Testing Hydrodynamic Equivalence of D$_2$ and $^3$He mixtures

- $20 \mu m$ CH
- $435-465 \mu m$
- $15$ atm D$_2$ equivalent

DDn Yield

- $D_2(15)$
- $D_2(6)^3He(12)$

hydro-equivalent scaling
1D simulation (norm. to exp.)
experimental

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Summary

- "Surrogate" fuels with advantageous nuclear properties (such as \( \text{D}_2 \) or \( \text{D}^3\text{He} \) for DT) are often used to study implosion dynamics.

- Interpretation of surrogate implosions typically assumes that fuels can be interchanged with minimal impact on implosion hydrodynamics.

- An investigation of hydrodynamic equivalence using different fill compositions was carried out using a mixture of \( \text{D}_2 \) and \( ^3\text{He} \).

- The experimental yield scaling was found to deviate from that expected assuming hydrodynamic equivalence.
Hydrodynamically equivalent fills have the same total number of particles (e + i) on full ionization

Fill pressures for different fill compositions are chosen such that there are the same total number of particles (e + i) when the gas is completely ionized.

For $D_2(X)^3He(Y)$ filled capsules, hydro-equivalence to a $D_2(15)$ capsule requires:

$$\frac{X}{15\text{ atm}} + \frac{Y}{20\text{ atm}} = 1$$

The mass density is the same for all such mixtures.

Driven with a 23 kJ, 1 ns square pulse

15 atm $D_2$ equivalent
Yields from two nuclear reactions are used to diagnose such implosions

\[ \text{D + D} \Rightarrow {^3}\text{He}(0.8) + n(2.5 \text{ MeV}) \]
\[ Y_{DDn} \propto X^2 \]

\[ \text{D + } ^3\text{He} \Rightarrow \alpha(3.6) + p(14.7 \text{ MeV}) \]
\[ Y_{D3He} \propto X \times Y \]
For hydrodynamically-equivalent implosions, DD-n yield scales as the square of D$_2$ fill pressure.

Anticipated Yield Scaling

\[ Y_{DDn} \propto X^2 \]
Yields have been normalized to the fill composition

\[ Y_{\text{norm}} = Y_{\text{DDn}} \times (15 \text{ atm}/X)^2 \]
Experimental yields deviate from the expected "hydro-equivalent" yield scaling

$$Y_{\text{norm}} = Y_{DDn} (15 \text{ atm}/X)^2$$
1D simulations also deviate from the expected "hydro-equivalent" yield scaling

\[ Y_{\text{norm}} = Y_{\text{DDn}} \times (15 \text{ atm}/X)^2 \]

![Graph showing DDn Yield (norm) with hydro-equivalent, lilac (norm), and experimental data points.](image)
Experimental D³He yields also deviate from the expected "hydro-equivalent" yield scaling

\[ Y_{\text{norm}} = Y_{\text{DDn}} \left( \frac{15 \text{ atm}}{X} \right)^2 \]

\[ Y_{\text{norm}} = Y_{\text{d³He}} \frac{6 \text{ atm} \times 12 \text{ atm}}{X \times Y} \]

- DD-n Yield (norm)

- D³He-p Yield (norm)
These yield trends are not due to differences in DD-n burn-averaged ion temperature

\[ Y_{\text{norm}} = Y_{\text{DDn}} (15 \text{ atm}/X)^2 \]

A 0.5 keV difference is needed to produce such a difference in yields
The observed yield trends could be due to higher convergence for D-rich fill

DD-n Yield (norm)

\[ Y_{\text{norm}} = Y_{\text{DDn}} \times (15 \text{ atm}/X)^2 \]

A simple density calculation to explain yield trends:

\[ \rho_{\text{D}_2} = 1.25 \rho_{\text{D}_3\text{He}} \]

…implies a higher convergence for pure D\(_2\) fills over 1 to 1 D\(^3\)He fills:

\[ C_{r,\text{D}_2} = 1.08 C_{r,\text{D}_3\text{He}} \]
1D simulations suggest that shock "preheating" leads to lower convergence for lower D₂ fraction.
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\[ Y_{\text{norm}} = Y_{\text{DDn}} \left( \frac{15 \text{ atm}}{X} \right)^2 \]

\[ Y_{\text{norm}} = Y_{\text{D³He}} \frac{6 \text{ atm} \times 12 \text{ atm}}{X \times Y} \]
Nuclear measurements are a sensitive probe of hydrodynamic equivalence

- An investigation of hydrodynamic equivalence using different fill compositions was carried out using a mixture of D$_2$ and $^3$He

- Observed trends of DD-n and D$^3$He yields differed significantly from those anticipated based on hydrodynamic-equivalence and on 1-D simulations

- The yield trends are not caused by a trend in ion temperature

- An 8% difference in the convergence ratio is sufficient to explain the experimental yield scaling