ROSATOM

RFNC VNIITF

State Atomic Energy Corporation «Rosatom»

THIN BARRIER METHOD USED TO STUDY KINETICS OF HE DECOMPOSITION NEAR THE DETONATION FRONT

V.I. Tarzhanov, A.V. Vorobiev, A.N. Eskov,
D.P. Kuchko, M.A. Ralnikov, R.V. Komarov

Snezhinsk - 2019

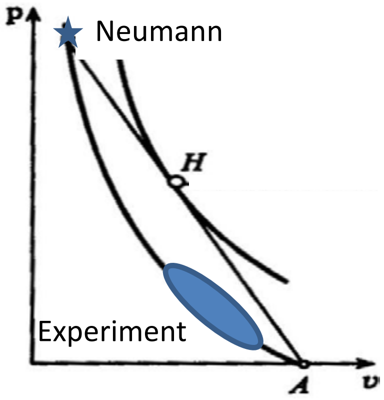
Introduction

РФЯЦ–ВНИИТФ

Data on shock compressibility of nonreactive explosives are obtained in the low-pressure range, i.e. at $p \leq 16$ Gpa.

Parameters of explosives at the Neumann spike ($p \approx 40$ GPa) are registrated and interpreted as points of the Hugoniot for unreacted HE.

Question arises as to how long this HE fails to react behind the detonation front and whether it continues to be non-reacting in case of repeated loading above the Neumann spike?

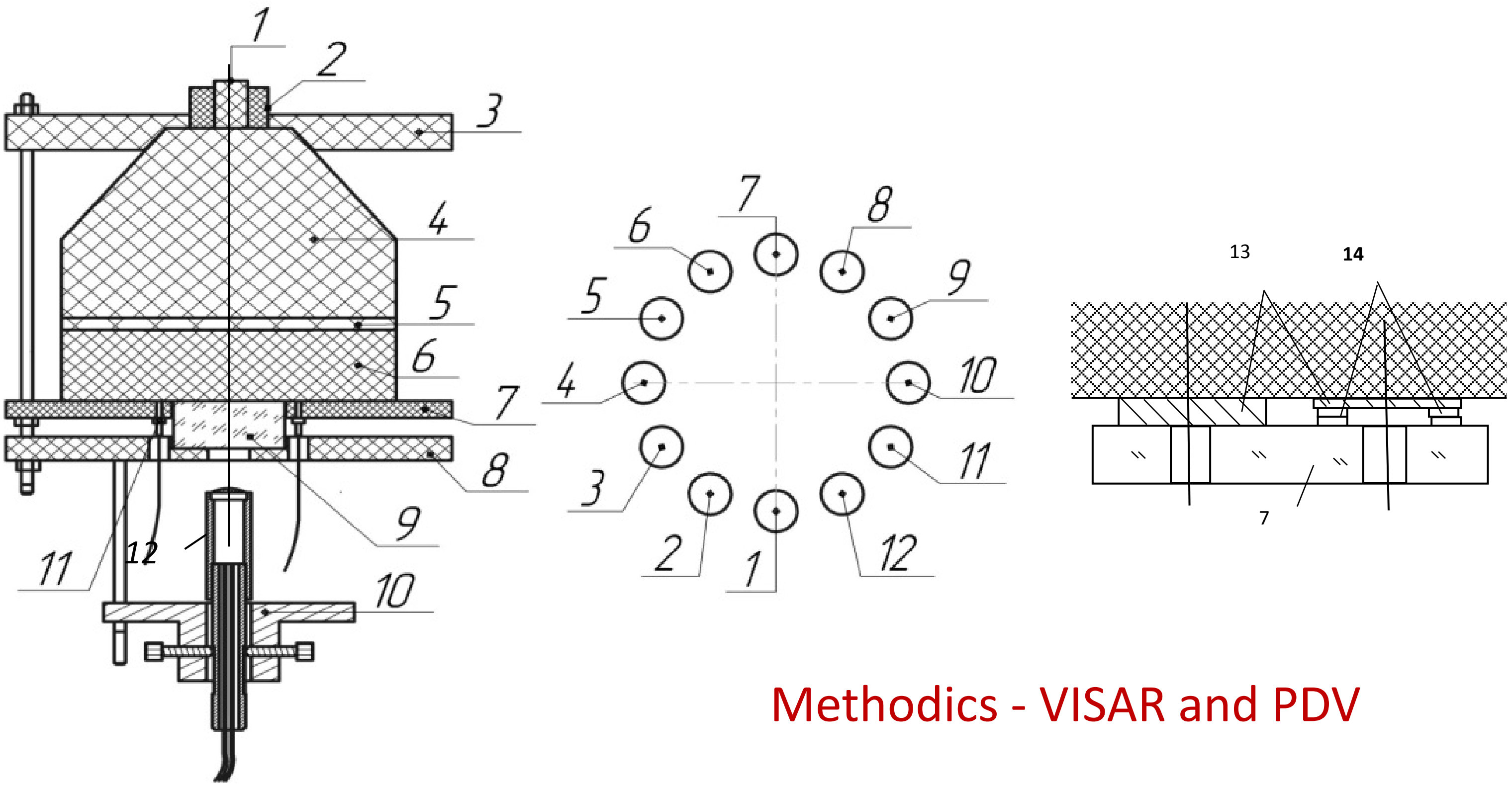


The experimental thin-barrier method are proposed that makes it possible to record HE decomposition immediately behind the detonation front using laser-interferometry.

