 are under investigation and will be documented as time and circumstances permit. Single examples of “\( V_1 \) Effects” (including those in Reference 1 and the present report) are not conclusive proof that the “\( V_1 \) Effect” is the “root cause” of the phenomena. However, as more suspected “\( V_1 \) Effects” examples are documented, the probability of fortuitous circumstances or mere chance occurrence is decreased.

In materials with marginally stable cohesiveness, the lattice perturbation from “\( V_1 \) Effects” may be sufficient to upset the rather precarious atomic arrangement and violent rearrangement (detonation) occurs. Certain so-called primary (or very sensitive) explosives fall into this category. The present report provides some “\( V_1 \) Effect” comparative evidence for lead azide which is a foremost primary explosive [5].

“Suspected \( V_1 \) effect” phenomena examples are not necessarily easy to document. The following information is needed.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ( m ) or ( m_{AV} ) and ( d_1 ) or ( d_{1AV} )</td>
<td>To compute ( V_1 ), for elements and certain compounds, this may not be difficult, but complex compounds or complex lattice structures may pose a debatable judgmental problem.</td>
</tr>
</tbody>
</table>
2. Shock velocity, \( U_s \), or elastic wave velocity, \( C_L \), as a function of particle velocity, \( U_p \).

3. Experimental shock induced reactive information as a function of \( U_p, U_s, \) and \( P_s \).

The above information should be for the same material (same composition; same density, \( \rho_0 \); same manufacturing history, etc.) or credibility will suffer. It is difficult to assemble this information for the same consistent material. Examples of this difficulty are evident in Section IV.

IV. EXPERIMENTAL REACTIVE SHOCK PressURES AND COMPARISON WITH \( P_v_1 \) PREDICTIONS

A. Dextrinated Lead Azide (DLA)

DLA is a mixture of lead azide and dextrin. Dextrination of lead azide provides handling and safety benefits [5, Vol. 2, Chpt. 1]. Reference 4 contains systematic experimental shock data for dextrinated lead azide (DLA) mixtures. The shock loading was accomplished via plate impact and exploding foil impact. Table 1 of Reference 4 lists shock pressure (\( P_s \)) data as a function of travel distance (\( T \)) in the DLA specimen (\( \rho_0 = 3.41 \text{ g/cc} \)). This information is plotted in Figure 1 of the present report. Note that for \( P_s \) \( < \) 4.0 kbars, the pressure remains relatively constant with travel distance (or time).

However, for \( P_s \) \( \geq \) 6.0 kbars, the pressure remains practically constant for a short distance and then increases rather abruptly in a step function fashion. This rapid pressure increase is an indication that detonation has begun. Consequently, the critical shock pressure to cause detonation via plate impact lies between 4.0 and 6.0 kbars. This critical pressure region for DLA with \( \rho_0 = 3.41 \text{ g/cc} \) is also plotted in Figure 2. It contains experimental shock induced firing stimulus data for DLA as a function of material density (\( \rho_0 \)) [6]. These results were acquired via Small Scale Gap Testing (SSGT). The SSGT results for \( \rho_0 = 3.41 \text{ g/cc} \) indicate an ignition at 3.0 kbars. This is approximately the impulse pressure necessary for a 50 percent detonation probability for DLA which was estimated using steel ball-drop test results [19]. This pressure was \( 2.8 \times 10^9 \text{ dyne/cm}^2 \) which is 2.80 kbars.

Also shown in Figures 1 and 2 are \( P_v_1 \) indicators where \( V_1 \) was computed via Equation 1 with the following atomic mass and interatomic distances:

a. Nitrogen atom, \( m_n \), and the average distance between atoms \( (d_{IN-N} = 1.18 \text{ Å}) \) in an azide group ([7] for S. C. \( \alpha - \text{PbNx} \)).

b. Nitrogen atom, \( m_n \), and the shortest distance between the \( N_3 \) azide ion groups ([8, p. 985]; N5 atom; azide II to N10 atom, azide IV). This distance is \( d_{IA-A} = 2.95 \text{ Å} \).
Table 1 contains numerical values for $V_1$ and $P_{v1}$. The elastic wave velocity ($C_{1e}$) employed to compare $P_{v1}$ was 1.223 km/sec which is given in Reference 4 for DLA ($\rho_0 = 3.41$ g/cc). The interatomic distances are for the $\alpha - PbN_6$ crystal since DLA is composed of small lead azide crystals surrounded by dextrin [5, Vol. 2, p. 29].

