Evidence for Fuel–Pusher Mixing in OMEGA Direct-Drive Implosions by Neutron Diagnostic

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Direct-drive implosion experiments are carried out on the 30-kJ, 60-beam OMEGA laser system in which surrogate-cryogenic capsules are irradiated with various laser pulse shapes. In the surrogate-cryogenic capsules the main fuel layer is a polymer shell (either CH or CD + CH), and the hot spot is provided by the fill gas (D_2, DHe^3, or H_2. During these experiments a suite of neutron diagnostics were used to measure the primary (DD) neutron yield, the secondary (DT) neutron spectra, the fuel ion temperature, and the neutron burn history. Evidence of fuel–pusher mixing is observed with these neutron diagnostics depending on pulse shape and beam uniformity. We compare these experimental results with 1- and 2-D hydrocode simulations. This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority.

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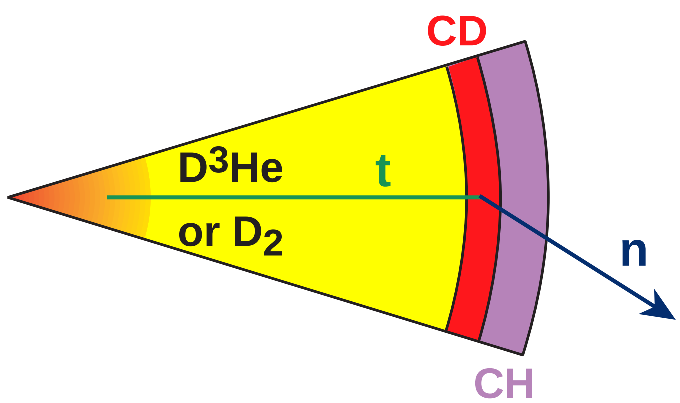

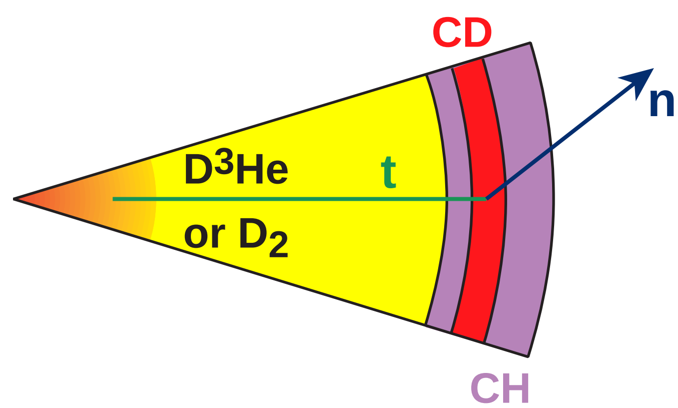

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Summary

The mixing of inner-shell material is studied using embedded CD layers and neutron diagnostics

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- Direct-drive ICF targets are Rayleigh–Taylor unstable during their deceleration phase.
- Large-amplitude perturbation could lead to mixing at the fuel–pusher interface and of various regions in the pusher.
- Tritons from fuel DD reaction probe the mix of the inner-shell material.
- For 1-ns square pulse an upper estimate of mix fraction decreases from 40% to 10% as the shell thickness increases from 20 μm to 27 μm.
- The higher shell temperatures of the thinner shell targets can lead to an overestimate of the mixing length.

Outline

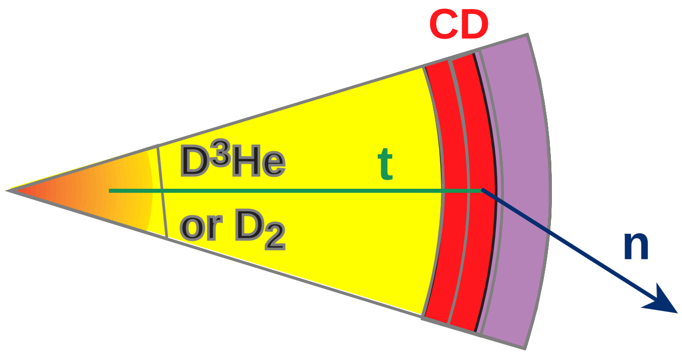
Estimation of fuel–pusher mixing in OMEGA direct-drive implosions by neutron diagnostic

