Neutron Capture in Plasmas at the National Ignition Facility (NIF)

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The nγplasma Collaboration

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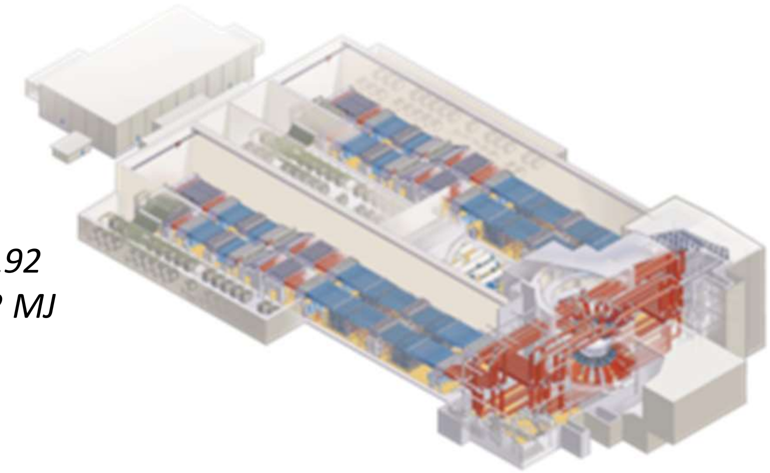
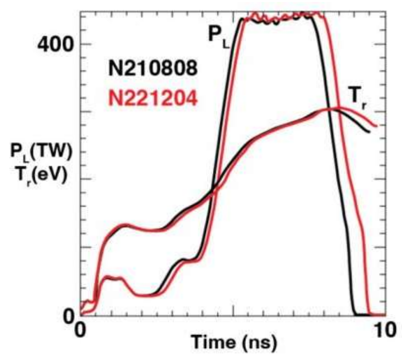
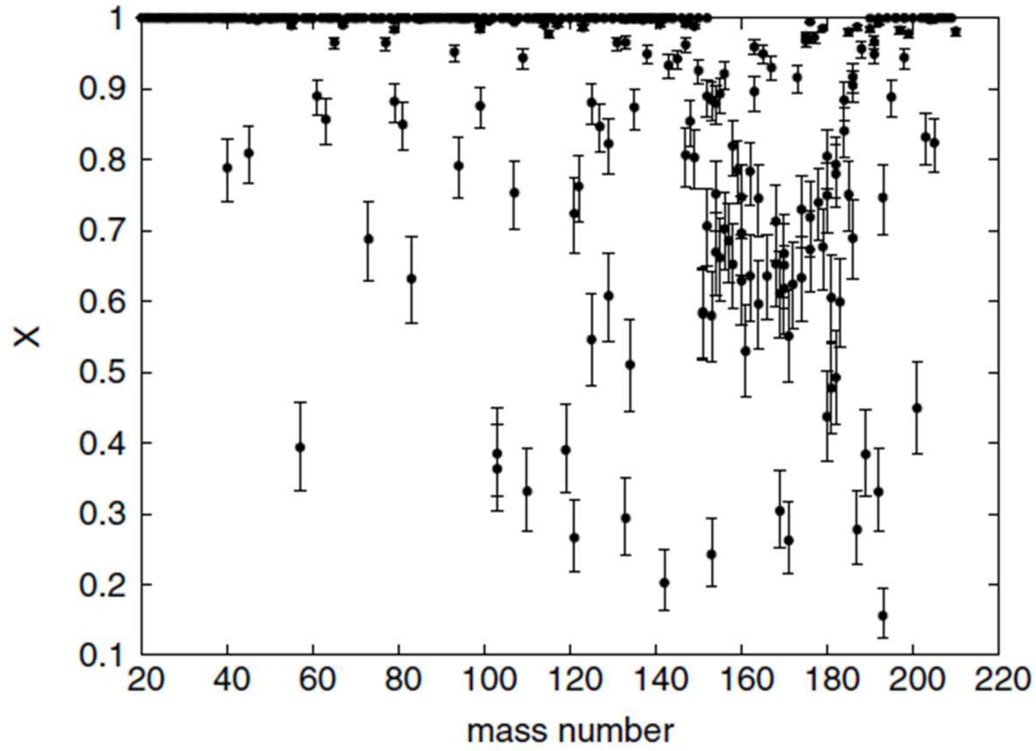
Inertial Confinement Fusion (ICF), NIF and neutron capture

