STUDY OF SHOCK-WAVE PROCESSES IN CERIUM

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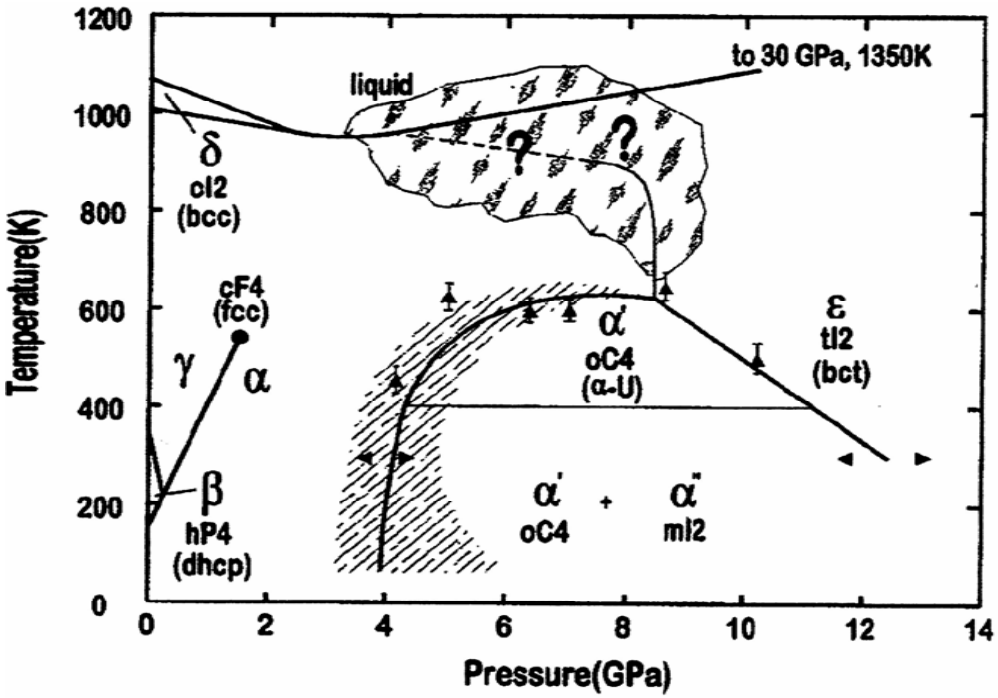
Introduction

- Cerium has properties unusual as compared to many metals.
- This properties include existence of the critical point in the solid state at the line of isomorphous transition (γ-α), abnormal behavior of compressibility, thermal extension, heat capacity, etc.
- The specificity of cerium characteristics is caused by peculiarities of change of its electronic structure during compression.
- Due to strong jumps of volume during phase changes, it is expected that cerium is melted in shock waves at very low pressures.
- So we need a complex of studies of cerium behavior in waves of shock compression and followed unloading.

Research on Cerium is progressing

- Cerium is a metal with a very complex phase diagram, as well as, having a complex dynamic response.
- Four solid phases known at zero pressure, with at least three more phases at high pressure.
- Complicated f-electron behavior.
- Phase diagram uncertain above 0.6 GPa.



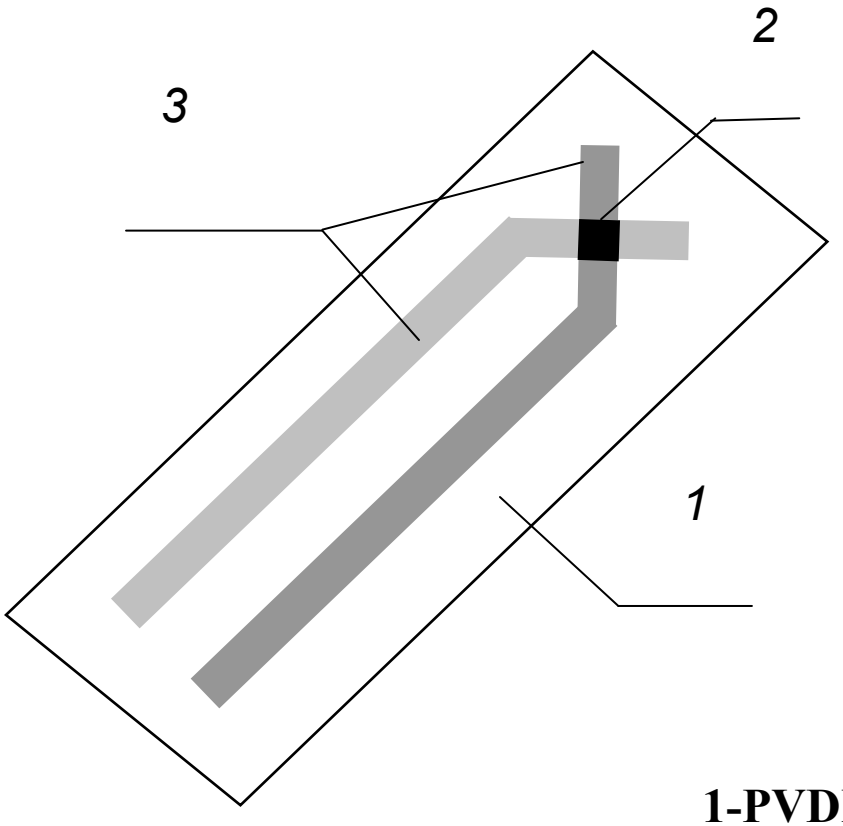
Objective of this work

- Determination the elastic C_L and plastic C_S sound velocities in the shock wave (SW) pressure region 2-140 GPa by the methods:
  - of overtaking unloading with use of indicator liquids (35-140 GPa),
  - of piezogauges based on manganine (2-35 GPa).
- Determination the values of Poisson's ratio ν and dynamic yield strength Yg (shear strength) of Cerium.
- Determination the melt boundary of Cerium on the shock adiabat.
- Experimental study of profiles of loading waves in cerium at shock compression in pressure range of 0.17÷12 GPa by the PVDF gauge method.
- Make the comparison of getting data with other available data.

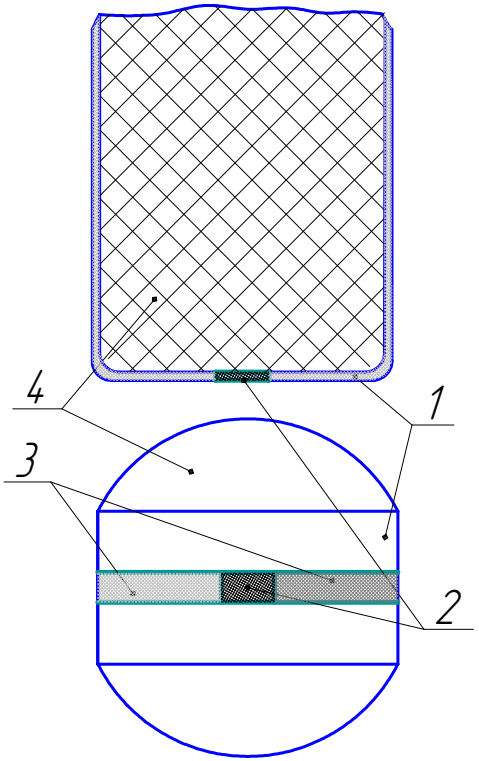
Cerium samples

- We studied samples of electrolytic cerium with a density of 6.75 g/cm^3 and purity of 99.83%. Contents of the other elements (mass %) were the following: La – 0.07%, Nd – 0.05%, Fe – 0.02%.