Laser interferometry is shown to open up new possibilities of the proposed method.

Experimental setup

РФЯЦ–ВНИИТФ

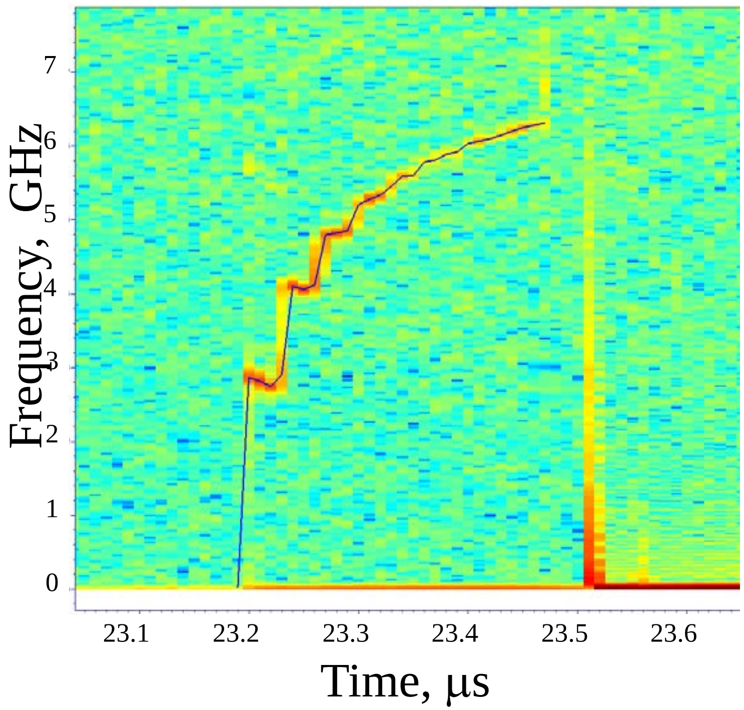


Methodics - VISAR and PDV

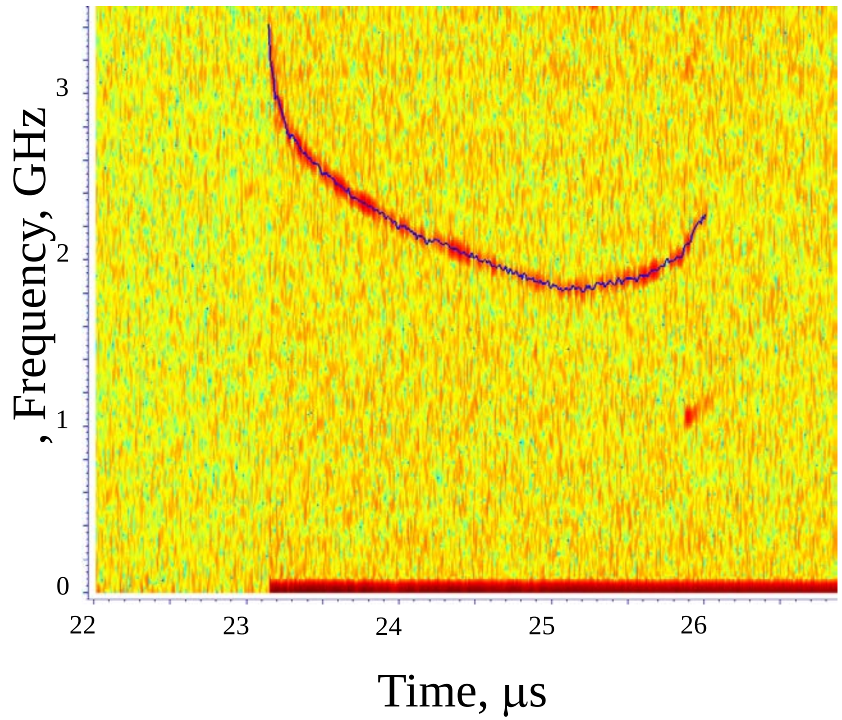
1 – electrical detonator; 2 – socket; 3 – centering mount; 4 – lens charge;
5 – TNT-RDX 50/50 cartridge with Ø120x10 mm; 6 – test HE with Ø120x40…60 mm;
7 – ferrules workholder; 8 – press-up clamp; 9 – window (LiF); 10 – measurement unit;
11 – PDV ferrules; 12 – “combined” head; 13 – foils; 14 – rings.

