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Author(s): Svingala, Forrest Robert
Leonard, Philip
Bartram, Brian Douglas
Gibson, Lloyd Lee
Jones, Justin Daniel
Houlton, Andrew Thomas

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Preliminary IHE Qualification of a PATO/Viton-A Formulation: Shock-to-Detonation Experiments

Forrest Svingala, Philip Leonard, Brian Bartram, Lee Gibson, Justin Jones, Andrew Houlton
M-9 Shock and Detonation Physics, Los Alamos National Laboratory, Los Alamos, NM

I. INTRODUCTION

All nuclear weapons in the stockpile require high explosive (HE) components to function. These explosives create safety hazards during storage, handling, and stockpile maintenance operations, where unintentional initiation can cause serious injuries, death, or significant damage to facilities and the environment. To mitigate these risks, the explosive formulation(s) used in these components should be as resistant to accidental initiation as possible. Mass-detonable explosives that are "so insensitive that the probability of accidental initiation or transition from burning to detonation is negligible" are defined by Chapter IX of the DOE Explosive Safety Standard as *insensitive high explosives* (IHE)[1]. The IHE in most common use in the DOE is currently PBX 9502 (95%wt TATB, 5%wt Kel-F800). The Los Alamos and Lawrence Livermore National Laboratories have established a series of experiments used to classify new HE formulations as either conventional HE (CHE) or IHE[2]. This report describes three sets of gas gun experiments on a new candidate IHE formulation consisting of 95.5%wt 3-Picrylamino-1,2,4-Triazole (PATO) and 4.5%wt Viton-A. These experiments provide a preliminary evaluation of the performance of this material on the shock-to-detonation (SDT) portion of this qualification standard.

II. EXPERIMENTAL METHODS

The design of each experiment presented here is based upon the requirements laid out in *IHE Material and IHE Subassembly Qualification Test Description and Criteria*[2]. In order to 'pass' each experiment the sample must show either a completely inert response (i.e., no growth of the input shock wave) or, if reaction does occur, it must be failing (i.e., any initial reactive growth of the shock must be in decline). These experiments use photonic Doppler velocimetry (PDV) on the back face of each target to evaluate reactivity rather than the embedded gauges specified in reference 2. Since $u_p(t)$ is only measured at a single location, these experiments can only 'pass' a material with a completely inert response, as it could not establish whether a partially reacting wave is in the process of failing or growing to a detonation wave. This substitution was made to reduce the complexity of these initial experiments while still providing a conservative evaluation of shock sensitivity.

A. Shot Design: Reactant Hugoniot

Before these experiments were undertaken, the reactant Hugoniot of PATO/Viton-A was unknown. To design these experiments, this Hugoniot was approximated using the reactant Hugoniot of PBX 9502, with the initial density shifted to that of the PATO/Viton-A. Results from this work are insufficient to parameterize a $U_s - u_p$ Hugoniot for PATO/Viton-A, but comparisons with the PBX 9502 Hugoniot will be made to validate this approximation. Hugoniots for the other materials used (Cu, LiF, Al-6061, Kel-F81), were obtained from references 3–5, respectively.