The NIF laser has 192 beams delivering 2 MJ energy in ~10 ns





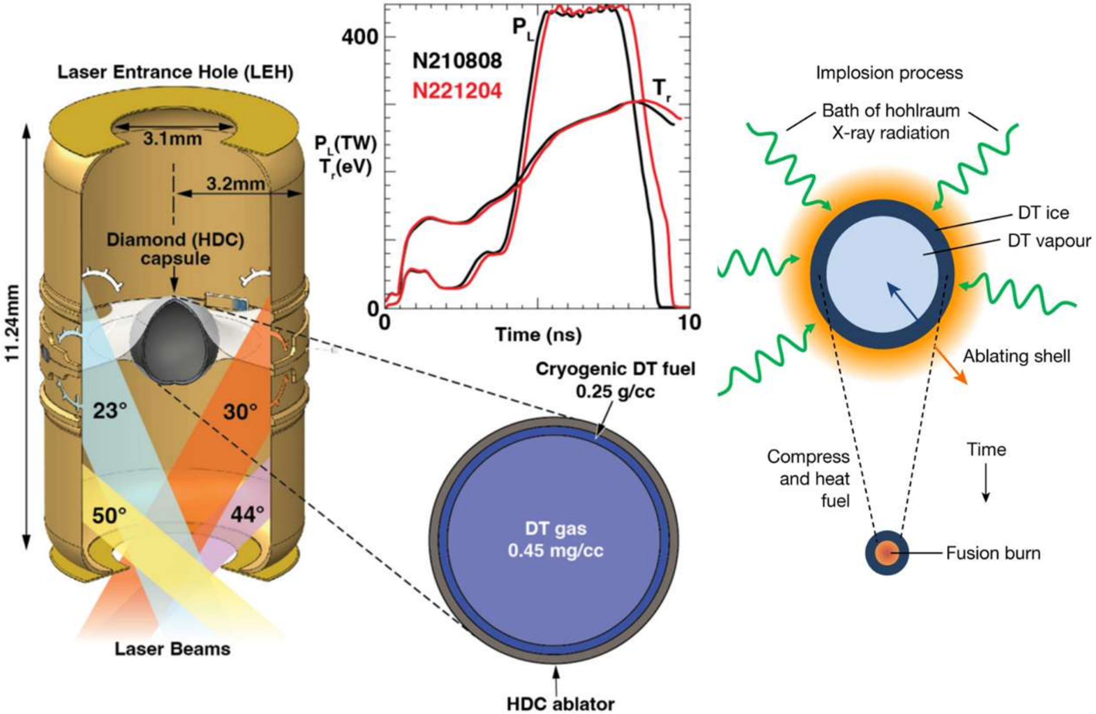


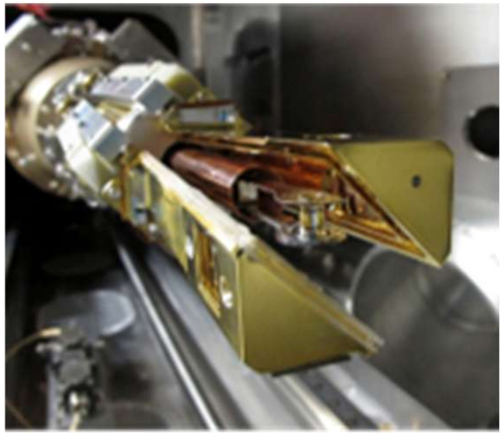
Estimated ground-state contributions X to stellar (n,γ) rate at 30 keV

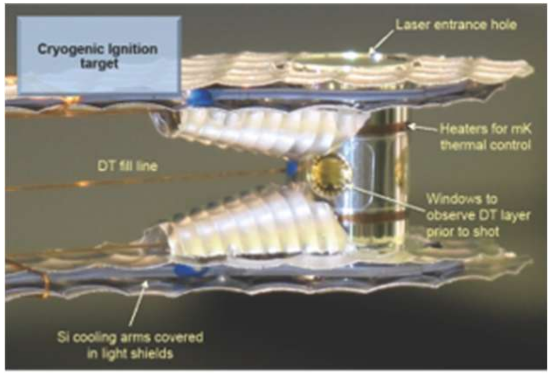
Can we measure (n,γ) cross sections of excited state nuclei on the NIF?

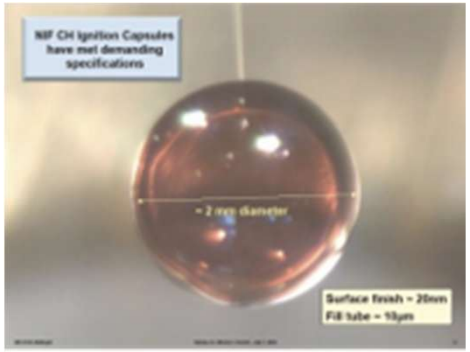
T. Rauscher et al, *Astrophysical Journal* 738:143 (2011)

