Mixing in thick-walled and pulse-shaped directly driven ICF capsule implosions.

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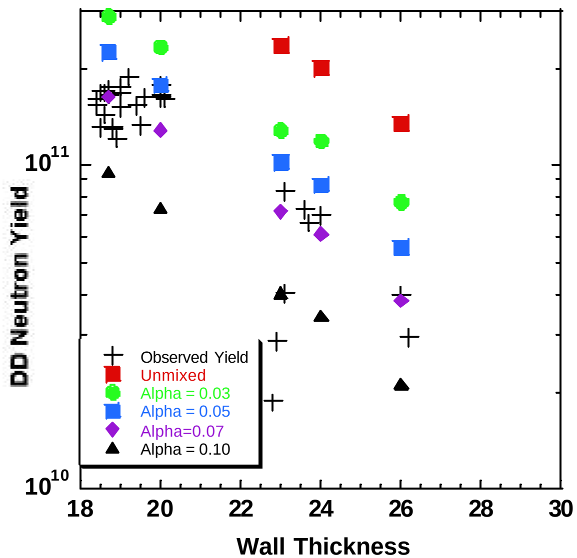

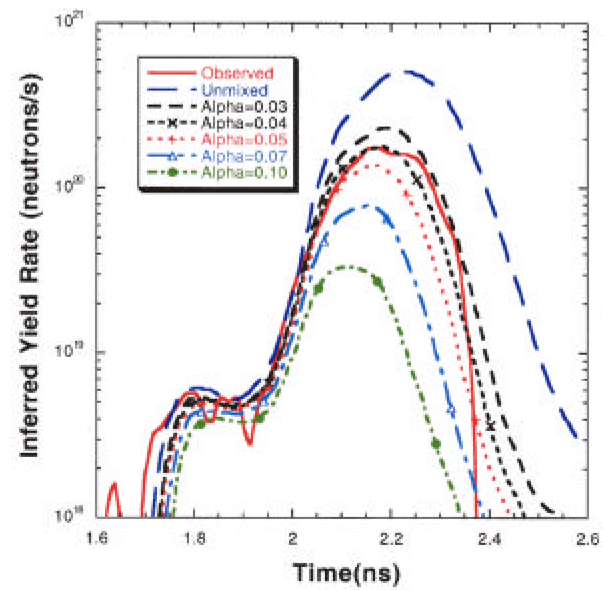

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Mixing in thick-walled and pulse-shaped directly driven ICF capsule implosions

Abstract

The mult-fluid interpenetration mix model of Scannapieco and Cheng (Phys. Lett A, 2002) has been applied to X-ray driven inertial confinement fusion capsules (ICF) (Wilson *et al*., Phys. Plamas, 2003), to double shell ICF capsules (Wilson *et al*. 2004a), and to directly driven capsules with a 20 mm wall thickness using a 1ns square laser pulse with both symmetric (Wilson *et al*., 2004b) and asymmetric illumination (Christensen *et al*., 2004). In general it was found that using atomic mixing the single mixing parameter could fit almost all the data with a value of 0.05 ±0.02. In this paper the model is tested against data from a wider range of directly driven capsules with wall thicknesses up to 32 mm, and with square, low adiabat pulse shapes (Marshall *et al*., 2000a,b, 2004). Comparison with measured and simulated burn histories shows mixing increases with time, as shown by the model. Yields with capsule with up to 30mm thick walls are well matched by a ~0.07-0.09. Implosions with the low adiabat pulse shape are ~3x more degraded than the model calculates. However measured burn temperatures are higher than calculated even without mixing, suggesting a better unmixed calculation is needed.

Our mix model introduces a collision frequency n between two interpenetrating species with only one adjustable parameter

- Hydrodynamic equations for each interpenetrating component are modified by including a collisional drag frequency ν_{ij} between pairs of components. (Scannapieco and Cheng, Phys. Lett. A, 299, **49**, 2002).

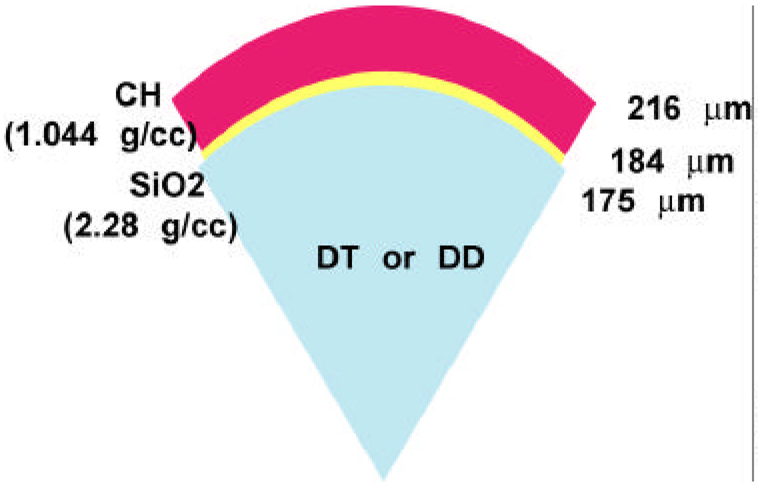
where
$$u_{12} \equiv \frac{C_{12}}{\Lambda + a \int_0^t \left(\frac{r(t)}{r(t)} \right)^{1/3} |u_1 - u_2| dt}$$

