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Heavy ion fusion science research for high energy density physics and fusion applications - Section 6

B. G. Logan, K. N. LaFortune, L. J. Perkins

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6. Applications to heavy ion fusion.

The success of high transverse and longitudinal beam compression in neutralizing plasma described in Sections 1 and 5 enable the application of heavy ion beams to direct drive in the ablative rocket regime at high rocket efficiency, which requires ion ranges a fraction of the initial ablator thickness for low adiabat implosions. Without plasma neutralization, the beam space charge would prevent adequate focusing of the ion beams at such low ion ranges required for efficient direct drive. With appropriate range, ions can couple energy into thick fuel capsule ablators at the peak in rocket efficiency, as efficiently as x-rays do in hohlraums, but without the conversion loss of beam energy into x-rays. High ablation velocities with heavy ion direct drive can mitigate hydrodynamic instabilities like with x-ray drive, but with higher overall beam-to-compressed fuel coupling efficiency.

A simple analytic implosion model with a heavy-ion dE/dx deposition model, together with hydrodynamic implosion calculations using both LASNEX and HYDRA [10 a] have been used to explore characteristic beam requirements for heavy ion direct drive in the ablative regime, for small 1 MJ drive DT targets as well as for larger Tritium-lean (> 90% DD) targets needing 5 MJ drive energy. Ion beams can couple 100 % of their incident energy into hydrogen or DT ablators (most electrons per unit mass) which also have lowest specific ionization energy << $u^2_{ex}/2$. However, ion beams can also suffer greater parasitic energy loss passing through ablation corona plasmas compared to laser or x-ray drive photons, despite the dE/dx Bragg peak near the end of the ion range. Increasing ion energy during the drive pulse (synergistic with velocity ramps used to drift compress the neutralized beams), can reduce the parasitic beam losses on ablated plasma.

Low adiabat implosions are found possible with an initial ion beam range is selected to be 25 % of the initial ablator ρr. Overall beam-to-fuel coupling efficiencies >15% are found for small targets driven by 1 MJ of ion beams with constant energy Argon ion beams at 50 MeV, 4 to 8 times better coupling than any hohlraum, and twice any laser direct drive, despite major parasitic beam losses that can be further reduced by optimizing parameters in the next set of calculations. Shock timing control with direct ion drive is sufficient for low adiabat implosions $\alpha<1.5$ enabling gains > 60 at 1MJ (adequate for accelerators of 25 % efficiency), with higher gains possible with more fuel mass. In another example, use of a late ion-driven shock for two-step implosion and ignition shows benefits like fast ignition. Ways to further mitigate the ion beam loss on ablation plasma are planned, as well as implosion symmetry requirements for future two-sided (polar) direct drive calculations.

These advances enable T-lean implosions [11a- 12a] with larger fuel masses sufficient to capture most neutron energy for low cost direct plasma MHD direct conversion [13a], as well as to self-breed sufficient tritium from D(d,p)T side reactions to avoid the need for any T breeding in external blankets. By varying the size (ρr) of the DT core for a fixed total ρr=13.5 g/cm^2, Figure 9 shows that in-situ T self-breeding ratios greater than unity are possible with reasonable total fusion yields around 500 MJ.

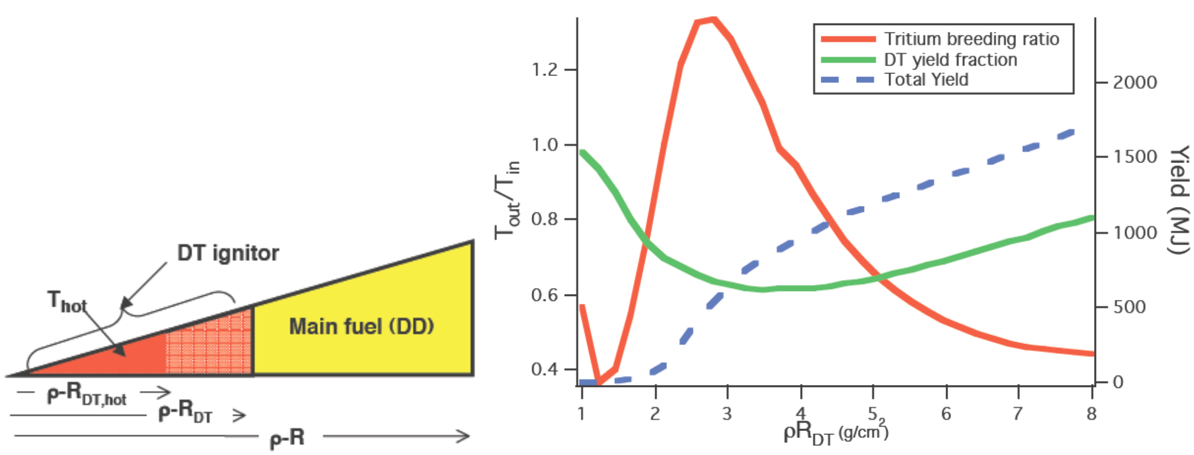

Figure 9: Tritium breeding ratio, DT yield fraction (mostly from T originating from D(d,p)T reactions of the majority DD fuel), and total fusion yield as a function of the DT core ρR_{DT}.

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