P-001209

Fundamental Nuclear Reaction Studies Using Time-Correlated ARC and NIF Shots

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February 12, 2025
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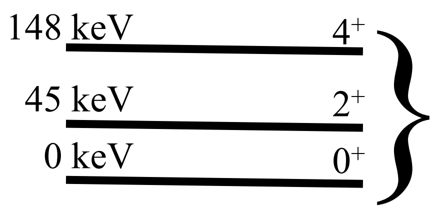
Nuclei with excitations at or near their ground state have low interaction rates with $k_BT \approx keV$ plasmas

The chance of a *keV* photon or electron from a plasma populating a level with a width of μeV *is* $\leq 1{:}10^9$



Each level has a $\Delta E \approx \mu eV$

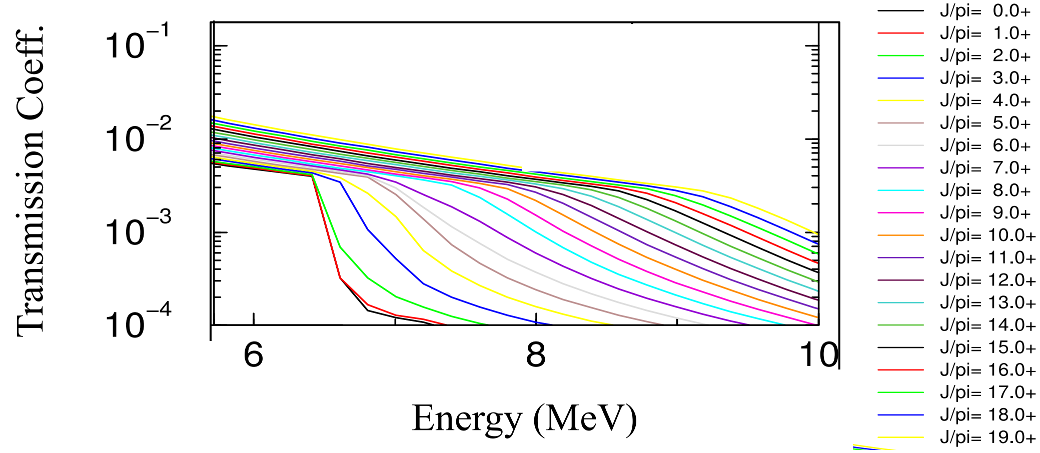
^{238}U

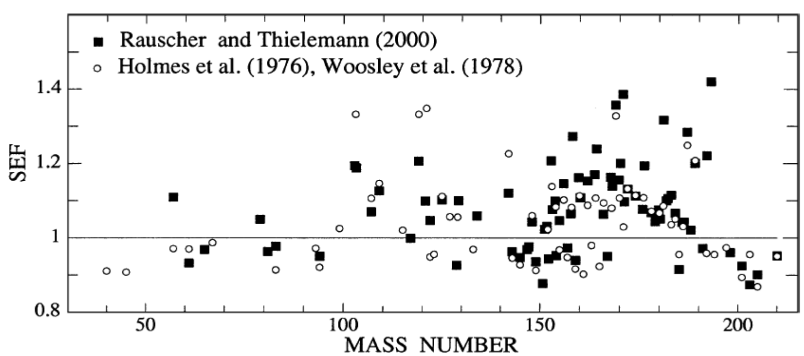
The resulting rate is much slower than *NIF HEDP* time scales (≤ns)

However, given enough time all *i* levels will be thermally populated with a probability given by their $(2J_i + 1)e^{-E_i/k_BT}$ divided by the partition function