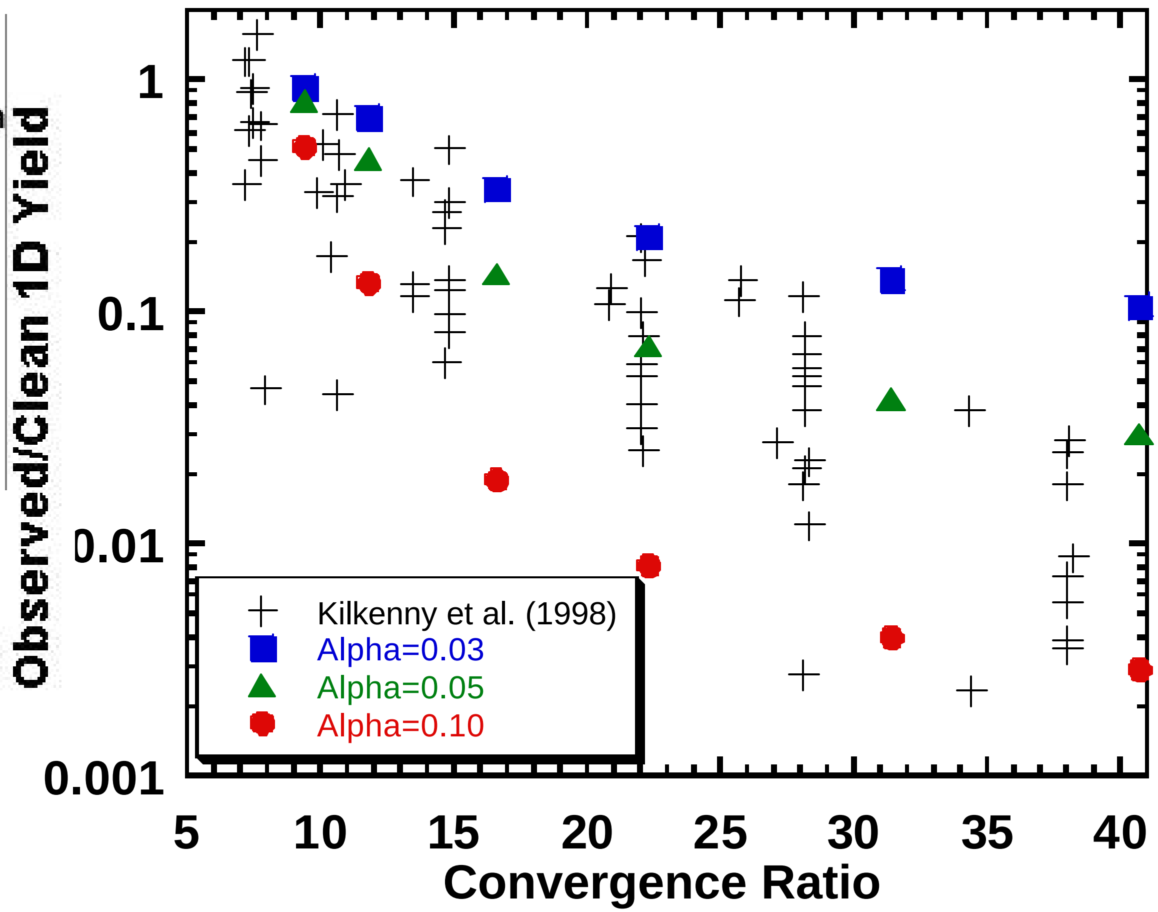
α is an experimentally determined constant, $\int_0^t \left(\frac{r(t)}{r(t)} \right)^{1/3} |u_1 - u_2| dt$ represents the compressed thickness of the mix layer.
and Λ is the collision length from S.I.Braginski, 1965 and L. Spitzer, 1962.

The Scannapieco and Cheng mix model has been applied to both directly laser driven and radiation driven ICF capsules of both single and double shell designs.

- α~0.03-0.05 explained the decrease of yield compared to clean (YOC) with increased convergence ratio of X-radiation driven capsules. (Wilson *et al*., Phys. Plasmas, 10, 4427, 2003).
- α~0.03-0.05 explained the decrease of yield compared to clean (YOC), burn history, atomic mix in directly laser driven capsules with 20μm walls and a 1ns square laser pulse. (Wilson *et al*., Phys. Plasmas, 11, 2723, 2004)
- Yields of thin X-radiation driven double shell capsules are matched by α~0.05, but thicker radiation and laser driven capsules are more degraded. (Wilson et al., IFSA 2003)
- When L=2 asymmetry was intentionally added to implosions, α ~ 0.07 modeled both the symmetric and asymmetric (Christensen *et al*., Phys. Plasmas, 2004, 11, 2771 (2004).
- This talk will focus on results from both thick walled and pulse shaped directly laser driven implosions.
- In the next talk G. Kyrala will discuss experiments to measure the time dependence of mix.

The mix model (with a ~ 0.05) shows the general decrease of YOC with convergence for radiation driven capsules.

