Effect of turbulent mixing on compression of shell targets

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The results of calculations of shell targets for LTF with allowance for turbulent mixing are given. It is shown that in a number of cases allowance for turbulent mixing may affect noticeably the compression of the target.

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In recent years, the shell targets, which, in contrast to the homogeneous targets, do not need a pulse of specific shape, have been the most promising targets for Inertial Thermonuclear Fusion.[1-3] These targets, however, develop contact boundaries between the different materials, which in the case of Taylor instability, are smeared out because of turbulent mixing. When the turbulent smearing is strong the design parameters of the targets deteriorate noticeably. The physical model of turbulent mixing and the quantitative estimates were described for the first time for a self-similar case in a paper by Belen'kiĭ and Fradkin.[4] Neuvazhaev and Yakovlev[5,6] further developed the model and incorporated it into a numerical gas-dynamical calculation. There are other approaches for taking into account turbulent mixing.[7,8] Below we discuss the results of calculations of the compression of shell targets, which were performed by using a single-temperature, gas-dynamical program with allowance for the electronic thermal conductivity and turbulent mixing.

1. Calculation of the target investigated in the experiment.[9] The glass-shell target with an outer radius $r_0 = 25\ \mu$m and a wall thickness $\Delta = 0.6\ \mu$m was filled with a DT mixture with a density $\rho = 3.4 \times 10^{-3}$ g/cm^3. The calculations showed that, although the boundary between the glass and the gas is unstable during the braking process, the mixing is not deep. This is attributable to convergence of the densities of gas and glass at the moment of braking (discharge and partial inward evaporation of glass), and the closer the density of the adjacent materials, the weaker is the mixing. The heating by fast electrons and by nonequilibrium radiation,[1,2] which was not taken into account in these calculations, may further weaken the mixing effect. Note that the experiment showed no evidence of strong mixing.[9]

2. Calculation of the cryogenic target. The inert-shell target with $r_0 = 1$ mm and $\Delta = 0.01$ mm formed DT-ice 0.02 mm in thickness on the inner wall. The 200-kJ pulse had a Gaussian shape and a duration of $\tau = 2$ nsec at half height. In the calculations with Thomas-Fermi equations of state,[10] the mixing at the contact boundary turned out to be small because of the small difference in densities at the moment of deceleration. But here the densities were equalized because compression was accomplished almost adiabatically. The electronic components of pressure of both materials were almost the same as those of the degenerate electronic gas, and the equality of pressures at the boundary indicated that the densities were approximately equal. Note that if the equations of state for ideal gases were used in the calculations, the mixing increased noticeably.

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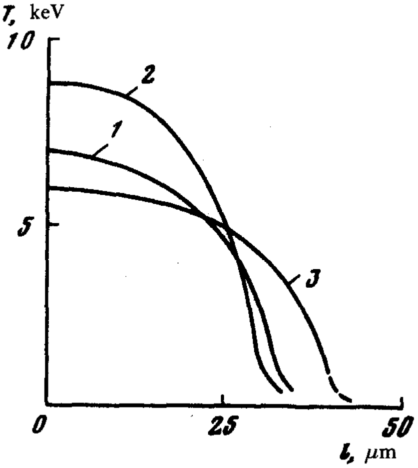

FIG. 1. Dependence of the temperature in the DT on the radius at the moment of maximum compression of the target.