$$Z = \sum_{i}^{\infty} (2J_i + 1)\, e^{-E_i/k_BT}$$

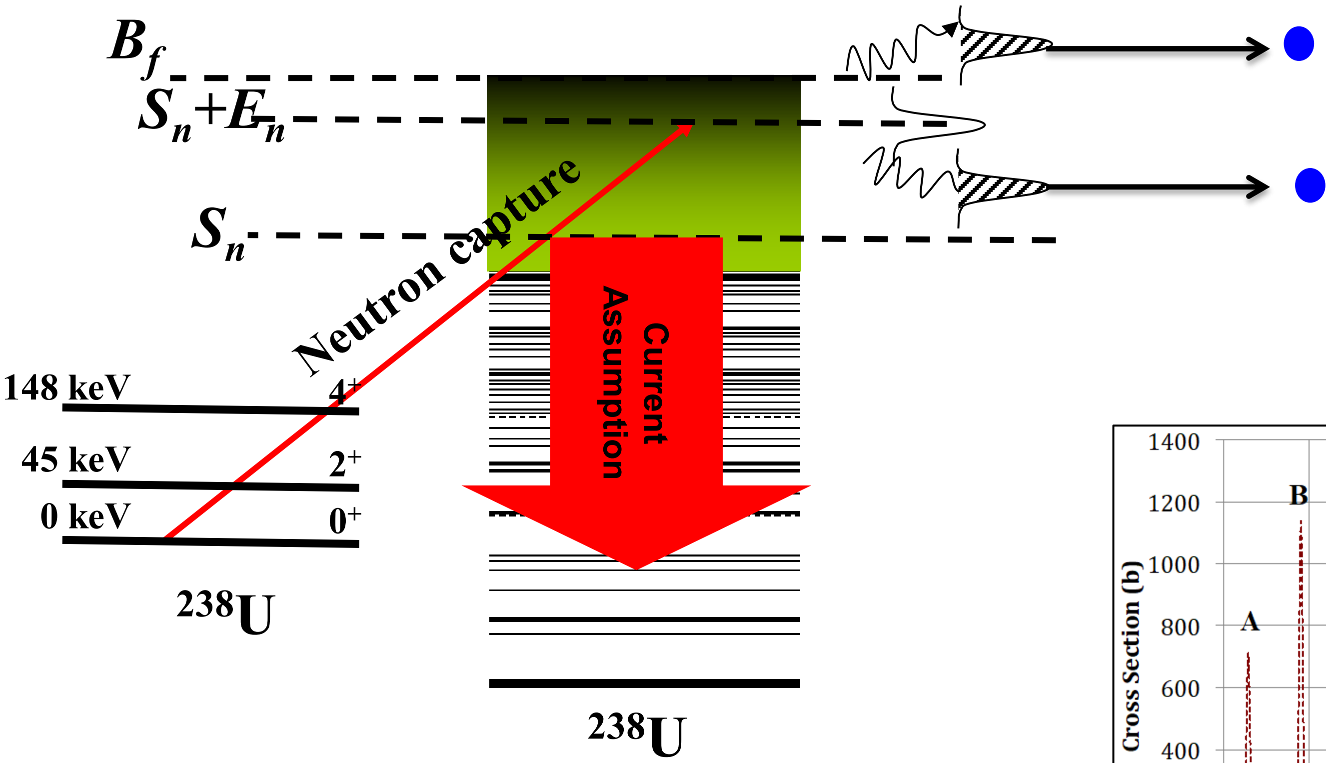
This in turn leads to an alteration in nuclear reaction rates due to the ability of the nucleus to the *J* dependence of nuclear transmission coefficients