Image of PVDF gauge

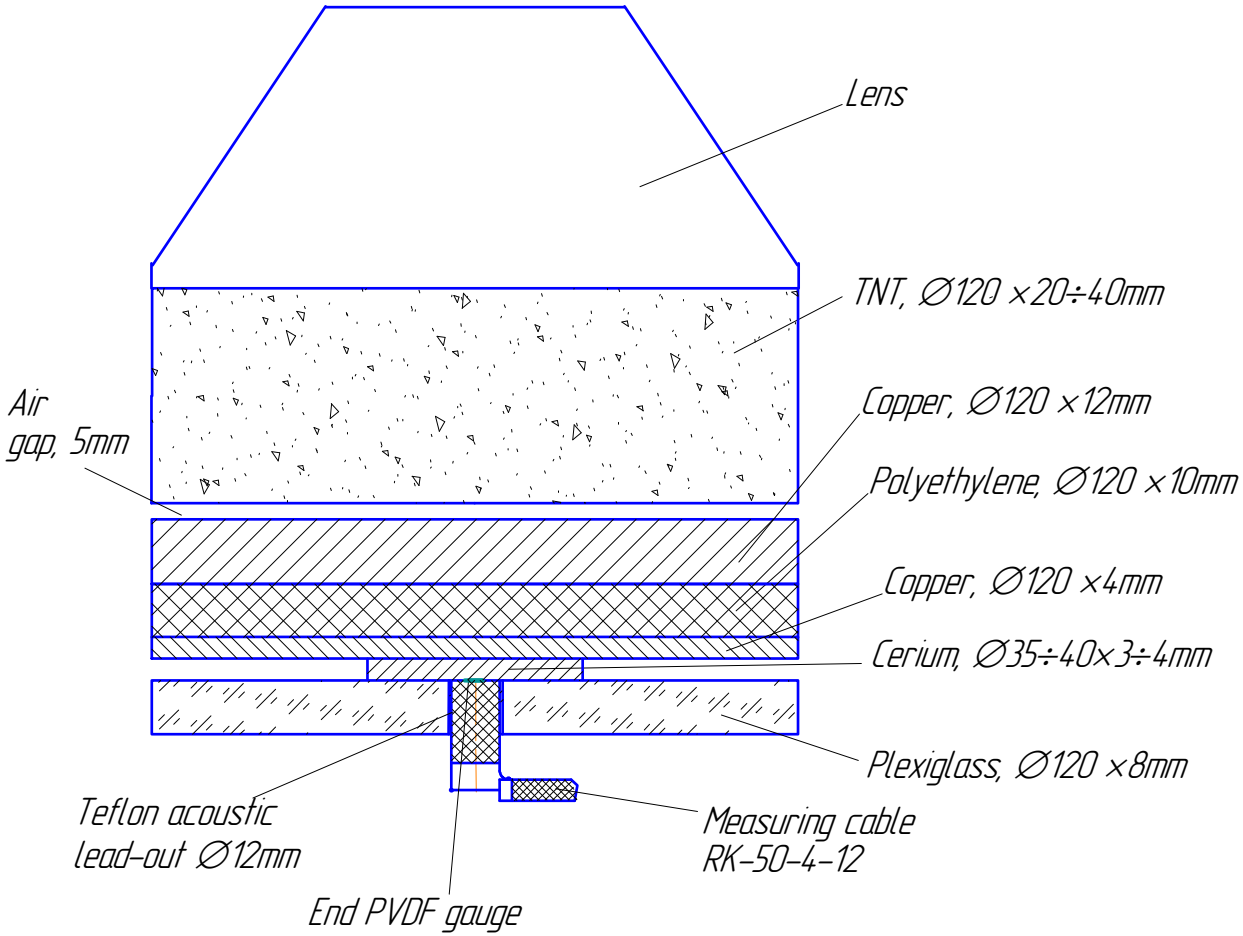


Gauge of “end” type



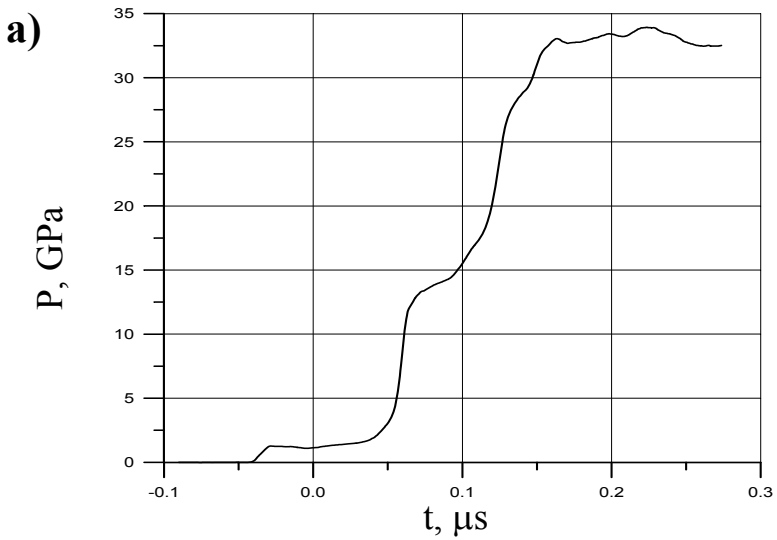
1-PVDF film (thickness of 10÷30 μm)
2-sensitive element
3-copper wireways (thickness ~0.5 μm)
4-acoustic lead-out

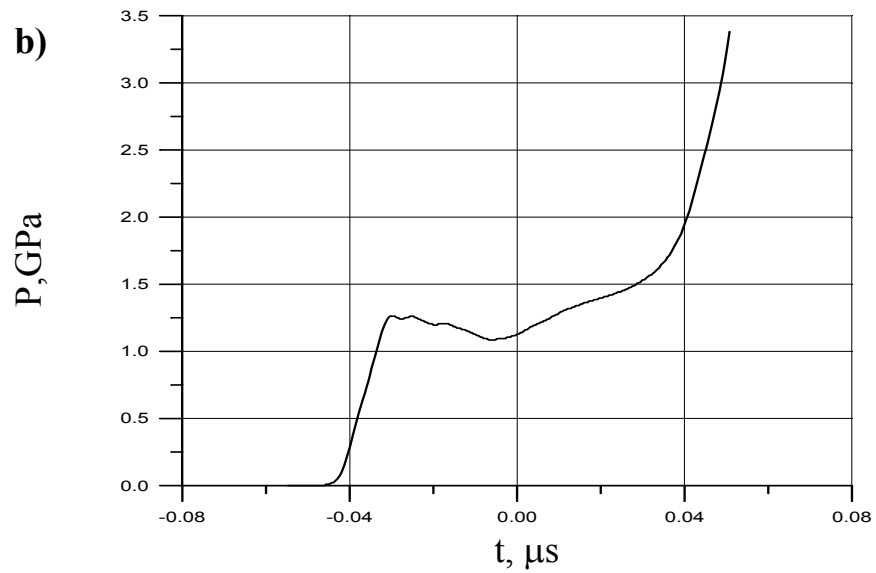
Scheme of experimental device



Results of test with steel sample having thickness of 3.03 mm

The applicability of PVDF gauges in studying phase transitions in metals was proven by performing calibration experiments with samples of Armco-iron .