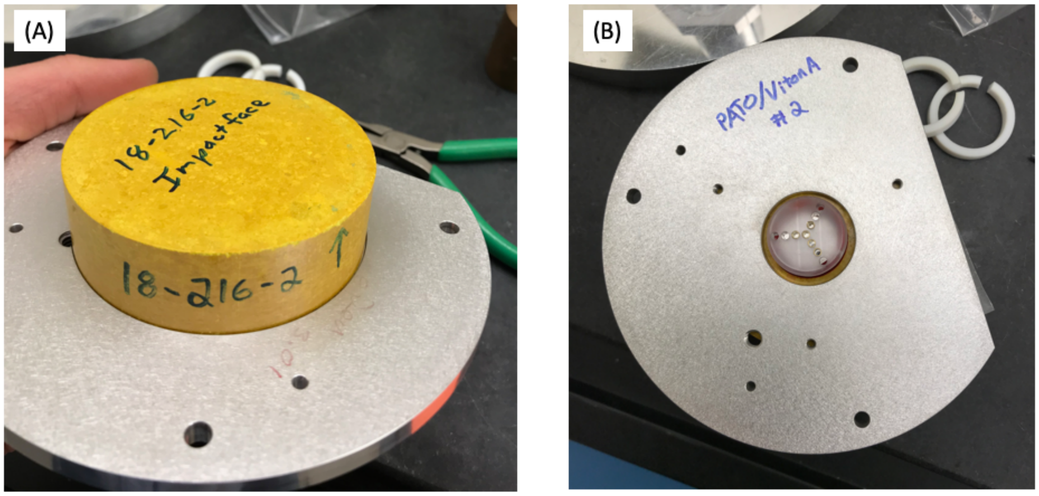

FIG. 1. Photos of the impact face (A), and the back surface (B) of a PATO/Viton-A target used for a sustained-shock experiment at 3.5 GPa.

B. Ambient Temperature Sustained Shock

The first experiment specified is a shock input lasting greater than 3 μs at 3.5 GPa and ambient temperature. This test used ⌀71 mm x 24 mm cylindrical samples of PATO/Viton-A, backed by LiF windows. Photos of one of these targets are shown in Figure 1. 10 mm thick Cu impactors were launched at 0.660 km/s using the single-stage gas gun.

C. Ambient Temperature Short Shock

The second experimental condition is a short shock of 500 ns duration and 5.3 GPa in the explosive. This input is intended to be analogous to the unsupported output from a number 8 blasting cap, which produces a high initial pressure followed by rapid relief. These conditions were achieved using a layered impactor of 1 mm Kel-F81 backed by 5.5 mm of Trelleborg Syntactic EL-34 foam to provide the relief. This impactor was launched at 1.49 km/s using the two-stage gas gun. This experiment used smaller ⌀25.4 mm x 9.7 mm cylindrical samples of PATO/Viton-A, pictured in Figure 2. Each sample was placed in a PMMA alignment tube with a mirrored LiF window and a PDV probe holder (not pictured).

D. Heated Sustained Shock

The final experimental condition calls for heating the IHE candidate to 10°C below the thermal explosion temperature for the explosive. While the DSC curve for PATO/Viton-A shows no exotherm until 325°C (Figure 3), a significant reaction was observed at 206°C during a heated deflagration-to-detonation (DDT) experiment called for by the IHE qualification standard. This reaction is believed to have been due to combustion of solvent gasses volatilized from the PATO/Viton-A formulation with air surrounding the test article[6]. To avoid this potential volatilization of solvents, the heated SDT tests were performed at 195°C.

To achieve the desired test conditions, a heated target cell was designed (Figures 4 and 5). In brief, the cell uses a resistive heater to heat the target, and 7 PDV probes to diagnose time of impact, impact tilt, and the velocity profile at the back surface of the sample.