Spectrograms

РФЯЦ–ВНИИТФ



a

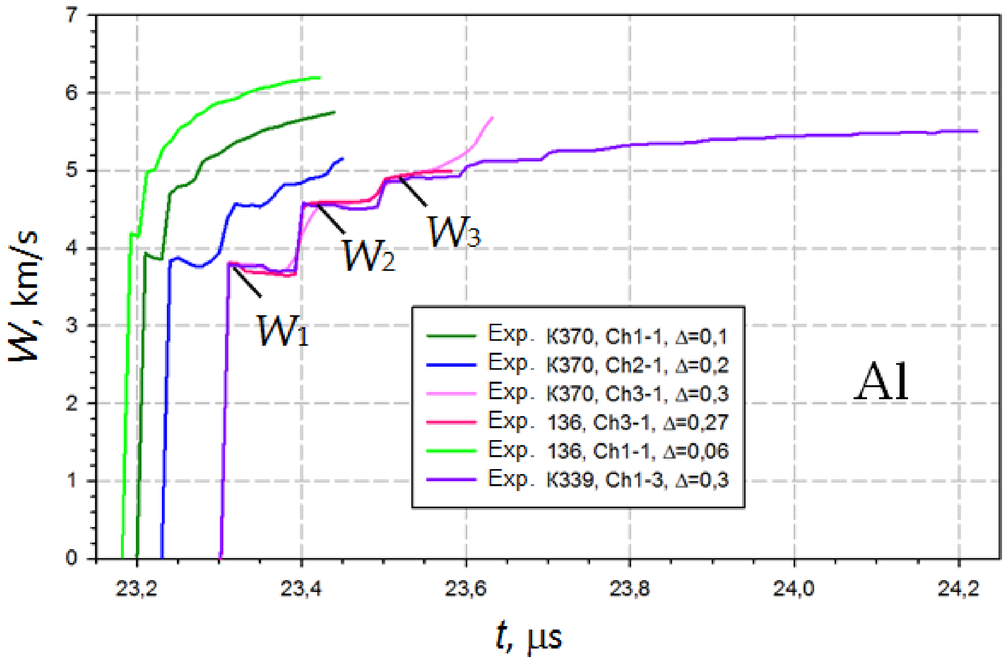


b

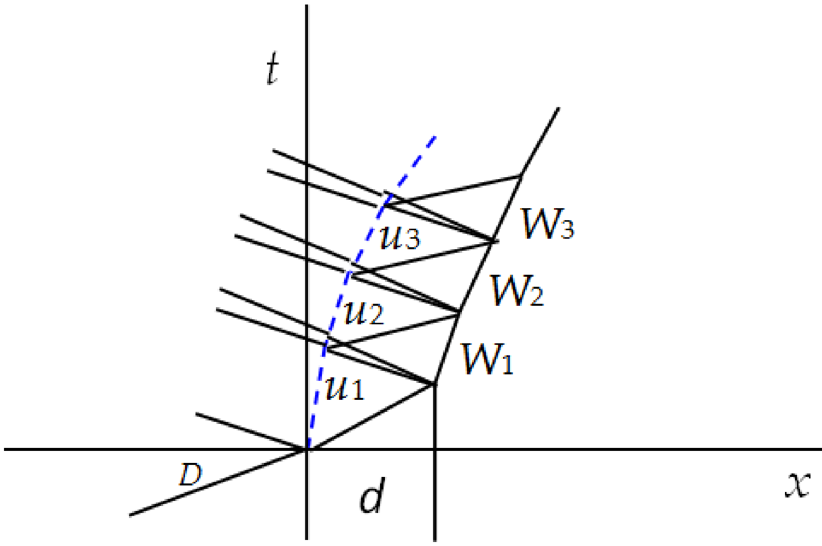
Typical PDV-spectrogram

a – recorded acceleration of Ni-foil having 0.09-mm thickness;
b – profile of the detonation wave with the chemical spike when recorded through the LiF-window

