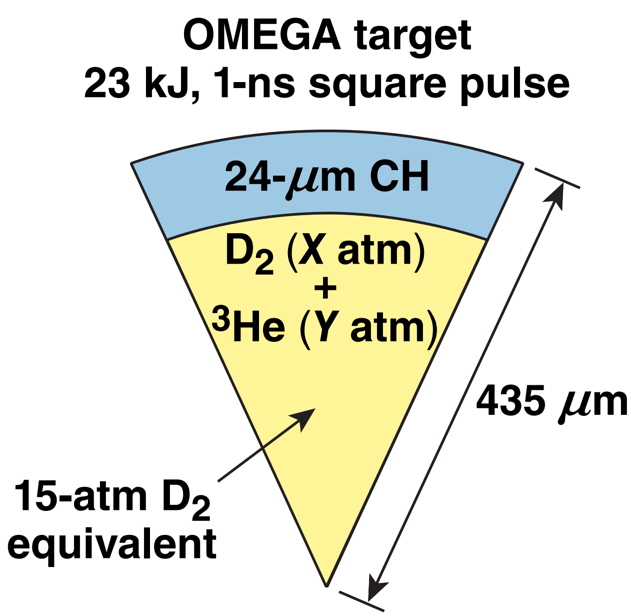
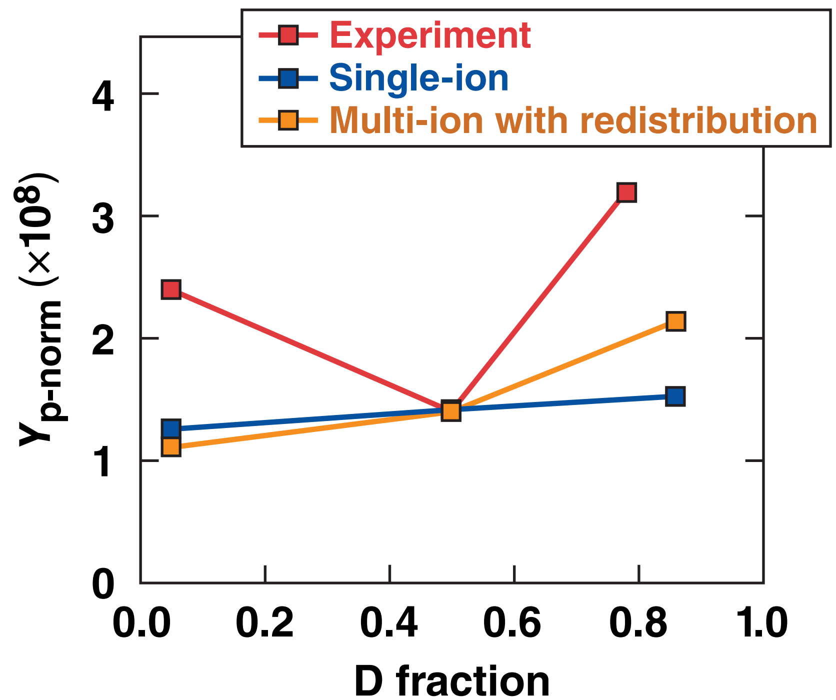
Modeling of Multiple-Ion Heat Transport in ICF Implosions

$$Y_{\text{p-norm}} = Y_p \frac{6\ \text{atm} \times 12\ \text{atm}}{X \times Y}$$





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Summary

Multiple-ion effects in thermal conduction and mix were studied using the Chapman–Enskog method

- The dependence of neutron and proton yields in D^3He implosions on the D_2 fraction[1] cannot be explained with hydrosimulation using single-ion transport models.

- The multi-ion effects modify ion thermal conduction and lead to species diffusion due to gradients in hydro profiles.

- Results of the model indicate that the modification of ion conduction due to multiple-species effects is small.

- The diffusion mechanism produces trends consistent with the experimental data for D fraction larger than 50%.