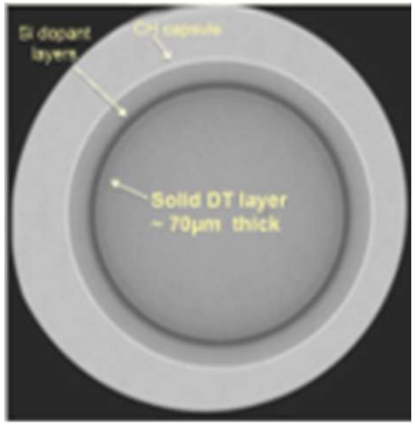
ICF experiments on the NIF laser







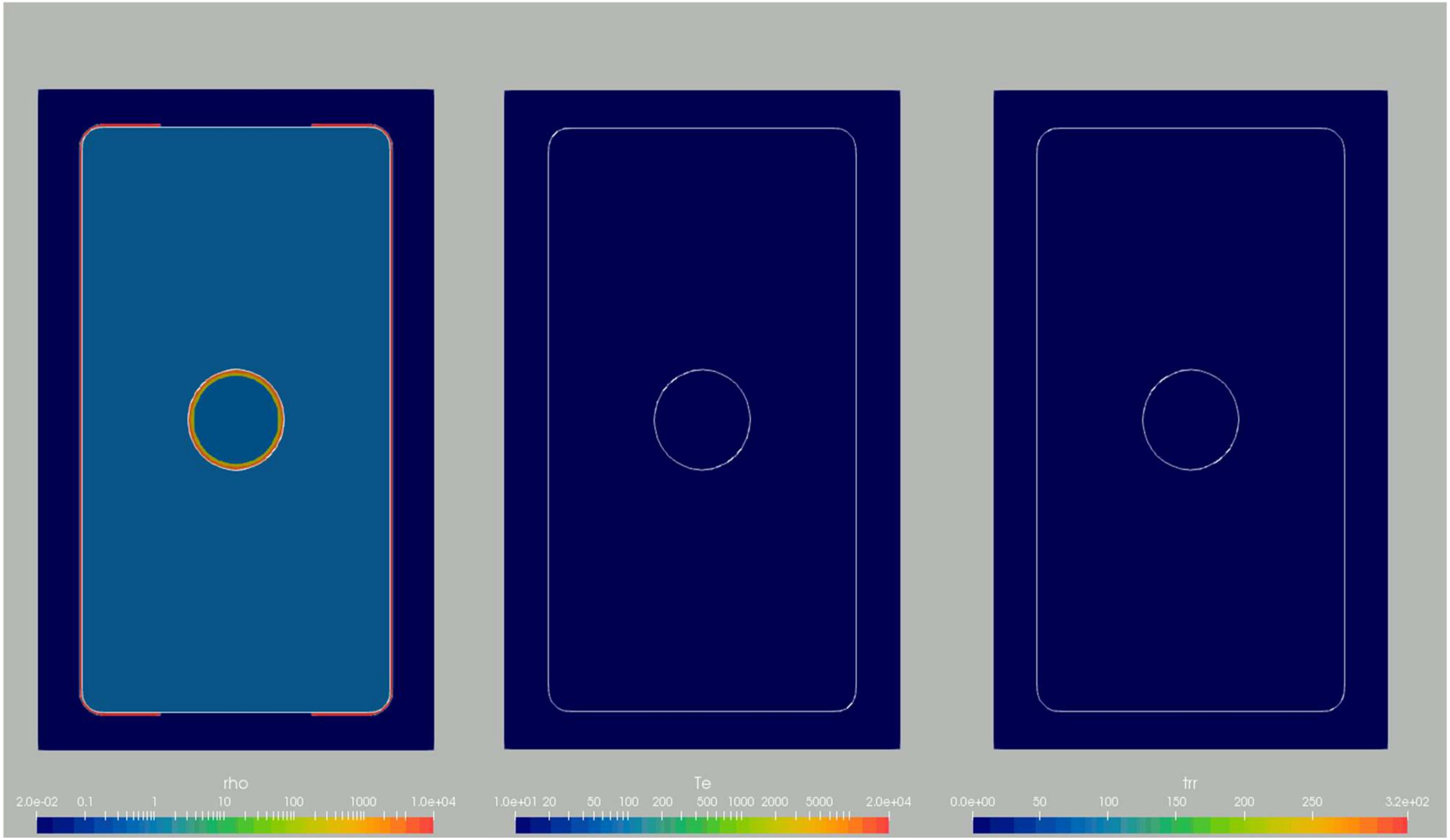




Indirect Drive: hohlraum converts laser energy to x-rays which drive implosion of DT fuel capsule.

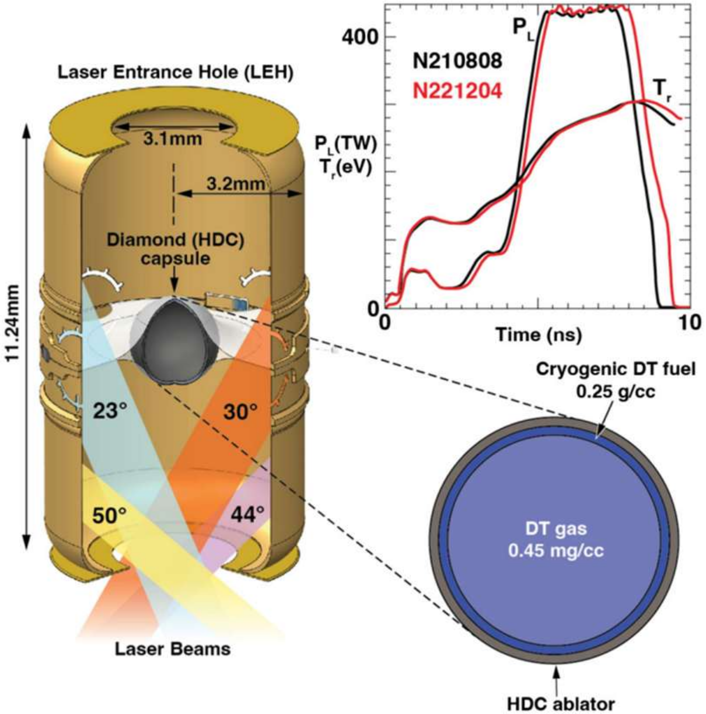
ICF experiments on the NIF laser

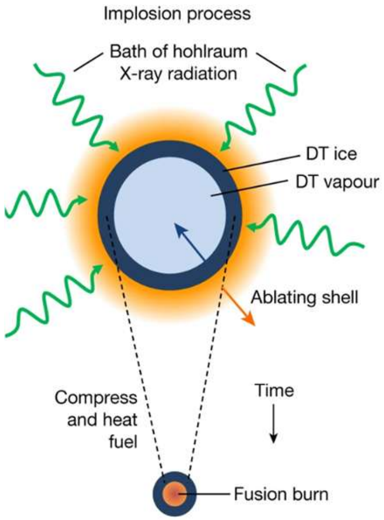
Mass density+ helium interface **Electron temperature** **Radiation temperature**