Results



a

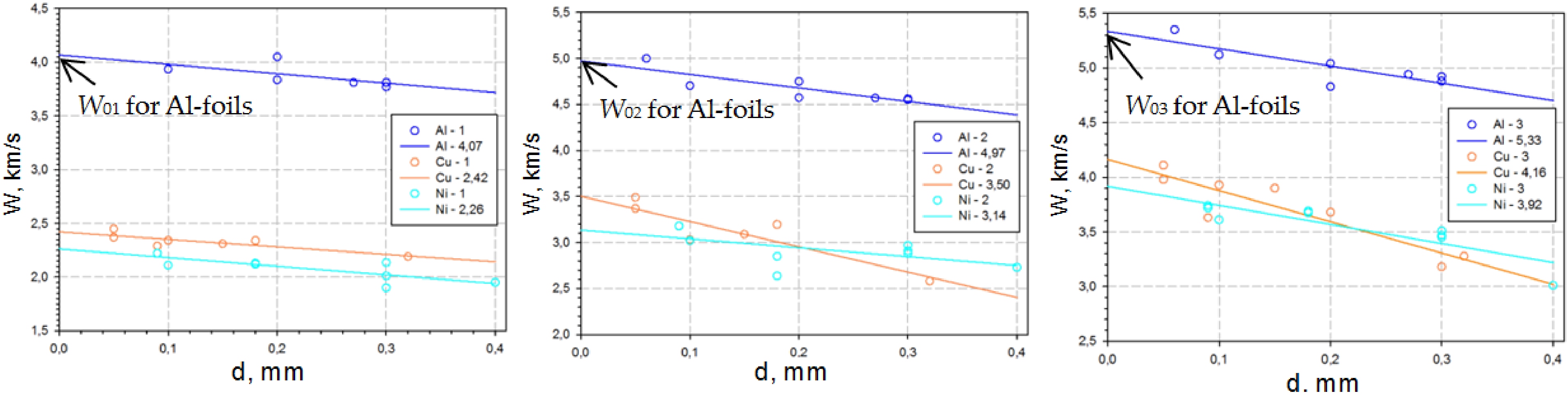


b

Acceleration profiles for different-thickness Al-foils in three experiments (a);
t, *x* – diagram of wave circulations in the foil (b)

Determination of W_{01}, W_{02} и W_{03}

РФЯЦ–ВНИИТФ



Recorded velocities at the foil free-surface Al, Cu и Ni with “shelves” on first jump– W_1 (a), on second jump – W_2 (b) $_{\text{and}}$ on third jump – W_3 (c) versus foils thickness.

Shock waves that enter the foil is attenuating while they travels through the foil thickness, it would be incorrect to use the values W_1 , W_2, W_3 directly for determining the state in HE close to the front under release.некорректно. We must use velocities W_{01}, W_{02} и W_{03} of the zero-thickness foil. Theas velocities can be found by extrapolating the experimental dependences on the foil thickness d till intersection with the Y-axis.

This method is actually the virtual probing method for HE states near the detonation front within the maximally short time being close to zero.