TC8309

[1] J. R. Rygg *et al*., Phys. Plasmas 13, 052702 (2006).

Collaborators

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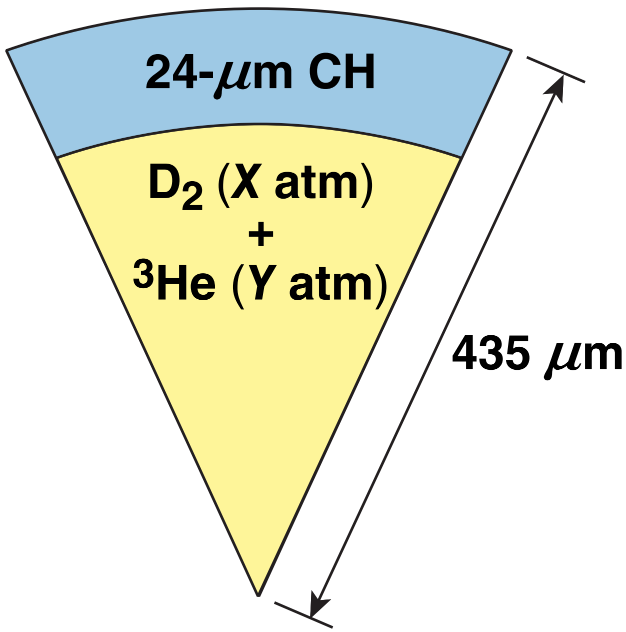
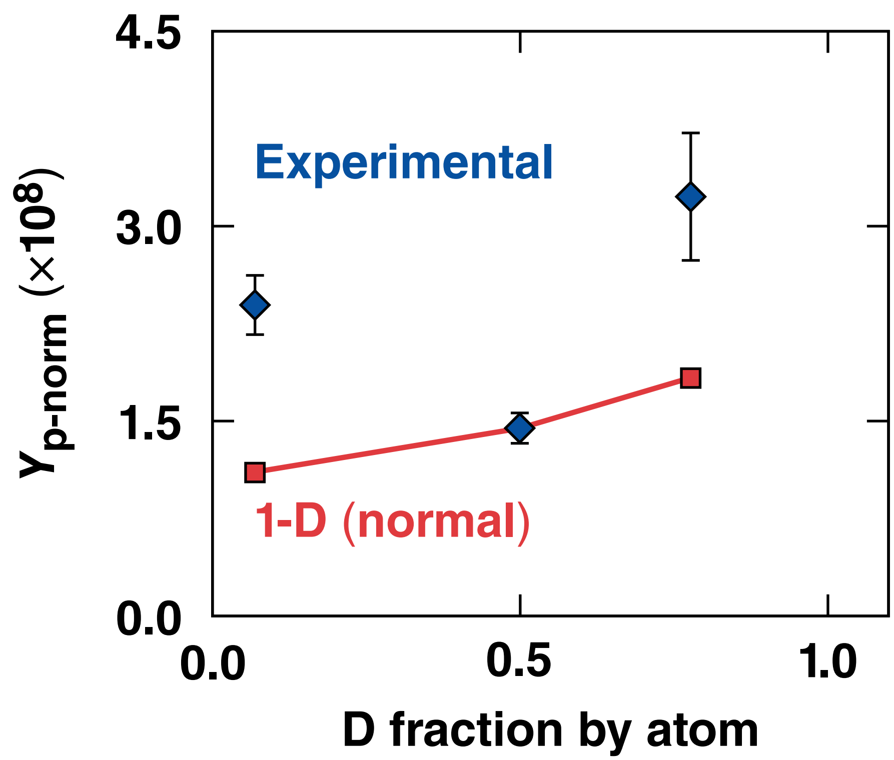
Motivation

