One-Dimensional Simulation of the Effects of Unstable Mix on Neutron and Charged Particle Spectra from Laser-Driven Implosion Experiments

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The effects of Rayleigh–Taylor flow in recent laser-driven implosion experiments are simulated in one dimension by the hydrocode *LILAC*. Mix is modeled as a diffusive transport process affecting material constituents, thermal energy, and turbulent mix-motion energy within a growing mix region whose boundaries are derived from a saturable, linear multimode model of the Rayleigh–Taylor instability. The linear growth rates and the feedthrough coupling between perturbations of different unstable interfaces are obtained analytically in terms of the one-dimensional fluid profiles. Mode evolution proceeds according to equations applicable to all phases of acceleration, and the effects of geometrically converging, compressible flow are taken into account. Simulated mix-diagnostic signals include time-resolved energy spectra of neutrons from core fuel and/or embedded deuterium shell layers and the energy spectra of charged primary and secondary products of nuclear reactions. 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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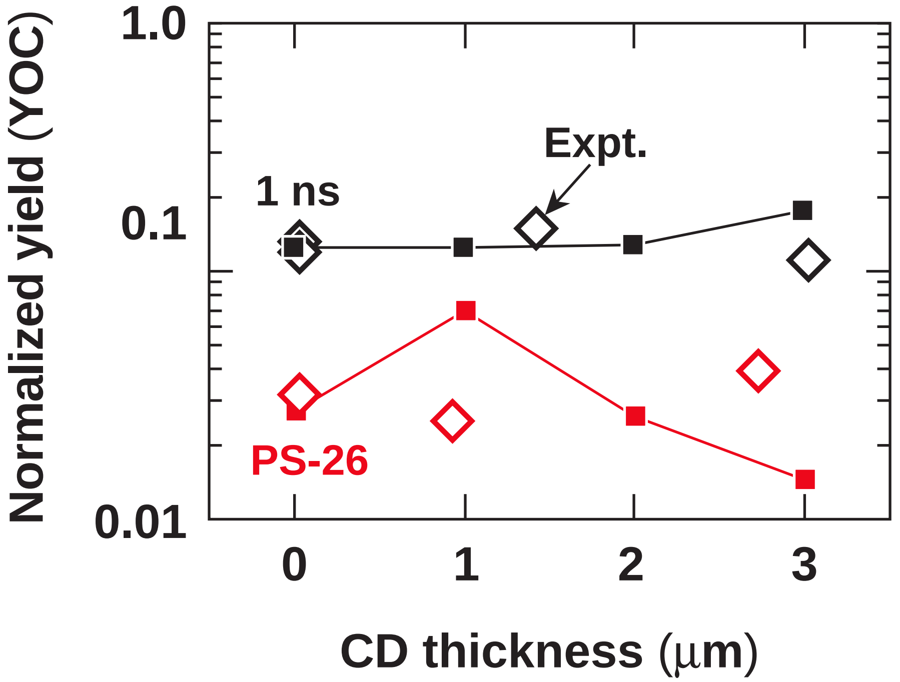

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41st Annual Meeting of the
American Physical Society
Division of Plasma Physics
Seattle, WA
15–19 November 1999