- Triton probing of mix
- Experimental conditions and diagnostics
- Experimental results
- Conclusion

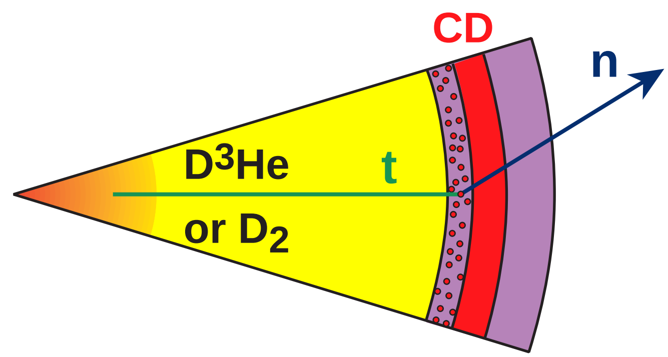
Triton probing of inner and offset CD layers allows an estimation of the shell mixing

$d + d \rightarrow p + t$ (1.01 Mev)
$d + d \rightarrow {}^3He + n$ (2.45 MeV)

$t + d \rightarrow \alpha + n$ (11 to 17 MeV)



Inner CD



Offset CD

- Tritons slow down quickly in the shell material, &1 μm (initial):

no mix | no mix | mix | fully mixed in 2 μm

CD 1 μm, CH 1 μm | CH 1 μm, CD 1 μm | CH 1 μm, CD 1 μm | CH 1 μm, CD 1 μm

$Y_{2n}/Y_n = \alpha$ | $Y_{2n}/Y_n = 0$ | $Y_{2n}/Y_n \Rightarrow$ fraction of mix over 1 μm | $Y_{2n}/Y_n = 0.5\ \alpha$

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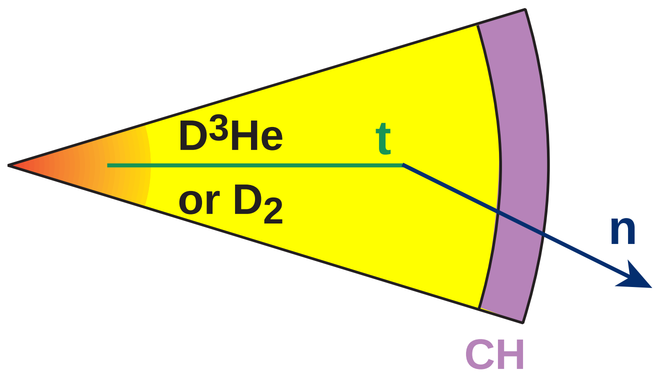
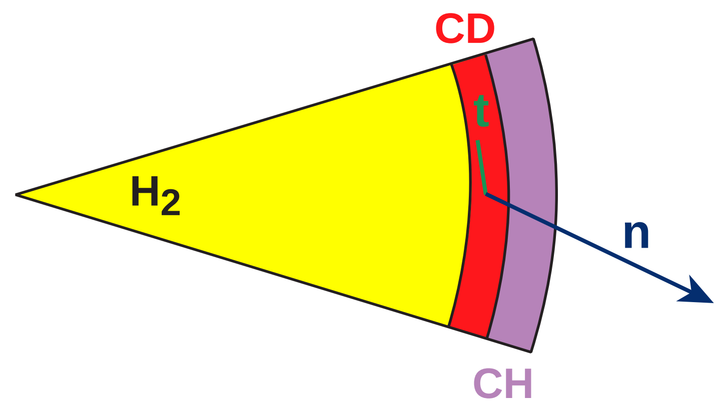
Two additional sources of secondary yield can be measured in separate shots and taken into account

1. Triton interaction in the target gas



2. Triton production and interaction in the CD shell



- The secondary yield is dominated by triton–CD interaction.
- Primary Y_n and secondary Y_{2n} neutron yields from the CD shell alone are about 10% of the yields of the D^3He and CD combination.