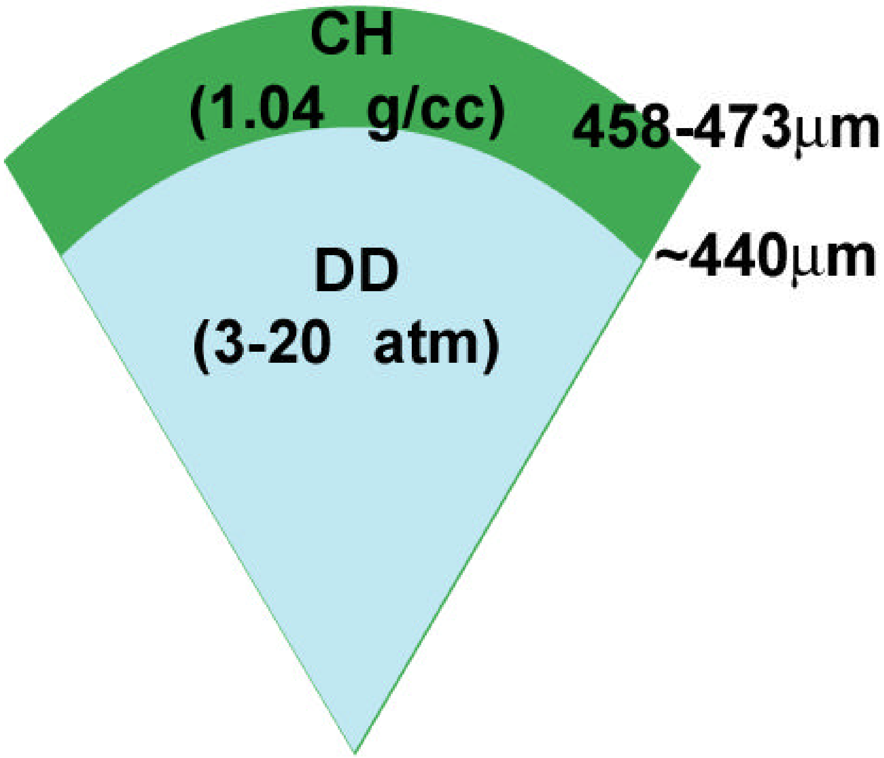




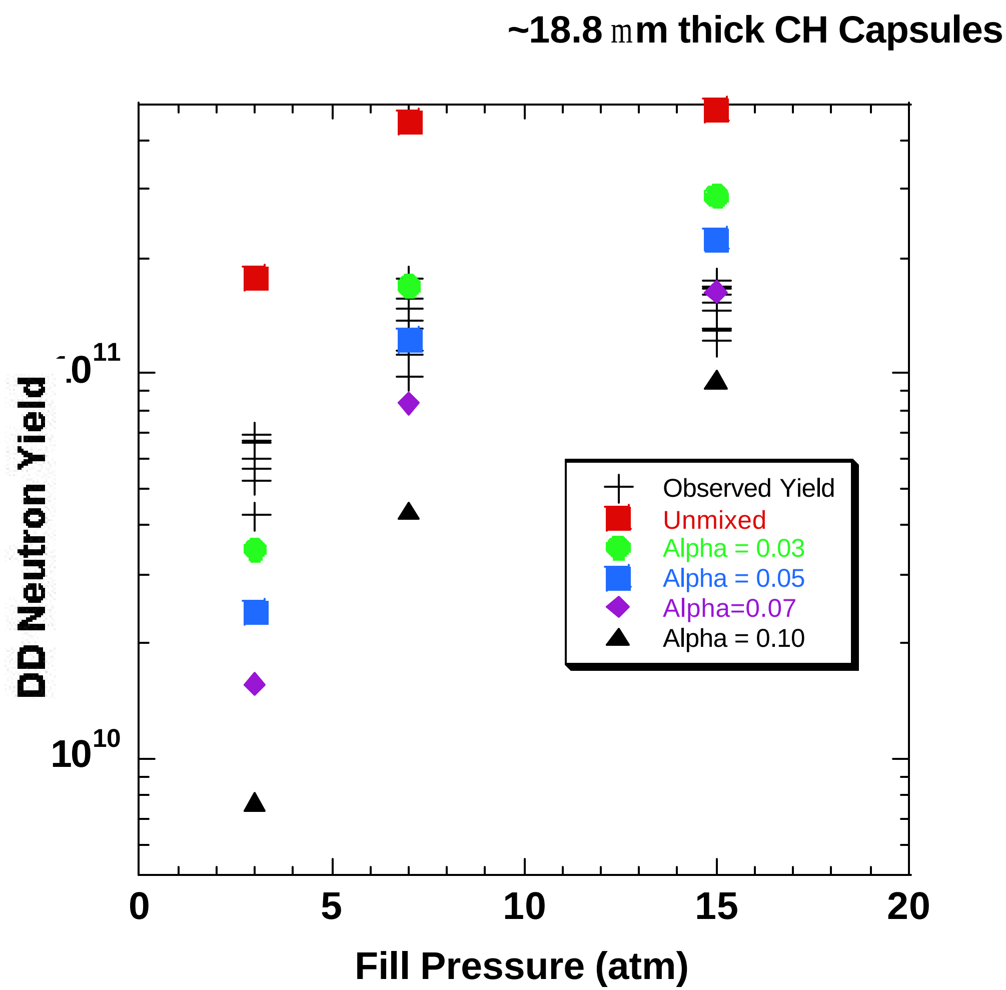
YOC º Yield (Measured or calculated) divided by unmixed (clean) Yield.

Radiation Hydrodynamic calculations simulate directly driven capsule implosions.

- Wall thickness varied from 18 to 33 mm and gas fills were 3,7,15 and 20 atm DD.
- Radii were not identical but were varied to match specific capsules.
- All "1ns square" implosions used the same laser pulse history.
- Time histories specific to each shot were used for the alpha 501 pulse.
- Although simulations are 1D, non-radial laser rays mock up the experimental beam spots
- An electron conduction flux limiter of 0.055 was used to model all implosions.
- Experimental data published in LLE Review, Vol 93, 2003.



Capsule yield compared to unmixed decreases as the gas fill pressure is reduced.



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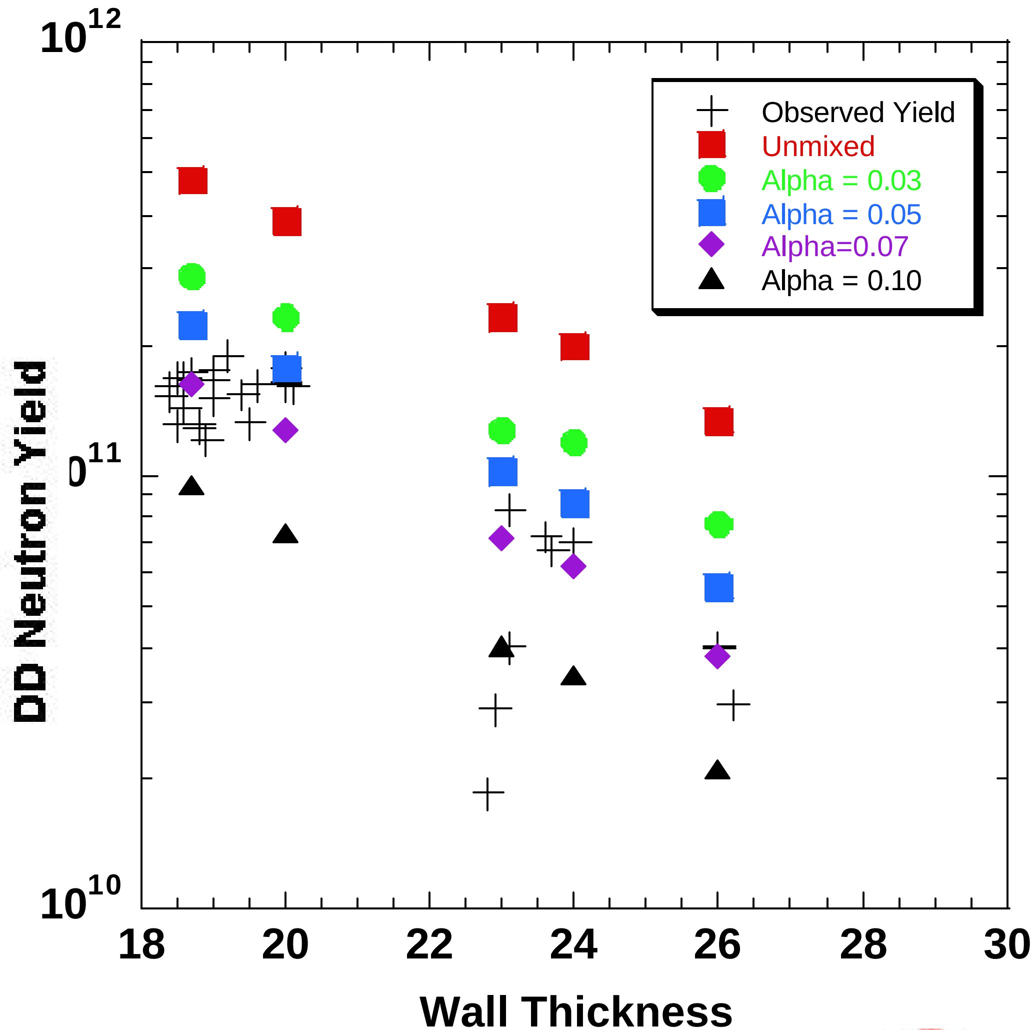
For 15 atm DD fill, the yield degradation is matched by a ~0.05- 0.07.