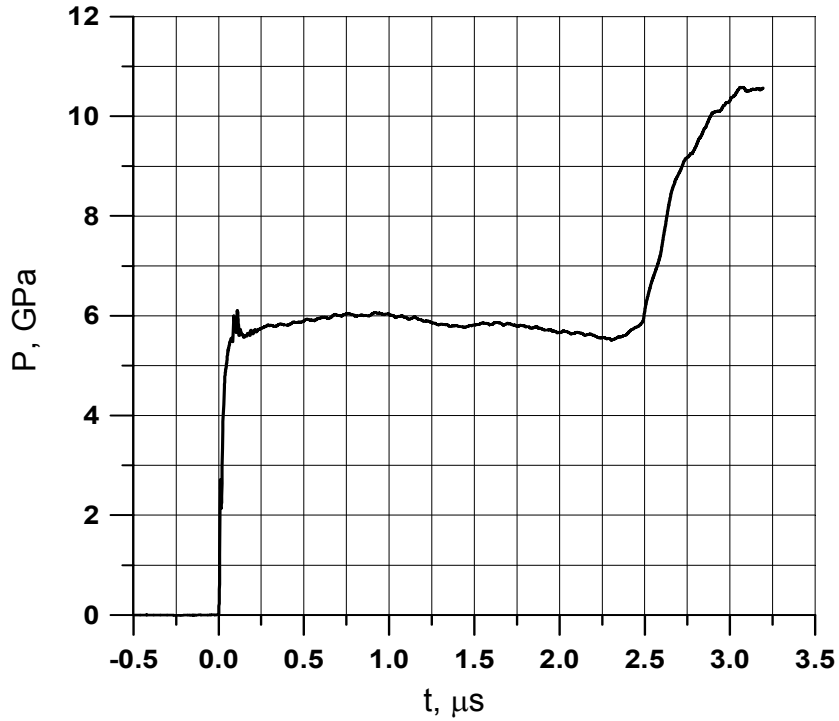


In iron, the multi-wave structure is a result of the α-ε phase transition.

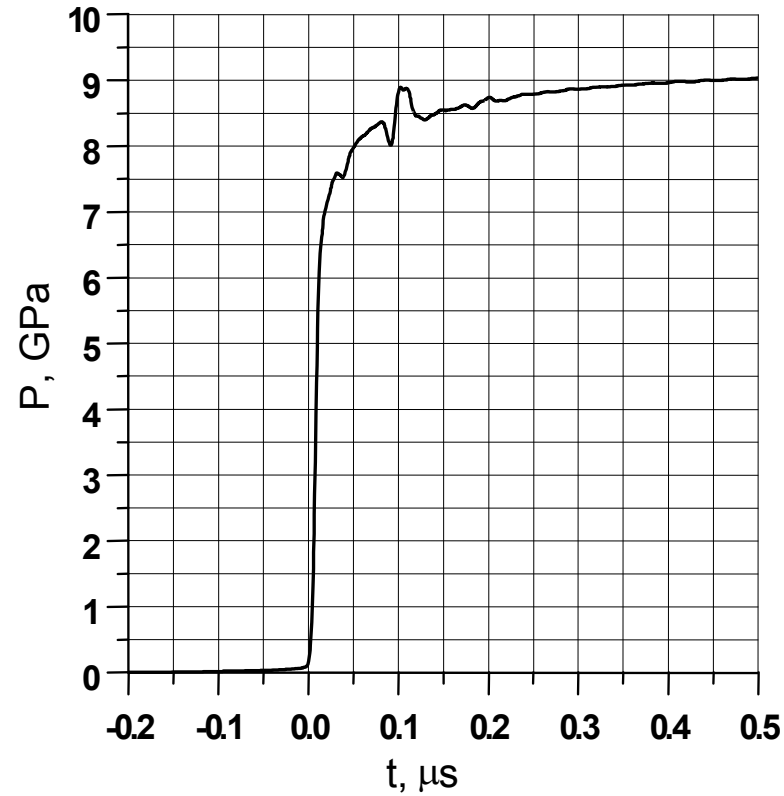
(a) – pressure in steel versus time;
(b) – initial part of P(t) in increased scale

Test with cerium. P=9 GPa

a)



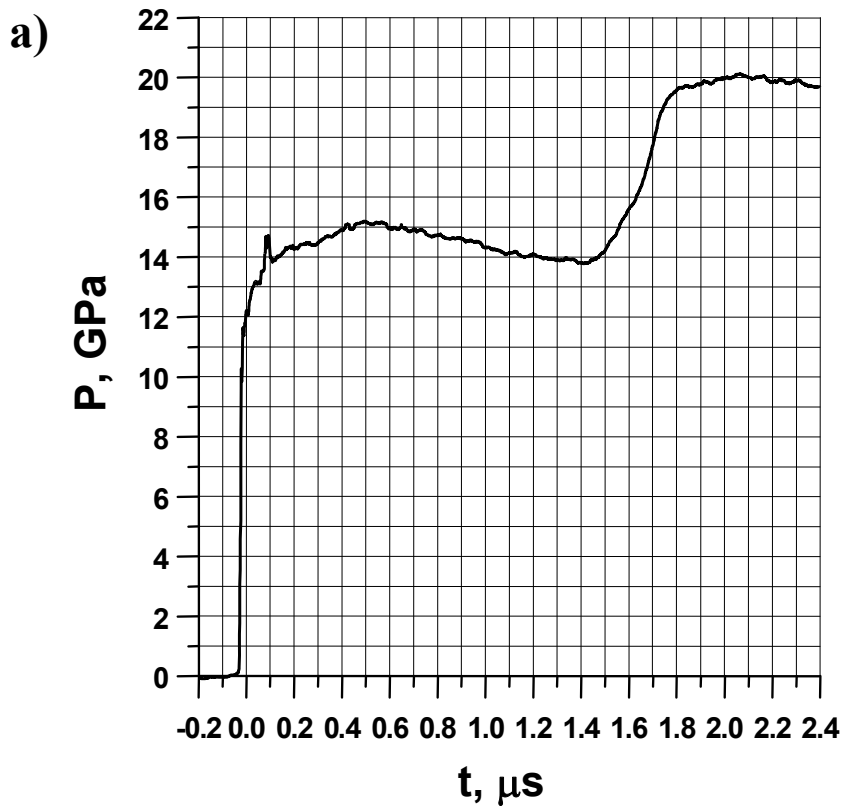
b)