Summary

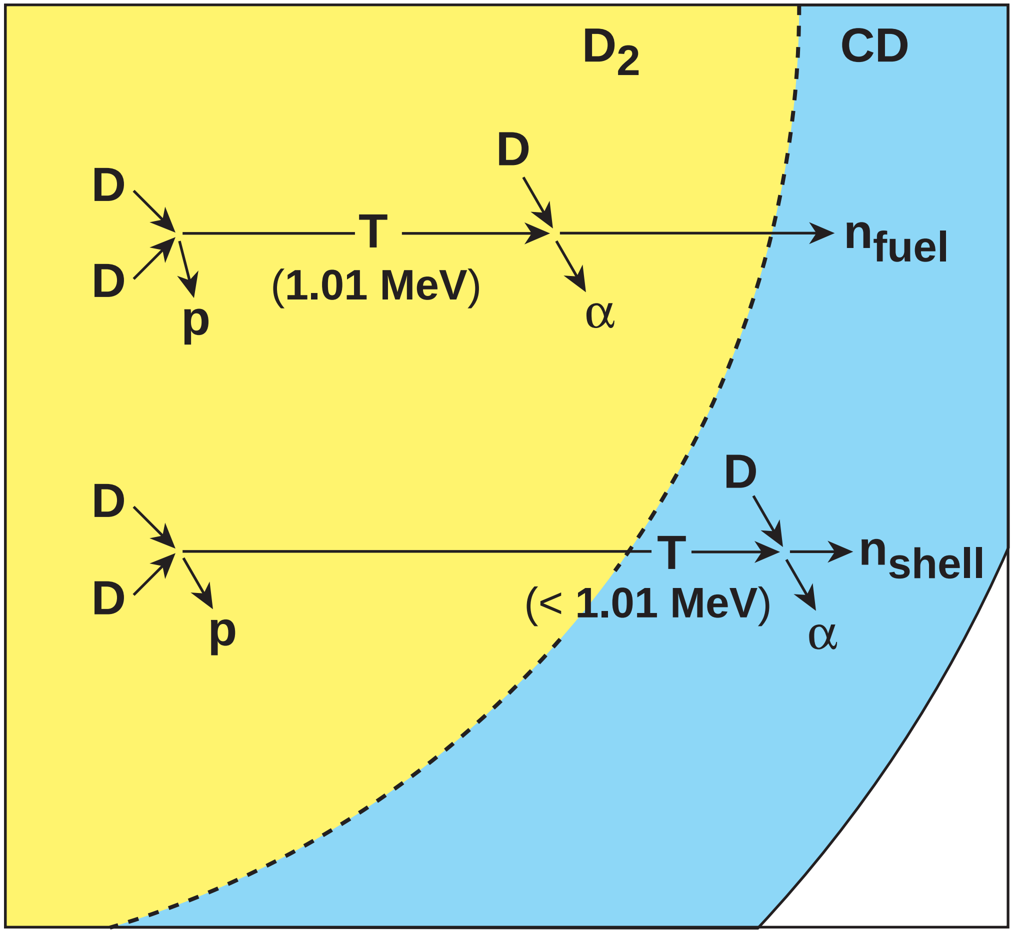
Modeling of mix in the 1-D hydrocode *LILAC* reproduces experimentally observed behavior of primary and secondary neutron production

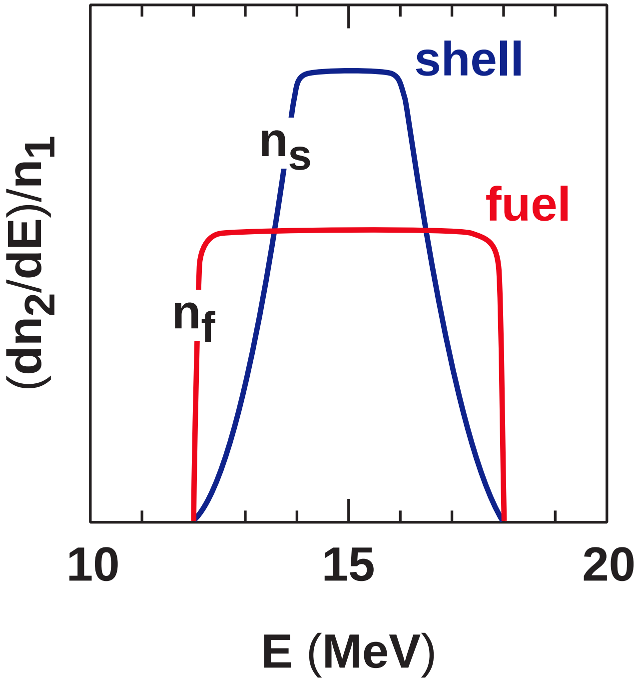
- The mix model includes the transport of target constituents, thermal energy, and turbulent energy due to both the acceleration and deceleration instabilities.
- Primary neutron yields are reduced by mixing fuel with cold shell material.
- Neutron-averaged source temperatures are higher when mix quenches the cooler outer core.
- Secondary neutron yield, energy spectra, and their dependence on target composition are significantly modified by mix.