Results

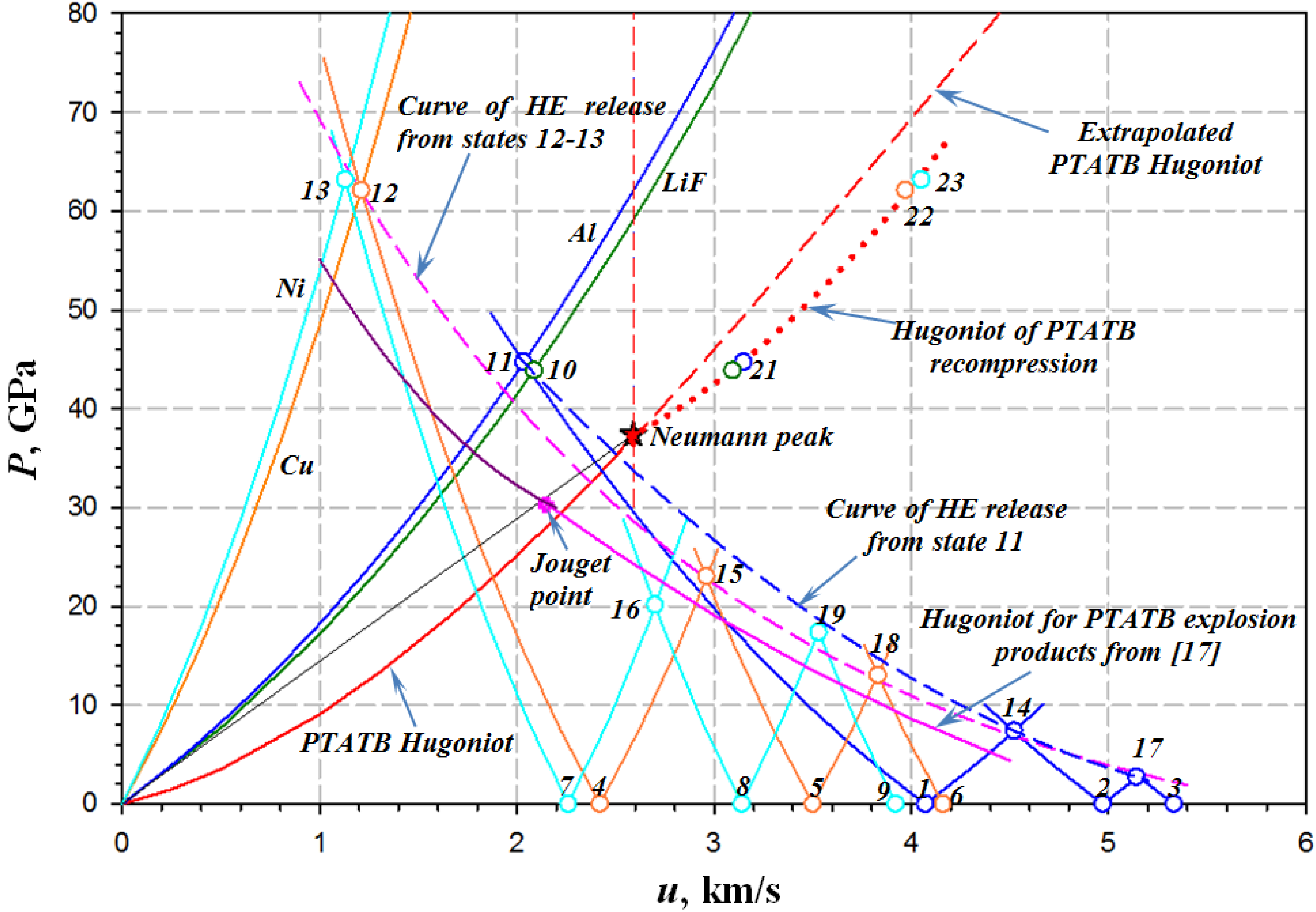
РФЯЦ–ВНИИТФ

Calculated W_{01}, W_{02}, W_{03}, as well as appropriate particle velocities u_{01}, u_{02}, u_{03} and pressures P_{01}, P_{02}, P_{03}

Foil material	W_{01}, km/s	W_{02}, km/s	W_{03}, km/s	u_{01}, km/s	u_{02}, km/s	u_{03}, km/s	P_{01}, GPa	P_{02}, GPa	P_{03}, GPa
Al	4.07	4.97	5.33	2.035	4.52	5.15	44.7	7.41	2.73
Cu	2.42	3.50	4.16	1.21	2.96	3.83	62.1	23.0	13.0
Ni	2.26	3.14	3.92	1.13	2.70	3.53	63.2	20.2	17.4

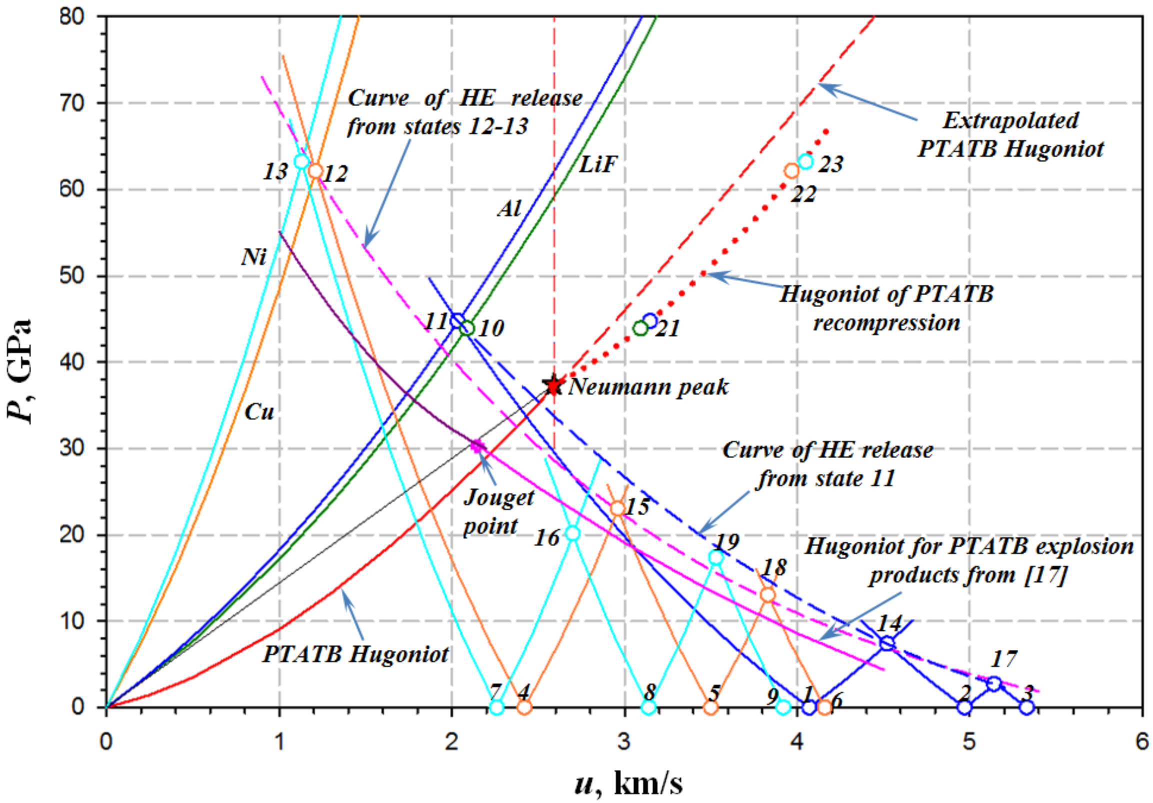
Determination of states in PTATB on the recompression Hugoniot