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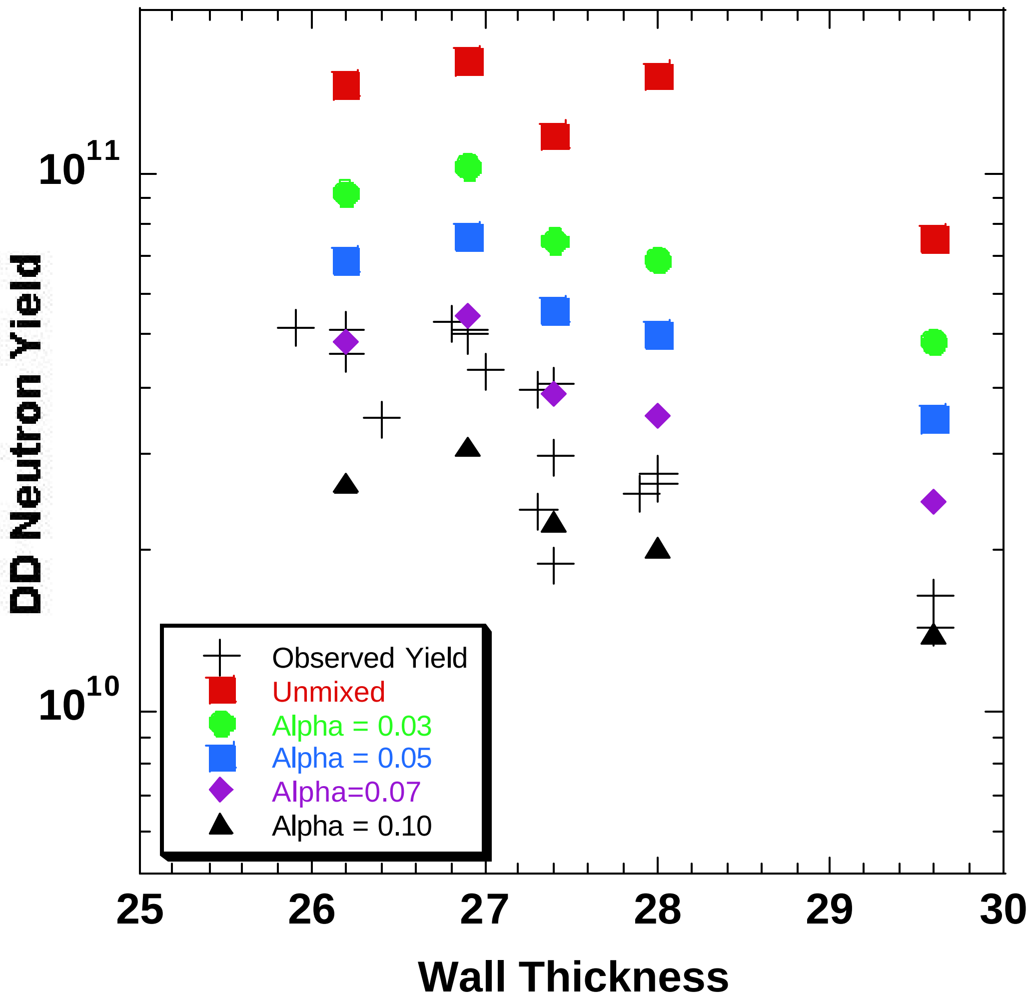
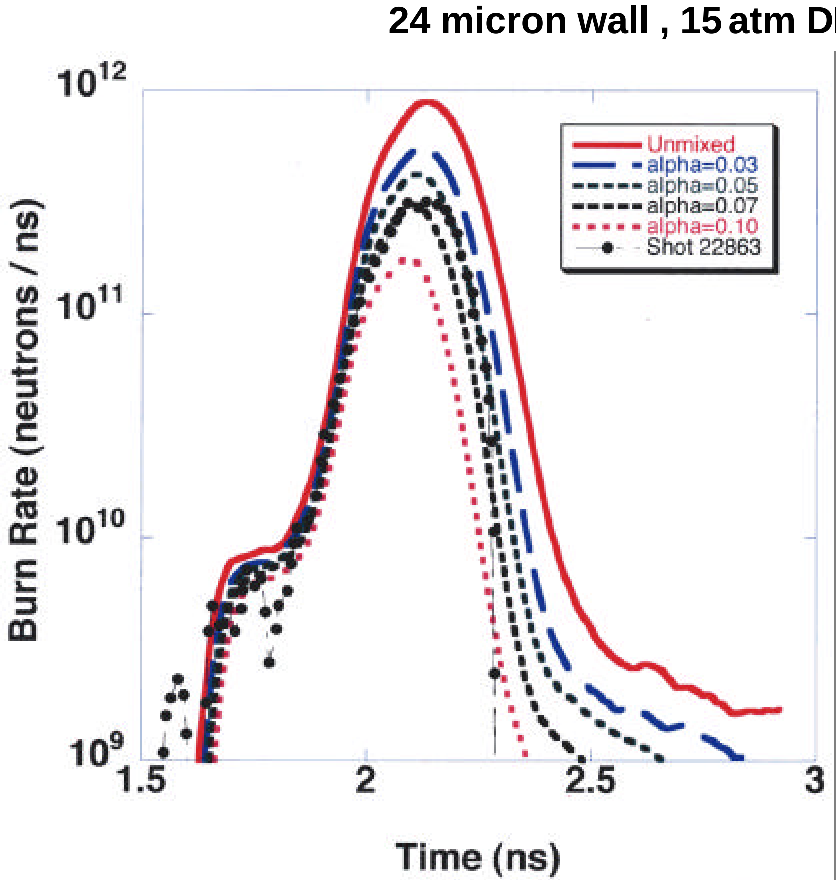
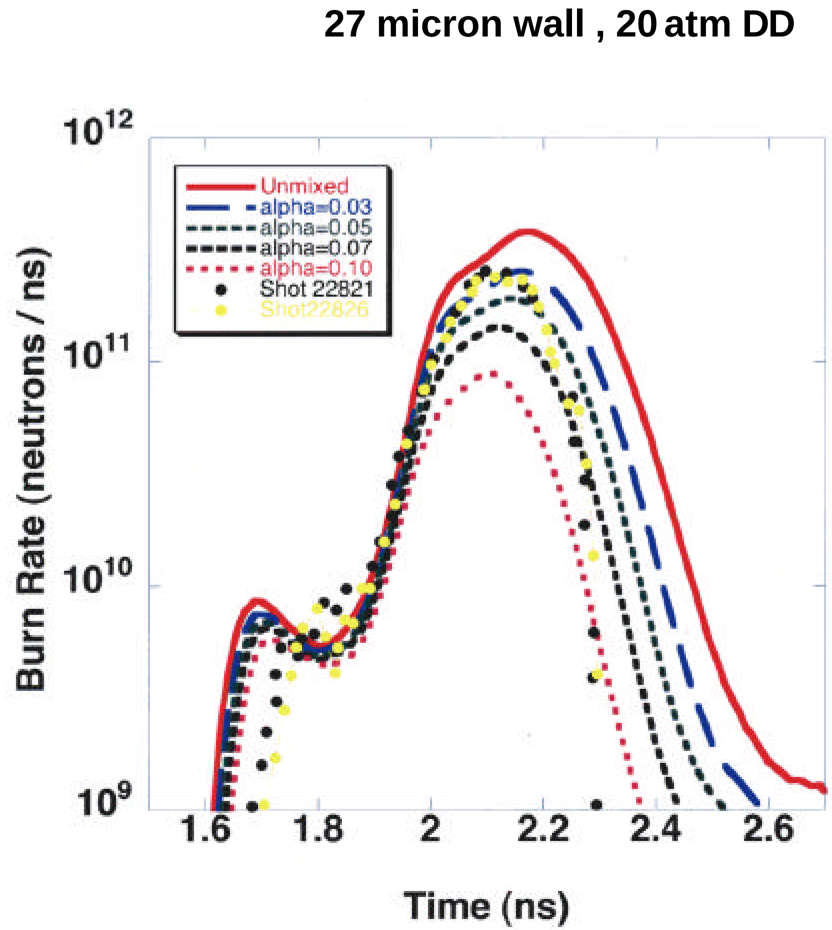
For 20 atm fill the yield is matched by a ~0.07-0.09