Outline

- Primary and secondary DD neutrons
- Modeling of mix in 1-D
- Modification of neutron production by mix
- Illustrative examples
- Conclusions

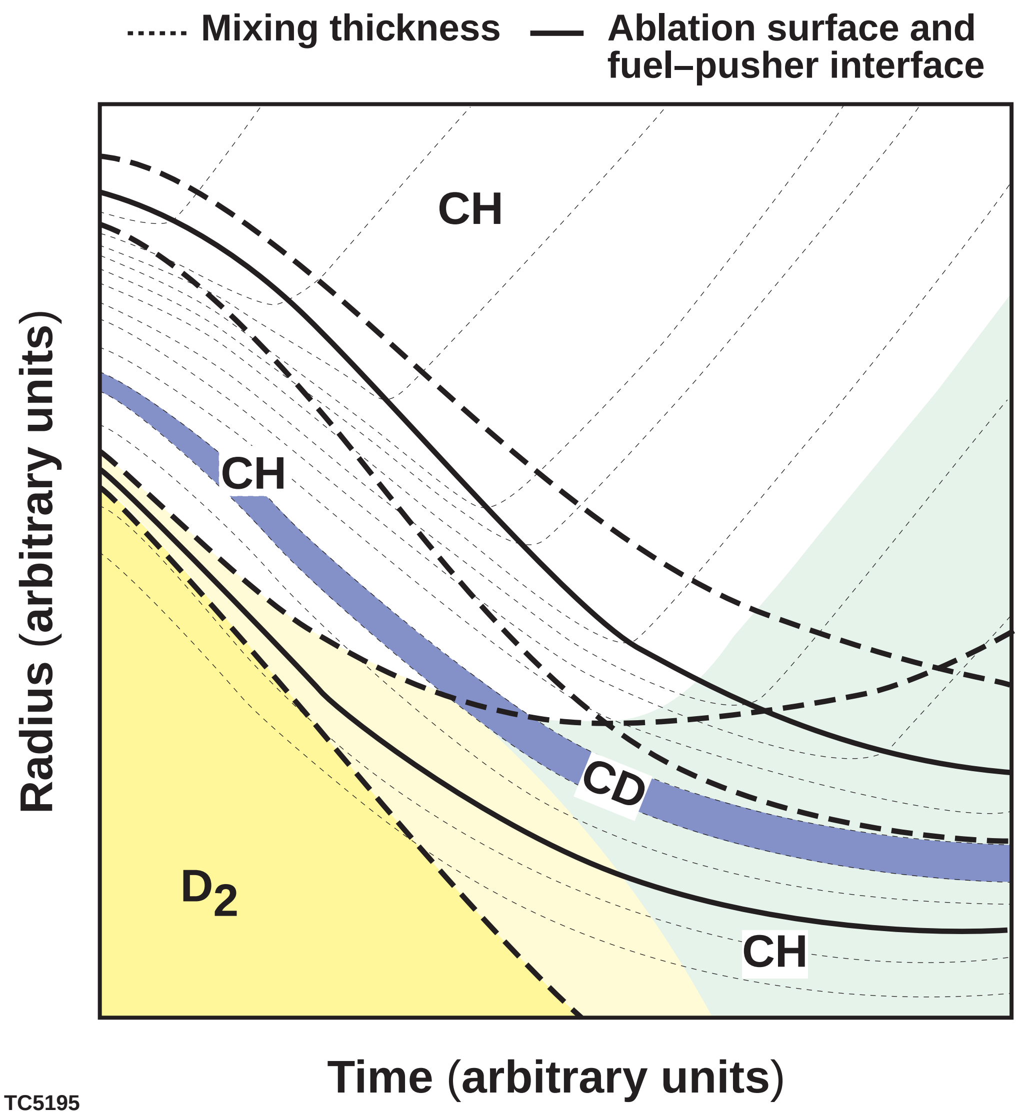
Secondary DT neutrons from the fuel and from CD layers have distinct energy spectra





H. Azechi, M. D. Cable, and R. O. Stapf,
Laser & Particle Beams 9, 119–134 (1991).

“Bubble and spike” mixing thickness is obtained from a multimode Rayleigh–Taylor perturbation model*