The samples used in the heated sustained shock experiments were ⌀25 mm x 10 mm

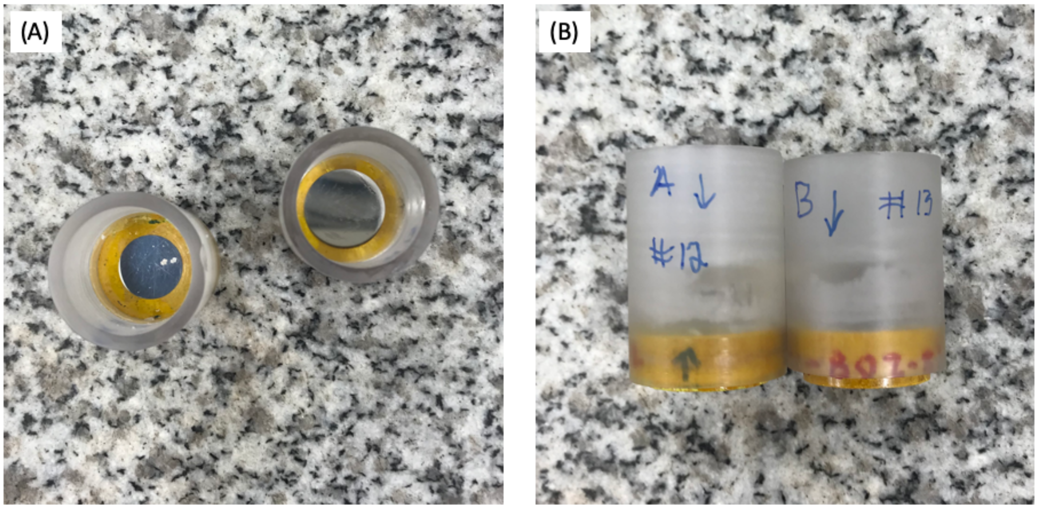

FIG. 2. Back (A) and side (B) views of the samples used in the 5.3 GPa short shock experiments.

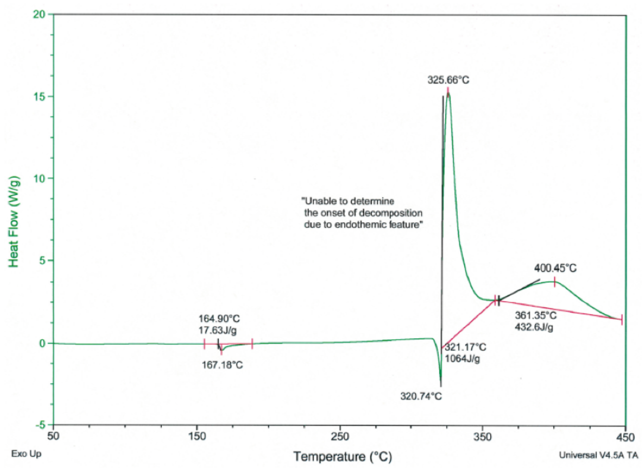

FIG. 3. DSC results for the PATO/Viton-A IHE candidate formulation. Note that the small endotherm at 160°C is due to melt of the Viton-A binder.

cylinders. Initially, plans had called for the use of the larger ⌀71 mm x 24 mm samples used in the ambient temperature sustained shock experiments, but this was reevaluated in hopes of reducing the amount of hazardous HE cleanup required post-shot. CTH calculations indicated that the smaller sample geometry would be adequate to allow the desired 1.5 GPa shock to traverse the sample for more than 3 μs, meeting the goal of the IHE Qualification standard. The impactor used was Al-6061, launched at an approximate velocity of 0.575 km/s.

Unlike the other two experiment types, the heated experiments use a buffer plate of 3 mm thick Al-6061 between the HE sample and the impactor. This encases the target in warm metal, creating a more uniform temperature within the sample. The details of the sample cell design and testing with an inert sample can be found in reference 7.

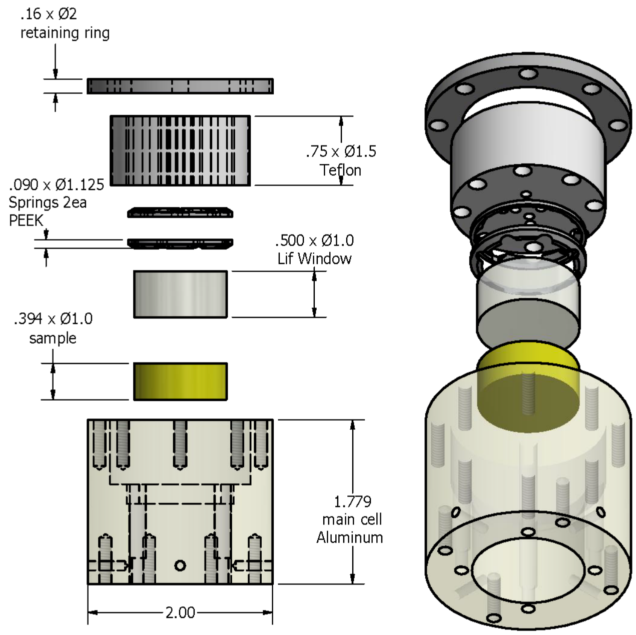

FIG. 4. An exploded schematic of the heated target used for the 1.5 GPa experiments. The buffer plate, which would also act as the impact surface, is not shown. All dimensions are in inches.