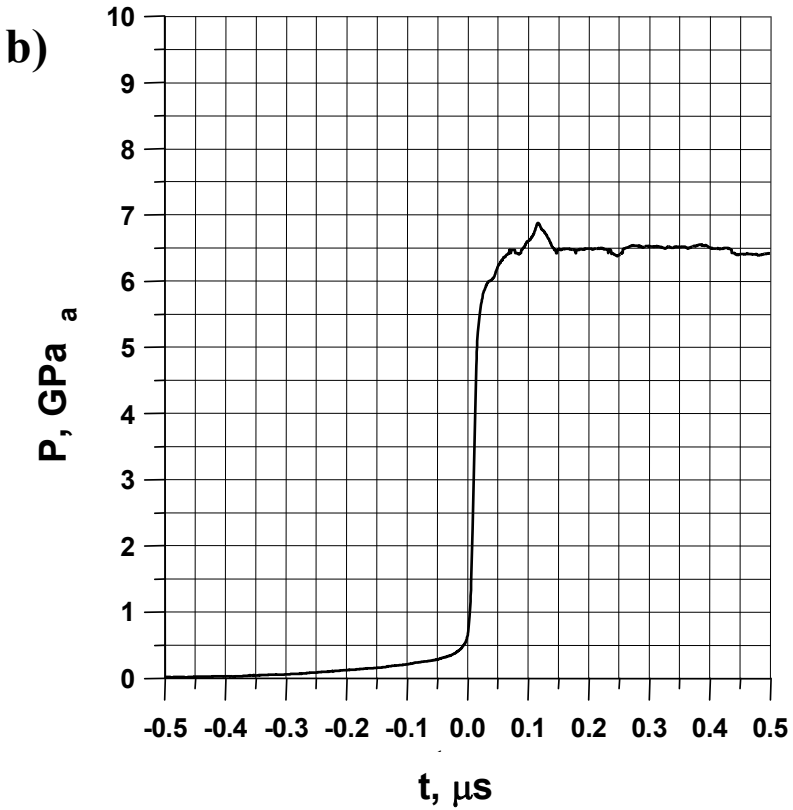


a) dependence of pressure in copper on time; base-plate Copper 12 teflon 10;

b) dependence of pressure in cerium (sample thickness-4 mm) on time

Test with cerium. P=7 GPa

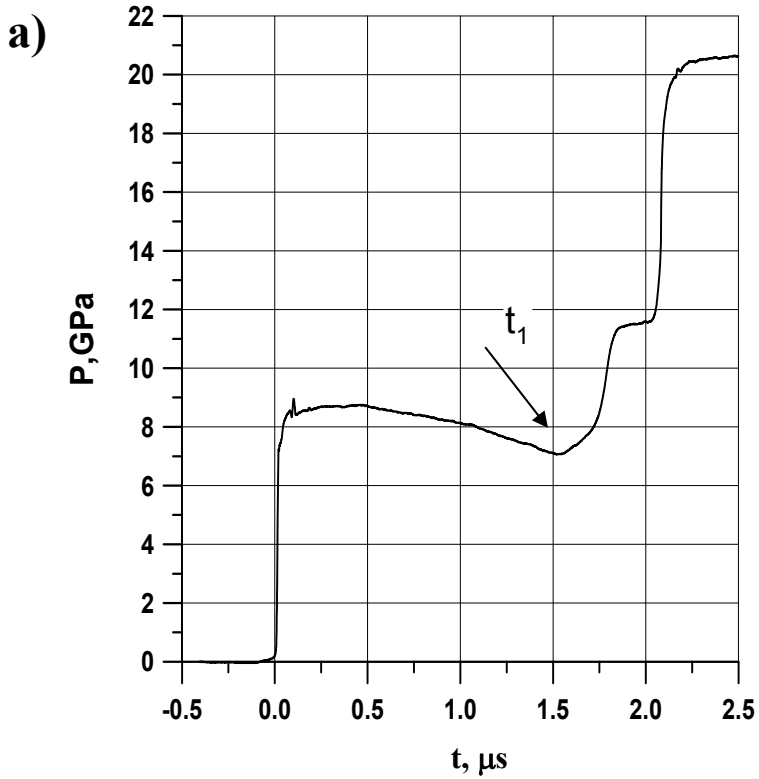


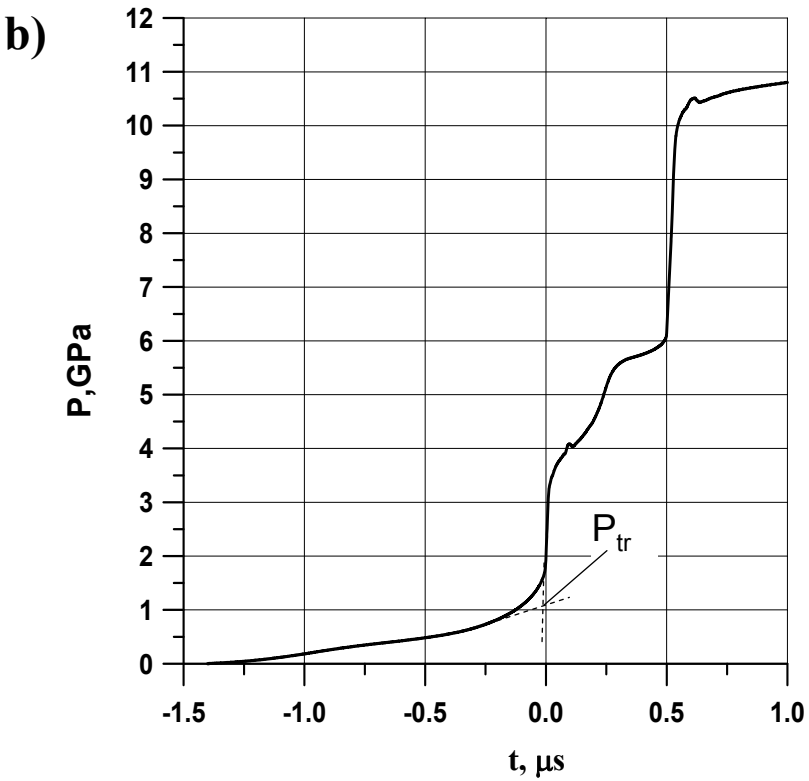


a) dependence of pressure in copper on time; base-plate Copper 12Teflon 10Copper 4;