As the capsule was is thickened an early "shock compression" peak is revealed in the measured burn history.





- The Neutron Temporal Diagnostic (NTD) is simulated by post-processing neutron transport through a 1mm thick plastic scintillator 2.0 cm from the capsule.

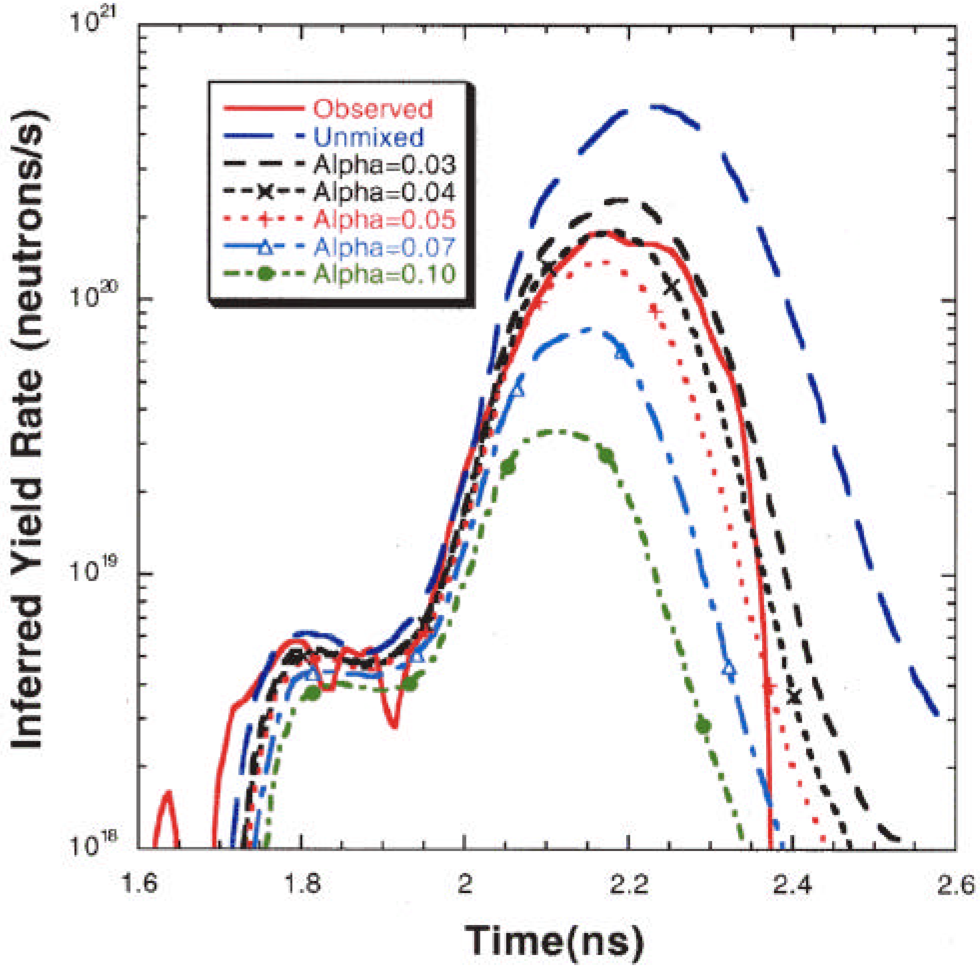
LA-UR-04-5273-10

Simulation of the measured burn history from a thick walled plastic capsule shows little mix degradation of the early yield and strong degradation later.

•The "first shock yield" is generated before the first shock reflected off the center reaches the shell at about 2ns. It should be little affected by mix.

•The compression yield is generated as the shell compresses the fuel to higher temperature. The shell/fuel interface is Rayleigh-Taylor unstable and mixing should grow with time, progressively reducing the yield rate.

•The relatively thick 26 μm wall CH capsule enhances the first shock yield compared to the compression yield.