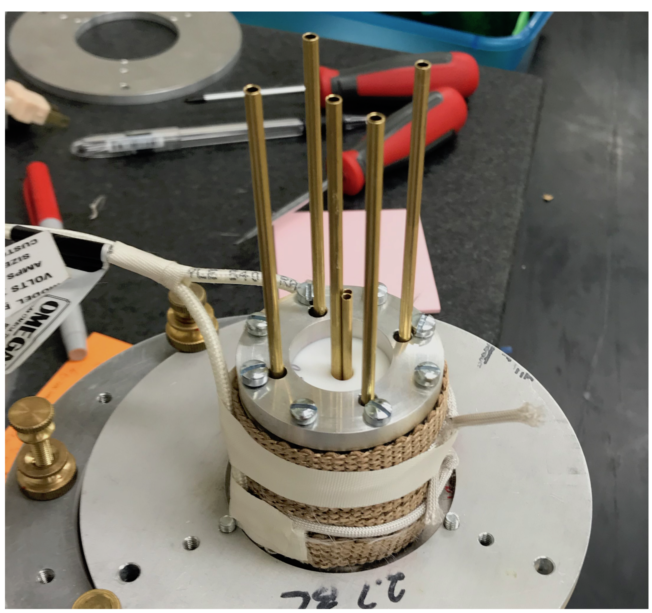

FIG. 5. Assembled target prior to application of insulation, showing the position of the heat tape and brass tubes used to align and stand off collimating PDV probes.

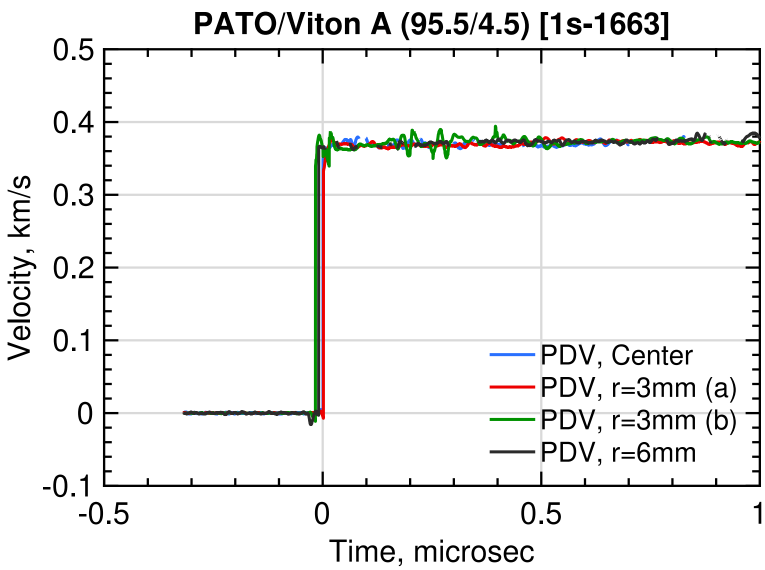

FIG. 6. 1-D portion of the PDV records from an ambient sustained shock experiment on PATO/Viton-A (shot number 1s-1663). The flat-topped wave profiles observed indicate no shock reaction took place.

TABLE I. Summary of the ambient temperature, sustained shock experiments. The u_p reported is the material velocity observed at the LiF/HE interface, with the LiF window correction of Rigg applied[3], averaged over the flat portion of the PDV record.

