Small-scale isotopic identification: simulations of NRTA using a linac vs. fusion source

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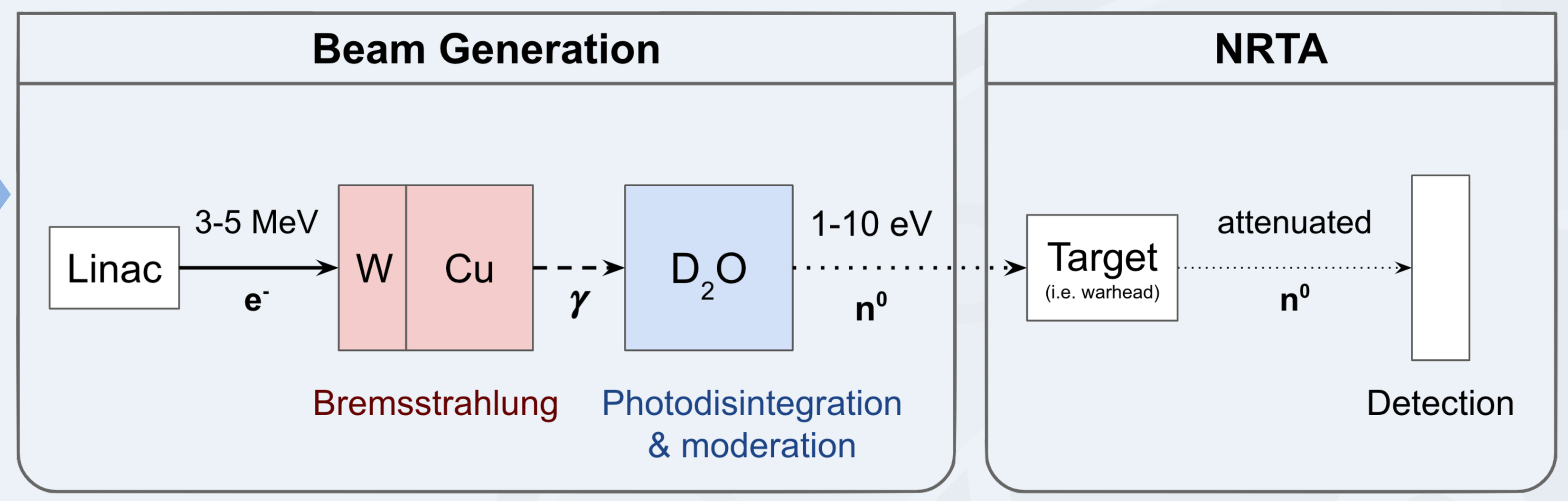
NRTA is useful for **fuel enrichment analysis** & **warhead verification** in arms control treaties.

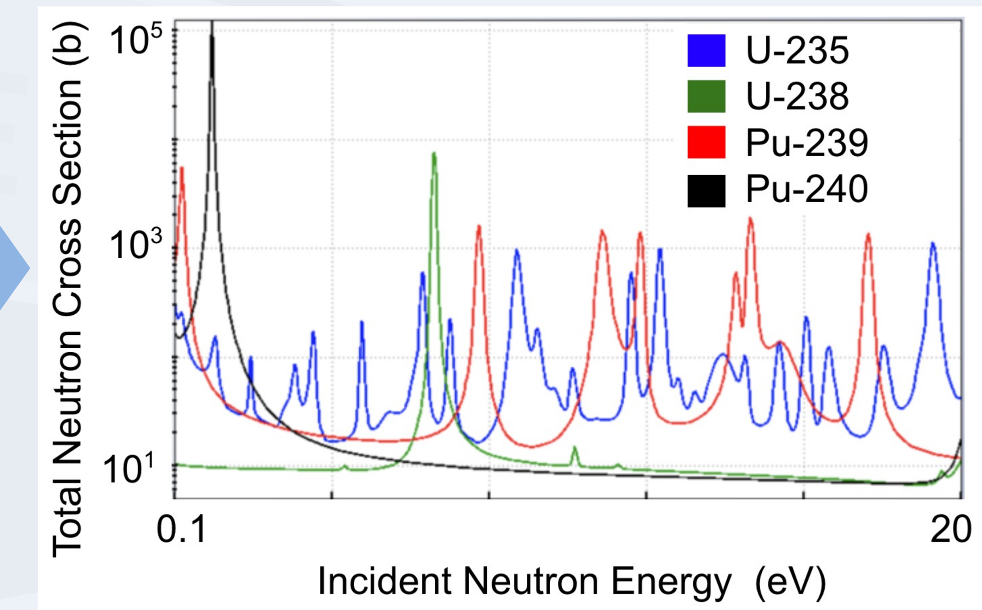
NRTA: Neutron Resonant Transmission Analysis

