RELATION BETWEEN EXPLOSION MECHANISM ONBOARD SPACECRAFT UNDER RADIATION AND IMPACT LOADS

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ABSTRACT

The possibility of correlating initiating conditions for explosion processes of chemically active substances onboard spacecraft under space ionizing radiations and impact loads is theoretically validated. The explosion process physical model is based on consideration of thermal process dynamics in "hot spots", representing a region of energy liberation of space debris particles or ionizing radiation, acting on the spacecraft. Proceeding from the comparison of the calculations with the experiment data on explosive initiation by microsecond pulse loads the developed theoretical model certainty is proved.

1. INTRODUCTION

The mechanism of onboard explosions taking place as a result of chemically-active substance initiation under space environment ionizing radiation was discussed at the Space Debris Interagency Meeting held in Russia in 1993. Similar processes may take place at impacts of chemically-active substances with space debris fragments (SDF).

The given paper is designed for comparing explosive initiation conditions under ionizing radiation's and impact load effects.

The adiabatically-approximated expression for an absorbed dose of radiation "Q" required for an explosive initiation was obtained based on the theory developed by the author of the present paper:

$$Q = c\left\{\frac{E_a}{R_o}\cdot\frac{1+\ln(\tau_r\cdot Z)}{\ln^2\cdot(\tau_r\cdot Z)} - T_o\right\}, \qquad (1)$$

where: c - explosive heat

Z,E - pre-exponential multiplier and explosive activation energy in Arenius law

To - explosive temperature initial

τ_r - radiation pulse duration

R - universal gas constant.

The explosive initiation processes under radiation and impact load effects feature a common thermal mechanism of activating the parent molecules decomposition exothermic reaction.

2. EXPLOSION UNDER IMPACT LOADS

According to thermal initiation model [1] an explosion at impact effects is brought about by the explosive heating up in its locale seats- "hot spots" formed due to molecule friction on the shift surface or substance breakup. The "hot spots " measure 10^{-4} to 10^{-3} cm. Within the "hot spots" region the adiabatic conditions are satisfied by the impact effect duration amounting to units of microseconds. Let us consider the experimental data on microsecond-duration impact load effects on an explosive.

Paper [1] describes at length, the explosive initiation procedure by microsecond-duration mechanical pulses. A metallic striking plate was accelerated by means of a sheet-shaped explosive blasting and then it collided with high explosive test pieces. The piece collision velocity reached about 10^2 to 10^3 $m\cdot s^{-1}$, thus ensuring the pressure pulse amplitude, P equal to about 0,2 ÷ 1,5 GPa. The pressure pulse duration was

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calculated as a striking plate thickness-to-sound velocity relation and amounted to 0,2 ÷ 1,5 mcsec. The experiment results allowed explosive initiation conditions identification depending on the pressure pulse amplitude and duration. Fig.1 demonstrates characteristic test data.