Shot Number	Sample Density g/cc	Impactor	$u_{projectile}$ km/s	Interface u_p km/s	Reaction Observed?
1s-1663	1.7458 ±0.0005	10 mm Cu	0.661 ±0.001	0.365 ±0.005	No
1s-1664	1.7455 ±0.0005	10 mm Cu	0.660 ±0.001	0.337 ±0.005	No

III. RESULTS

A. Ambient Temperature Sustained Shock Experiments

The results of the ambient temeprature sustained shock experiments are summarized in Table I. In both experiments, the PDV profiles at the HE/LiF interface were flat-topped, which indicates no significant reaction took place (Figure 6). After each experiment the interior of the target tank was coated in yellow dust, presumed to be unreacted PATO/Viton-A (Figure 7).

These experiments were insufficient to define a point on the PATO/Viton-A Hugoniot, as the only measured quantity is the u_p in the re-shock condition at the HE/LiF interface. A consistency check was made using the measured projectile velocities to calculate the expected HE/LiF interface velocity if the HE were PBX 9502. The calculated HE/LiF interface velocity for this case was 0.370 km/s; a 5.4% difference from the average of the measured interface velocities in these experiments. This suggests that, at this pressure, the shock impedance of PBX 9502 is similar to the PATO/Viton-A, and the use of the PBX 9502 Hugoniot to design these shots was reasonable.

FIG. 7. Photo of the target tank after an ambient sustained-shock experiment. The tank is coated in yellow dust, which is unreacted PATO/Viton-A.

TABLE II. Summary of the ambient temperature, short shock experiments.

Shot Number	Sample Density g/cc	Impactor	$u_{projectile}$ km/s	Reaction Observed?
2s-1069	1.7350 ±0.0005	0.962 mm ±0.004 mm Kel-F81 5.469 ±0.004 mm EL-34 Foam	1.610 ±0.001	No
2s-1070	1.7410 ±0.0005	1.035 mm ±0.004 mm Kel-F81 6.033 ±0.004 mm EL-34 Foam	1.550 ±0.001	No

B. Ambient Temperature Short Shock Experiments

The ambient temperature short shock experiments are summarized in Table II, and PDV velocity profiles taken at the HE/LiF interface are shown in Figure 8. When the wave reaches the back surface of the HE sample, the short, 500 ns, flat-topped shock that entered the sample has been completely eroded by the arrival of release waves from the foam layer of the impactor. Qualitatively, the shape of the wave does not indicate shock reaction. Quantitatively, the peak particle velocity observed is approximately 100 m/s below that measured in the ambient temperature sustained shock experiment. This indicates that the wave is not experiencing reactive growth, and is dominated by the release waves from the foam layer of the impactor.

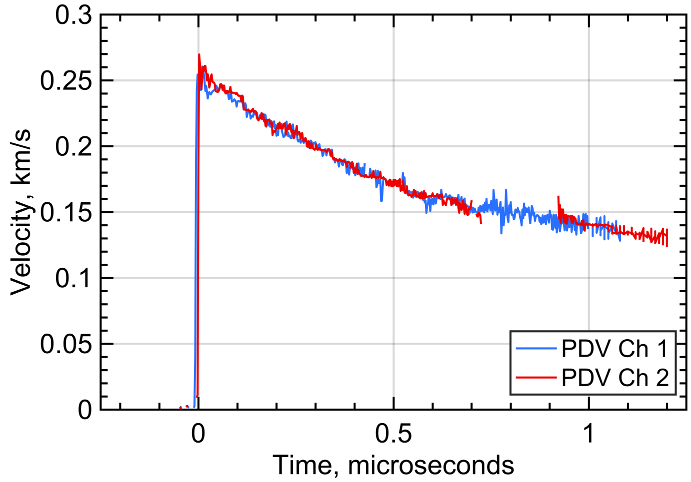

FIG. 8. 1-D portion of the PDV records from an ambient short shock experiment on PATO/Viton-A (shot number 2s-1069). The 500 ns flat-top shock that entered the sample has been completely eroded by release waves from the foam layer of the impactor. A window correction for LiF has been applied to all velocities[3].