The single-ion model deviates from the experiment measurement of neutron and proton yields

$$Y_p \propto X \times Y$$



$$Y_{\text{p-norm}} = Y_p \frac{6\text{ atm} \times 12\text{ atm}}{X \times Y}$$



TC8310

The Chapman–Enskog method is used to derive transport coefficients

$$\frac{\partial f_1}{\partial t} + \vec{\upsilon}\frac{\partial f_1}{\partial \vec{r}} + \frac{e\vec{E}_1}{m_1}\frac{\partial f_1}{\partial \vec{\upsilon}} = J_{11} + J_{12} + J_{1e} \qquad f_1 = f_M^1 + \delta f_1$$

$$\underbrace{(\upsilon - u)_i \left(x - \frac{5}{2}\right)\frac{\partial(\ln T)}{\partial r_i} + (\upsilon - u)_i d_i}_{\text{Ion heat flux}} + \underbrace{\frac{m_1}{T} V_{ij} \frac{\partial u_i}{\partial r_j}}_{\text{Ion viscosity}} = \frac{J_{11} + J_{12}}{f_1}$$

$$d_i = \frac{\partial(\ln P_1)}{\partial r_i} - \frac{m_1}{\rho T}\frac{\partial P_T}{\partial r_i} + \frac{1}{P_1}\frac{\partial P_e}{\partial r_i}\frac{n_1 Z_1^2}{n_1 Z_1^2 + n_2 Z_2^2} + \frac{n_2 Z_1 Z_2 (Z_1 - Z_2)\, eE_i}{T\left(n_1 Z_1^2 + n_2 Z_2^2\right)}$$

TC8311

The Chapman–Enskog method is used to derive transport coefficients

$$\frac{\partial f_1}{\partial t} + \vec{\upsilon}\frac{\partial f_1}{\partial \vec{r}} + \frac{e\vec{E}_1}{m_1}\frac{\partial f_1}{\partial \vec{\upsilon}} = J_{11} + J_{12} + J_{1e} \qquad f_1 = f_M^1 + \delta f_1$$

$$x = \frac{m_1(\upsilon - u)^2}{2T} \qquad (\upsilon - u)_i(\upsilon - u)_j - \frac{1}{3}(\upsilon - u)^2\delta_{ij}$$

$$(\upsilon - u)_i\left(x - \frac{5}{2}\right)\frac{\partial(\ln T)}{\partial r_i} + (\upsilon - u)_i d_i + \frac{m_1}{T}V_{ij}\frac{\partial u_i}{\partial r_j} = \frac{J_{11} + J_{12}}{f_1}$$

Ion heat flux

Ion viscosity

$$d_i = \frac{\partial(\ln P_1)}{\partial r_i} - \frac{m_1}{\rho T}\frac{\partial P_T}{\partial r_i} + \frac{1}{P_1}\frac{\partial P_e}{\partial r_i}\frac{n_1 Z_1^2}{n_1 Z_1^2 + n_2 Z_2^2} + \frac{n_2 Z_1 Z_2 (Z_1 - Z_2)\, eE_i}{T\left(n_1 Z_1^2 + n_2 Z_2^2\right)}$$