The nitrogen atom mass and interatomic distances were employed to compute $V_1$ since it is the destabilized $N_3$ azide ion groups which will recombine to form $N_2$ gas in an exothermic reaction [5, Vol. 1, pp. 195 and 452].

$$2N_3 \rightarrow 3N_2 + \text{HEAT ENERGY} \tag{3}$$

Now according to Garner [9]:

"Sufficient energy is set free to activate three or four neighboring $N_6$ groups if this energy were all available for this purpose. A chain reaction is thus a possibility."

Garner [9] also says that actually two or three adjacent $N_6$ ion groups would have to decompose simultaneously (within $10^{-13}$ sec) to produce a self-sustaining detonation wave. This would be an explosion nuclei, or the beginning of a "hot spot."

Note also the remarks of Soderquist [10] in regard to sensitiveness and decomposition of copper (II) azide, $Cu(N_3)\_2$. He suggests that $N_2$ gas will be released and will propagate rapidly in the channels or voids in the atomic lattice. He also says that the $N - N$ distances in the $N_3$ azides ($d_1 \approx 1.18 \text{ Å}$) are close to the observed distances ($1.10 \text{ Å}$) for dinitrogen gas ($N_2$).

This probably accounts for the sensitivity of $PbN_6$ and $CuN_6$ since the "$V_1$ Effect" would only have to perturb the azide atoms a small amount ($\leq 0.10 \text{ Å}$) to destabilize the precarious arrangement.

In Figure 1, $Pv_1$, for $V_1$ where $d_{1N-N} = 1.18 \text{ Å}$ was employed, is 5.0 kbars which lies between the 4.0 and 6.0 kbar critical limits established by plate impact testing. $Pv$, for $V_1$ where $d_{1A-A} = 2.95 \text{ Å}$ is 2.0 kbars and is somewhat less than this 4.0 to 6.0 kbar critical region. However, this $Pv_1$ value (2.0 kbars) is comparable to the SSGT result (3.0 kbars) for a 50 percent probability of ignition.

Considering the differences in the experimental testing and the judgmental $V_1$ computations, the $Pv_1$ predictions and the experimental results exhibit reasonable agreement.

It is worth noting that if the lead atom mass $mpb$, and distances ($d_{1pb - p_b}$), are utilized for $Pv_1$ predictions, then $V_1$ is exceptionally small and $Pv_1$ is much less than 1.0 kbar. Perhaps this is an explanation of the extreme sensitivity of lead azide which is occasionally mentioned. However, DLA ($\rho_0 = 3.41$ g/cc) was not this sensitive, so that "$V_1$ Effects," based on lead atom parameters were considered unlikely for this density. However, the dextrin’s presence could negate this extreme sensitivity so that lead atom motion cannot be entirely ruled out.
B. Single Crystal Lead Azide (S. C. \( \text{PbN}_6 \))

Reference 8 states that there are four polymorphic forms of lead azide. These are designated as the \( \alpha, \beta, \gamma, \) and \( \delta \) forms. Crystal structure investigations of \( \alpha - \text{PbN}_6 \) are documented in References 7 and 8. Although only two elements are present, the lattice structure is rather complex.

Chaudhri [11] performed a shock induced initiation study of S. C. \( \beta - \text{PbN}_6 \) via the impact of thin steel plates. Four significant data points from this investigation for different impact velocities, \( V_1 \), are as follows:

- \( V_1 \geq 105 \text{ m/s} \), detonation always occurred.
- \( V_1 = 95 \text{ m/s} \), initiation of fast reaction.
- \( V_1 = 90 \text{ m/s} \), initiation did not occur.
- \( V_1 \leq 75 \text{ m/s} \), detonation never occurred.