Direct-drive implosion experiments were carried out on the 30-kJ, 60-beam OMEGA laser system with 2-D SSD

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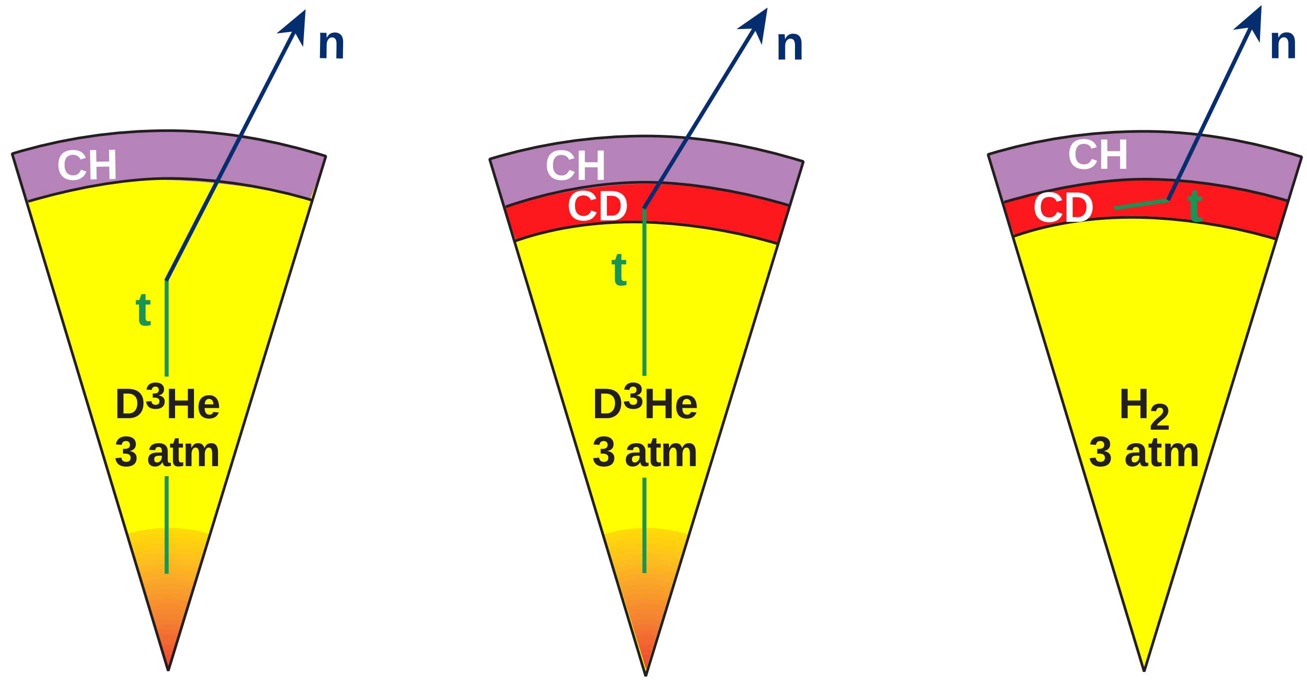
- Primary (DD) neutron yield was measured by a system of neutron time-of-flight (nTOF) scintillating counters.
- Secondary (DT) neutron yield was measured by a Multi-Element Detector Using a Scintillator Array (MEDUSA).
- Plastic capsules a with different thickness of embedded CD layer were used.
- Fill gases (D_2, D^3He, H_2) were used to adjust yield to MEDUSA working range.
- A laser pulse shape of 1-ns square was used in these studies.