b) dependence of pressure in cerium (sample thickness-4 mm) on time

Test with cerium. P=3.8 GPa

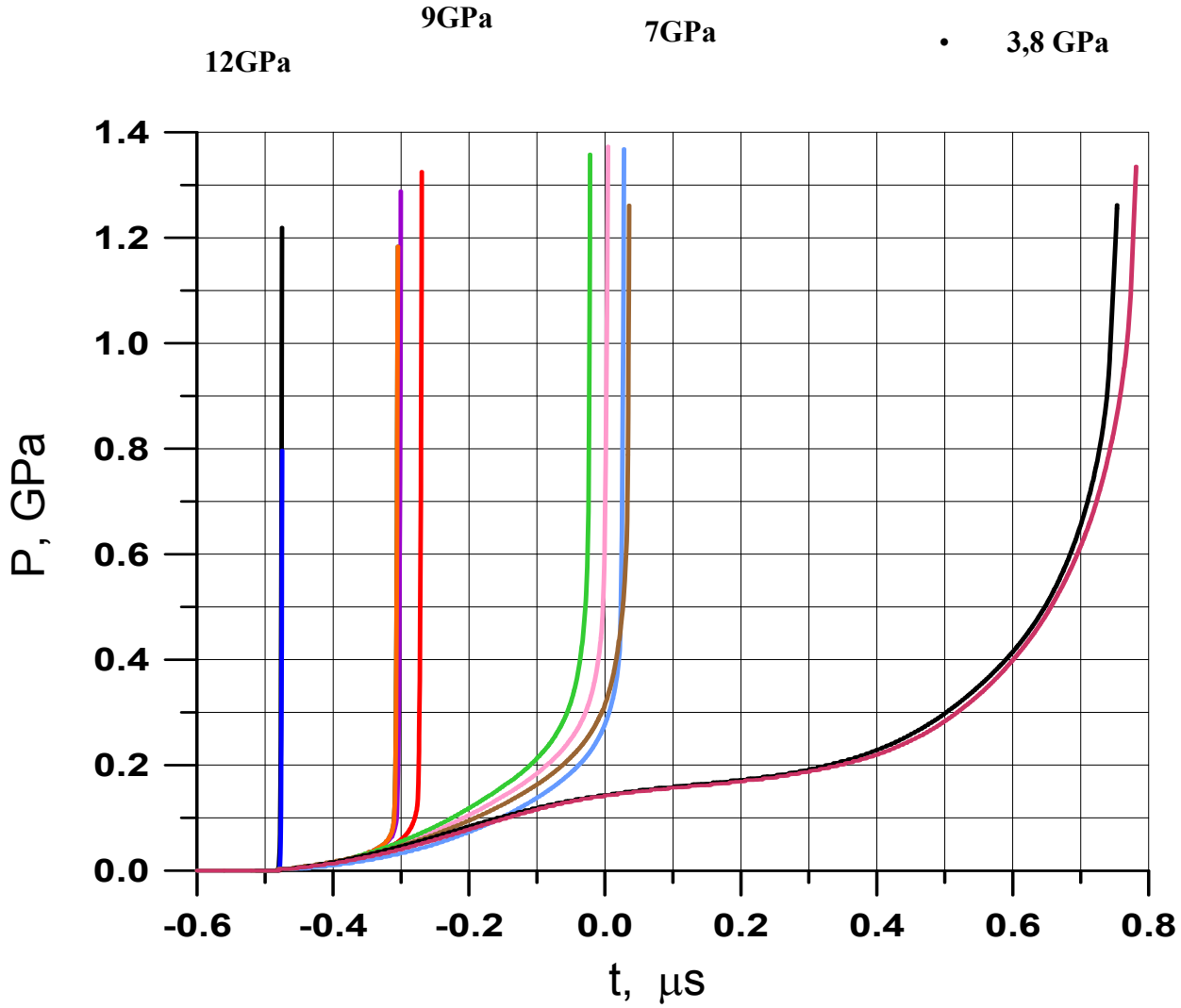




a) dependence of pressure in copper on time; base-plate copper 12 Polyethylene 10 Copper 4 ;

b) dependence of pressure in cerium (sample thickness-4 mm) on time

Initial parts of pressure profile in cerium at various shock-wave loading



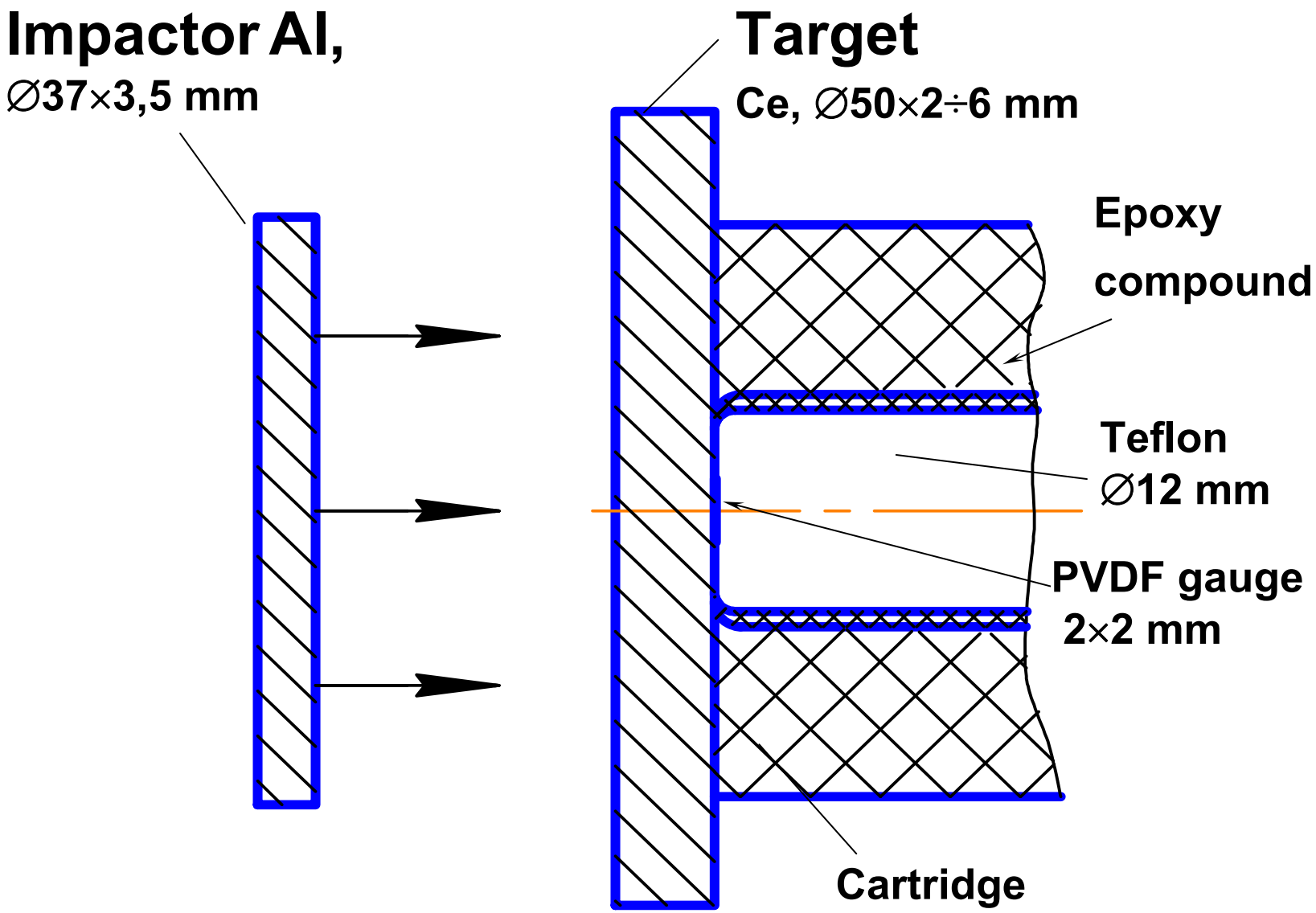
The pressure of the phase transition

- So, in the pressure range from 4 to 12 GPa PVDF gauges recorded a two-wave structure, which consisted of the head wave of isentropic compression and a shock wave followed after it.
- The pressure where the phase transition is completed, is determined as 1.0 – **1.2 GPa**, as depicted test with cerium, P=3.8GPa.

