Cross-Cutting Motivations for Fusion-Relevant Nuclear Data

– and Some Experimental Challenges

Keegan J. Kelly

2025 Workshop for Applied Nuclear Data Activities

LA-UR-25-21268

Similar Nuclei Are Widely Interesting, but for Different Reactions and Outputs

NA-22 γ-Prod. Interests

1st Pri.	2nd Pri.	Remaining
H	He	F
C	Li	Mg
N	Be	P
O	Cl	S
Na	Cr	Ar
Al	Mn	K
Si	Ni	Ca
Fe	Ge	Ti
Cu	Br	As
Pb	Cd	Kr
W	I	Mo
U	Cs	Sn
Pu	La	Sb
	B	Xe
		Gd
		Bi
		Np
		Am

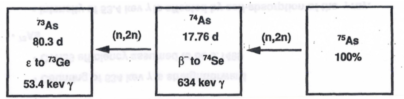
- NA-113 interests span neutron transport more broadly
- NA-22 nonproliferation interests include γ-production for active interrogation
- FES interests include tritium breeding, n multiplication, and activation
  - ^{6}Li(n,t), ^{9}Be(n,$2n$), ^{208}Pb(n,$2n$)
  - Suite of additional (n,$2n$) and (n,$3n$) rxns

NA-114 / DOE SC NP evaluation support is fundamental for impact from any new measurement

$\rightarrow$ Evaluations correlate all reactions on a single compound system

Fusion Activation & Rad. Chem.

Table of Contents



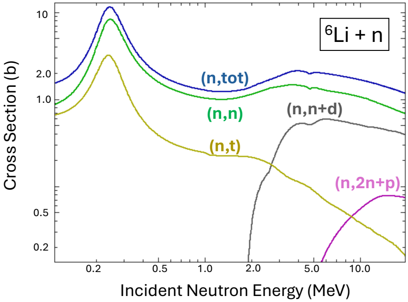
151gEu	(n,2n)	150gEu
	(n,2n)	150mEu
	(n,3n)	149gEu
	(n,ds)	FPP
	(n,g)	152mEu
	(n,g)	152gEu

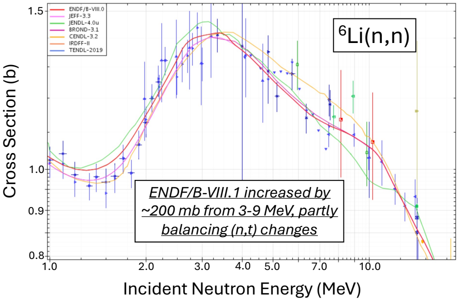
- NA-113, SC FES & NP, NA-114, NA-22
- Space-based physics extend to 50 MeV
- 14 MeV includes variety of (n, xn) rxns

- Keksis (2021) LA-UR-21-23034
- O. N. Jarvis, (1982) EUR–8315–1 EN

Reaction
$^{11}B(n,p)^{11}Be$
$^{14}N(n,2n)^{13}N$
$^{16}O(n,p)^{16}N$
$^{51}V(n,a)^{48}Sc$
$^{65}Cu(n,2n)^{64}Cu$
$^{55}Mn(n,2n)^{54}Mn$
$^{59}Co(n,2n)^{58}Co$
$^{19}F(n,2n)^{18}F$
$^{63}Cu(n,2n)^{62}Cu$
$^{89}Y(n,2n)^{88}Y$
$^{48}Ti(n,d)^{47}Sc$
$^{45}Sc(n,2n)^{44}Sc$
$^{90}Zr(n,2n)^{89}Zr$
$^{52}Cr(n,2n)^{51}Cr$
$^{47}Ti(n,d)^{46}Sc$
$^{58}Ni(n,2n)^{57}Ni$
$^{64}Zn(n,2n)^{63}Zn$
$^{23}Na(n,2n)^{22}Na$
$^{90}Zr(n,2n)^{89}Zr$
$^{35}Cl(n,2n)^{34}Cl$
$^{46}Ti(n,2n)^{45}Ti$
$^{39}K(n,2n)^{38}K$
$^{50}Cr(n,2n)^{49}Cr$
$^{176}Lu(n,3n)^{174}Lu$
$^{54}Fe(n,2n)^{53}Fe$
$^{203}Tl(n,3n)^{201}Tl$
$^{169}Tm(n,3n)^{167}Tm$
$^{191}Ir(n,3n)^{189}Ir$
$^{197}Au(n,3n)^{195}Au$

^{6}Li + n Dominated by Uncertain Elastic XS





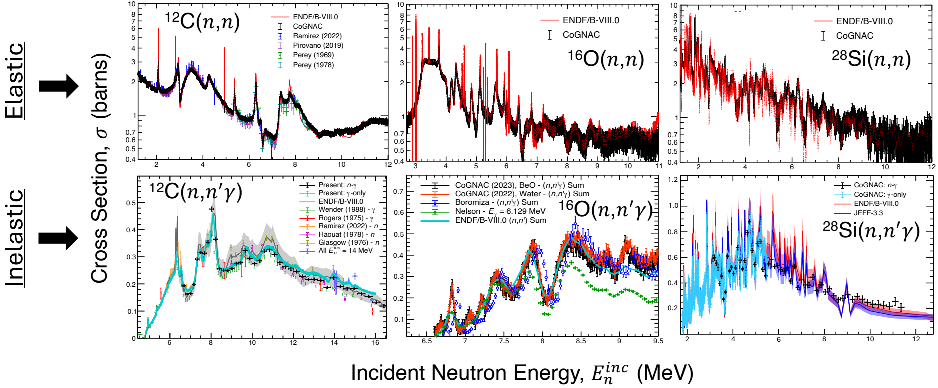
- ^{6}Li(n,t) is ≈50× less likely than (n,n) at 14 MeV
- ^{6}Li(n,n) measurements vary wildly
- ^{6}Li(n,t) is only a standard until 1 MeV; Unc. climbs to 10% by 4 MeV
- ENDF/B-VIII.1 shows (n,n) uncertainties of 10-15% above 1 MeV