РФЯЦ–ВНИИТФ



Release of reloading HE

РФЯЦ–ВНИИТФ

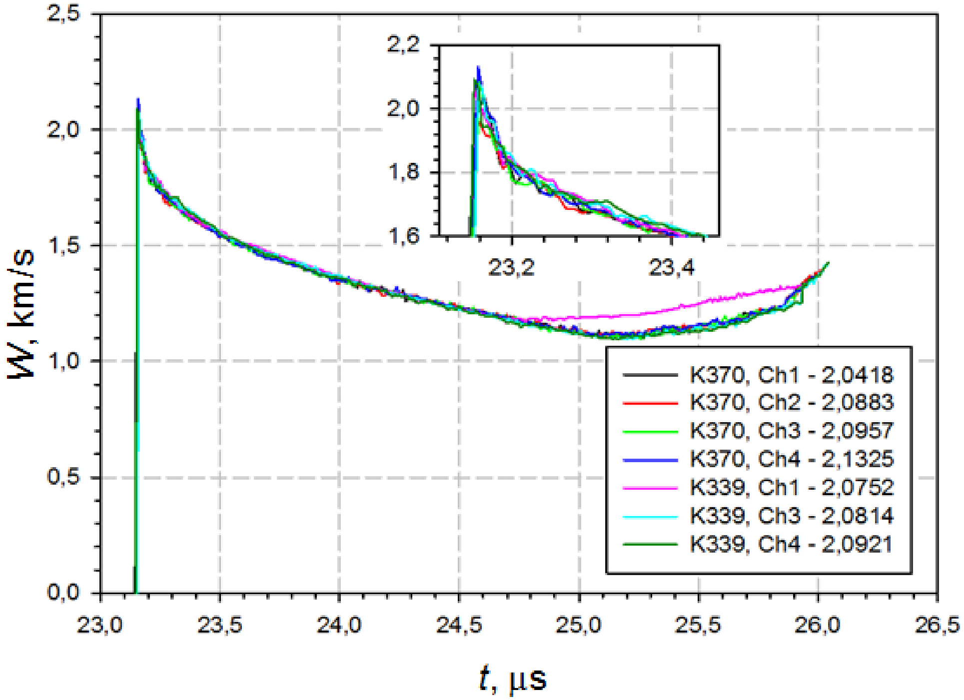


Values of W_{01} and W_{02} for all foil materials were used to find states 14, 15, and 16 with particle velocities u_{02} in these materials invoking using Hugoniots for foil materials. States 17, 18, and 19 with particle velocities u_{03} in these materials were found with W_{01} и W_{02} These states are simultaneously states of PTATB after, respectively, single and doulbe releases from the reloading states 11 – 13.

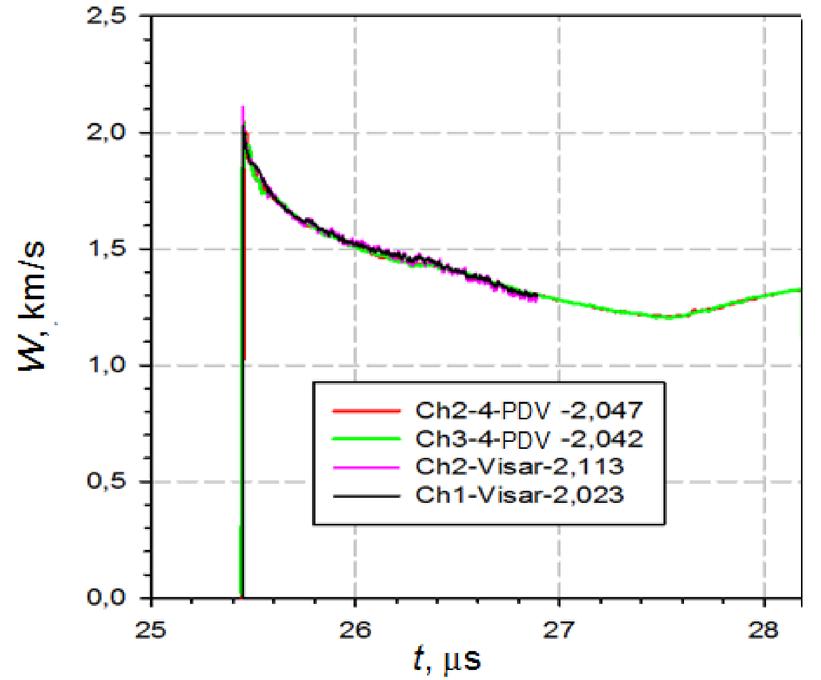
Release curves approximate the experimental data. These release curves go above the equilibrium explosion-product Hugoniot with the Jouget point.