The pressure of the phase transition

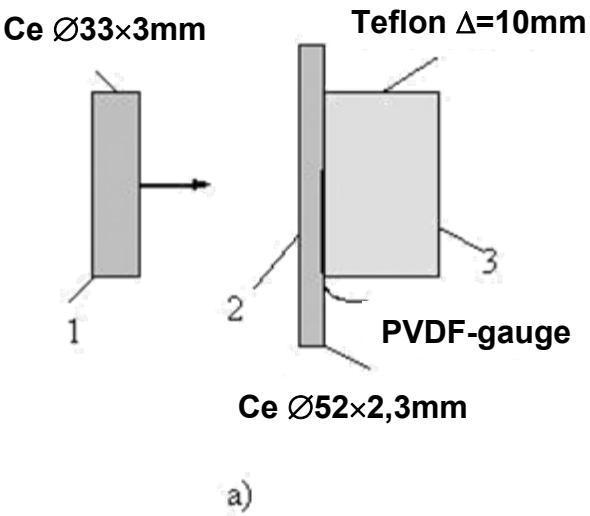
- The loading conditions were chosen to provide pressure (0.17 to 3 GPa) in the cerium samples both lower and higher than the value of pressure of completion of the phase (γ-α) transition (by light-gas gun).

Scheme of loading by light-gas gun