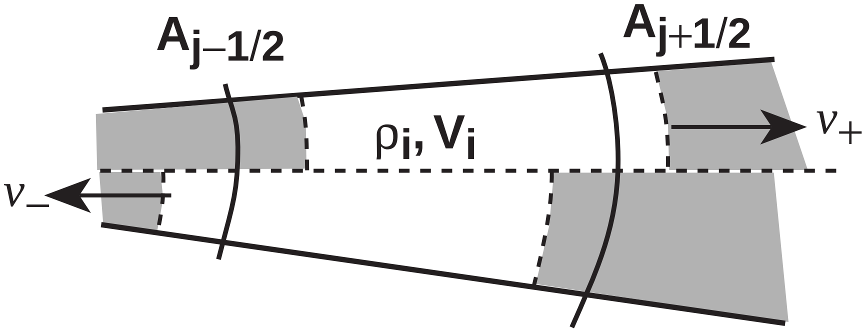
- $\frac{d^2}{dt^2} A_l = \gamma^2(t)\, A_l$ including Bell-Plesset effects
- Takabe form for $\gamma^2(t)$
- Haan saturation procedure for

$$A_l(t) \;.\; \frac{2R(t)}{l^2}{}^*$$

- Initial perturbation spectrum $A_l(t = t_0)$ specified at ablation surface and fed through to fuel–pusher interface over time.
- Mix is modeled as a diffusive transport process.

*S. W. Haan, Phys. Rev. A 39, 5812 (1989).

Mix is modeled in 1-D as a diffusive transport process



Advection to and from nearest-neighbor zones is expressed as diffusion in 1-D.

$$\frac{\partial}{\partial t}\begin{bmatrix}\rho\\ n_e\\ n_H\\ C_v T_e\\ \vdots\end{bmatrix} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\sigma}{\beta_m}\frac{\partial}{\partial r}\begin{bmatrix}\rho\\ n_e\\ n_H\\ C_v T_e\\ \vdots\end{bmatrix}\right), \quad \text{where } \sigma = v_{mix}\lambda * \frac{4(r_b - r)(r - r_s)}{(r_b - r_s)^2}$$

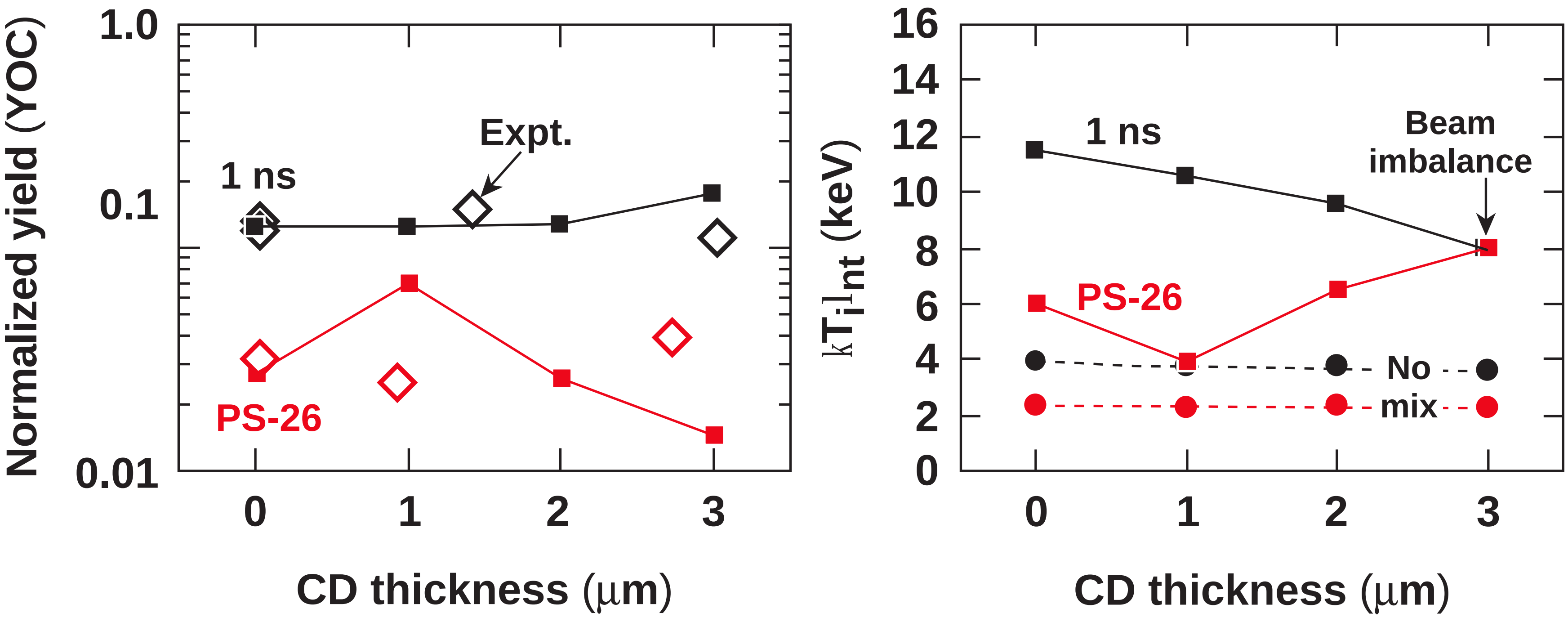
v_{mix}: obtained from trajectories of mix-region boundaries

