Targets and parameters of lasers for producing a flash and for a hybrid reactor

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The results of calculations of LTF targets, which were performed using the "Zarya" program with allowance for the spectral transfer of radiation, α particles, fast electrons, and the limitation of electronic thermal conductivity, are discussed. The specifications for the targets and parameters of a laser for producing a flash and for a hybrid reactor, are determined.

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1. The "Zarya" program is based on the two-temperature gas-dynamic model,[1] which describes the motion of matter with allowance for several dissipative processes and energy transfer by nonequilibrium radiation.[2,3] Distinctions are made between electronic, ionic, and photonic components in both the termodynamic functions as well as the dissipative processes. The quasi equilibrium and nonequilibrium components are identified in each component: fast electrons produced as a result of interaction of laser radiation with the plasma, neutrons and charged products of fusion reaction, and nonequilibrium radiation. The energy and momentum transfer of charged particles can be examined in the one-group approximation with effective mean free paths and in the spectral formulation. In describing the interaction of laser radiation with a plasma, we must take into account the inverse, bremsstrahlung, resonant, and parametric absorption by the density profile, which is deformed by the ponderomotive forces, and stimulated-scattering processes (see review article [4]). The possible limitation of electronic thermal conductivity is taken into account.[5]

2. After a refinement[6,7] of the theoretical design model by means of the existing experiments with gas-filled shells,[8,9] calculations were performed [7] to determine the scale of the laser and possible target design for obtaining a flash ("breakeven"). Before performing the calculations, we had to determine the laser requirements (energy E, power P, wavelength λ, and the pulse shape), which are imposed by different target designs.

Many target designs have been published up to now: homogeneous targets that required a shaped pulse[10] and shell targets,[11-15] in which high compression can be achieved with a simple pulse shape. In choosing possible target designs, however, allowance must be made for the following facts. The effects associated with heating of the shell by nonequilibrium radiation prevent the use of materials with $Z \gtrsim 6$ in the evaporating part of the target.[14] The gravitational instability and turbulent mixing do not allow a large density difference at the contact boundaries of thin shells[15-16]; if, however, such density difference is necessary, then the shells must be sufficiently thick.

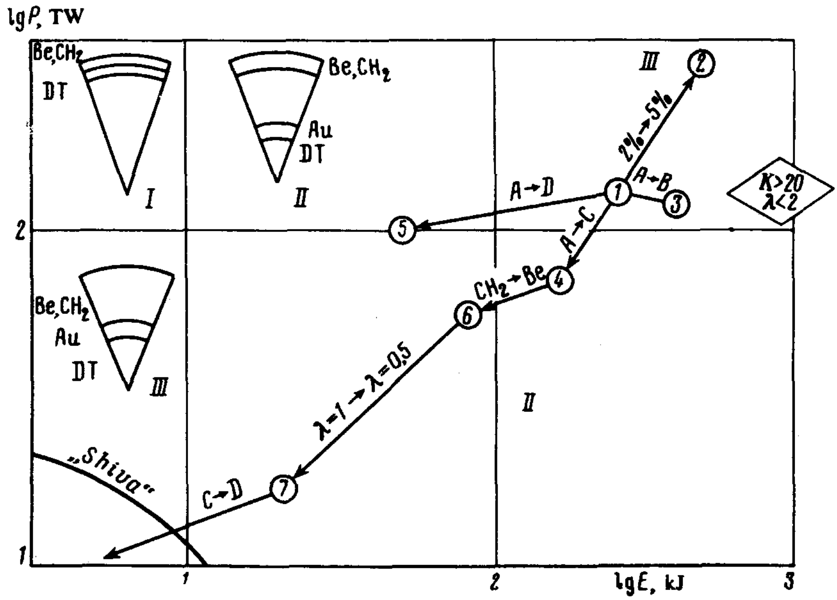

FIG. 1. Requirements for a laser system for obtaining thermonuclear flash. The positions of various laser-target systems, which differ in target type, pulse shape, and laser wavelength, are shown in the energy-peak laser power plane. The specific features of type-I target calculations (1-7) are listed in Table I. A flash can be obtained in the existing "Shiva" system by changing to the second harmonic of a Nd laser and using a shaped pulse and type-I cryogenic targets.