The secondary neutron yield is dominated by triton–CD layer interaction

20-μm shell
1-ns square

Gas | CD layer | CD shell



	Gas	CD layer	CD shell
Y_n	3×10^9	7×10^9	7×10^8
Y_{2n}	4×10^5	2×10^7	2×10^6
Y_{2n}/Y_n	2×10^{-4}	2×10^{-3}	3×10^{-3}
	Shot #16055	Shot #16056	Shot #17715

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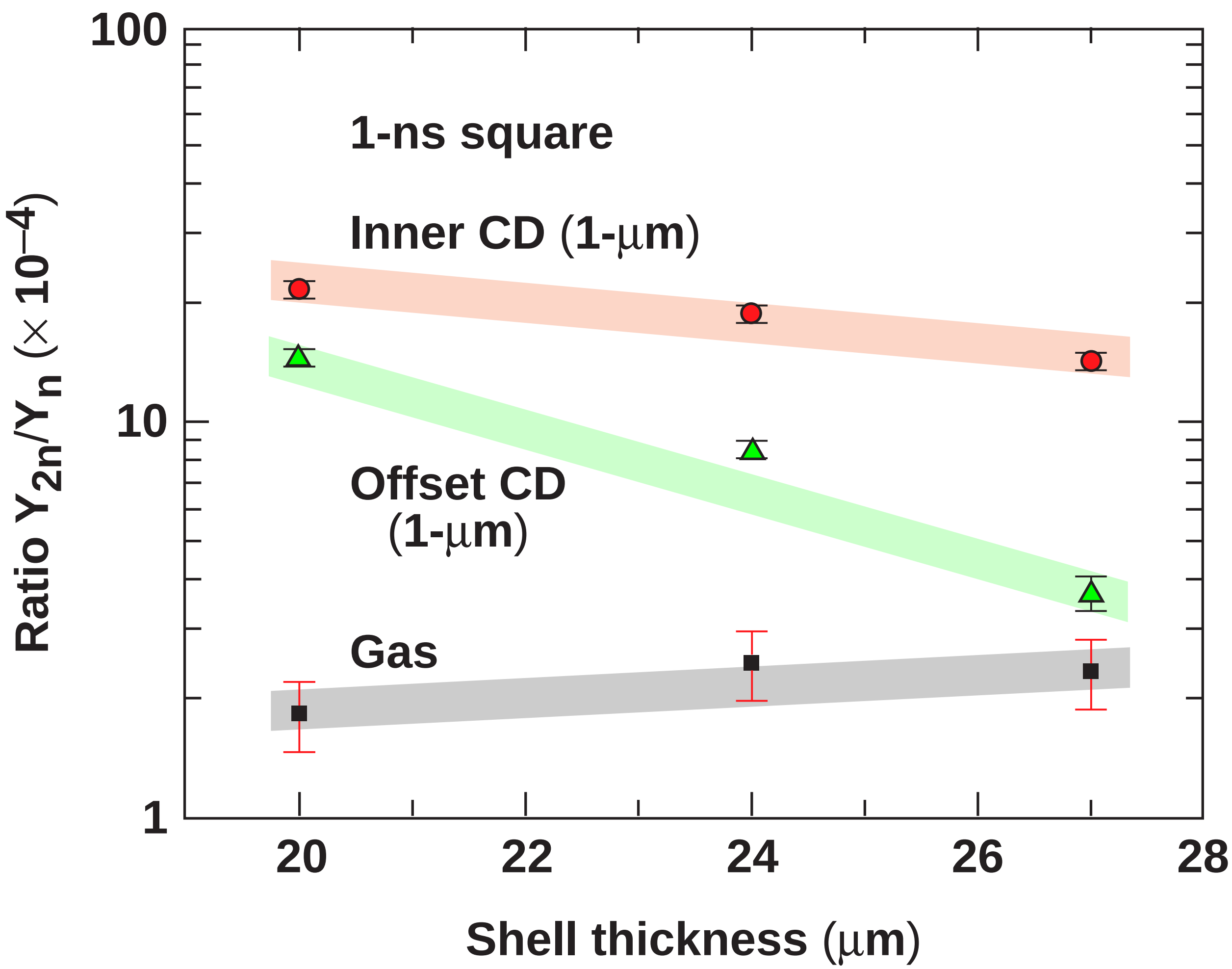
We have measured the ratio Y_{2n}/Y_n by averaging from 3 to 5 shots for each shell thickness