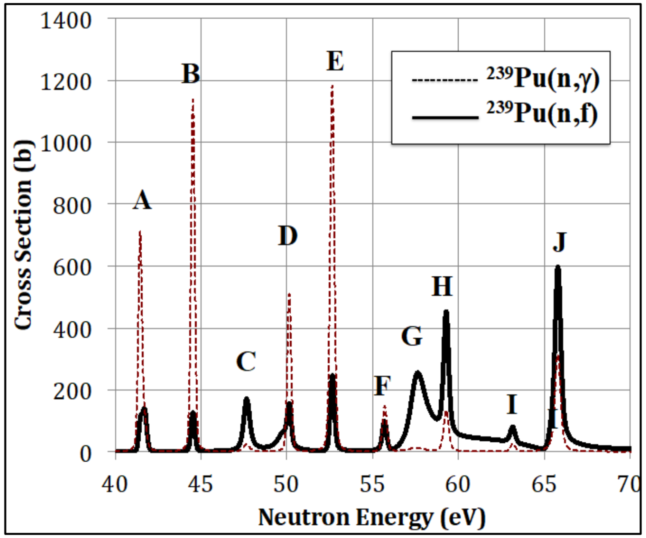




This effect is taken into account in modeling stellar neutron capture rates

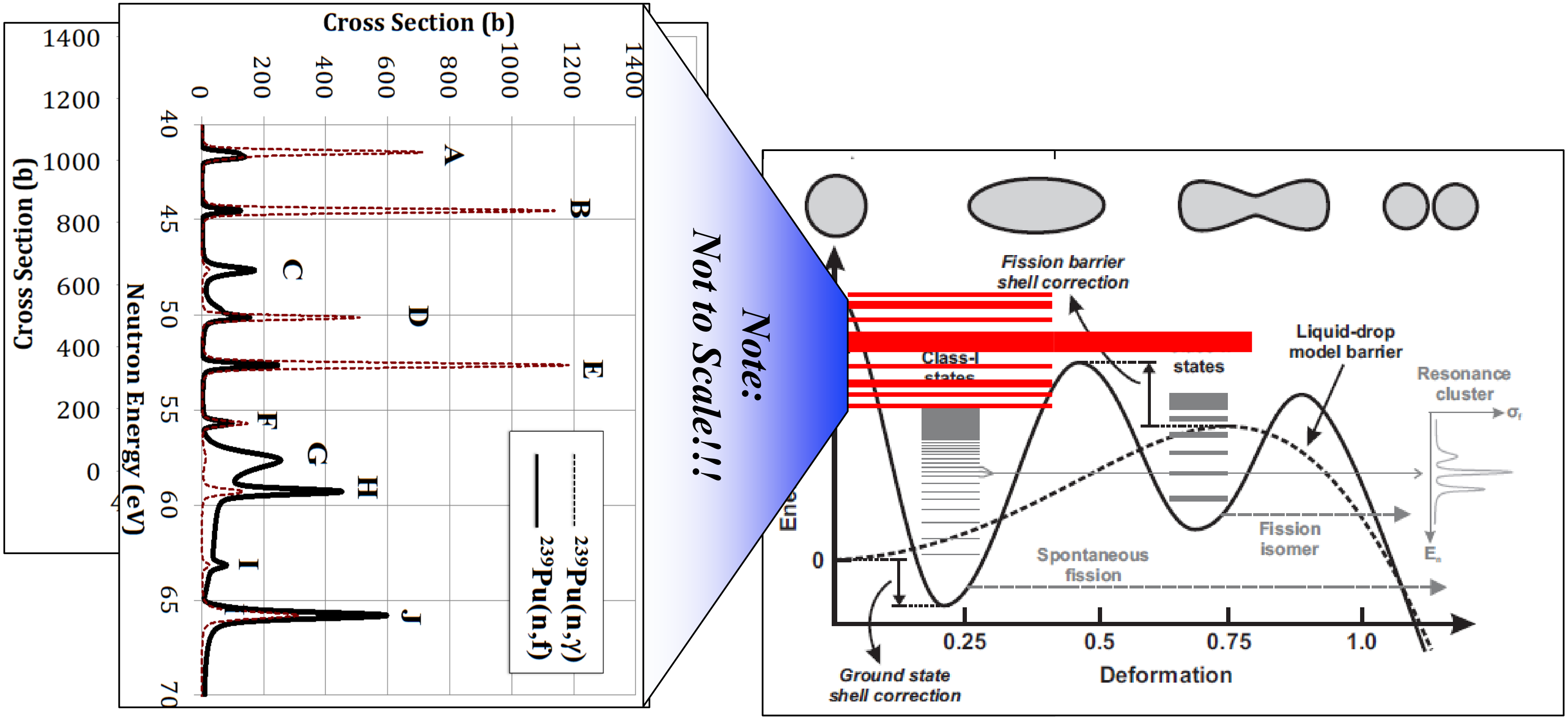
HOWEVER, the states populated immediately after a nuclear reaction have MUCH better overlap with a $k_B T \approx keV$ HEDP