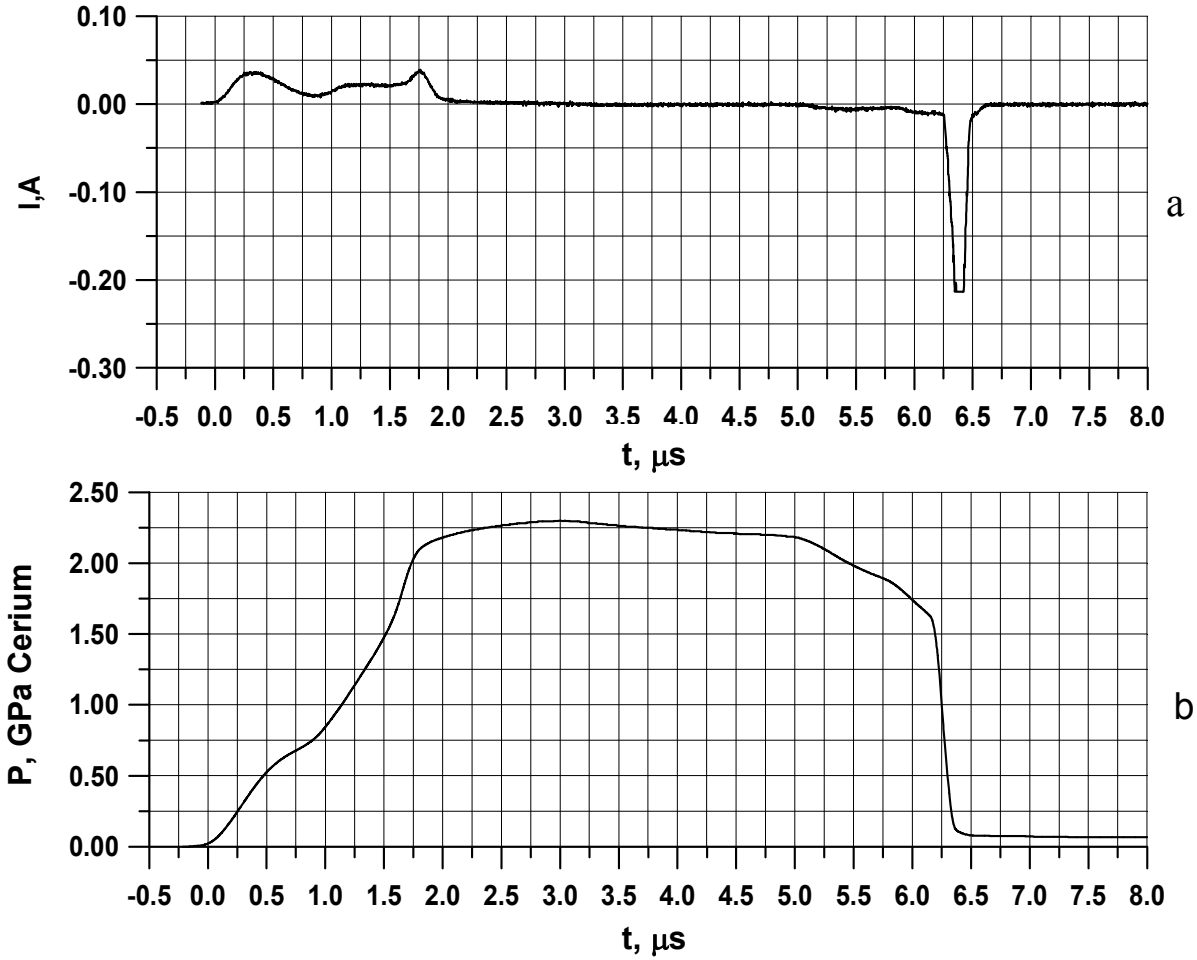


Cerium. Projectile is from cerium

Experimental setup



Result of the experiment

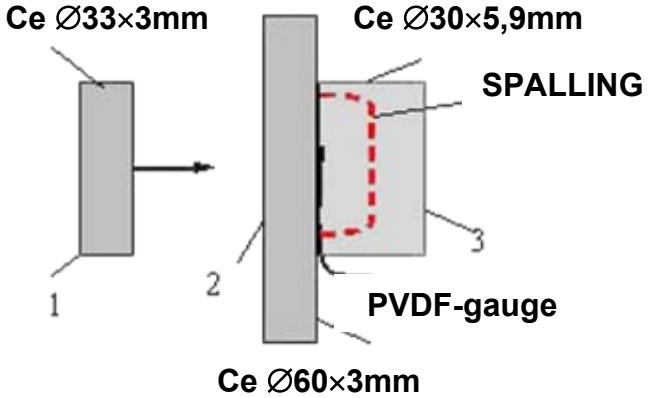


a) current via time

б) pressure via time

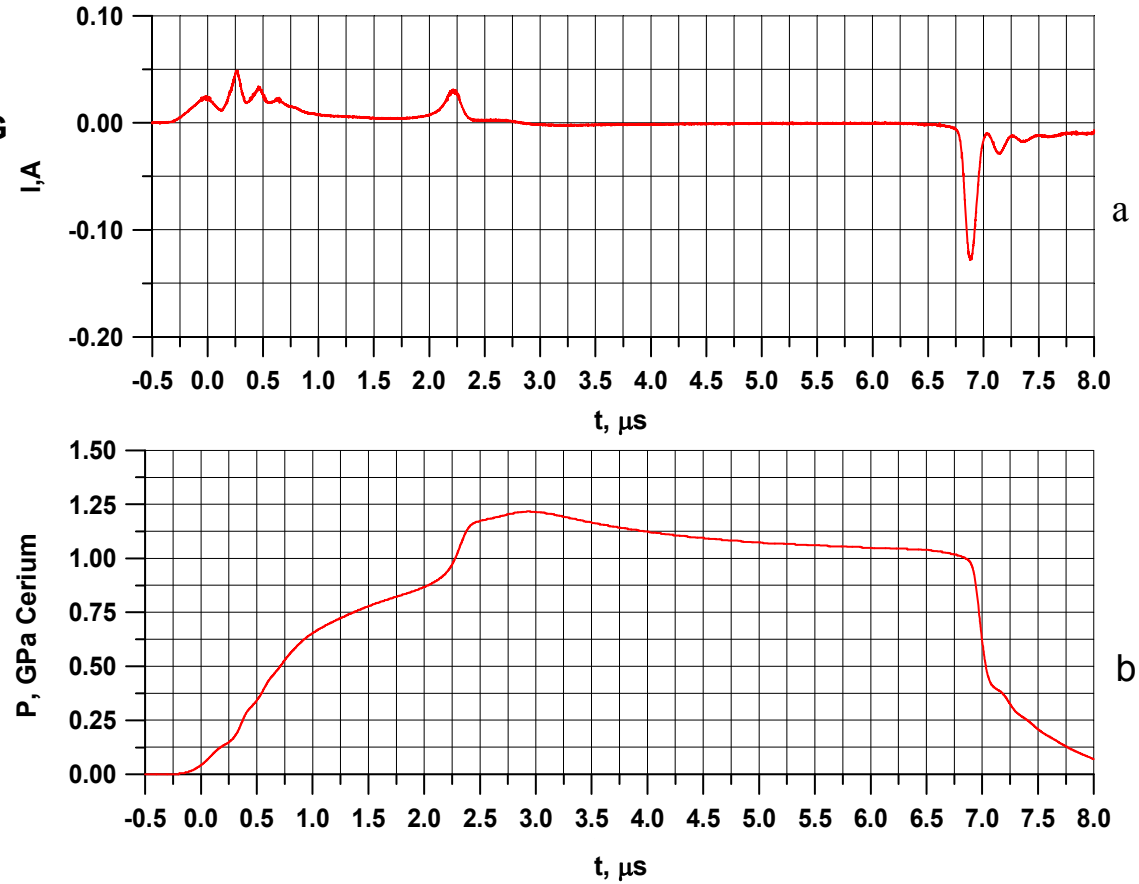
Cerium. Projectile is from cerium

Experimental setup



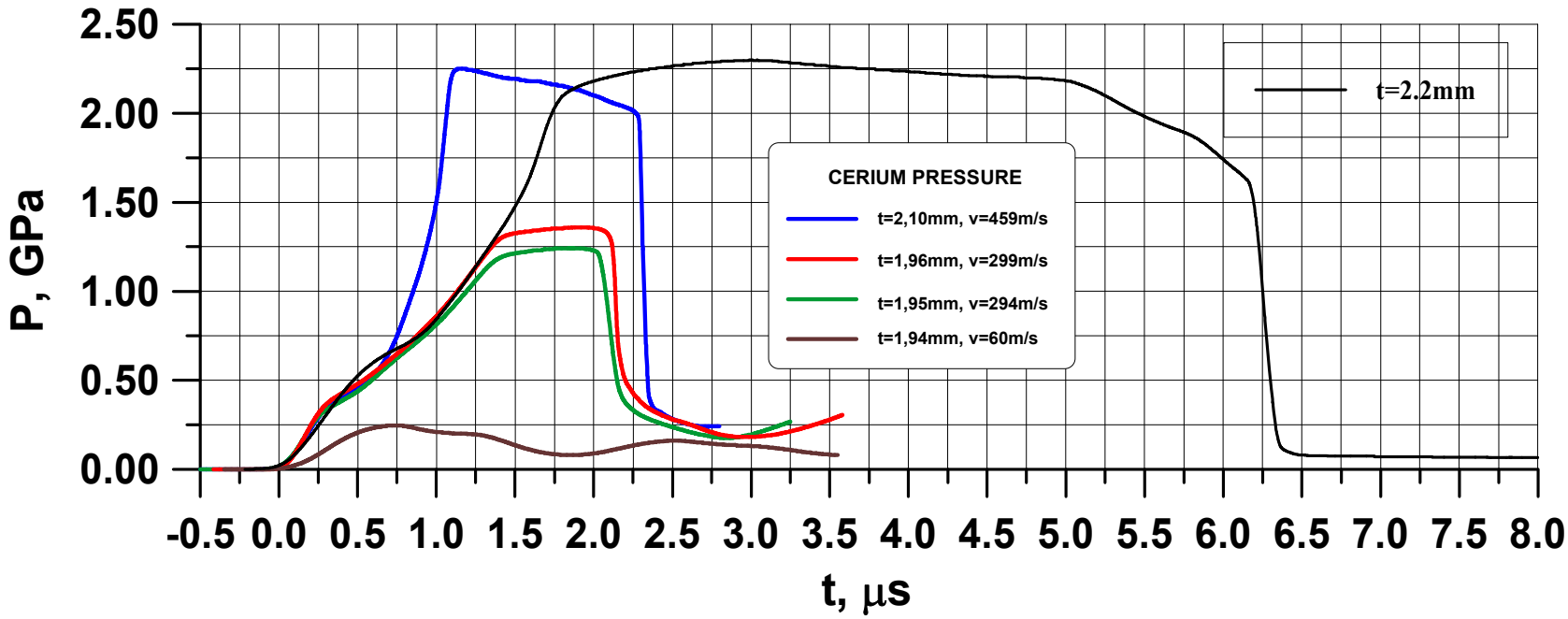
b)