- **The Neutron Temporal Diagnostic (NTD) is simulated by post-processing neutron transport through a 1mm thick plastic scintillator 2.0 cm from the capsule.**

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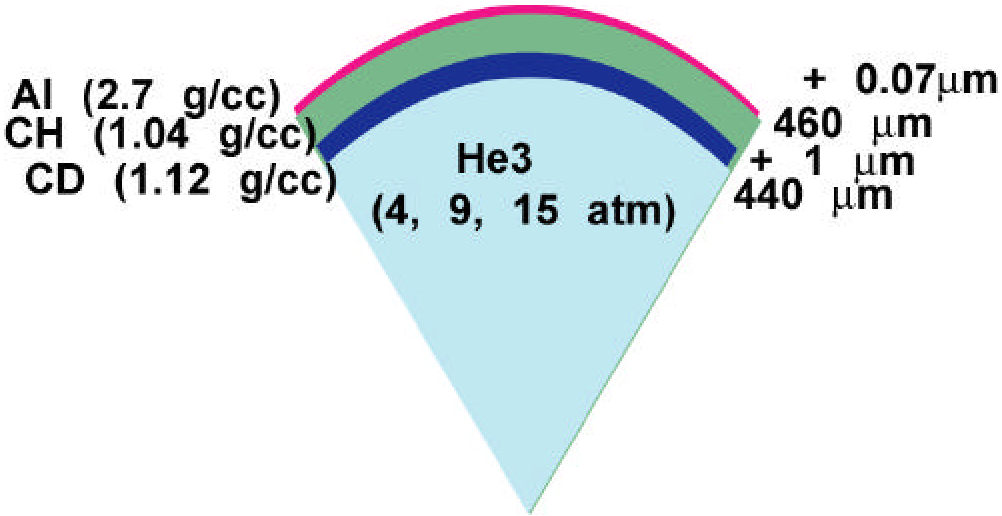
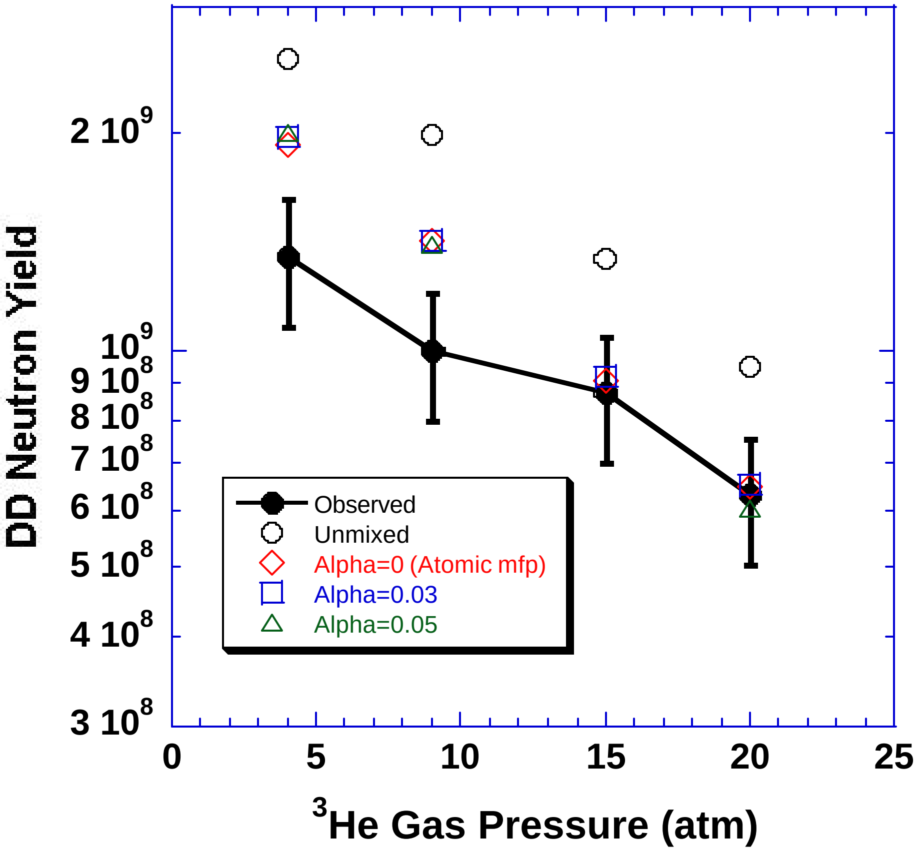
LLE experiments (Li et al. PRL 2002 and Radha, Phys. Plasmas 2002) reported data to test atomic mix

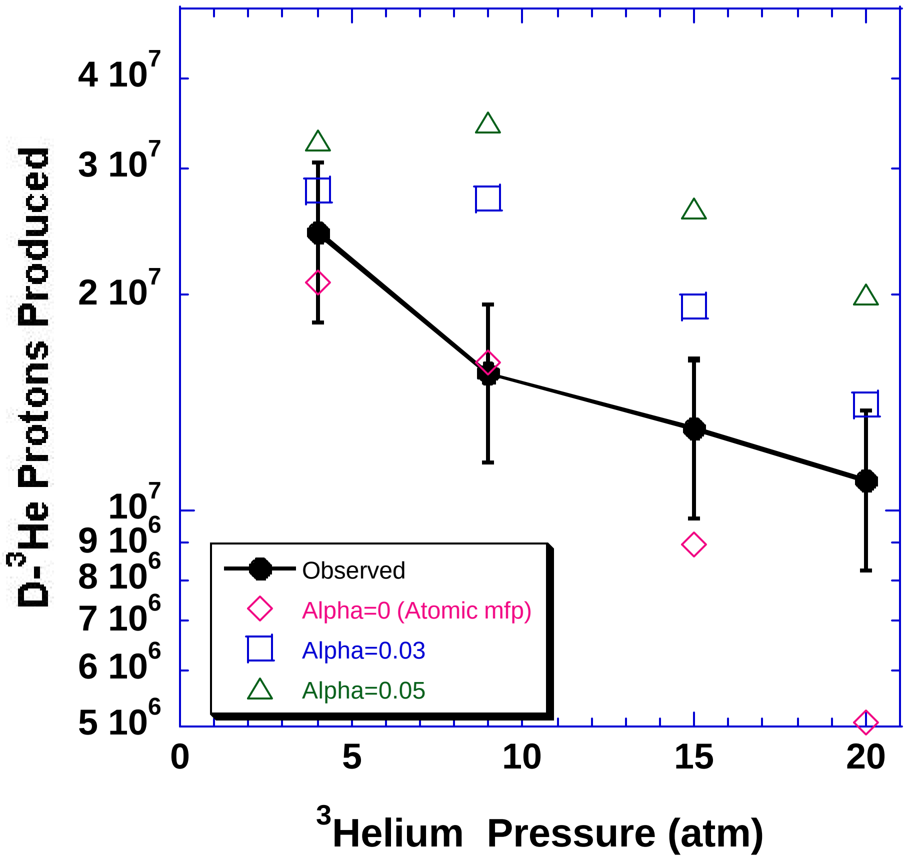


- The D-3He proton can only be produced by atomic mix. Distorted but separate CD and ^{3}He regions would not produce the protons.

- Both the D-^{3}He proton and the D-D neutrons are observed for 4, 9, 15, and 20 atm.

Modeling the D-D neutron and D-^{3}He proton yields are consistent with 50-100% atomic mix.





