Inertial Fusion: A Possible New Program

Stirling Colgate, T-6; Walt Atchison and Hui Li, X-1; and Steve Slutz, Sandia National Laboratories

A theoretical program, with the submission of three proposals (none funded) continues development of a different approach to Inertial Confinement Fusion (ICF) ignition using existing facilities—the capacitor banks of the Z-pinch at Sandia National Laboratories (SNL), and the Atlas Facility at Los Alamos. The advantage of such an approach is the difference in cost of 3 to 4 orders of magnitude less relative to the National Ignition Facility, (~1 to 10 million vs 10 billion) and the use of local facilities. The result would be, if successful, the fusion burn of ~10 micrograms of deuterium (DT) at a density of ~200 g/cm^3. It is the tradition of Theoretical (T) Division to suggest new programs within the Lab. This is one such possibility that has involved others in T-Division, Applied Physics (X) Division, and SNL.

There are two, less conventional key elements to such a program: 1) the use of the kinetic energy of a magnetically driven cylindrical "liner" implosion, and 2) the ignition of high-density DT in equilibrium with its radiation.

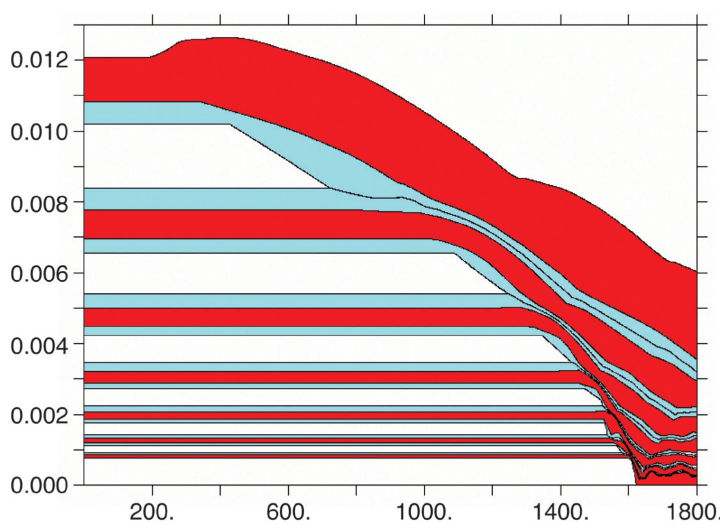

Fig. 1.
A calculation of a sequence of seven cylindrical heavy metal shell collisions, lined inside and out with a low-density plastic "cushion" to attenuate shocks and make each collision more elastic or efficient. The steeper slope (negative) after each collision indicates an increasing velocity of implosion at the expense of a decreasing mass. In this example the velocity increased by a factor of 8 in 7 collisions.

Conventional wisdom is that a magnetic liner implosion is far too slow, ~0.5 cm/μs by nearly two orders of magnitude, (x 40 higher velocity is required for ignition). Hence, an energy-efficient mechanism to trade mass for velocity is required. This is the purpose of the multiple shell bounce process, leading to a high velocity, ~20 cm/μs, innermost shell of dense, high atomic number matter, e.g., gold. This high-velocity innermost shell, a "pusher" then contains a useful fraction, ~5%, of the initial kinetic energy of the magnetically accelerated liner.

A further conventional wisdom is that radiation only quenches ICF ignition by its escape and hence, causing catastrophic cooling. The contrary view of the use of high atomic number matter at high density for ICF ignition has been discussed in Ref. [1]. Here, high atomic number matter, e.g., gold, is initially maintained in pressure equilibrium with the hot, high-density DT fuel and hence, because of the resulting extreme pressure, and provided the confining high atomic number matter is not shock heated itself, then the resulting confining matter densities and associated energy densities overwhelm the radiation and therefore fusion ignition proceeds independent of its equilibrium radiation. Under these conditions the fusion ignition temperature is considerably less than in the transparent fuel case, 2.5 keV vs ~10 keV, placing less demands on the preheat mechanisms.

Before discussing the "shell bounce" velocity multiplication process, we first consider the mass matching of an optimized magnetic liner to a hydromagnetic driver. The magnetic acceleration by a high current (20 M A pinch) of a "liner", a thin cylindrical shell of just the right material of the proper thickness, density, electrical resistivity, and refractory melting properties is made difficult because of hydromagnetic instabilities in progressively melting and accelerating materials. However, current experiments indicate that a metal shell of 200 g, can be accelerated to 0.5 cm/μs or a kinetic energy of 2.5 MJ and is now practical.