The following targets were examined: type I target consisting of a shell made from a material with small Z (CH_2 and Be) and with a layer of DT-ice on the inner surface with a total relative thickness of $\sim 3\%$; type II target consisting of two concentric shells—an inner Au shell with a 10–15% relative thickness filled with DT liquid and an outer CH_2 (or Be) shell with a two-three times greater mass and a 2–5% relative thickness—with a low-density gas between the shells; and type III target, which differs from type II target because it has no gap between the shells.

The calculations were carried out for the following laser-pulse shapes: A—right triangle, B—isosceles, C—Gaussian pulse, and D—a shaped pulse with a power differential of $\lesssim 10^3$.

The target and pulse parameters were varied until a noticeable thermonuclear burning appeared in the calculations. To facilitate comparison of the different targets, pulse shapes and laser radiation wavelength, the positions of the various "target-laser" systems are indicated in Fig. 1 in energy vs. peak laser power coordinates (E,P), assuming that the burning temperature is two to three times higher than the compression temperature. This condition can be defined as the "breakeven". The notations used in Fig. 1 for type I targets are listed in Table I.

Figure 1 also shows the requirements for the laser (for $\lambda = 1\ \mu$m and a Gaussian pulse shape) that are imposed by type II and III targets. As seen in this figure, the scale of the device for producing the flash strongly depends on the wavelength, pulse

TABLE I. Wavelength, laser pulse shape, material, and relative thickness of the inert shell for type-I targets illustrated in Fig. 1.

№	1	2	3	4	5	6	7
λ μm	1	1	1	1	1	1	0.5
Pulse	A	A	B	C	D	C	C
Target	CH_2–2%	CH_2–5%	CH_2–2%	CH_2–2%	CH_2–2%	Be–2.5%	Be–2%

shape, and target design. These exploratory calculations showed that: a) cryogenic targets, whose shell consists of 2–3% of a material with small Z and high initial density (Be) whose inside surface has a frozen layer of DT ice with a relative thickness of $\sim 1\%$, are needed to obtain a flash. Using such a target, we can obtain a flash in a device with parameters $E \sim 100$ kJ, $P \sim 50$ TW, and $\lambda = 1$ μm for a Gaussian pulse shape; b) we can reduce the laser energy and the power required for the "breakeven" condition by making the target design and pulse shape more complicated: use of type II targets makes it possible to reduce the peak powers by a factor of two; use of a shaped pulse allows a five- to sixfold reduction; c) the scale of this device can be radically reduced by decreasing the wavelength of $\lambda \lesssim 0.5$ μm; in this case the results of the calculation are more stable with respect to the constraints imposed on the electronic thermal conductivity and on the fast-electron spectrum; d) when the second harmonic of the neodymium-laser radiation, a shaped pulse, and cryogenic targest are used, the scale of this device is comparable to that of the existing "Shiva" laser system.

3. Achievement of the "breakeven" condition makes it possible to experimentally verify that a hybrid reactor using LTF can be built.[13] A possible "laser-target" system for a hybrid reactor is as follows. Laser: 1–2% efficiency, simple pulse with $P \approx 100$ TW, $E \sim 1$ mJ, and $\lambda \lesssim 1$–2 μm. Target: inert shell with a layer of DT ice of total relative thickness $\sim 3\%$.[13] At present, the maximum gain for a Gaussian pulse shape in the calculations using the "Zarya" program, which was obtained for a shell of DT ice with a moderate thickness, is equal to ~ 150 for $E = 1$ mJ. Our calculations showed that an appreciably higher (five- to sixfold) gain for $E \approx 1$–10 mJ cannot be obtained either for targets with ultrathin shells[11] or for type II targets in which a part of the outer shell is replaced by DT ice.[17]

We think that the requirements of relatively low cost, improved reliability, and high energy gain can be satisfied by using type-I targets.

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