Detonation wave profiles in PTATB. Chemical spike (Neumann spike)

РФЯЦ–ВНИИТФ



Seven profiles of the detonation wave in PTATB at the boundary with the LiF window. in two experiments

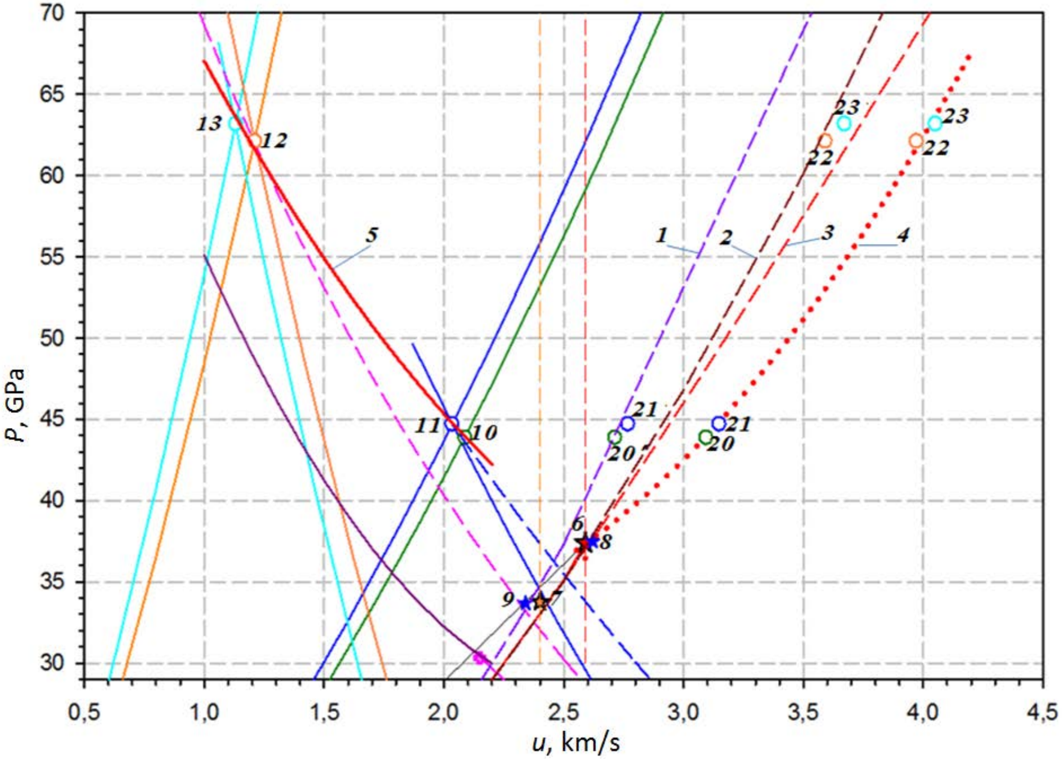


Four detonation profiles in PTATB at the boundary with the Al-foil contacting the LiF window

The mean of the maximum velocity for profiles observed in three experiments is 2.084 km/s. Pressure in LiF, which corresponds to this particle velocity, will be 43.8 GPa. This state in LiF is simultaneously the state in the PTATB, realized under its reloading on LiF from the state in the chemical spike.

Discussion - Chemical spike brake curve

РФЯЦ–ВНИИТФ



Part of the *P*, *u* –diagram of states in foils, LiF, and PTATB

Four experimental points are obtained for the Hugoniot of the PTATB recompression from the state in the chemical spike. Curve 5 is plotted to approximate the experiment It can be called the chemical spike brake curve.

The data is few to extrapolate it till its intersection with the Hugoniot of the nonreactive HE.

In addition, we have no such a reliable Hugoniot.

The figure shows three well-known Hugoniots for TATB-based explosive compounds. Available data on the state of TATN-based HE in the chemical spike turn out to be obviously different.

Discussion

РФЯЦ–ВНИИТФ

Question dealing with physics: whether these are explosion products that accelerate foils after the detonation front arrival thereat or perhaps this is still non-reacted inert HE existing at chemical spike width. The foils are thin and the time needed for the waves to circulate once or twice in them can turn to be less than the period of the test PTATB decomposition zone. In this case, we can assume that during the first wave circulation (10 – 100 ns), HE fails to significantly decompose. And in addition, we extrapolate $W_i(d)$ to the zero thickness of foils, i.e. to extremely small times**. From here it follows that HE shall remain solid both shortly behind the shock front of reloading, and also under "instantaneous" release.**

Once again we can ask a quastion: whether a solid HE or gaseous explosion products there are in states 14 – 19. In the first case, the release curve must be close to the mirrored shock adiabat of unreactive PTATB. In the second case, it could go equidistantly to the explosion-product Hugoniot as in [17]. Unfortunately, it is impossible to decide on one of variants with the available number of experiments. Note that the obtained release curves would not merge with the explosion-product Hugoniot from [17] during the follow-on wave circulations in foils as the excess energy acquired by the material in the course of reloading remains therein during release as well.