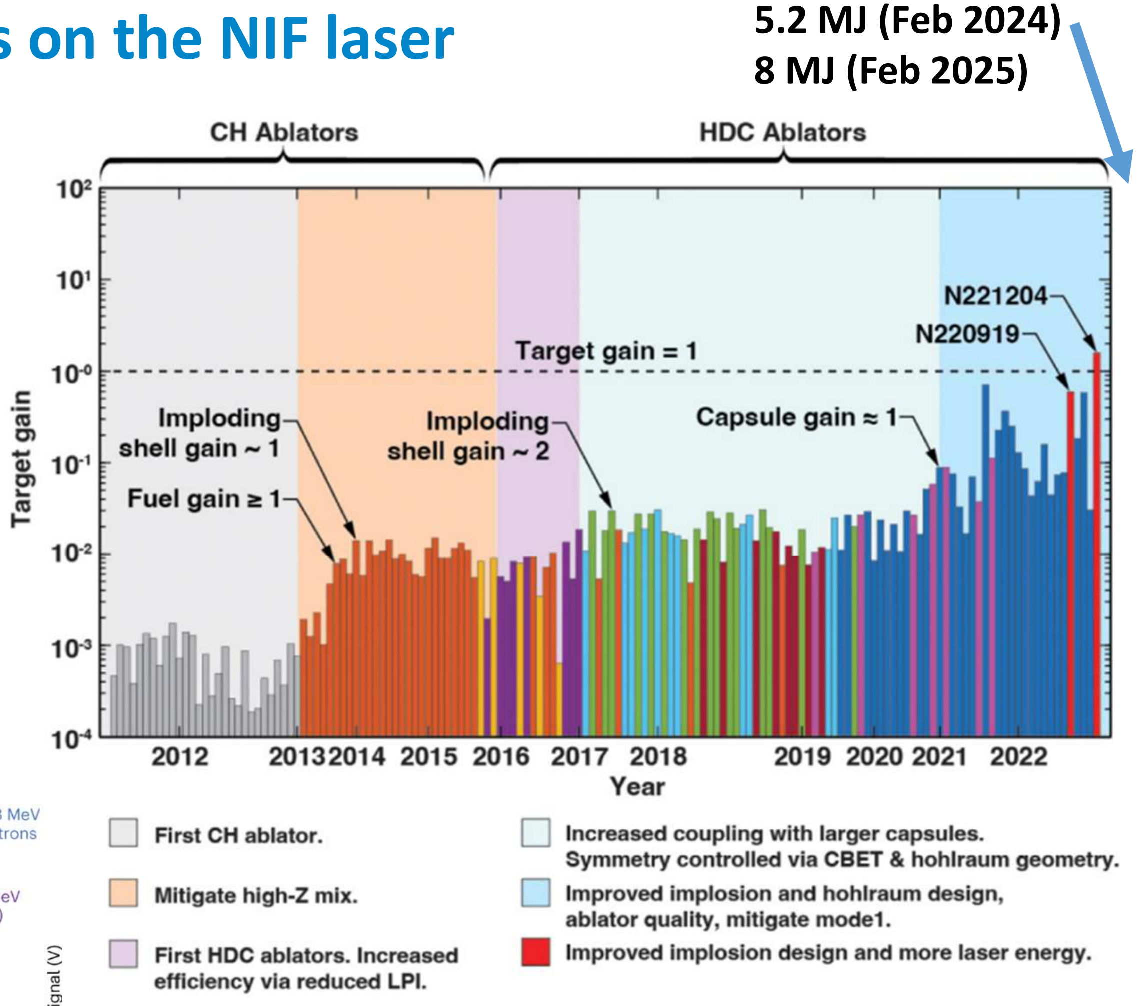


ICF experiments on the NIF laser

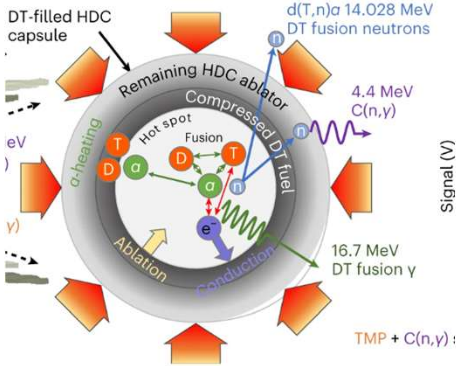
5.2 MJ (Feb 2024)
8 MJ (Feb 2025)





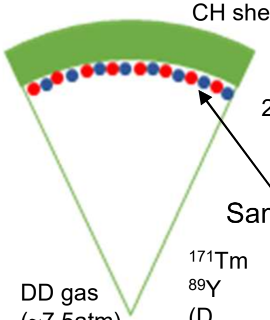


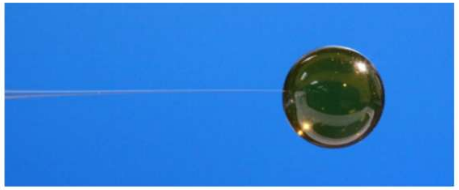
Thermonuclear burn phase:
Duration ~100 – 400 ps
Temperature ~10 keV
Density ~10^{31} m^{-3}
Neutron yield ~10^{18} neut
Neutron flux ~10^{34} neut m^{-2} s^{-1}



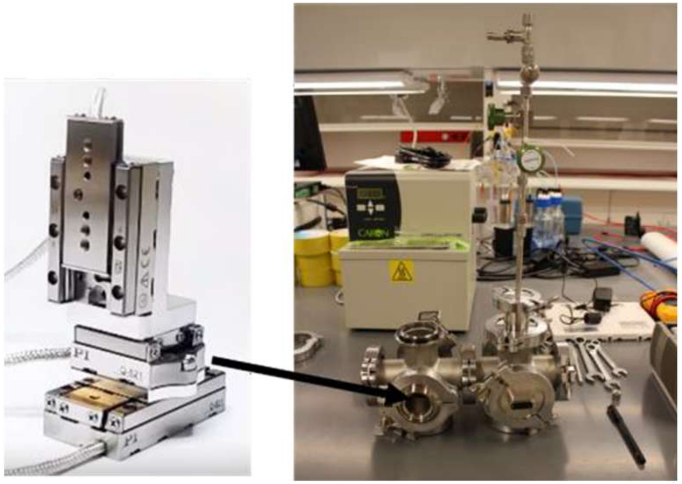
H Abu-Shawareb *et al* (2024) *Phys. Rev. Lett.* **132**, 065102