λ: scale length of turbulence structure from rms perturbation wavelength

k: turbulent energy density, $P_T = \frac{2}{3}k$, etc.

Cooling due to mix reduces the neutron yield, but raises the neutron-averaged ion temperature

- **20-µm, 900-µm diameter shell, 1-ns pulse**
- **27-µm, 900-µm diameter shell, shaped PS-26 pulse**

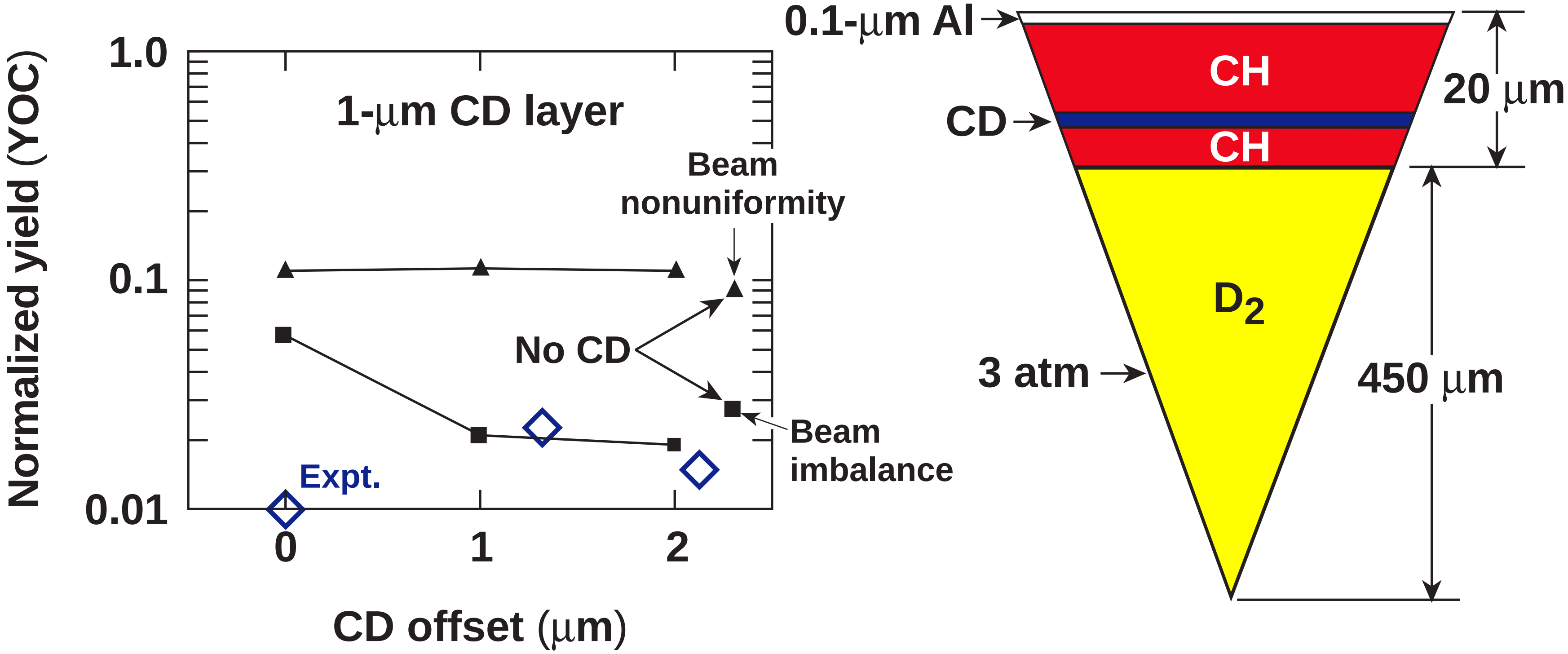


- - ● - - No mix —■— Beam imbalance ◇ Expt. data