TC8311

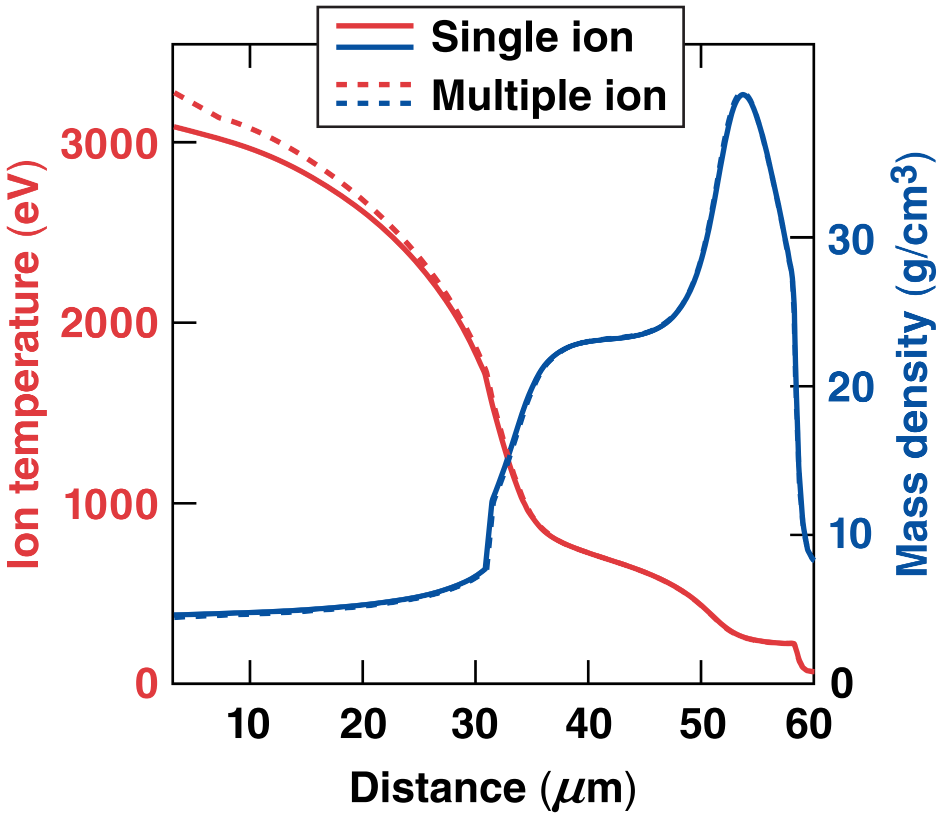
Ion heat flux and diffusion velocity depend on ion temperature and pressure gradient

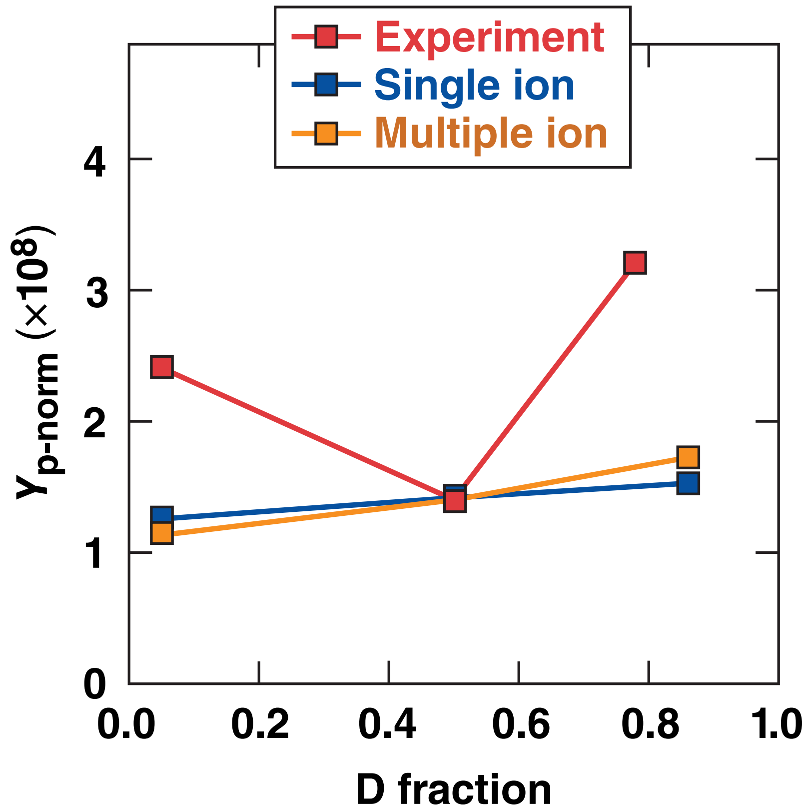
$$\delta f_1 = f_M^1 (\upsilon - u)_i \left[\Phi_1(\upsilon) \frac{\partial \ln T}{\partial r_i} + \Phi_2(\upsilon) d_i \right]$$

$$\Phi(x) = \sum_n a_n L_n^{3/2}(x)$$

$$\vec{q}_1 = \int \vec{\upsilon} \frac{m\upsilon^2}{2} \delta f_1 d\vec{\upsilon} \qquad \delta\vec{u}_1 = \frac{1}{n_1} \int \vec{\upsilon} \delta f_1 d\vec{\upsilon}$$