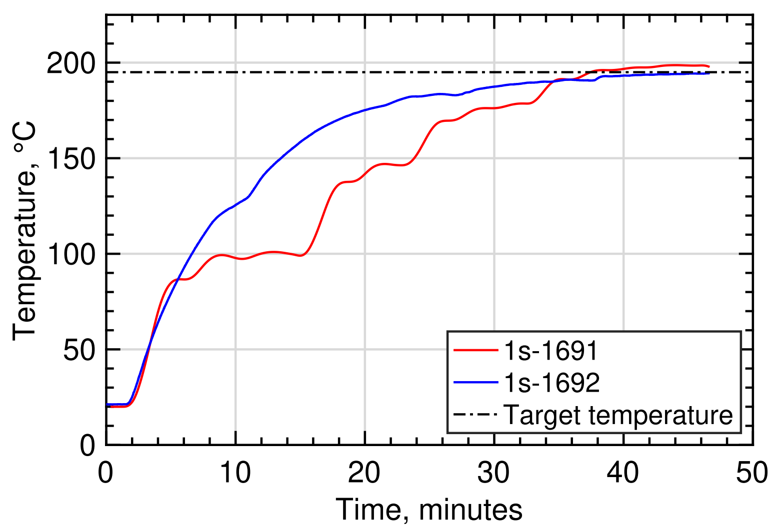

FIG. 9. Thermocouple records from both heated shots in this work. Heating was performed in several steps in 1s-1691 to avoid overshooting the target temperature. This was found to be unnecessary, and target temperature was approached directly in 1s-1692.

C. Heated Sustained Shock Experiments

Experimental conditions for the heated experiments are summarized in Table III. The temperature of each target as a function of time, is plotted in Figure 9. The target temperature was approached in 4 steps during the first shot (1s-1691) to avoid overshooting by more than 5 degrees. Both targets were held at temperature for 10 minutes prior to firing to allow the target to approach thermal equilibrium. Much like the ambient sustained shock experiment, the wave at the back surface of the sample is flat-topped, showing no sign of shock reactivity under these conditions (Figure 10). Transit time of the shock wave was measured in these experiments, which allows calculation of the rest of the shocked condi-

TABLE III. Summary of the heated sustained shock experiments. The u_p reported is the material velocity observed at the LiF/HE interface, with the LiF window correction of Rigg applied[3], averaged over the flat portion of the PDV record.

Shot Number	Ambient Density g/cc	Impactor	$u_{projectile}$ km/s	Interface u_p km/s	U_s km/s	Reaction observed?
1s-1691	1.7439 ±0.0005	12 mm Al-6061	0.576 ±0.001	0.231 ±0.005	3.06 ±0.05	No
1s-1692	1.7410 ±0.0005	12 mm Al-6061	0.579 ±0.001	0.218 ±0.005	3.06 ±0.05	No