The initial pressure, \( P_s \), at the impact interface is given by:

\[
P_s = \left( \frac{\rho_1 w_1 \rho_2 w_2}{\rho_1 w_1 + \rho_2 w_2} \right) V_1
\]

This is written in Reference 11 notation where the Index 1 refers to \( \beta - \text{PbN}_6 \) and the Index 2 refers to the steel plate. Numerical values are as follows:

- \( \rho_1 = 4.93 \text{ g/cc} \) = S. C. \( \beta - \text{PbN}_6 \) density.
- \( w_1 = 2.00 \text{ km/sec} \) = wave front velocity in S. C. \( \beta - \text{PbN}_6 \).
- \( \rho_2 = 7.84 \text{ g/cc} \) = steel density.
- \( w_2 = 5.85 \text{ km/sec} \) = wave front velocity in steel.

Also at the contact interface:

\[
P_s = \rho_1 w_1 U_{p1} = \rho_2 w_2 U_{p2}
\]

So that:

\[
U_{p1} = \frac{P_s}{\rho_1 w_1} = \text{particle velocity in S. C. } \beta - \text{PbN}_6
\]

\[
U_{p2} = \frac{P_s}{\rho_2 w_2} = \text{particle velocity in steel}
\]
In addition, the sum of the particle velocities at the contact interface is equal to \( V_1 \), which can serve as a check on the computations.

\[ V_1 = U_{p1} + U_{p2} \quad (8) \]

Table 2 contains numerical values of the impact pressures and particle velocities for the four impact conditions listed above. The pressures are also listed below.

\[ V_1 = 105 \text{ m/s, } P_s = 8.5 \text{ kbars.} \]
\[ V_1 = 95 \text{ m/s, } P_s = 7.7 \text{ kbars.} \]
\[ V_1 = 90 \text{ m/s, } P_s = 7.3 \text{ kbars.} \]
\[ V_1 = 75 \text{ m/s, } P_s = 6.1 \text{ kbars.} \]

Indicator symbols for these \( P_s \) values are shown in Figure 2 on the dotted line for S. C. \( \beta - \text{PbN}_6 \) (\( \rho_0 = 4.93 \text{ g/cc} \)).

\( V_1 \) and \( P_{v1} \) were not computed for S. C. \( \beta - \text{PbN}_6 \) since the authors were unable to locate a source for the interatomic distances (which are probably similar to those found for \( \alpha - \text{PbN}_6 \)). Also there is some uncertainty about what value of \( w_1 \) to utilize in the S. C. \( \beta - \text{PbN}_6 \) \( P_{v1} \) computations.

Chaudhri and Field [12, p. 308] say that the longitudinal wave velocity for S. C. \( \beta - \text{PbN}_6 \) varies from 1.85 to 2.45 km/sec. As noted above, Chaudhri [11] suggests a wave velocity (\( w_1 \)) equal to 2.00 km/sec for S. C. \( \beta - \text{PbN}_6 \). However, this value of \( w_1 \) yields \( P_s = 8.5 \) kbars for \( V_1 = 105 \) m/sec. This differs from the 9.5 kbars mentioned for \( V_1 = 105 \) m/sec which may have merely been suggested as an approximate impact pressure for this condition. If \( w_1 = 2.25 \) km/sec, then \( P_s = 9.4 \) kbars.

Rather than speculate to some extent on both \( V_1 \) and \( C_L \) (or \( w_1 \)), \( P_{v1} \) for S. C. \( \beta - \text{PbN}_6 \) was not computed. However, \( P_{v1} \) was computed for \( \alpha - \text{PbN}_6 \). The \( V_1 \) values are the same as discussed in Part A of this section, since they are were based on \( \alpha - \text{PbN}_6 \) nitrogen bond length data from References 7 and 8. The elastic wave front velocity (\( C_L \) or \( w_1 \)) for S. C. \( \alpha - \text{PbN}_6 \) was determined from Young’s modulus (\( E_{<100>} \)) information contained in Reference 13.