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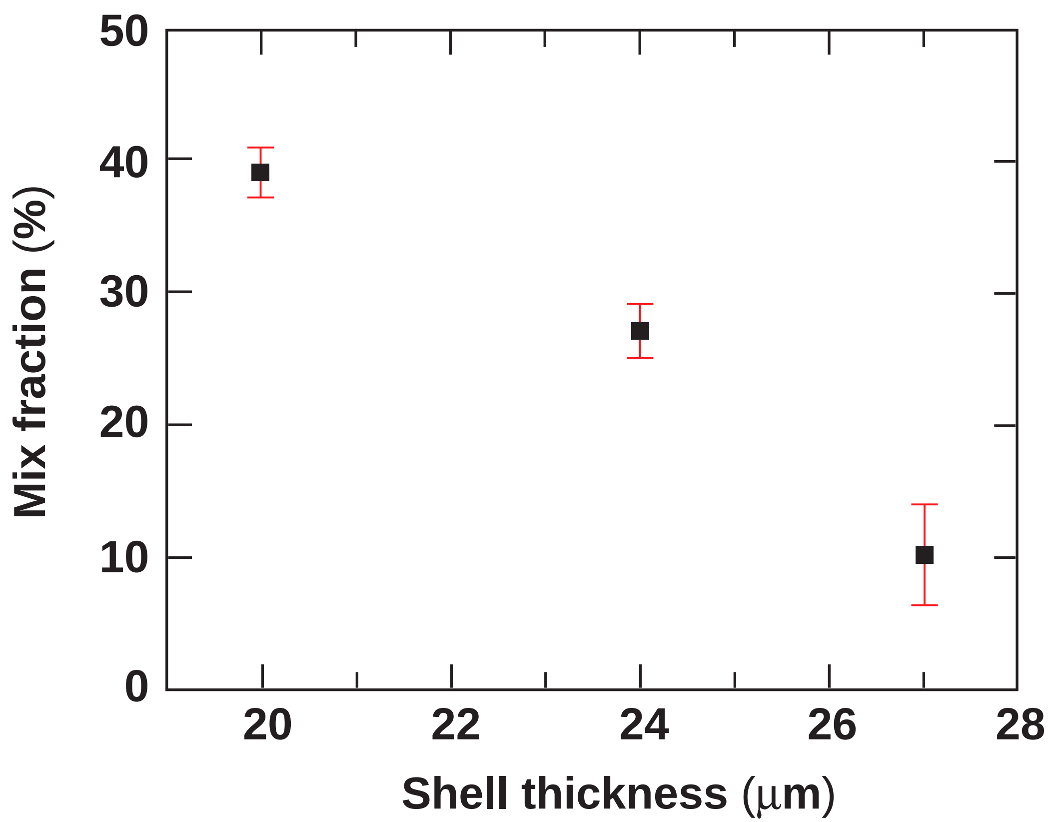
Assuming that triton penetrate less than 1 μm of initial inner-shell thickness we can calculate the mix fraction

$$R = \frac{Y_{2n}/Y_n \text{ (offset CD)} - Y_{2n}/Y_n \text{ (gas)}}{Y_{2n}/Y_n \text{ (inner CD)} - Y_{2n}/Y_n \text{ (gas)}}$$

$$\text{Mix fraction} = \frac{R}{1+R}$$



- For higher shell temperatures, the calculated mix fraction is an upper estimate.

Summary/Conclusions

Inner-shell mixing in OMEGA direct-drive implosions is estimated with neutron diagnostic

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