The modifications due to multi-ion conduction to the hydro profile are small

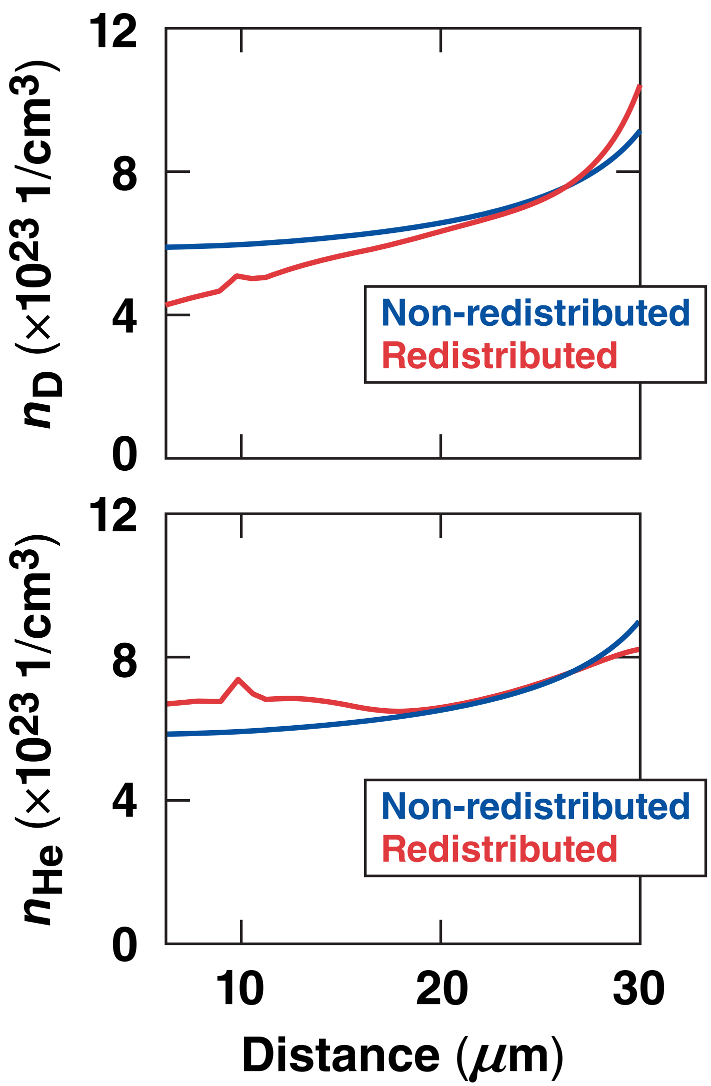


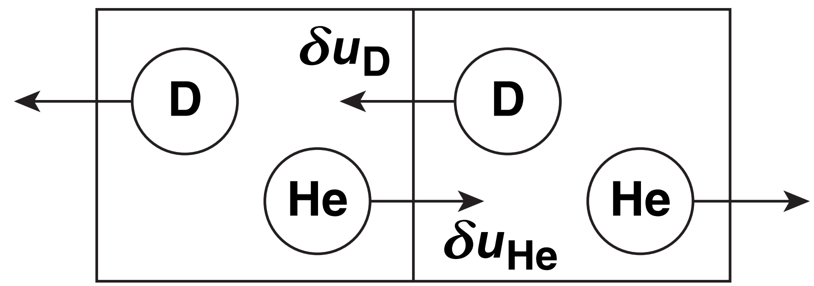


Only the modifications to the thermal conduction are included.