- **In a simple interpretation, over-predicting the D-^{3}He proton yield by a factor of 2 means the mixture is only 50% atomic mixed.**

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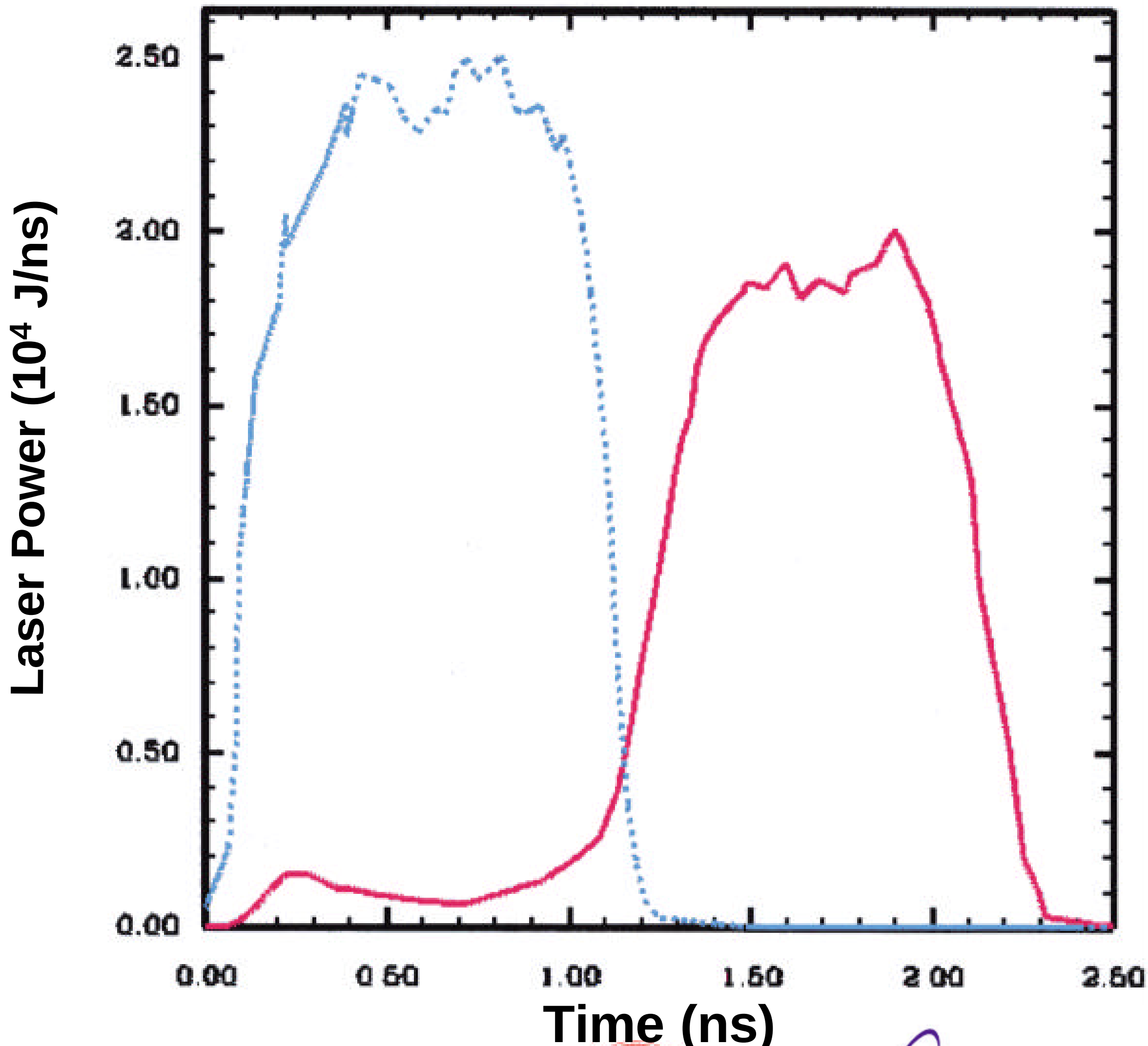
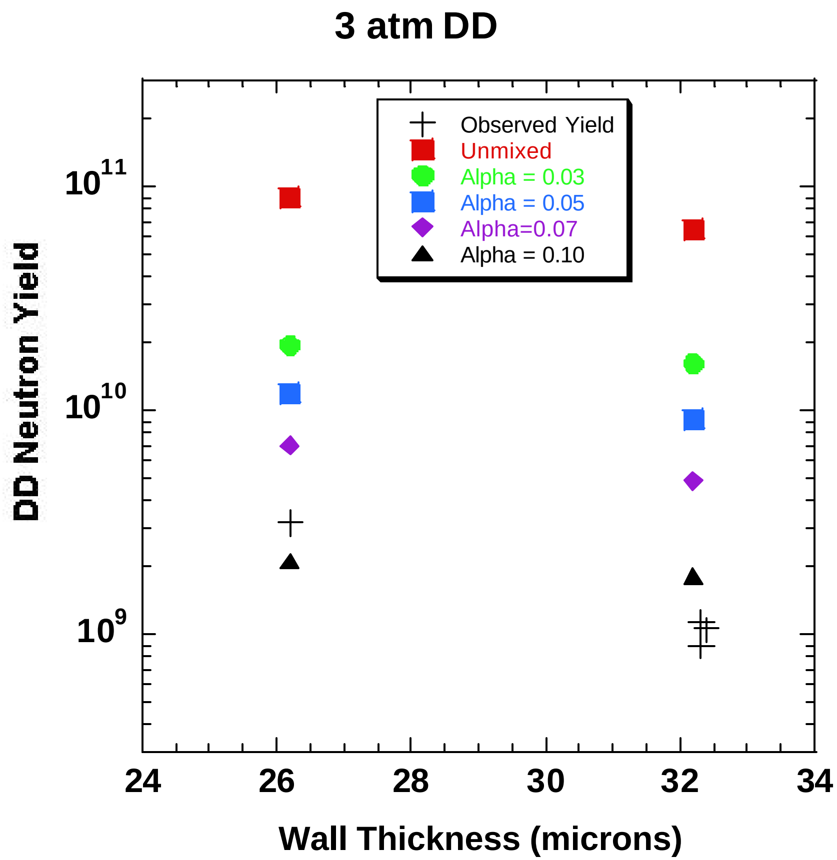
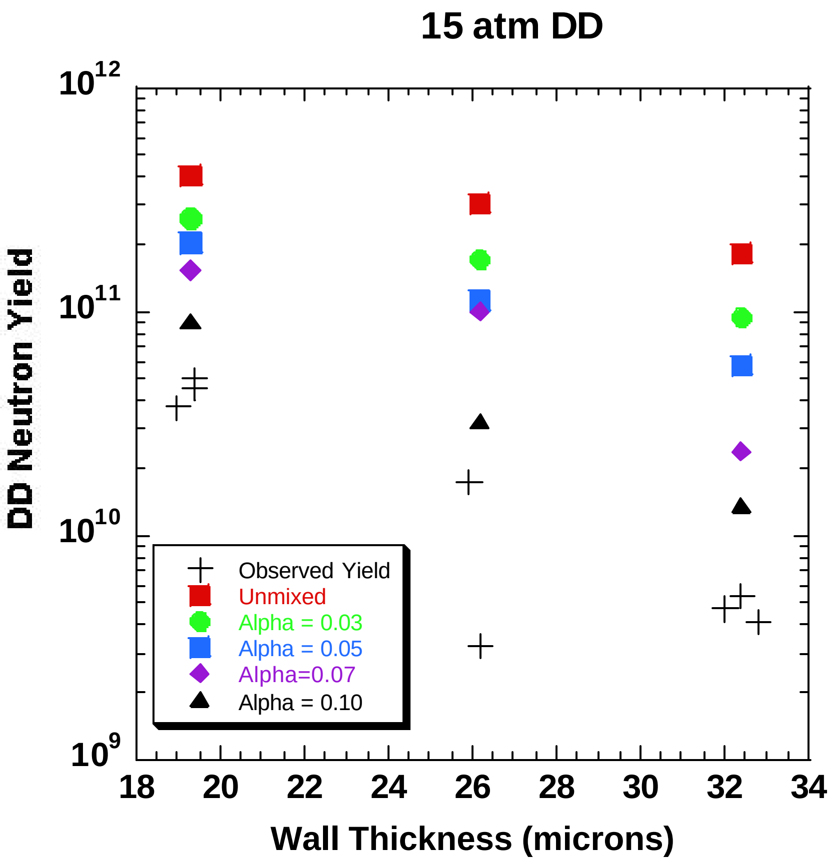
The 1ns long foot of the alpha 501 pulse (red) places the capsule on a lower adiabat that the "1ns square" pulse (blue).