The elastic wave front velocity (\( C_L \)) in S. C. \( \alpha - \text{PbN}_6 \) is:

\[ C_L = \sqrt{\frac{E_{<100>}}{\rho_0}} = 1.856 \text{ km/sec} \quad (9) \]

\[ = \text{velocity in } <100> \text{ direction} \]

\[ E_{<100>} = 1.62 \times 10^{10} \text{ Newtons/(meter)}^2 \]
\[ = 16.2 \times 10^6 \left(\frac{g}{\text{cc}}\right) \left(\frac{\text{cm}}{\text{sec}}\right)^2 \quad (10) \]

\[ = \text{Young’s modulus from tensile tests in } <100> \text{ direction.} \]
This $C_L$ value for S. C. $\alpha - PbN_6$ appears reasonable in view of the wave velocities discussed above for S. C. $\beta - PbN_6$.

The $\text{Pv}_1$ values (4.2 and 10.5 kbars) for S. C. $\alpha - PbN_6$ bracket the experimental critical $P_s$ magnitudes (6.1 to 8.5 kbars) for S. C. $\beta - PbN_6$. This is still true if the experimental values should be increased about a kilobar since $C_L$ may be about 2.25 km/sec instead of 2.00 km/sec as discussed above. The critical particle velocities in the S. C. $\beta - PbN_6$ are obviously close to $V_1$ magnitudes so that instability due to a perturbing $V_1$ effect is feasible.

Fox [13] indicates that shock pressures of approximately one kilobar ($\sigma_{CR} \approx 1.0$ kbar) are sufficient to cause an explosive reaction in S. C. $\alpha - PbN_6$. These results were obtained for very small crystals (length = 1 mm) via a microtensile testing machine described in Reference 14. From Figure 2 of Reference 13, the maximum tensile stress as a function of strain rate for fresh lead azide is $14.0 \times 10^7$ n/m$^2$ or 1.4 kbars. This point ($\sigma_{CR} = 1.4$ kbars) is shown in Figure 2 on the S. C. $\alpha - PbN_6$ indicator line. Its magnitude is obviously much less than the $\text{Pv}_1$ predictions (based on nitrogen parameters) and plate impact experimental results [11] for S. C. $\beta - PbN_6$.

Consequently, it is recommended that plate impact testing of S. C. $\alpha - PbN_6$ crystals be performed in a manner similar to that for S. C. $\beta - PbN_6$ [11]. Larger S. C. $\alpha - PbN_6$ should be employed than utilized by Fox [13]. In Reference 8, it is noted that S. C. $\alpha - PbN_6$ was available in prism form which was 3 mm thick, 5 mm wide, and 8 mm long. This is much larger than the tensile test specimen [13] which were only about 1.0 mm long. In Reference 7, it is noted that their work was made possible by an advancement in growing lead azide crystals which is documented in Reference 15. If possible, it is recommended that these relatively large, stable $\alpha - PbN_6$ crystals be tested via flat plate impact for comparison with the S. C. $\beta - PbN_6$ results reported in Reference 11 and the present $\text{Pv}_1$ predictions.
V. CONCLUSIONS

From the comparative analysis presented in Section IV, it is apparent that the plate impact and SSGT induced shock pressures (or particle velocities), sufficient to cause detonation in lead azide, are very close to feasible $P_{V_1}$ pressures (or $V_1$ magnitude particle velocities). Consequently, it is possible that the De Broglie/Fitzgerald "$V_1$ Effect" is a factor in lead azide detonation phenomena. Additional $P_{V_1}$, $V_1$ comparisons with other azides ($\text{AgN}_3$ and $\text{CuN}_6$) and primary explosives are required to provide a more definite conclusion. These comparisons will be made and documented when appropriate experimental results are available.

The present document is Number 4 in a series of reports [1, 16, and 17] whose primary purpose is to suggest that certain critical particle velocities could be a "root cause" of low pressure level shock induced reactions observed in solid materials. That is, particle velocity criteria as discussed in these reports are believed to provide a unified explanation for certain shock induced reactions and phenomena. As far as probable primary causes of detonation are concerned, it is obvious from Chaudhri's introductory remarks in Reference 18, that new ideas and concepts, albeit perhaps unusual or even bizarre, merit attention and exploration.