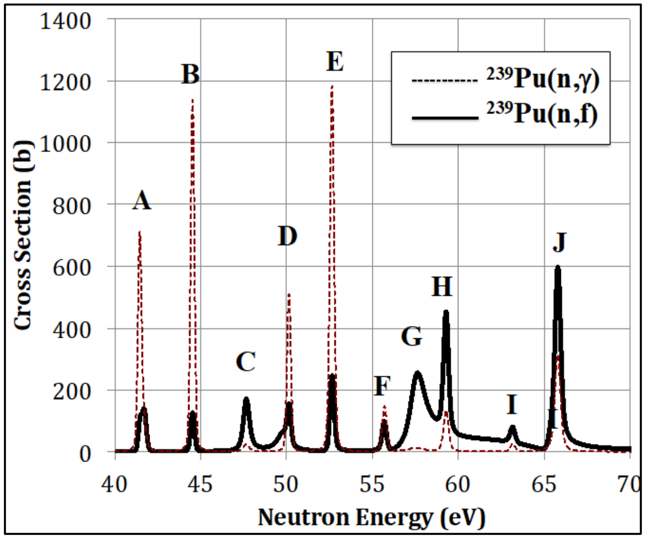
These highly-excited levels have $\Delta E \approx eV$ → 10^{9+} greater excitation rates → an alteration of J → different reaction cross sections

Fission proceeds through the same sort of highly-excited *"Doorway States"* populated via neutron absorption

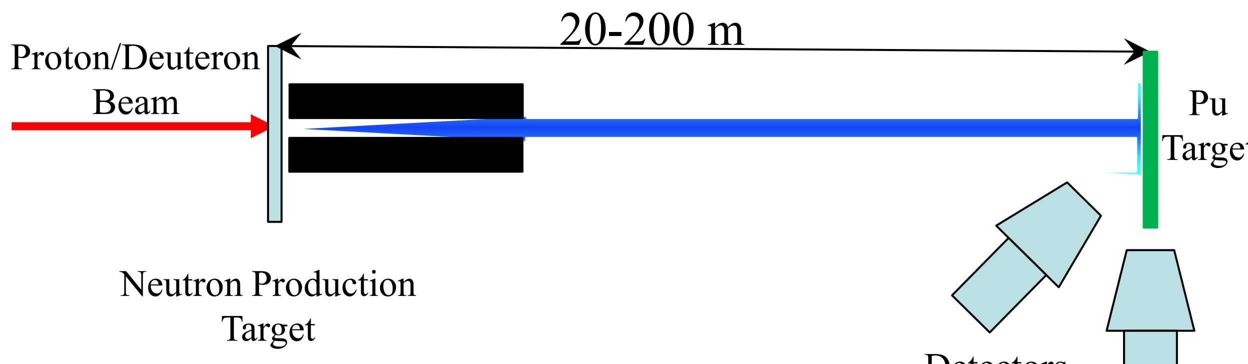


HEDP-induced transitions between doorway states could affect fission leading to alternations in r-process abundances and the interpretation of archival radiochemical data from testing

We saw evidence during the "Wheel Experiments" that different Fission Products result from different doorway states