Capsule doping

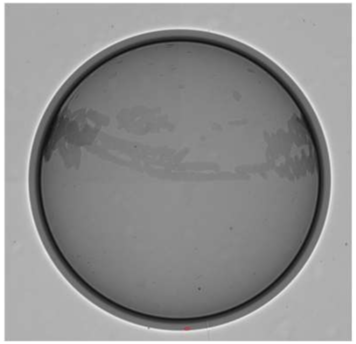




Capsule and fill tube



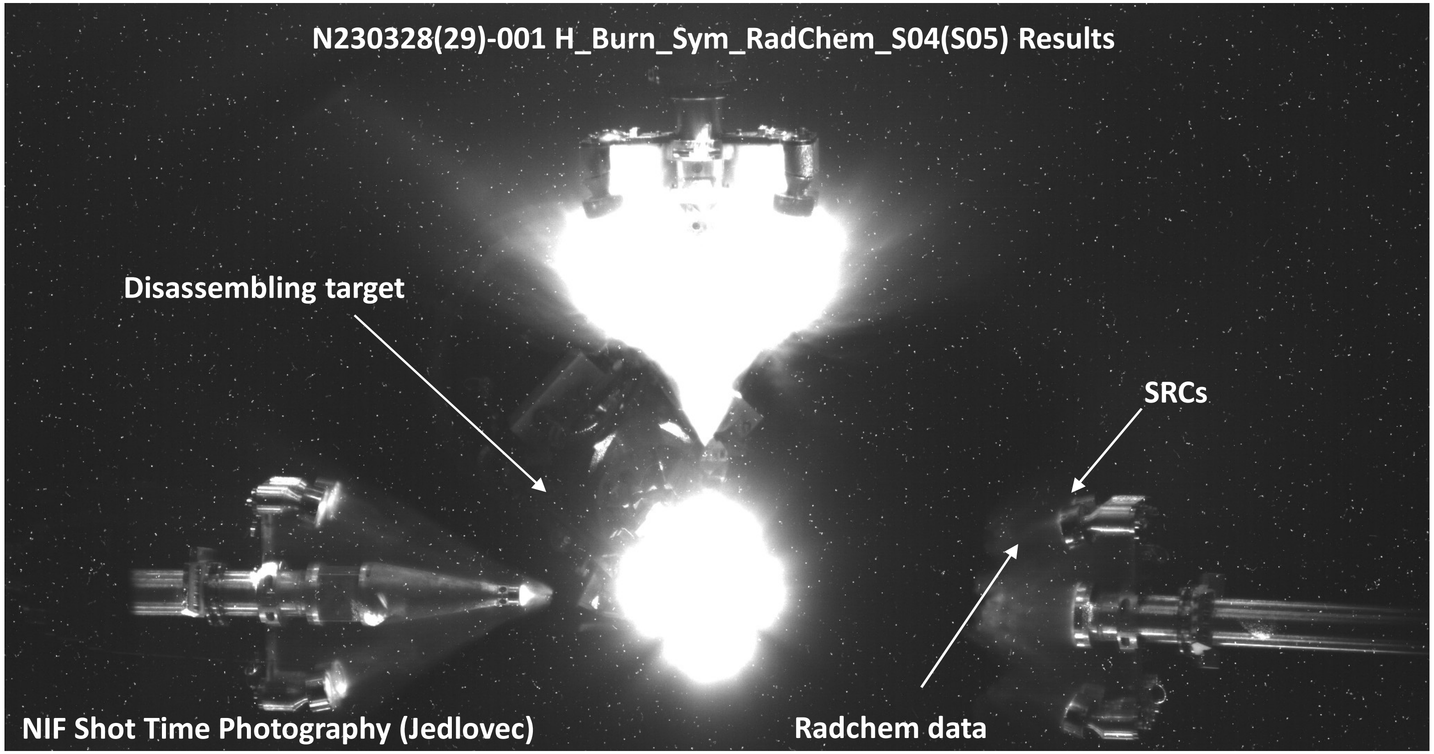
VORCAN: Vacuum Optimized Radionuclide-to-Capsule Administer for NIF



X-ray image of HDC capsule doped with Y89, Tm169, Eu152 for N230702

Trace amounts of stable and radioactive isotopes can be added to interior of fuel capsules

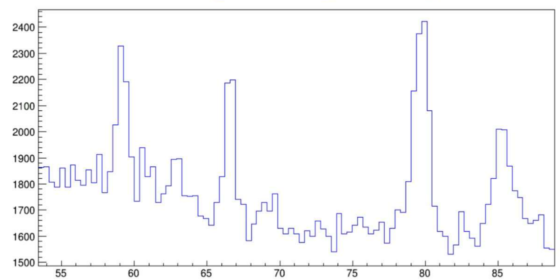
Solid Radiochemistry diagnostics on the NIF



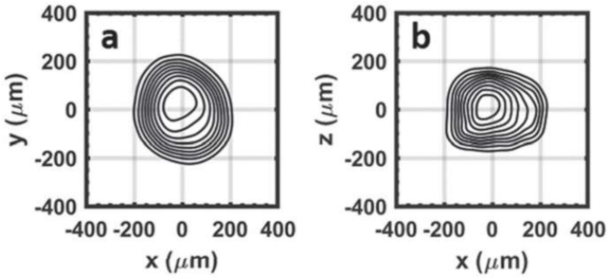
Recent measurement of Y89(n,2n) cross section on the NIF using this system

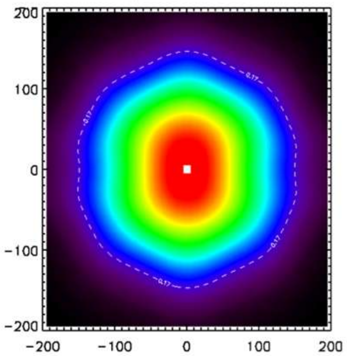
Solid radiochemistry collectors (SRCs)