TC8313

The difference in diffusion velocity leads to the particle redistribution





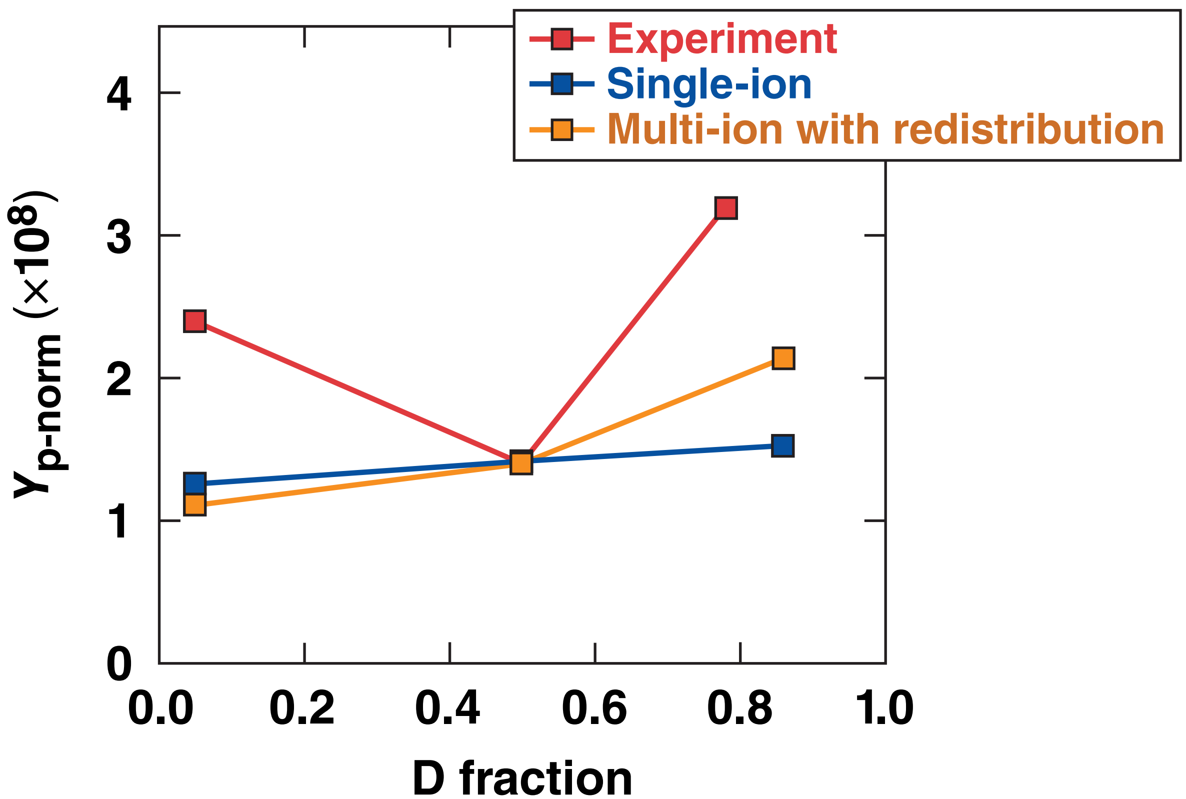
$$\delta u_D \neq \delta u_{He}$$

$$m_D n_D \delta u_D + m_{He} n_{He} \delta u_{He} = 0$$

Redistributed density is used only to calculate the reaction rate.

TC8314

The trend predicted by the diffusion mechanism is consistent with the experiment for large D fraction



- $Q_{ie}\,(\text{single-ion}) = \dfrac{3m_e}{\langle m_i \rangle} \dfrac{n_e}{\tau_{ei}} (T_e - T_i)$
- $Q_{ie}\,(\text{multi-ion}) = 3m_e n_e (T_e - T_i) \left(\dfrac{1}{m_1 \tau_{e1}} + \dfrac{1}{m_2 \tau_{e2}} \right)$

TC8315

Summary/Conclusions

Multiple-ion effects in thermal conduction and mix were studied using the Chapman–Enskog method

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