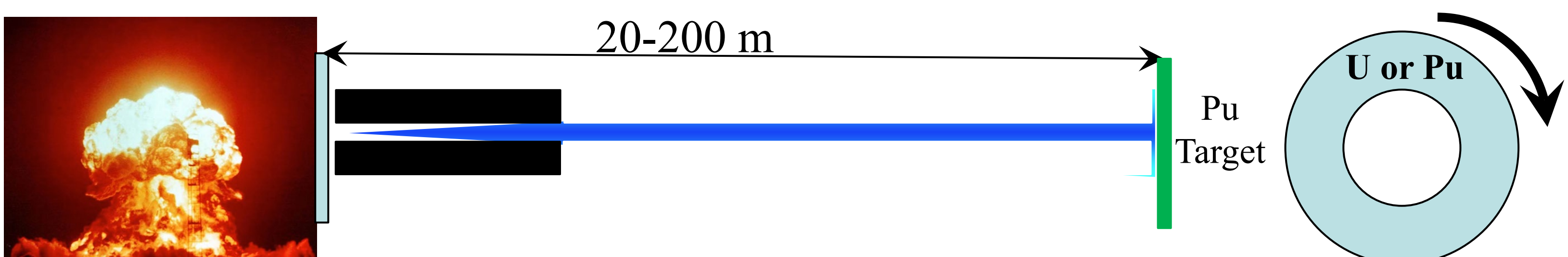


"Time-of-Flight" (TOF) technique – Multi-Day Experiment



Longer Path → Better Energy Resolution

Best TOF – Experiment – LOTS of neutrons in one pulse viewed from REALLY far away



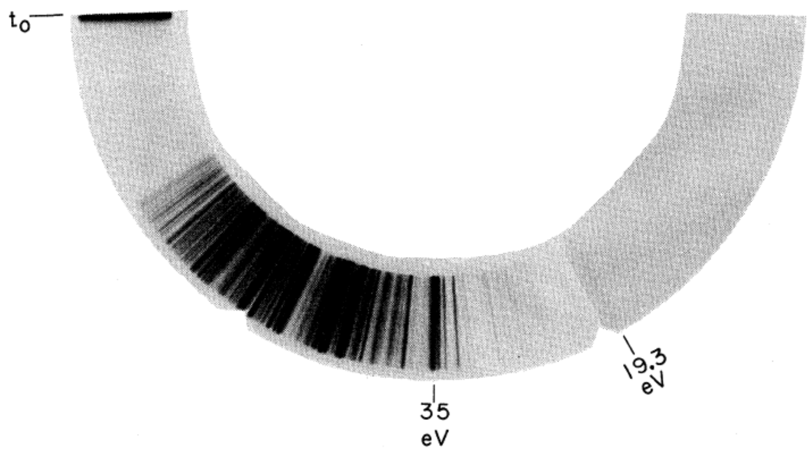
Longer Path → Better Energy Resolution

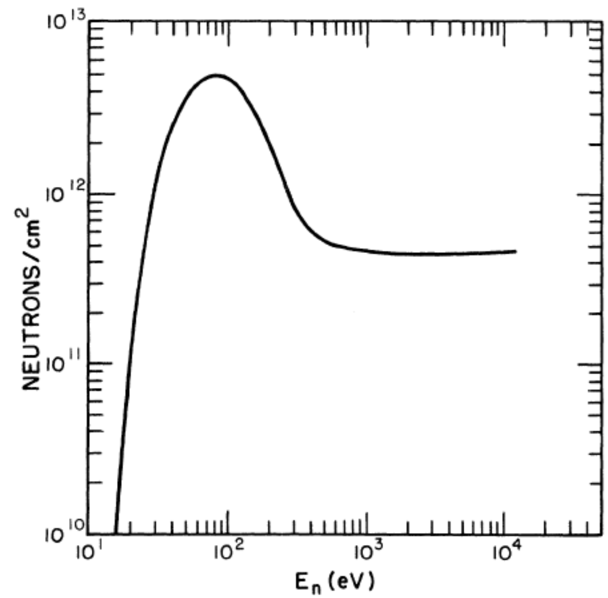
Different Doorway States Lead to Different Fission Products

PHYSICAL REVIEW C VOLUME 2, NUMBER 2 AUGUST 1970

Symmetry of Neutron-Induced ^{235}U Fission at Individual Resonances. III*

G. A. Cowan, B. P. Bayhurst, R. J. Prestwood, J. S. Gilmore, and G. W. Knobeloch
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico 87544
(Received 13 February 1970)