BOWA detector signal of 66.7 keV from Tm171

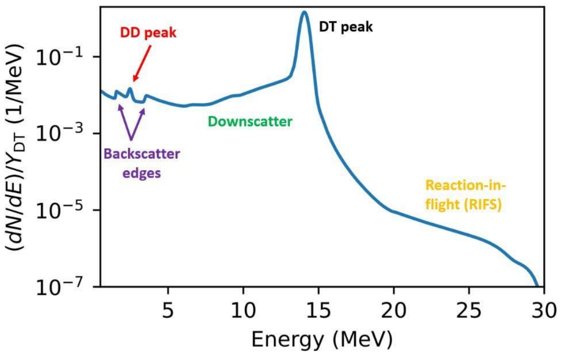


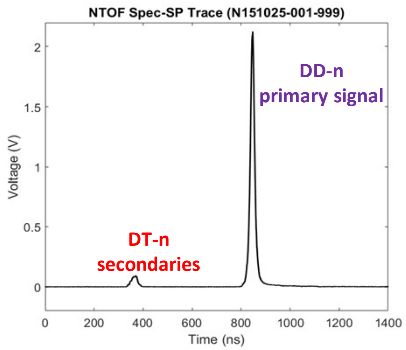
Plasma diagnostics on the NIF

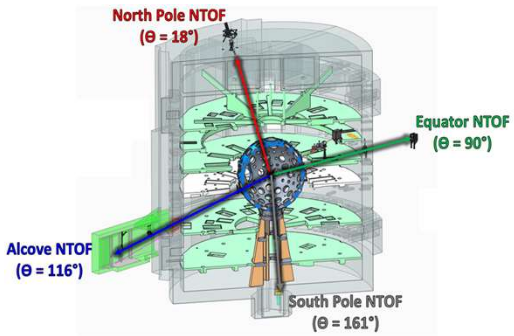




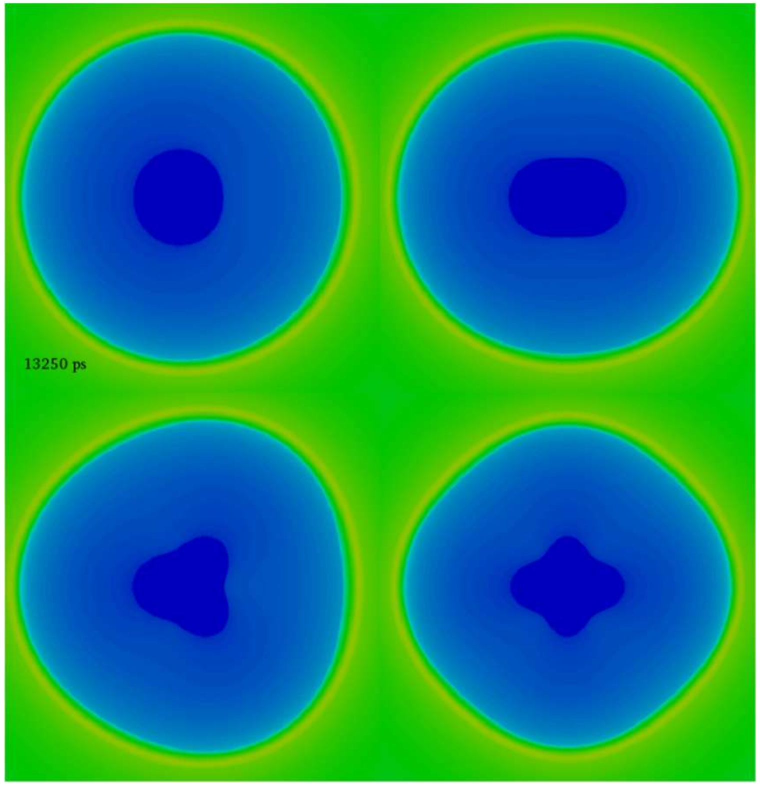
Experimental (top) & simulated (bottom) neutron images







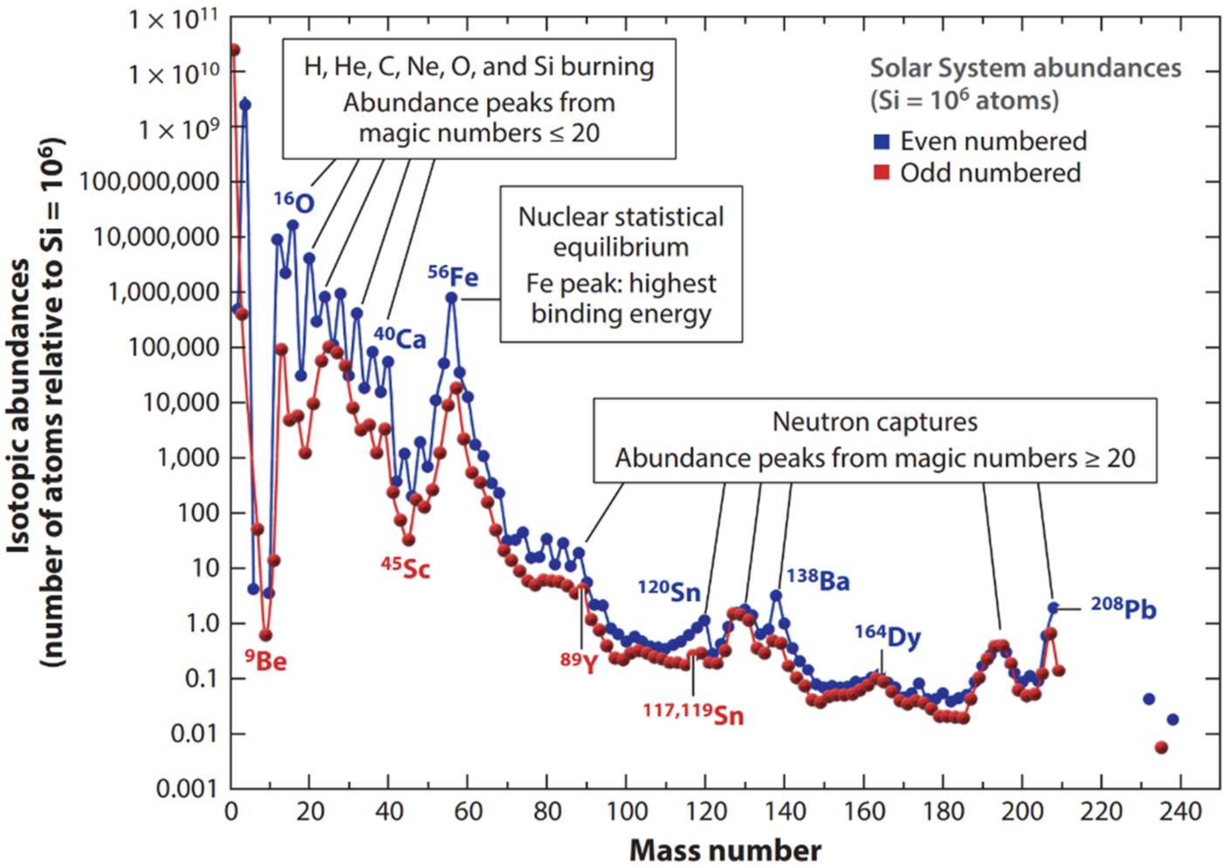
Neutron time-of-flight detectors can measure plasma temperature