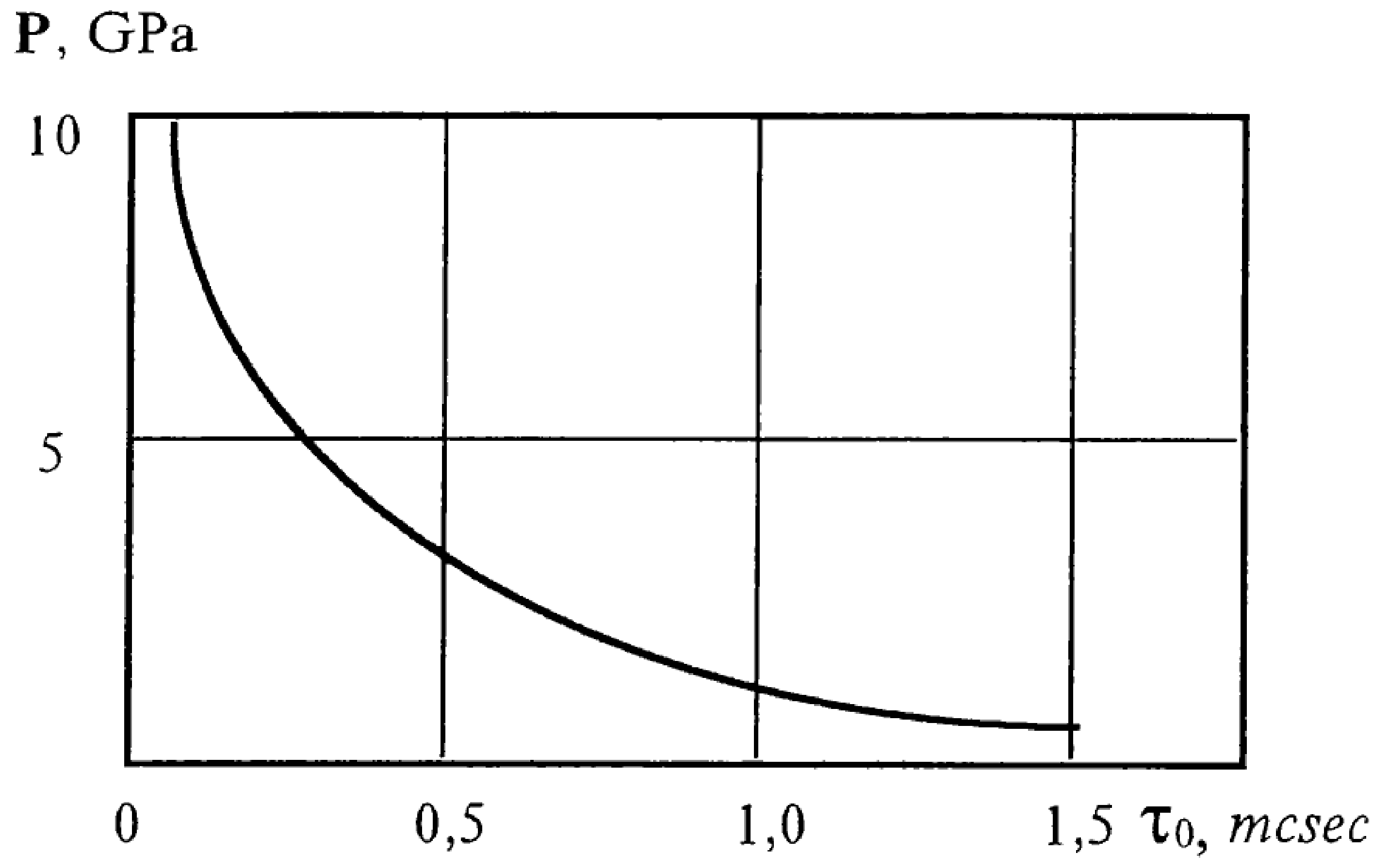

Figure 1. Experimental data on explosive initiation conditions under impact loads

The P curve depicts the explosive detonation region boundary: complete or partial detonation takes place above the curve, while beneath it there is no detonation. The stated dependence is clearly expressed at low $\tau_0 \leq 0{,}5$ to 1 mcsec and is weak (P ~ const) at more than several microseconds. As is noted in paper [1] the pressure amplitude is the only criterion for detonation initiation within $\tau_0 > 10$ mcsec without dependence on the impact effect duration. Within τ_0 ~0,2...1,5 mcsec the $P = P(\tau_0)$ function is well approximated by the analytical dependence:

$$P \cdot u \cdot \tau_0 = \text{const}, \qquad (2)$$

where u- substance mass velocity behind the shock wave front.

Relation (2) is a criterion condition of an explosive detonation at an impact and known in the literature as the critical energy condition [2]. Really, the $P \cdot u \cdot \tau_0$ determines the energy transferred by the shock wave through the unit surface area of a test explosive piece. At a constant shock wave velocity value D in the tested material the relation follows from the pulse conservation law:

$$\rho \cdot D \cdot u = P, \qquad (3)$$

which permits to transform expression (2) in the following manner:

$$P^2 \cdot \tau_0 = \text{const}. \qquad (4)$$

The constant value in (4) depends on impact condition and explosive composition. For the trotyl condition (4) appears as:

$$P^2 \tau_0 = 2{,}8 \cdot 10^{12}\, H^2 \cdot \text{sec} \cdot m^{-4} \qquad (5a)$$

$$P^2 \tau_0 = 5{,}24 \cdot 10^{12}\, H^2\, \text{sec} \cdot m^{-4} \qquad (5b)$$

for steel and aluminum striking plates accordingly.

3. EXPLOSION UNDER RADIATION

During the interaction of ionizing radiation with an explosive the radiation energy is transformed into thermal energy causing an intercrystal pressure increase. The absorbed dose of radiation and intercrystal pressure are bound by Grunaizen's relation:

$$P = Gr \cdot Q \qquad (6)$$

where Gr - Grunaizen's coefficient

Q - absorbed dose of radiation.

While identifying the pressure brought about by radiation effects with shock wave front pressure let us transform (4) as:

$$Q^2\, \tau_r = \frac{const}{G_r^2 \cdot \rho^2} \qquad (7)$$

where the constant value amounts to $(2{,}8 \div 5{,}24) \cdot 10^{12}\, H^2 \cdot s \cdot m^{-4}$. Formula (7) was obtained on the test result basis to initiate an explosive by impact loads, but it determines substance irradiation conditions under which an explosion occurs.

4. INITIATION CONDITIONS UNDER RADIATION AND IMPACT LOADS

Fig 2 gives the $Q=Q(\tau_r)$ describing explosive initiation conditions in compliance with formula (7) (the shaded region) and formula (1) (the dotted line). The calculation results agree satisfactorily in the region of $0{,}5 < \tau_r < 1$ mcsec. With $\tau_r > I$ mcsec the theoretical model predicts higher energy release levels as compared within impact initiation conditions. The fact may be interpreted as follows. If $\tau_r \leq 1$ mcsec or $P \geq 1 \div 2$ GPa, then number of local initiation seats - "hot sports" is so much that they overlap each other and provide an explosive volumetrical initiation corresponding to the theoretical model in accordance with formula (1). With $\tau_r \geq 1$ mcsec and $P \leq 1$ GPa the "hot sports" do not overlap and the energy release criterion level becomes lower during explosive impact initiation than in case an explosive is heated up homogeneously by irradiation.