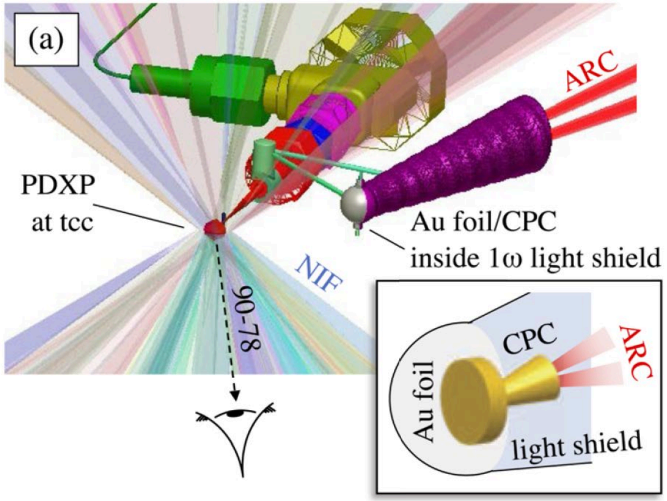


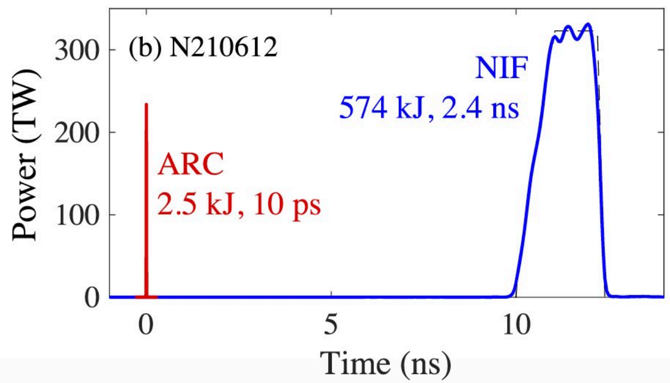


"If the results are averaged separately for the two apparent groups, the first group (I) has an average ^{115}Cd/^{99}Mo ratio which is 0.593.times the thermal value; the second-group (II) average is 1.11 times the thermal value."

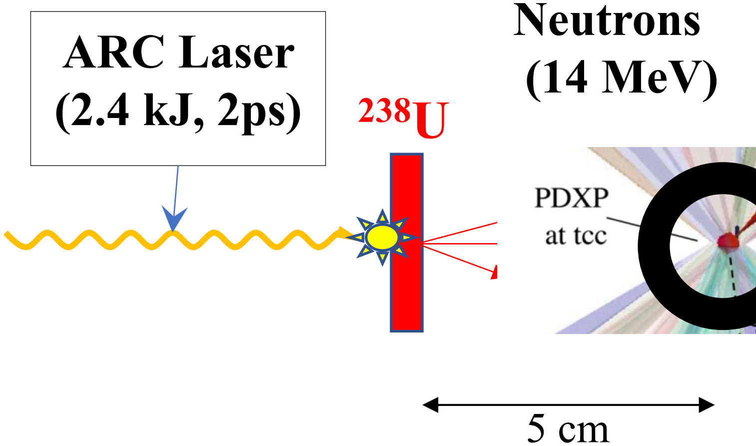
Note that these foils were NOT in an HEDP

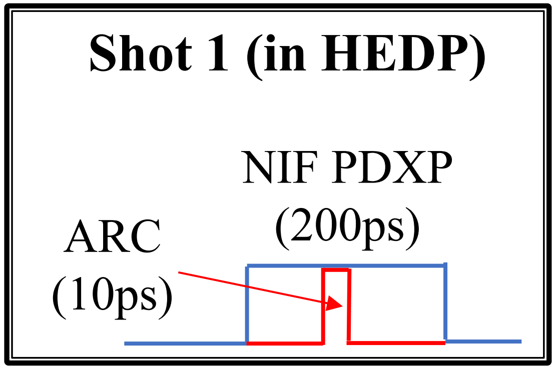
Laser and Target Requirements
Our configuration is equivalent to N210612 with a uranium foil instead of gold and the ARC-NIF order reversed*