TC5196

Cooling by fuel-pusher mix lowers DD neutron yield to observed levels

- **1-µm CD in 900-µm diameter, 27-µm shell, shaped 21-kJ PS-26 pulse**



◇ Expt. data —▲— Single-beam nonuniformity —■— Beam imbalance

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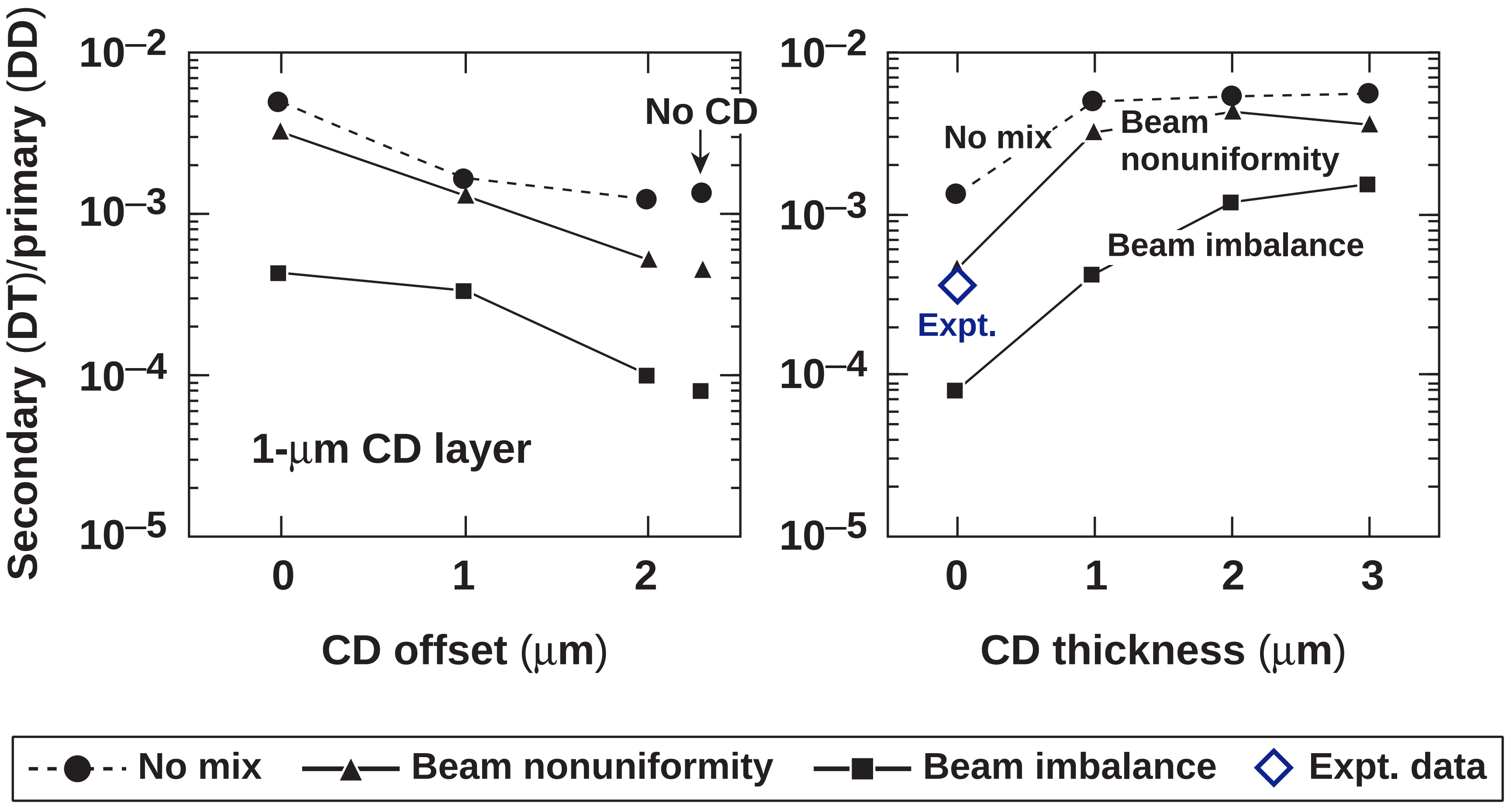
Mix reduces the dependence of secondary DT neutron yield on the offset and thickness of the CD layer

