Generation of neutrons as a result of explosive initiation of the DD reactions in conical targets

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A neutron yield of approximately 10^6 neutrons was recorded as a result of deceleration in deuterium-filled conical targets of metallic liners accelerated by detonation of solid explosives. Theoretical calculations of the neutron-generation process were performed, taking into account the cone deformation in the final stage of compression and heating of deuterium.

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Promising designs of pulsed thermonuclear fusion facilities are based on compression of a reactive material by a heavy liner that is accelerated as a result of ablation produced by intense electron, ion, or laser irradiation.[6] A design making use of conical targets is suitable for physical investigations. The initiation of thermonuclear reac-

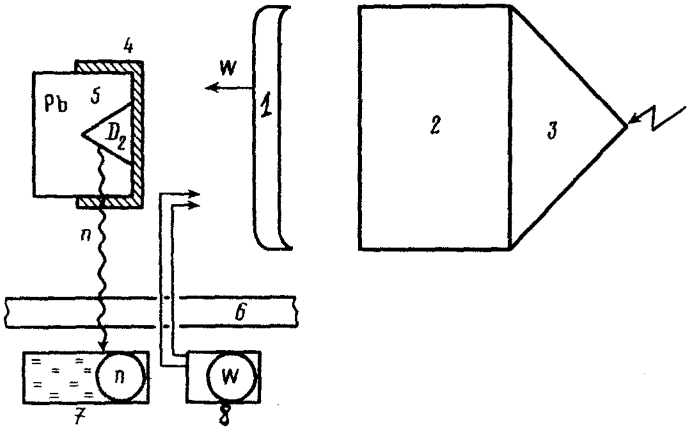

FIG. 1. Experimental setup: 1—striker (liner); 2—explosive charge; 3—detonation lens; 4—target cover; 5—target; 6—steel shield; 7—neutron recording apparatus; 8—striker-velocity measuring device.

tions in such targets by laser,[1,2] electron beam,[3] and explosive compression[4] was investigated in a number of papers.

In this paper we describe experiments on generation of neutrons from the DD reactions in conical targets. The compression and heating of a gas occurs when metallic liners, accelerated by detonation of solid explosive materials (EM), are decelerated. In contrast to Ref. 4, where a complex cummulation system characterized by a low reproducibility was used, we used linear projectiles[5] with stable parameters. The preliminary theoretical calculations showed that such devices can produce an easily recordable neutron yield, so that at least in the first stage, cummulation need not be used. The experiment confirmed this conclusion.

The experimental setup is shown in Fig. 1. The liner (1) was accelerated by exploding a cylindrical charge (2) of a solid high explosive in which a plane explosive wavefront is produced by means of a shaped explosive lens. The liner (1) is a 2-mm-thick aluminum disk, placed in a steel mount. The liner strikes the target (5) at a distance of 2.5 cm from the charge with the speed of 5.4 km/sec that allows enough time for relaxation of the explosion-induced wave processes. Earlier experiments[5] showed that the propelling systems are capable of reproducing the dynamic parameters to within 2% accuracy and a highly symmetric motion of the liner (radius of curvature 50 cm).

The experiments, which were performed with conical targets made of lead, were similar to those described in Refs. 1 and 2; the targets were filled with deuterium at the initial pressure close to the atmospheric. The input aperture of the targets was covered by a 0.25–0.30-mm-thick aluminum cover (4). In a number of experiments, polyethylene or a 50-μm-thick Lawson foil was placed between the cover and the gas. The target design and the filling procedure eliminated the loss of deuterium or the flow of air into the cone.

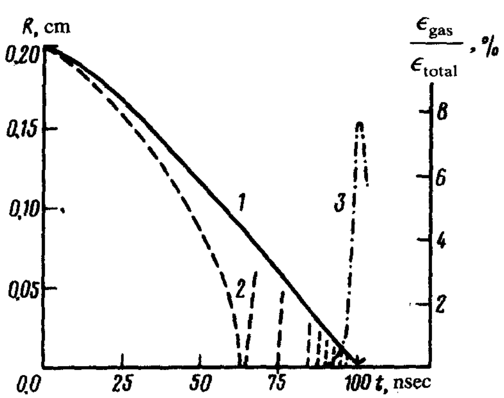

FIG. 2. Numerical calculation of compression dynamics: 1—motion of the liner's inner wall; 2—shock waves; 3—fraction of energy transferred to deuterium plasma.

The neutrons were recorded by a plastic scintillation counter placed 80 cm from the target behind a 4-cm-thick armored shield. A high-speed scanning oscillograph was used to record the signals from the counter. In addition to neutron counting, we measured the liner velocity in the vicinity of the target by using a baseline electrical contact method. To exclude possible noise in the measuring channel, we performed control experiments without deuterium before the experiments with deuterium-filled targets.

In the experiments we recorded stable neutron yield of the order of 10^6 neutrons per explosion. The neutron yield increased as a result of decreasing the initial pressure of deuterium

To analyze the processes in the targets and to optimize the experimental parameters, we performed a series of numerical calculations for compression of the deuterium plasma by the liner. The calculations were carried out within the framework of a simple spherically symmetric, two-temperature hydrodynamic model with allowance for transport processes, for radiative losses and for thermonuclear reactions. This model was used earlier to describe the dynamics of conical targets in the laser experiments.[2] A typical calculation is shown in Fig. 2. The compression occurs in two stages. First, a series of shock waves successively reflect from the liner and the center heat and ionize the gas, and set up homogeneous profiles of hydrodynamic variables with respect to the radius; then, the plasma is further compressed adiabatically with the entropy determined by the irreversible processes in the first stage. Estimates show that the effect of nonsphericity of the liner is negligible. The shock waves set up in lead as the liner collides with the target have no effect on the compression process. Thus, the initial stage of real compression is described adequately by the one-dimensional model. The noticeable effects of multidimensionality can be expected in the final stage, when the cone is deformed substantially. This stage may be considered adiabatic, and the critical parameters for calculating the neutron yield can be estimated, if the specific entropy of the plasma is known and the semi-empirical equation of state for lead is used. The calculation gives the values $P \approx 50$–100 Mbar, $T \approx 0.3$–0.5 keV, and $\rho/\rho_0 \approx 10^3$, which correspond to a neutron yield in the range 10^4–10^8.

The calculation correctly reproduces the qualitative picture of compression and heating of the deuterium plasma observed experimentally. Because of the complex geometry of the experiment and a limited information on the thermodynamic and transport characteristics of the target and liner materials, it is difficult to expect a real improvement in the accuracy of the calculation when two-dimensional models are used.

In conclusion, we note that the experiments on explosive compression provide an interesting approach to the study and optimization of targets for pulsed thermonuclear fusion. In addition to considerably broadening the energy range, the explosive method offers a means to study the hydrodynamics of compression in a pure state, without examining the complex processes of interaction of the electron beams or light with the plasma.

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