The plasma conditions are inhomogenous and change rapidly with time

Measurements (spectra, imaging, intensity vs time, etc) of neutron, gamma & x-ray emission can be used to infer plasma temperature, density, size, duration, etc

Isotopic abundances in the Universe



M. Lugaro et al, *Annu. Rev. Nucl. Part. Sci.* 2023. 73:315–40

Can we measure (n,γ) cross sections of excited state nuclei?

1. Observing $n\gamma$ reactions in NIF implosion	**2. Understanding nuclear excitation in plasmas**	**3. Measuring $n\gamma$ cross section of excited state nuclei**	**4. Varying neutron spectra in plasma (moderation)**

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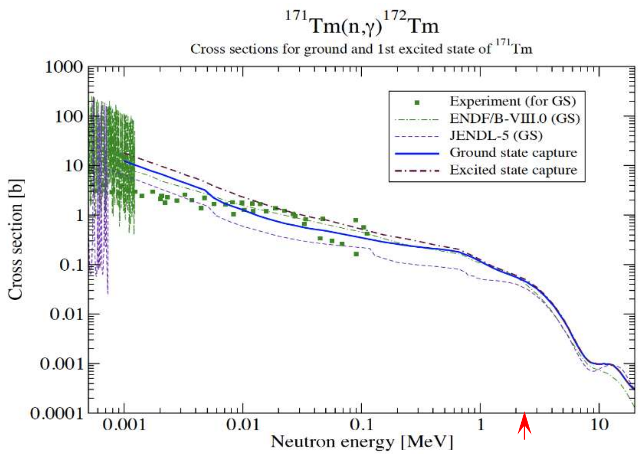
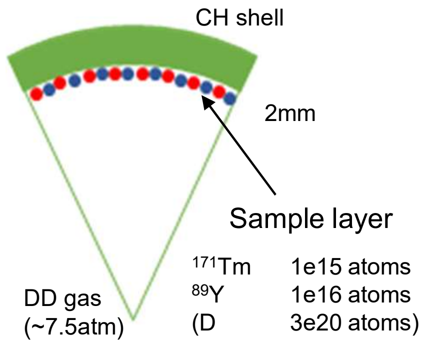
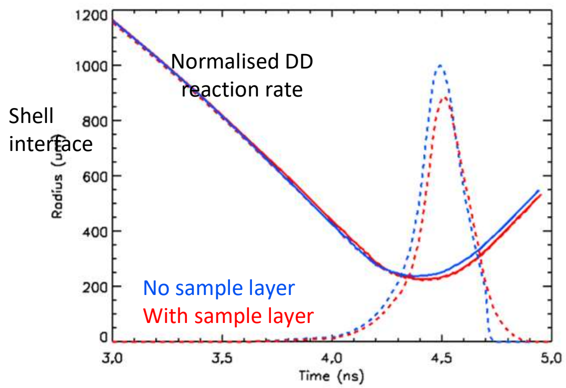


Tm171 $n\gamma$ cross section (gs and 1st exs)

- Experiments in July 2026
- Tm171(n,γ)Tm172 at neutron energy of 2.45 MeV



	Nominal DD	With samples
Yield (DD n)	2.1e14	1.9e14
Tion (keV)	7.66	7.61
Bang time (ns)	4.49	4.51
Neutron size (um)	145	127



Rad-Hydro simulations of PDD targets with a dopant layer

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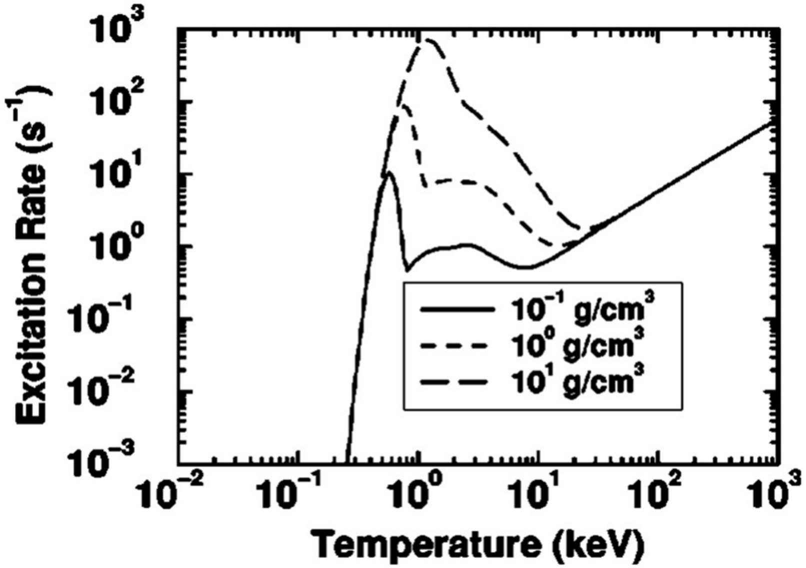