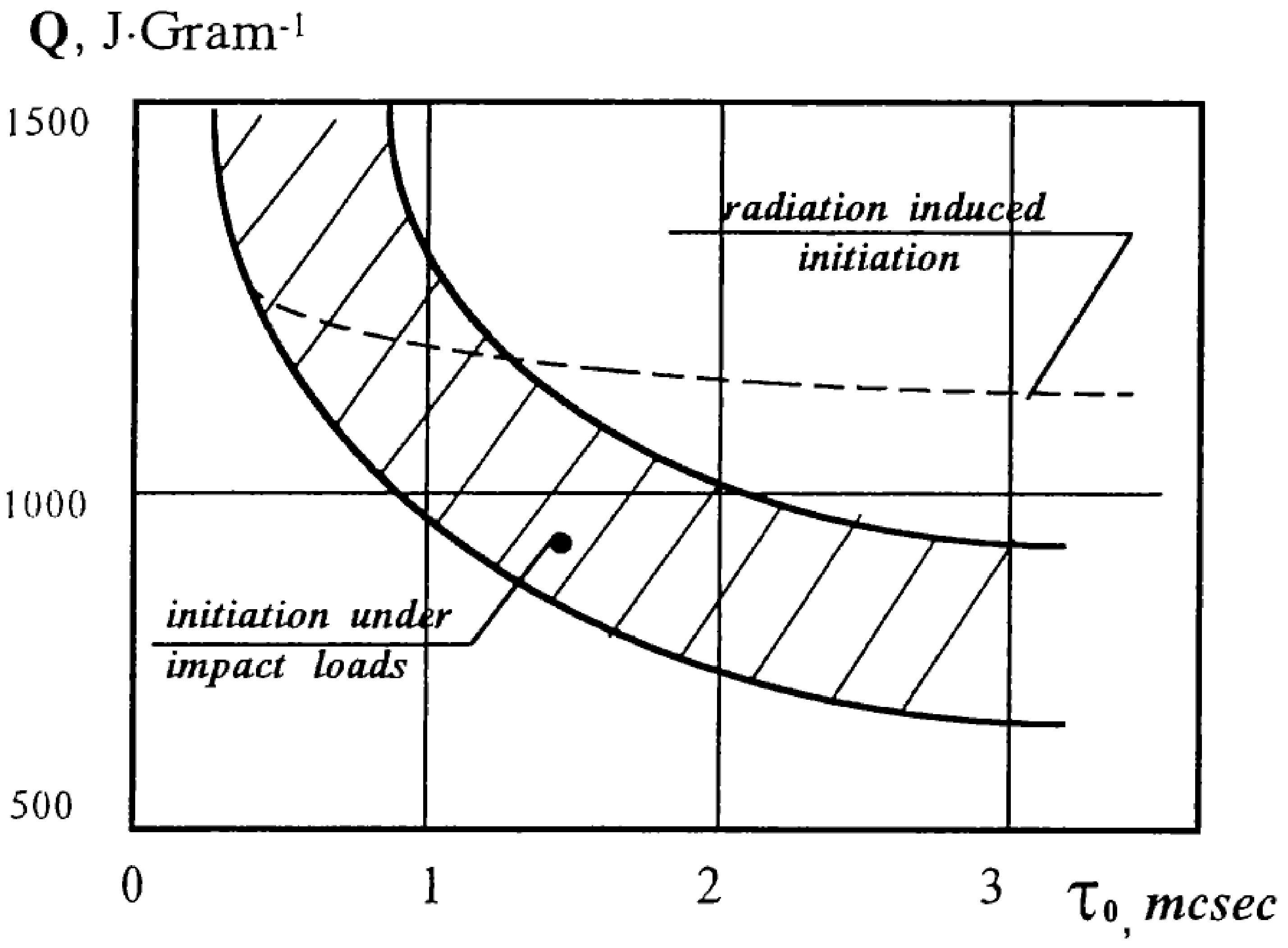

Figure 2. Comparison of explosive initiation conditions under radiation and impact

So, the possibility of correlating explosive initiation conditions under radiation and impact load effects are evidenced and the developed theoretical models confidence is supported by the analysis results.

REFERENCES

1. A.P. Pogrebov, S.A. Novikov - The Combustion and Explosion Physics, 1977, N 2., p.274.

2. V.A. Glushak, S.A. Novikov - The Combustion and Explosion Physics, 1984, N 4, p.77.

3. V.A. Glushak, S.A. Novikov - The Combustion and Explosion Physics, 1983, N 3, p.122.