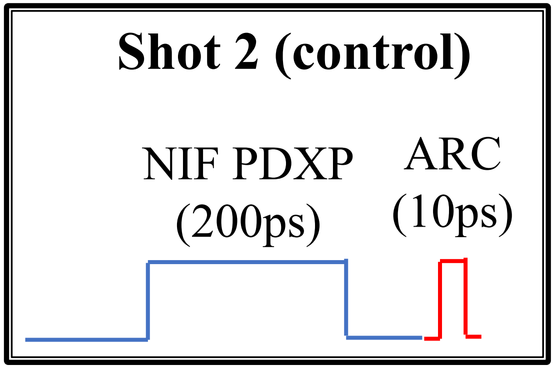




*M. Hohenberger *et al.*, "A combined MeV-neutron and x-ray source for the National Ignition Facility" [Rev. Sci. Instrum. 93, 103510 (2022)]







Fission gases are collected post-shot using RAGS

What sort of photo/electron-induced absorption rate would result in an interaction during the ARC timescale?

- In an ARC irradiate capsule at 5 keV we have (per 10 ps):

$$\phi_e = 4 \times 10^{22} \frac{electrons}{cm^2} \; (\rho_U)$$

$$\phi_\gamma = 9 \times 10^{22} \frac{photons}{cm^2} \; (5\ keV\ Planckian)$$

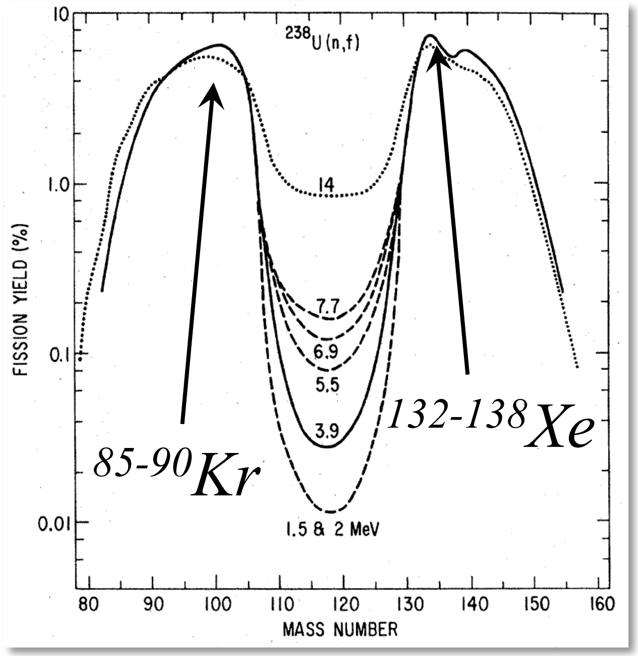
- Nuclear Level Density @ $E_x = S_n$ *is* $\geq 10^3$ levels/keV

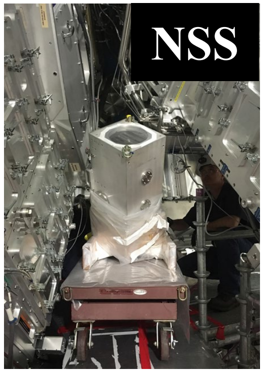
Even a ***10 mb NPI cross section*** *would be sufficient to lead to transitions between "Doorway states"*

Any change in fission observable would alter the way we model nucleosynthesis in stellar settings

Diagnostic Requirements

- RAGS (at LN temperatures) is essential to observe both *Kr* and *Xe* fission fragments.
  - Quick retrieval allows for wide isotope coverage!
- Solid radchem would be a real plus
- X-ray diagnostics needed to observe *kT* etc. in the uranium foil
  - NSS (NIF Survey Spectrometer)
- Spider needed for burn-width measurement.
- FFLEX





Team

- NIF: Hui Chen, Dean Rusby, Dieter Schneider Jackson Williams, Matthias Hohenberger, Dan Kalantar
- UC Berkeley: Lee Bernstein (faculty), C.J. Henderson (Student), S. Tannous (Student)

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Signal and Temperature Calculations