Excitation of Mo93 by NEEC and photon absorption

G. Gosselin and P. Morel 2004 *Phys. Rev. C* **70** 064603

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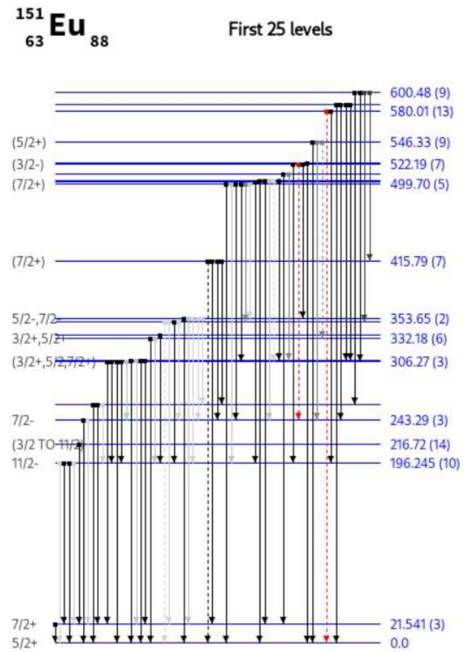
Isotope	cx GS [mb]	cx L1 [mb]	Ex Ener [MeV]	cx ratio
Eu151	30.28	34.40	0.022	1.136
Zr88	39.04	28.52	1.057	0.730
Nb93	6.01	5.35	0.031	0.890
La139	5.25	4.25	0.166	0.809
Sc45	1.35	1.14	0.012	0.842
Cr50	2.64	3.68	0.783	1.391
Co57	5.84	4.38	1.224	0.750
Co59	2.54	2.15	1.099	0.847
Zn64	10.33	8.88	0.992	0.860
Mo98	3.52	2.17	0.735	0.616
Cs133	19.35	16.72	0.081	0.864

Candidate isotopes for measuring $n\gamma$ cross section of excited states



Energy levels of Eu151 nucleus

- Experiments in late 2027
- Eu151(n,γ)Eu152 at neutron energy of 2.45 MeV

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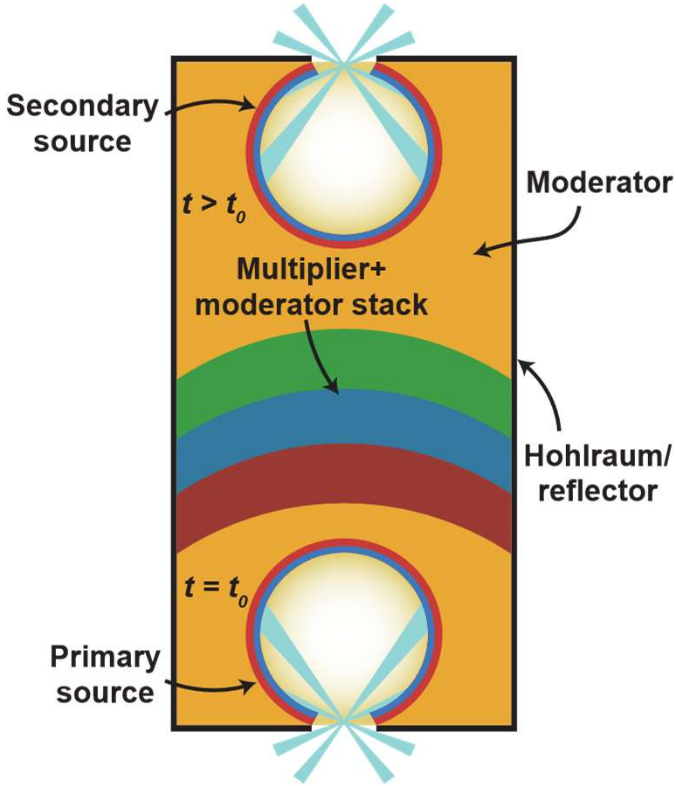

Nick Schwartz, MIT

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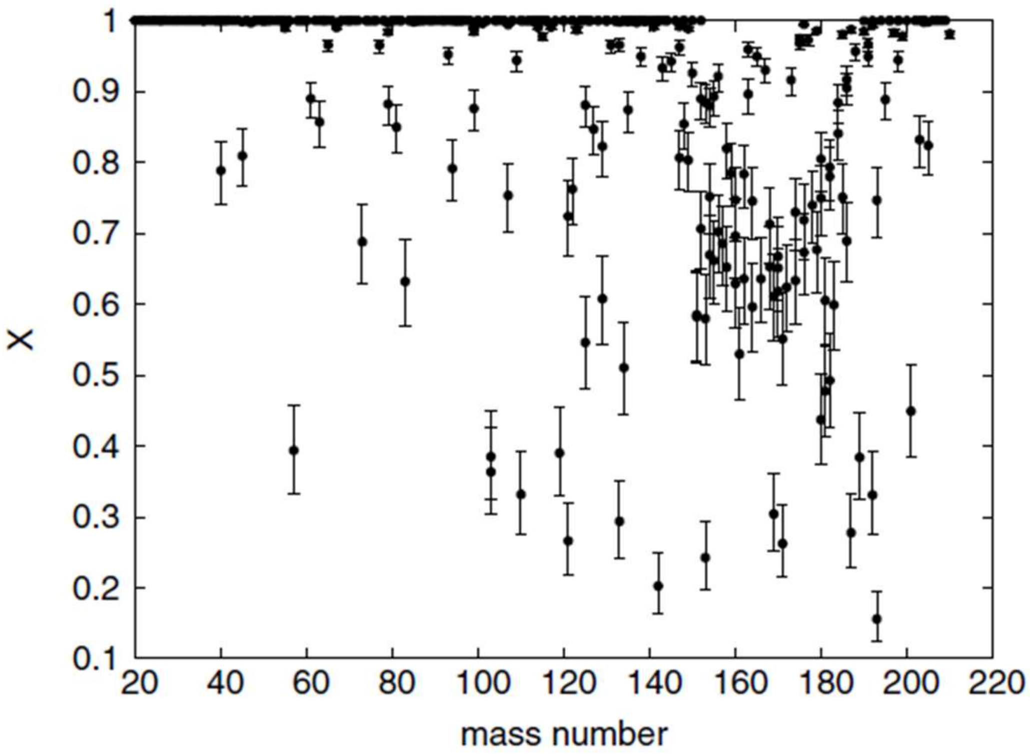

Estimated ground-state contributions X to stellar (n,γ) rate at 30 keV