3. Calculation of the target with a heavy layer. Nuckolls *et al.*[1] and Fraley *et al.*[2] suggested that a layer of material with a large atomic number (Z) be placed between the DT and the evaporating part of the target to protect against heating by fast electrons and to improve compression. The density of this material is much higher than that of the surrounding layers, and a boundary, which is unstable during accel-

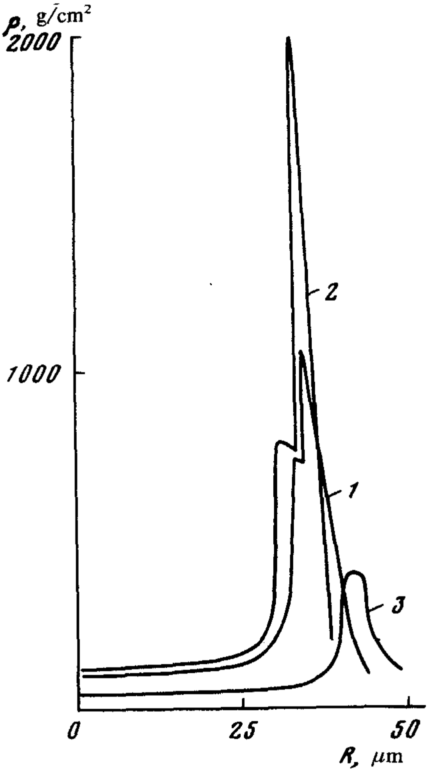

FIG. 2. Dependence of the density on the radius at the moment of maximum compression of the target.

eration, appears. The same unstable boundary appears in most targets examined in Refs. 1–3 (between the ablator and the solid propelling shell and between the ablator and the non-heat-conducting barrier). To investigate the effect of mixing or compression of this type of target, the material of the unevaporated part of the inert shell was replaced by a material with a large density (~ 20 g/cm^3) while conserving the mass. Figures 1 and 2 show the density and temperature profiles at the moment of maximum compression of the target for the following cases: 1) Calculation without replacement of the unevaporated shell; 2) calculation with replacement of the unevaporated part but without allowance for mixing at the incipient contact boundary; and 3) calculation with allowance for mixing. The mixing at the boundary with the DT and the effect of thermonuclear reactions on compression of the target were not taken into account in any of the cases. The mixing effect, which turned out to be significant, was caused by the turbulent heat conductivity,[5] which produced heating of the entire inert shell and decreased the compression parameters. The calculation with mixing but without turbulent heat flow gave the same results as the calculation without the introduction of the heavy layer.

Thus, the mixing effect due to compression is small only in simple targets. A modification of the target—introduction of heavy layers, ablators, additional shells—as a rule, enhances the mixing effect, which in this case must be taken into account.

[1] I. Nuckolls *et al.*, J. Plasma Phys. and Contr. Nucl. Fusion Research, 1974, IAEA, Vienna, 1975, Vol. 2, p. 535.

[2] G. S. Fraley *et al.*, J. Plasma Phys. and Contr. Nucl. Fusion Research, 1974, IAEA, Vienna, 1975, Vol. 2, p. 543.

[3] Yu. V. Afanas'ev, N. G. Basov, P. P. Volosevich, E. G. Gamaliĭ, O. N. Krokhin, S. P. Kurdyumov, E. I. Levanov, V. B. Rosanov, A. A. Samarskiĭ, and A. N. Tikhonov, Pis'ma Zh. Eksp. Teor. Fiz. **21**, 150 (1975) [JETP Lett. **21**, 68 (1975)].

[4] S. Z. Belen'kiĭ and E. S. Fradkin, Trudy FIAN SSSR **29**, 207 (1965).

[5] V. E. Neuvazhaev and V. G. Yakovlev, Zh. Vys. Mat. i Mat. Fiz. **2**, 440 (1976).

[6] V. E. Neuvazhaev and V. G. Yakovlev, PMTF **4**, 74 (1976).

[7] R. L. McGrory and R. L. Morse, Phys. Fluids **19**, 175 (1976).

[8] V. N. Andronov, S. T. Bakhrakh *et al.*, Zh. Eksp. Teor. Fiz. **2**, 806 (1976) [Sic.].

[9] G. Charatis *et al.*, J. Plasma Phys. and Contr. Nucl. Fusion Research, 1974, IAEA, Vienna, 1975, Vol. 2, p. 317.

[10] R. Latter, Phys. Rev. **99**, 1854 (1955).