This energy, mass, and velocity must be transformed, i.e., matched into a more concentrated form, a "driver" of a cylindrical high density metal (e.g., gold) shell of radius 0.5 cm, 0.05 cm thick, and 1 cm long. This corresponds to a mass of 6 gm moving at a velocity of 2 cm/μs with a kinetic energy of 1.25 MJ or half of that of the original liner and thus an energy efficiency from liner to driver of 50%, typical of many experiments performed on Atlas.
This driver shell of 2 cm/μs must be transformed into a dense, high-velocity shell moving at 20 cm/μs. Figure 1 shows a calculation of "shell bounce" with a sequence of multiple cylindrical shells and "cushions" optimized to multiply velocity at the expense of mass at as high an efficiency as possible.
The velocity ratio shell to shell was calculated to be 1.345 for a mass ratio $(1 + \sqrt{2})$ or 2.414. (The velocity ratio for 100% efficiency would be 1.414.) Thus in eight shell collisions we would expect the velocity to increase to $(1.345)^8 = 10$ times, and thus leading to an innermost shell velocity ~20 cm/μs.

The last or innermost shell is called a pusher because it "pushes" the hot DT fuel together. This high-velocity dense metal shell, with its shock-attenuating cushion, is sufficient to compress a gold "pusher" to 3000 g/cm^3 at a pressure of 300,000 MBars, provided the last cushion adequately attenuates the shock.

It is the pressure and density of the pusher which confines and isolates the preheated DT fuel to a density of 200 g/cm^3 at 2.5 keV temperature in equilibrium with its radiation, whose pressure, in turn is negligible, ~1% of the fuel at ignition. Figure 2 shows a diagram of the various states that describe the DT fuel as it alone is shock heated from a frozen solid and compressed by the pusher. Ignition should occur at the uppermost points where the temperature and density is highest. The specific volume, the inverse of the density, is plotted on the axis.

The experimental program can be directly compared to the theoretical calculations, because the cylindrical geometry allows easy access to the various compressed, heated, and moving materials.

For more information contact Stirling Colgate at colgate@lanl.gov.

[1] K.S. Lackner, et al., "Equilibrium Ignition for ICF Capsules," *11th International Workshop on Laser Interaction and Related Plasma Phenomena,* Monterey, CA, Oct. 25–29, 1993, (AIP, 1994) Vol. **318.**

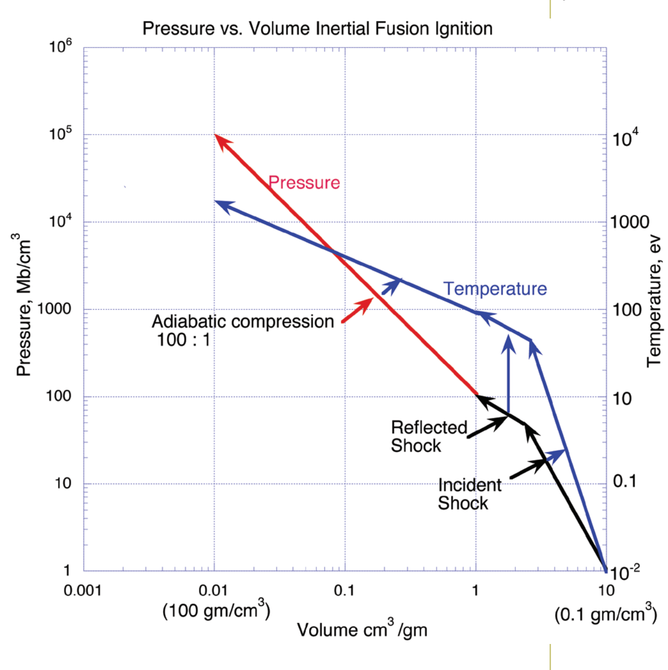

Fig. 2.
A proposed sequence of temperature and specific volume (1/density) of solid hydrogen after being shocked (and reflected shock) to 120 eV followed by a relatively slow adiabatic compression of x100 in density by the heavy metal pusher.