Conclusions

- The experimental thin-barrier method that makes it possible to record HE decomposition immediately behind the detonation front using laser-interferometry is proposed. **Actually this is the method of virtual probing of HE states shortly behind the detonation front within an extremely short period.**
- Four experimental points are obtained for the Hugoniot of PTATB recompression from the state in the chemical spike. The curve that approximates the experiment can be called the chemical spike brake curve.
- Six experimental points that correspond to PTATB states after single or double fast release from the reloading state are obtained. Release curves that approximate the experiment are plotted to go above the equilibrium explosion-product Hugoniot.
- **HE is stated to remain solid** both shortly behind the shock front of reloading, and also under “instantaneous” release.
- **Generally, new results obtained at times less than 10…300 ns demonstrate the proposed method to be promising for investigations of HE states in the chemical spike zone.**

Literatura

РФЯЦ–ВНИИТФ

1. LASL Explosive Property Data / Eds. T.R. Gibbs, F. Popolato.–University of California Press.: Berkeley - Los Angeles - London, 1980.
2. Dick J.J., Forest C.A., Ramsay J.B., Seitz W.L. The Hugoniot and Shock Sensitivity of a Plastic-Bonded TATB Explosive PBX 9502 // J. Appl. Phys. 1988. 63 (10).
3. Sheffield S.A., Bloomquist D.D., Tarver C.M. Subnanosecond Measurements of Detonation Fronts in Solid High Explosives // J. Chem. Phys. 1984. 80 (8).
4. Shorokhov E.V., Litvinov B.V. Shock Compressibility of TATB-Based Explosive Compositions in the Range of Pressures from 0.1 to 40 GPa // J. Chem. Phys. 1993. V. 12. No.5. pp. 722-723.
5. Lubyatinsky S.N., Loboiko B.G. Detonation Reaction Zones of Solid Explosives // Proc. of 12th Symp. on Detonation.: Snowparticle. Colorado. USA. 1998.
6. Fedorov A.V., Mikhailov A.L., Antonyuk L.L., Nazarov D.V., Finyushin S.A. Determination of Detonation Wave Parameters in PETN and HMX Single Crystals // Combustion Explosion and Shock Waves (Fizika Goreniya i Vzryva). 2011. V. 47, No.5.
7. Fedorov A.V. Parameters of the Neumann Peak and the Detonation Wave Front Structure of Condensed Explosives // J. Chem. Phys. 2005. V.24, No.10. 3-21.
8. Fedorov A.V., Mikhailov A.L., Antonyuk L.L., Nazarov D.V., Finyushin S.A. Determination of Parameters of Chemical Reaction Zone and Chapman-Jouguet State in Homogeneous HE and Heterogeneous HE. // Book of Abstracts for XI International Conference "Zababakhin Scientific Talks". June 02-06, 2012. p.94.
9. Kolesnikov S.A., Utkin A.V., Mochalova V.M., Anantin A.V. Modes of Steady-State Detonation in Pressed TNETB // Combustion Explosion and Shock Waves (Fizika Goreniya i Vzryva). 2007. V.43, No. 6.
10. Kozlov E.A., Tarzhanov V.I., Telichko I.V., Vorobiov A.V., Levak K.V., Matkin V.A., Pavlenko A.V., Malyugina S.N., Dulov A.V. Reaction Zone Structure for the Detonating Fine-Grained TATB // Proceedings of SWCM-2012. Kiev, pp. 58-60, 2012.
11. Kozlov E.A., Tarzhanov V.I., Telichko I.V., Vorobiov A.V., Levak K.V., Matkin V.A., Kuchko D.P., Ralnikov M.A., Boyarnikov D.S., Pavlenko A.V., Malyugina S.N., Dulov A.V. TATB Reaction Zone Structure under Normal and Overdriven Detonation // International conference "XV Khariton's Topical Scientific Readings", March 18 – 22, 2013, Sarov.
12. Duff R.E., Houston E.F. Measurement of the Chapmen-Jouget Pressure and Reaction Zone Length in a Detonating High Explosive // J. Chem. Phys. 1965. 23, 1268.
13. Dremin A.N., Pokhil P.F. J. Phys.Chem. 1961. 34 (11). 2561.
14. Zeldovich Ya. B., Kompaneets. Detonation theory.–M.: 1955.– p. 268.
15. Kozlov E.A., Tarzhanov V.I., Telichko I.V., Pankratov D.G., Kuchko D.P., Ralnikov M.A. On Combining the optical Lever and Laser Heterodyne Techniques to Study Dynamic Properties of Structural Materials // Book of Abstracts for XII International Conference "Zababakhin Scientific Talks". June 02-06, 2014. .
16. Strand O.T., Goosman D.R., Martinez C., Whitworth T.L., Kuhlow W.W. A Novel System for High-Speed Velocimetry Using Heterodyne Techniques // Rev. Sci. Instrum. 2006. 77. 083108.
17. Aminov Yu.A., Gorshkov M.M., Zaikin V.T., Kovalenko G.V., Nikitenko Yu.R., Rykovanov G.N. Studying brake of TATB-based explosive detonation products // Combustion Explosion and Shock Waves (Fizika Goreniya i Vzryva). 2002. V.38, No. pp 121-124.
18. Experimental Data on Shock-Wave Compression and Adiabatic Expansion of Condensed Materials / Edited by R.F. Trunin. Sarov: RFNC-VNIIEF, 2006.531 p.

Thank you for attention!