Result of the experiment

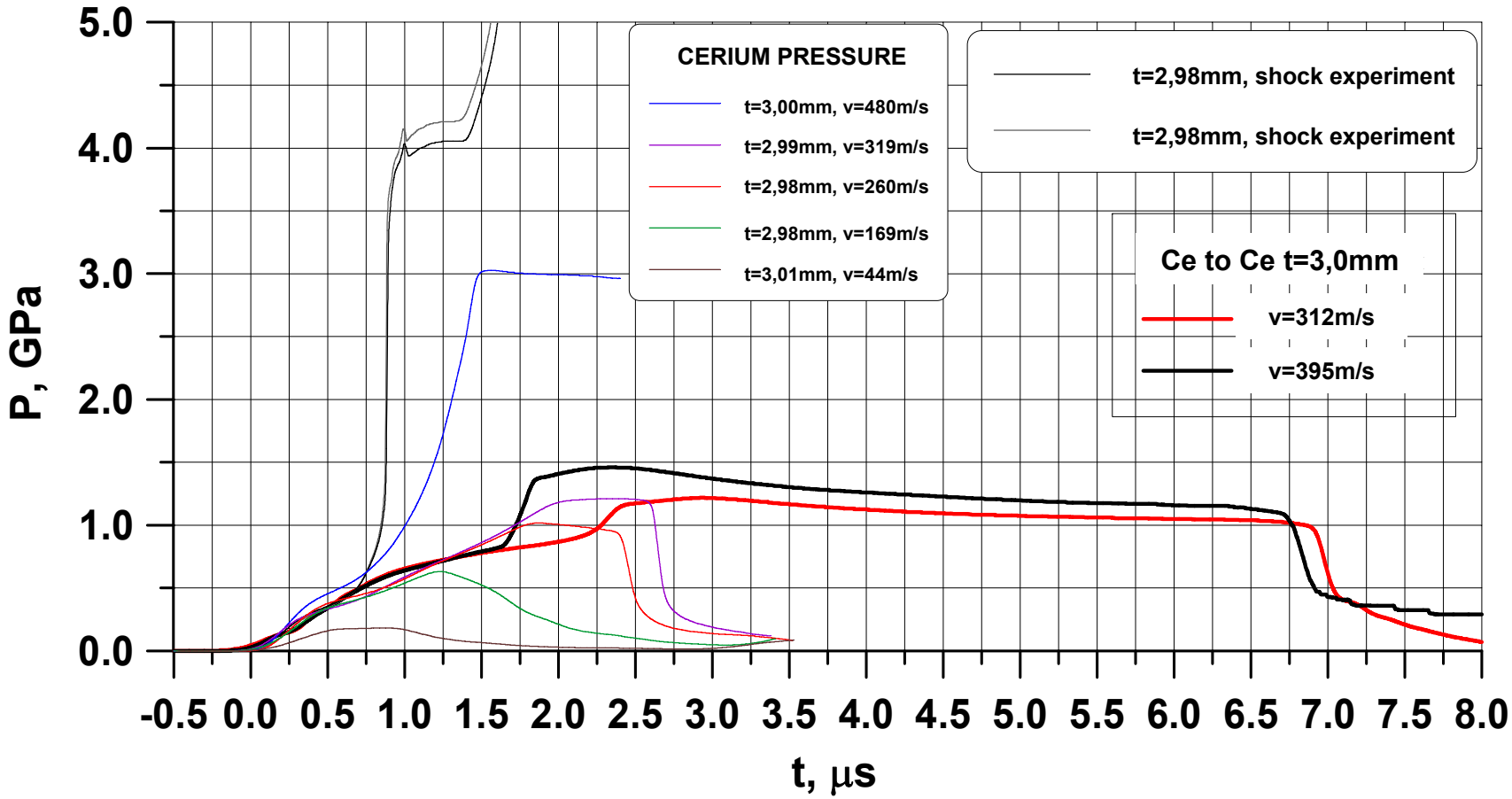


а) current via time
б) pressure via time

Results of experiments on the light gas gun with the aluminum projectiles and with cerium projectile



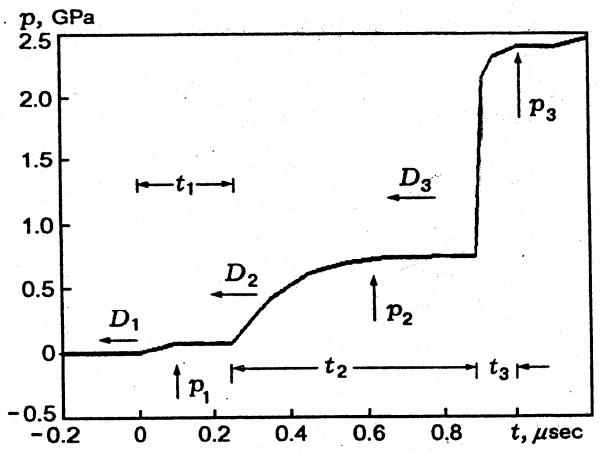
Results of experiments on the light gas gun with the aluminum projectiles, with cerium projectile and two shock experiments



Photograph of the survived samples

Comparison of PVDF and manganin data

- Similar measurements were performed using manganin gauges (1999) by Pavlovsky M.N. & Komissarov V.V. [4]. The profile of the shock front had a three-wave structure, including an elastic precursor (0.08 GPa) and two plastic waves (0.76 and 2.42 GPa). The amplitude of the first plastic wave is associated with the phase transition pressure.



Comparing the pressure profile measurements from manganin gauges and PVDF gauges, there are significant differences, namely, three-wave and two-wave structures, respectively. Nevertheless, values of the pressure of phase transition are in satisfactory agreement, namely, 0.76 GPa (manganin) and 1.0 – 1.2 GPa (PVDF). Differences in the structure of the shock front are probably related to the differences in sample thickness.

Summary

- The optical analyzer technique at pressures of 35 GPa and greater showed a one-wave structure in the rarefaction behavior recorded in measuring the sound velocity in cerium.
- The rarefaction wave structure obtained by the optical method and the manganin gauge method, indicates that **the upper boundary for cerium melting on the Hugoniot is ~12.3 GPa.**
- **The phase (γ-α) transition occurs at pressures in cerium higher than 0.6 GPa.** However, it has incomplete character at the used impactor velocities (light-gas gun). As a result, the material is a mixture of γ and α phases.
- **Because of (γ-α) transition the two-wave structure in cerium consisted of a leading isentropic compression wave followed by a shock wave.** The situation is vice versa during unloading, and a rarefaction shock wave is formed.
- The shock profiles did not exhibit any particular features corresponding the polymorphic (α-ε) phase transition.
- **Additional experiments are needed in order to obtain a more accurate determination of the cerium melt transition on the Hugoniot and the phase (γ-α) transition's pressures.**

References

1. M.V.Zhernokletov, A.E.Kovalev, V.V.Komissarov, M.G.Novikov, M.A.Zocher, F.J.Cherne. Measurement of sound velocities andshear strength of cerium under shock compression. SCCM – 2007, edited by M.Elert, M.D.Furnish, R.Chau, N.Holmes, J.Nguyen. AIP Conference Proceedings 955, p.p.117-120.

2. V.G.Simakov, V.A.Borisenok, V.A.Bragunets, V.A.Volgin, M.V.Zhernokletov, M.A.Zocher, F.J.Cherne. Study of phase transitions in cerium by PVDF gauge. SCCM – 2007, edited by M.Elert, M.D.Furnish, R.Chau, N.Holmes, J.Nguyen. AIP Conference Proceedings 955, p.p.105-108.

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4. Pavlovsky M.N., Komissarov V.V., Kutsar A.R. FGV. 1999. V.35. #1. P. 98.

Future investigations

We propose to study the wave structure and spall phenomena in cerium samples in the area of incomplete and complete phase transitions (≤10GPa). The shock wave front structure will be supplemented with metallographic analysis of pre-experiment and the post experimental samples. This analysis will provide information regarding the spall fracture mechanisms and an understanding of the loading parameters required for pore and crack nucleation.

THANK YOU