- 20-µm, 900-µm CH shell, 1-ns pulse



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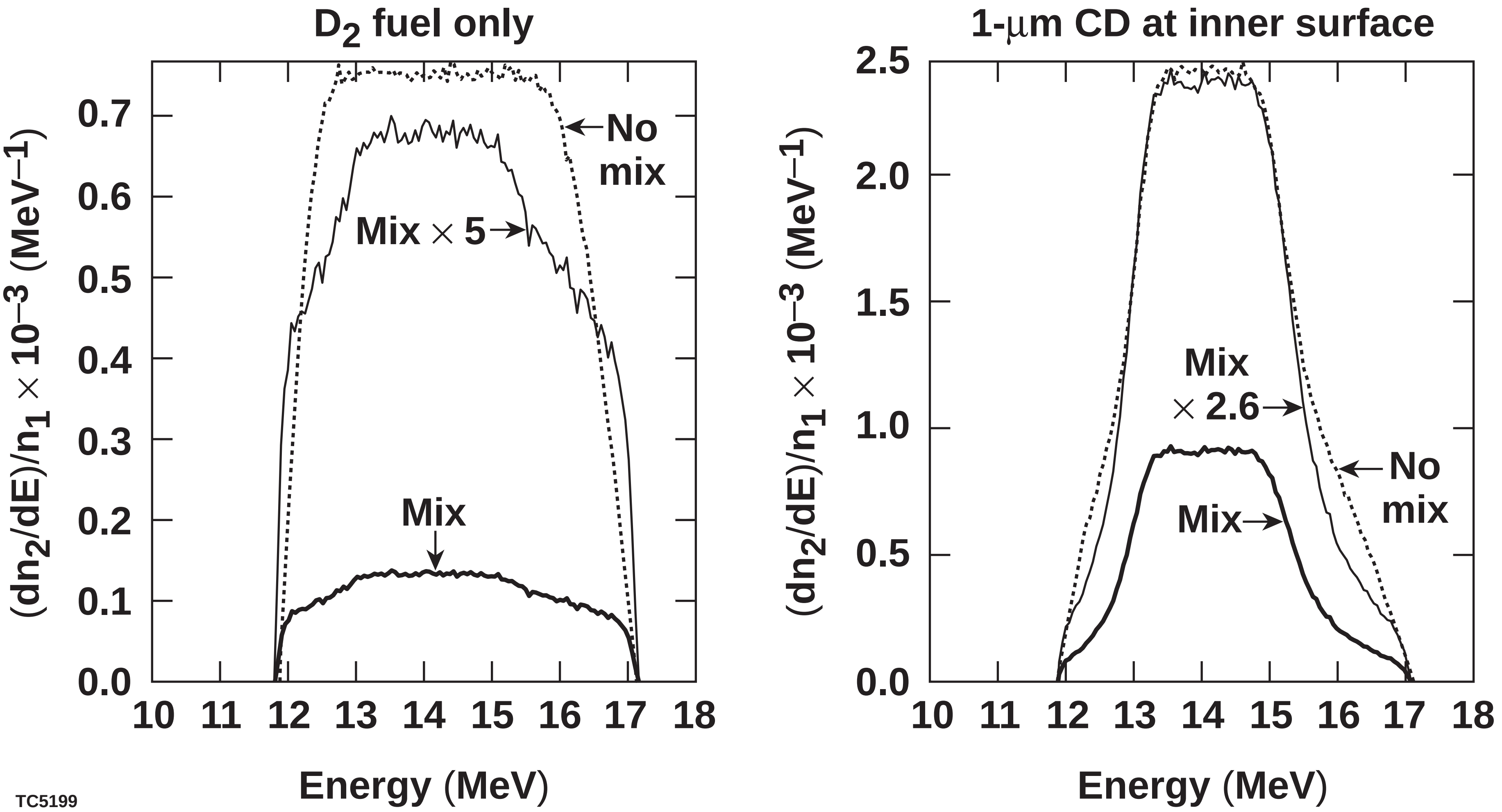
Mix modifies the distinct energy spectra of secondary neutrons originating from the fuel and shell

- 27-μm, 900-μm diameter shell, shaped PS-26 pulse
- *IRIS* Monte-Carlo post-processor



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