Enables verifiable nuclear reductions; verifies treaty compliance



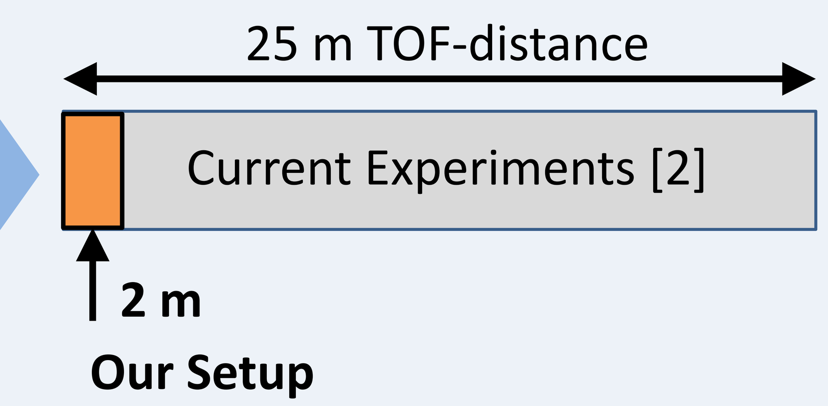
Shown: linac conversion method (later compared to DT/DD generators)

NRTA uses resonant neutron absorption unique to individual nuclei to identify isotopic compositions.



Isotopic signatures for special nuclear materials in 0.1-20 eV range [1]

This work aims to design a smaller, mobile NRTA setup.



The choice between DD, DT, and linacs is a **tradeoff between complexity and required flux**. Where cost and size allow, the **5.5 MeV linac** is preferred. Where limited, the **DT generator** is preferred.

	Beam	Neutron Flux at Tally Surface* (10^6 n s^{-1}, 1-10 eV only)
Linac (MeV)	3.0	~DT 1.57 ± 0.04
	3.5	5.0 ± 0.1
	4.0	10.8 ± 0.3
	4.5	18.9 ± 0.5
	5.5	~24x DT 43 ± 1
Fusion	DD**	0.398 ± 0.006
	DT**	1.80 ± 0.07