Uranium Mass	1	mg		
Uranium area	1	cm^2	<--------------	The foil needs to be self-supporting. It could be thinner and larger, but yields wouldn't increase
Areal Density	2.53025E+18	atoms/cm^2		
Yield	1.00E+15	neutrons		
Distance	5	cm	<--------------	What distance can we put the uranium foil at?
Solid angle fraction	0.003183099			
# of fissions	9.26E+06			
Collection efficiency	0.005	<--------------	This is a number for RAGS.	
# of fissions collected	4.63E+04			
Peak yield	6%	<--------------	This is the peak fission fragment yield	
# of specific isotope	2.78E+03			
Uncertainty	1.90%			
<u>ARC stuff</u>				
ARC Energy	2400	J	<--------------	Total ARC laser energy. All beamlets on the uranium foil

Number of Shot Days

- A minimum of two shots is required.
  - First shot– Uranium in HEDP when 14 MeV neutrons hit
  - Second shot – Uranium NOT in HEDP when 14 MeV neutrons hit
- Could be done in one day, but preferably two to allow for decay of fission products between shots

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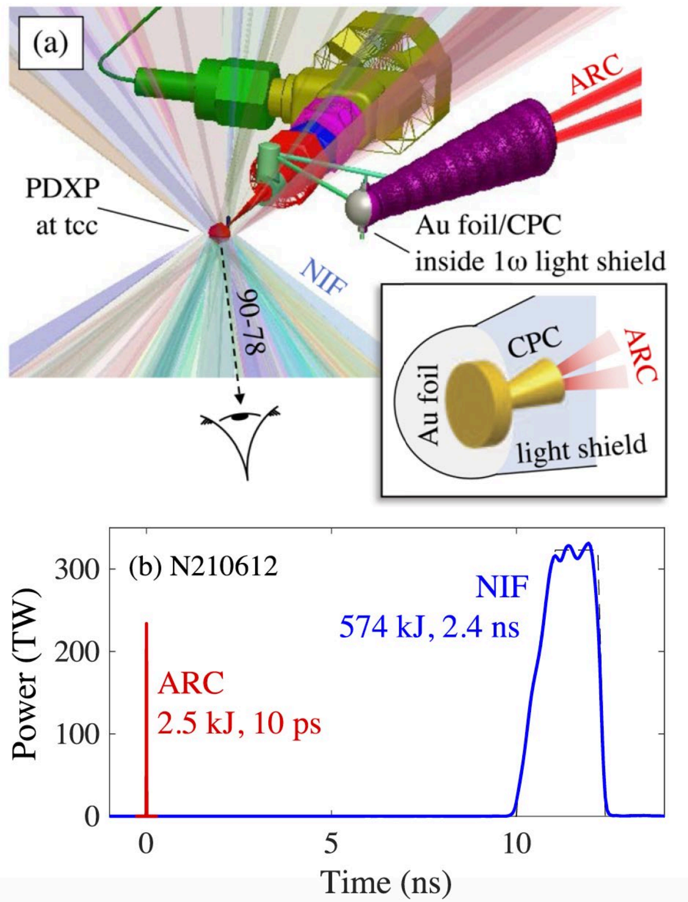

Shot ID	N201130	N210612
PDXP target	3-mm diam GDP, 18 μm wall, 30 μm fill tube	
Gas-fill	D_2	DT
NIF energy (kJ)	561	574
NIF peak power (TW)	313	323
Pressure (atm)	7.93	7.98
Neutron yield	$(6.16 \pm 0.62) \times 10^{13}$	$(4.78 \pm 0.15) \times 10^{15}$
T_i (keV)	9.73 ± 0.18	10.46 ± 0.15
x-ray bang time (ns)	n/a	2.89 ± 0.06
x-ray burnwidth (ps)	n/a	341 ± 23
n fluence at 4.1 cm	3.0×10^{11} (2.45 MeV)	2.3×10^{13} (14.1 MeV)
γ_{MeV} target	0.5 mm gold disk, with CPC	
ARC beamlets	2	4
ARC energy (kJ)	1.33	2.46
ARC pulse width	10 ps	
T_{MeV}	2.6 ± 0.1	1.8 ± 0.1
Au dose at 4.1 cm	1.6 +0.4/−0.7	7 +2/−3

***M. Hohenberger *et al.*, "A combined MeV-neutron and x-ray source for the National Ignition Facility"** [Rev. Sci. Instrum. 93, 103510 (2022)]