Implosions with the alpha 501 pulse are ~3 times more degraded than expected from the mix model.





- **The alpha 501 implosions also seem to require a lower flux limiter (more energy) to model the implosion time (as noted by Delettrez (LLNL)).**
- **Experimental data published in LLE Review, Vol 93, 18,2003.**

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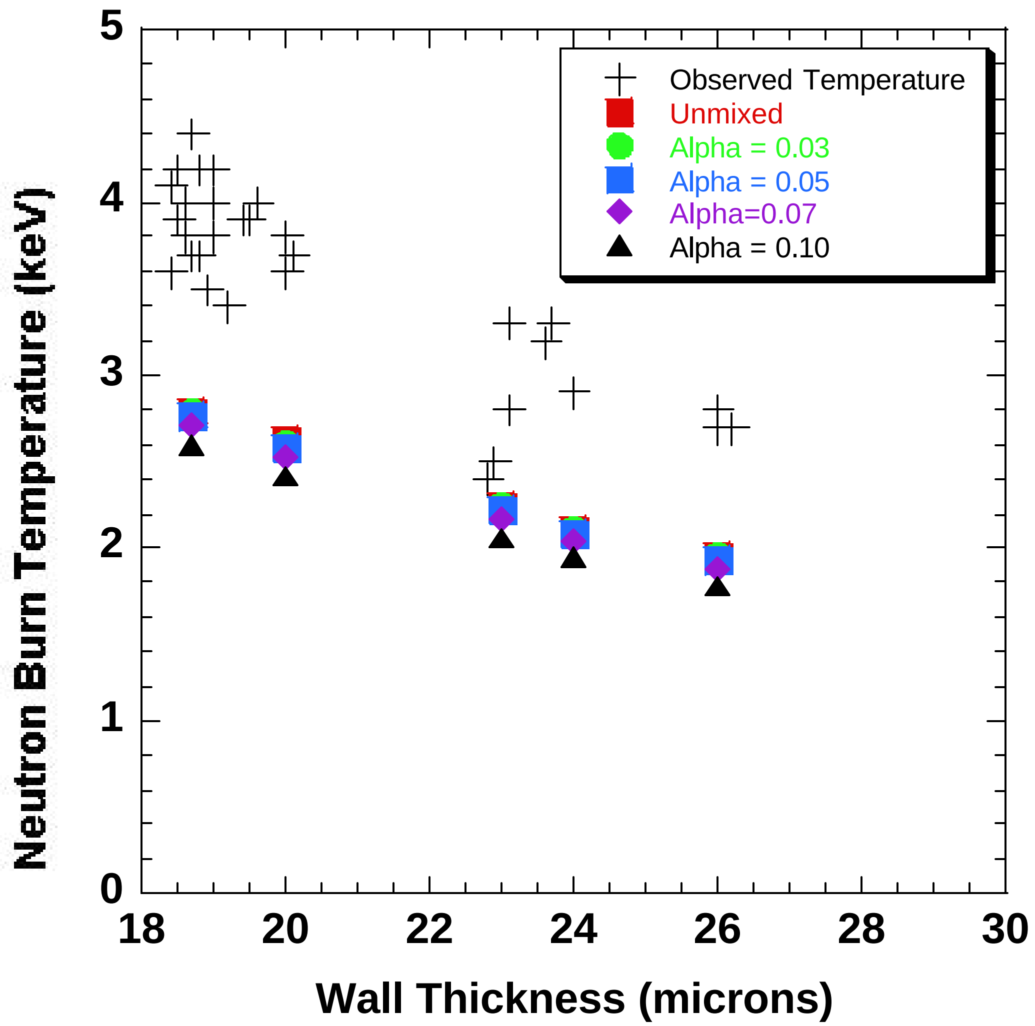
The calculated and observed burn temperatures disagree, suggesting a better clean calculation is needed



The Scannapieco and Cheng model matches much, but not all of the degradation of thick walled directly driven ICF implosions.

- The model shows the substantial degradation in yield with fill pressure.
- For 15 atm DD fill, the yield degradation is matched by a ~0.05- 0.07, for 20 atm fill a ~0.07- 0.09
- The burn histories from thick walled plastic capsules show little mix degradation of the early yield and strong degradation later.
- Modeling the D-D neutron and D-^{3}He proton yields are consistent with 50-100% atomic mix.
- The calculated and observed burn temperatures disagree, suggesting a better clean calculation is needed.
- At this time the Scannapieco and Cheng model does only a fair job at modeling mix in thick walled capsules. It may need to be changed, better clean calculations need to be done, and other degradation mechanisms need to be included.