VI. RECOMMENDATIONS

As noted in Section II, the importance of methodical and consistent testing cannot be over emphasized. The following testing recommendations have been made in prior sections.

1. Plate impact testing of S. C. $\sim \text{PbN}_6$ to determine critical reaction pressure levels (or particle velocity).

2. Plate impact testing of additional azides and primary explosives to determine critical reaction pressure levels (or particle velocity).

If this information is currently available, its documentation is unknown to the authors.
TABLE 1. Tabulation of $V_1$ and $Pv_1$ for $PbN_6$.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>$m$ grams $\cdot 10^{-23}$</th>
<th>$d_1$ Å $(10^{-8} \text{cm})$</th>
<th>$V_1$ km sec</th>
<th>$\rho_0$ grams cm$^{-3}$</th>
<th>$C_L$ km sec</th>
<th>$Pv_1$ kbars</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha - PbN_6$ (SINGLE CRYSTAL)</td>
<td>2.3259 (nitrogen atom)</td>
<td>1.179 (N - N)</td>
<td>0.1208</td>
<td>4.705</td>
<td>1.856</td>
<td>10.55</td>
</tr>
<tr>
<td></td>
<td>2.3259 (nitrogen atom)</td>
<td>2.950 (A - A)</td>
<td>0.0483</td>
<td>4.705</td>
<td>1.856</td>
<td>4.22</td>
</tr>
<tr>
<td>Dextrinated Lead Azide (DLA)</td>
<td>2.3259 (nitrogen atom)</td>
<td>1.179 (N - N)</td>
<td>0.1208</td>
<td>3.41</td>
<td>1.223</td>
<td>5.04</td>
</tr>
<tr>
<td></td>
<td>2.3259 (nitrogen atom)</td>
<td>2.950 (A - A)</td>
<td>0.0483</td>
<td>3.41</td>
<td>1.223</td>
<td>2.01</td>
</tr>
</tbody>
</table>

\[
P_{st} = \rho_0 C_L V_1 = \left( \frac{g}{\text{cm}^3} \right) \left( \frac{\text{cm}}{\mu \text{sec}} \right) \left( \frac{\text{cm}}{\mu \text{sec}} \right) = \text{mbars}
\]

\[
P(\text{kbars}) = 10^3 P (\text{mbars})
\]

1 kbar = 14,504 lbs/in$^2 = 10^6$ Newtons/meter$^2$
<table>
<thead>
<tr>
<th>$V_1$</th>
<th>$U_{p1}$ ((\text{PbN}_6))</th>
<th>$U_{p2}$ ((\text{STEEL}))</th>
<th>$P_s$</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>km/(\text{sec})</td>
<td>km/(\text{sec})</td>
<td>km/(\text{sec})</td>
<td>kbars</td>
<td>~</td>
</tr>
<tr>
<td>0.105</td>
<td>0.0864</td>
<td>0.0188</td>
<td>8.52</td>
<td>ALWAYS DETONATION ABOVE THIS $V_1$.</td>
</tr>
<tr>
<td>0.095</td>
<td>0.0782</td>
<td>0.0168</td>
<td>7.71</td>
<td>FAST REACTION, [11], FIG. 2.</td>
</tr>
<tr>
<td>0.090</td>
<td>0.0740</td>
<td>0.0160</td>
<td>7.30</td>
<td>NO REACTION, [11], FIG. 3.</td>
</tr>
<tr>
<td>0.075</td>
<td>0.0617</td>
<td>0.0133</td>
<td>6.09</td>
<td>ALWAYS NO DETONATION BELOW THIS $V_1$.</td>
</tr>
</tbody>
</table>
Figure 1. Stress Amplitude Versus Travel Distance for Dextrinated Lead Azide, \( p_0 = 3.41 \text{g/cc} \).
Figure 2. $P_{\text{v1}}$ Comparison with Test Results for Lead Azide.
REFERENCES


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