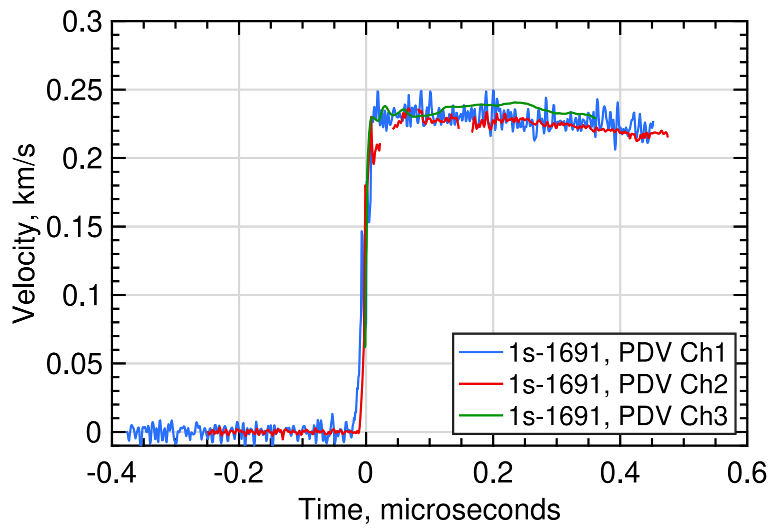

FIG. 10. 1-D portion of the PDV records from a sustained shock experiment on PATO/Viton-A at 195°C (shot number 1s-1691). All profiles are flat-topped, indicating no shock reaction took place. A window correction for LiF has been applied to all velocities[3].

tions (primarily u_p and P) by impedance matching. Initial density of the PATO/Viton-A at 195°C was estimated by assuming the density reduction was proportional to that of PBX 9502. The shock transit times and calculated pressures were $3.45\mu s$ and 2.1 GPa, respectively, exceeding the values required by the IHE qualification standard ($3.0\mu s$, and 1.5 GPA). U_s-u_p points are plotted against the Hugoniots for 130°C and 250°C PBX 9502 in Figure 11[5,8].

TABLE IV. Calculated values of initial heated density, u_p, and P in the PATO/Viton-A sample. Measured shock velocity is also reproduced here.

Shot Number	Est. Density at 195°C g/cc	PATO/Viton-A u_p km/s	U_s km/s	Pressure GPa
1s-1691	1.619 ±0.001	0.426 ±0.01	3.06 ±0.05	2.11 ±0.1
1s-1692	1.622 ±0.001	0.428 ±0.01	3.06 ±0.05	2.13 ±0.1

IV. CONCLUSION

This work reports the results of 6 plate impact experiments on a new candidate IHE formulation (95.5%wt PATO, 4.5%wt Viton-A). Three experiment types were performed, two sustained shock (one at ambient and a second at elevated temperature), and one short shock experiment. All experiments were diagnosed with PDV on the back surface of the

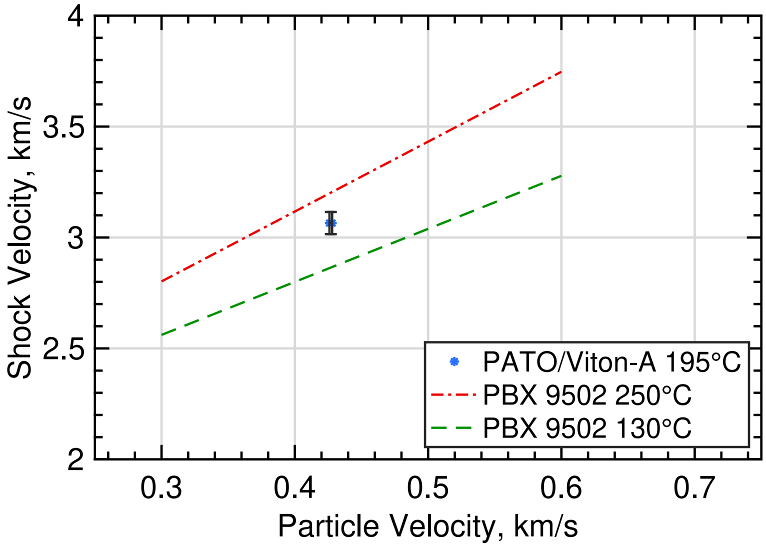

FIG. 11. U_s-u_p Hugoniot plot showing the two (overlapping) points from this work and fits to PBX 9502 at 130°C and 250°C.

HE sample to determine if shock reaction occurs at the specified input conditions. In all experiments, the PATO/Viton-A formulation did not show evidence of shock reaction. This formulation therefore satisfies the requirements laid out in the shock-to-detonation section of *IHE Material and IHE Subassembly Qualification Test Description and Criteria*[2].

V. REFERENCES

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