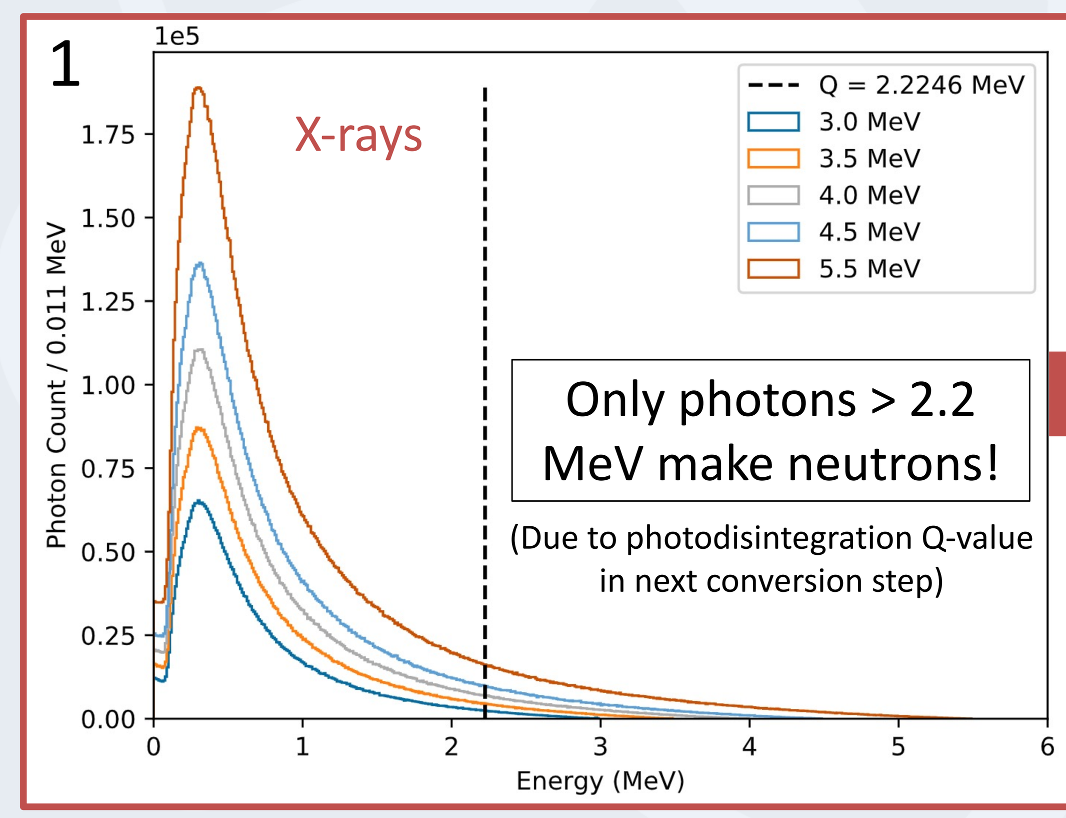
Increasing flux

*The tally surface is an open-ended coaxial cylinder surrounding the D_2O moderator, 20 cm in z-axis

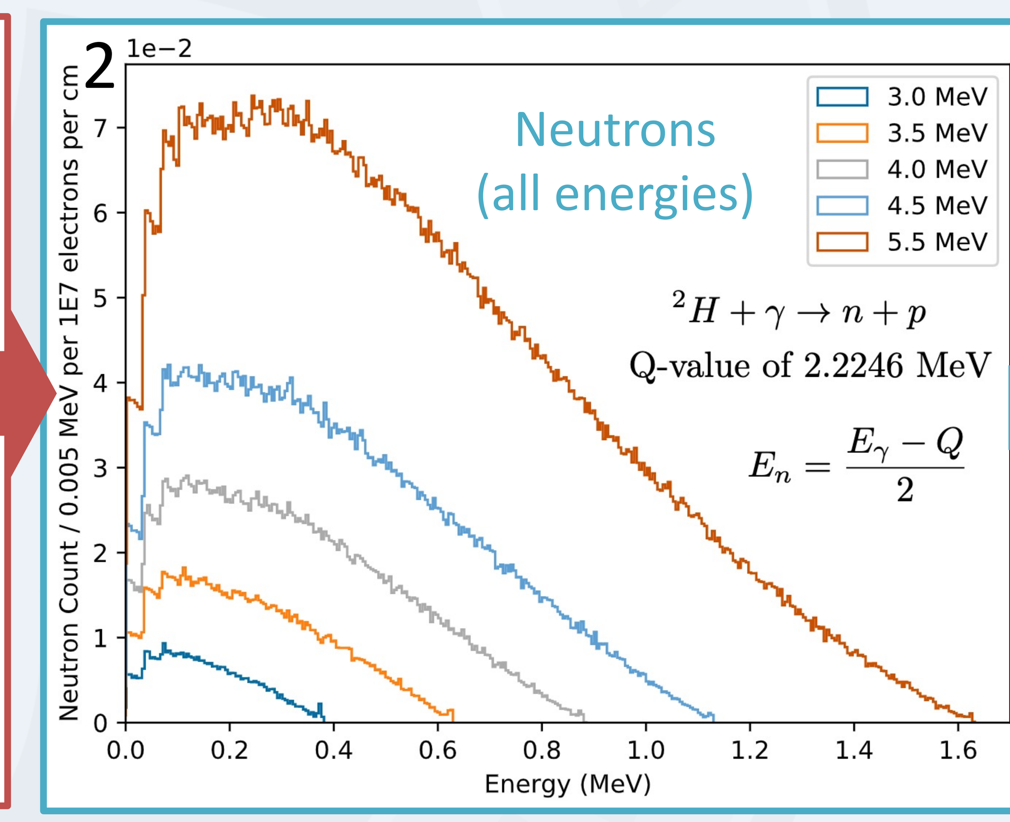
**Assumes generated neutron flux (all energies) of 1 x 10^7 (DD) and 3 x 10^8 (DT) neutrons s^{-1}

Future work should investigate optimal geometries and NRTA absorption line resolutions in simulation & experiment.

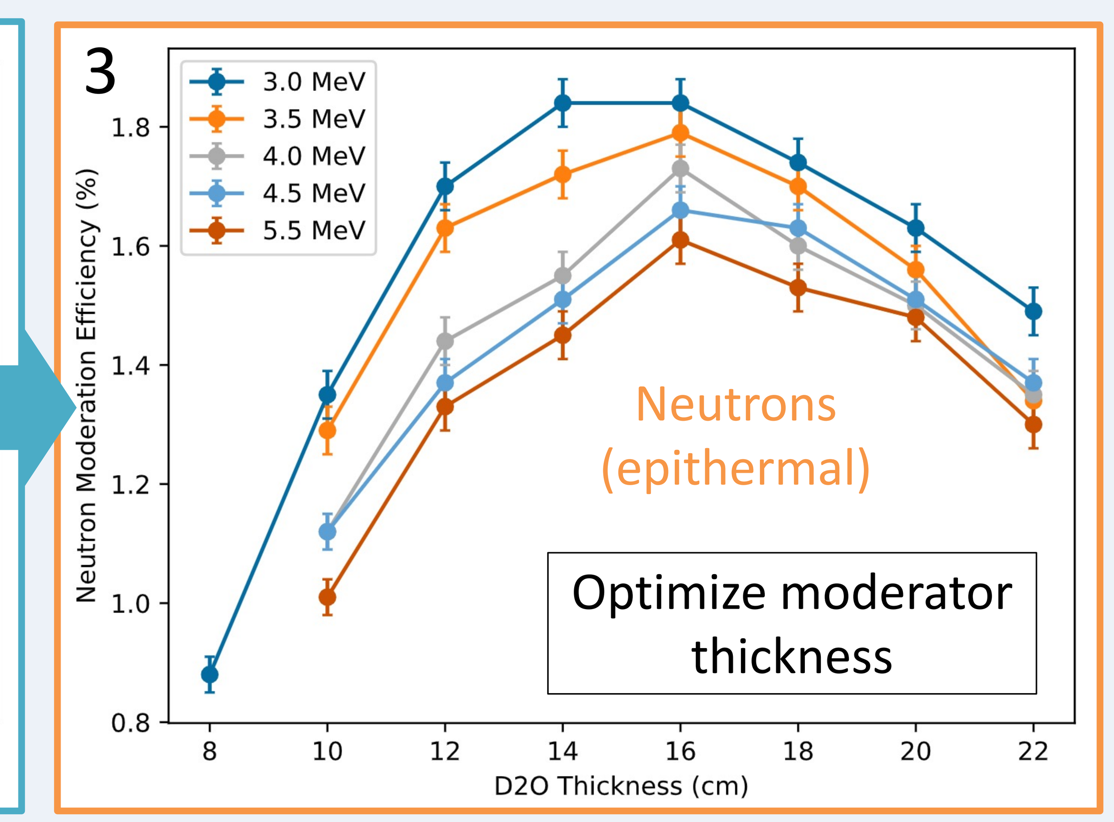
Linac conversion requires 3 steps to convert electrons to epithermal neutrons: (1) bremsstrahlung, (2) photodisintegration, (3) neutron moderation. Final epithermal neutron flux indicates measurement duration of a few hours.



Bremsstrahlung



Photodisintegration



Moderation

Simulated Epithermal Flux

$$\Gamma_{n,1-10\text{eV}}(E_{e^-}) = \Gamma_{e^-} \cdot \int_0^{E_{e^-}} \left[\eta_{\text{brem}}(E_{e^-}, E_\gamma) \cdot \int_0^x \Sigma_{^2H(\gamma,n)p}(E_\gamma) dx' \cdot \eta_{\text{mod}}\left(E_n(E_\gamma)\right) \right] dE_\gamma$$

	Linac	Fusion: 2.5 MeV (DD), 14.1 MeV (DT)
✓	Well known, high-flux system for radiation damage studies	Simple, compact system directly produces neutrons
✗	Complex; bremsstrahlung x-rays need significant shielding	DD has low flux; DT neutrons need more shielding

References

[1] ENDF/B-VII.1. National Nuclear Data Center. Brookhaven National Laboratory. 2018. Adapted from "Development of a portable system for epithermal neutron resonance analysis," Ethan Klein, 2020 MTV Conference.

[2] "NIST Center for Neutron Research." Center for Research in Extreme Batteries. 2021.

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