This is a problem

Continuous White-Source (n,n) + (n,n') at LANL

^{6}Li(n,n) measurements are particularly challenging

- Contaminants, mono-E beams, no active targets, no γ-ray tags
- But: Techniques for white-source elastic scattering measurements have recently been unlocked at LANSCE with CoGNAC

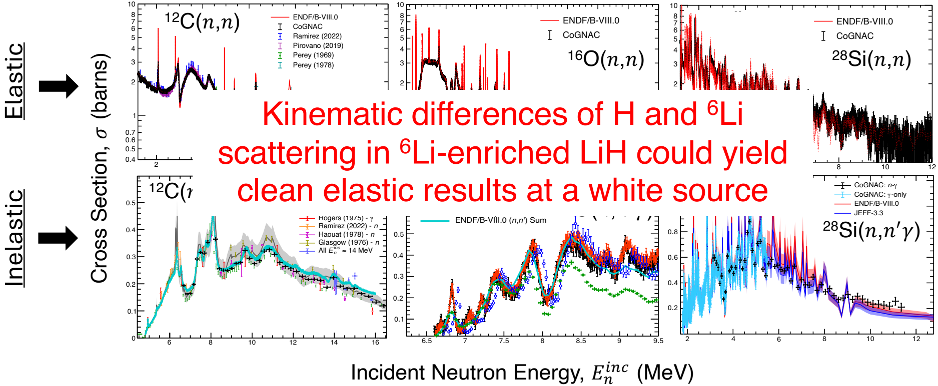


Funded by DNN R&D (NA-22) and OES (NA-113)

Continuous White-Source (n,n) + (n,n') at LANL

^{6}Li(n,n) measurements are particularly challenging

- Contaminants, mono-E beams, no active targets, no γ-ray tags
- But: Techniques for white-source elastic scattering measurements have recently been unlocked at LANSCE

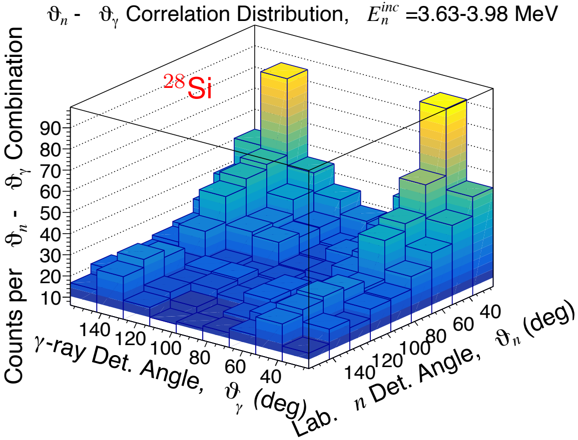


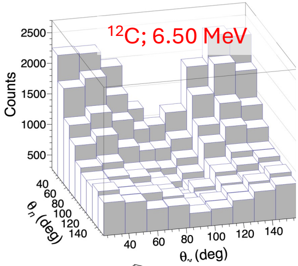
Kinematic differences of H and ^{6}Li scattering in ^{6}Li-enriched LiH could yield clean elastic results at a white source

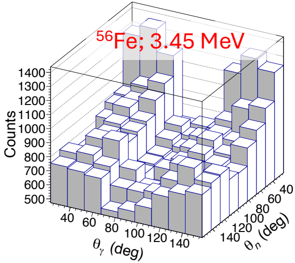
Funded by DNN R&D (NA-22) and OES (NA-113)

Continuous White-Source (n,n) + (n,n') at LANL

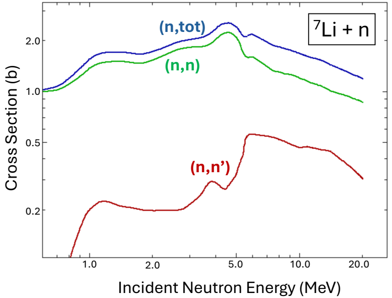
Producing first-ever n-γ correlation measurements from $(n,n'\gamma)$

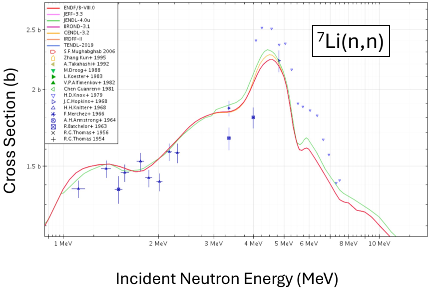






^{7}Li + n Also Elastic, but $(n,n'\gamma)$ Shows Promise





- Effectively only neutron scattering reactions are available
- ^{7}Li$(n,n'\gamma)$: First Ex. at 477.6 keV
- Higher excited states are broad, complicating measurements

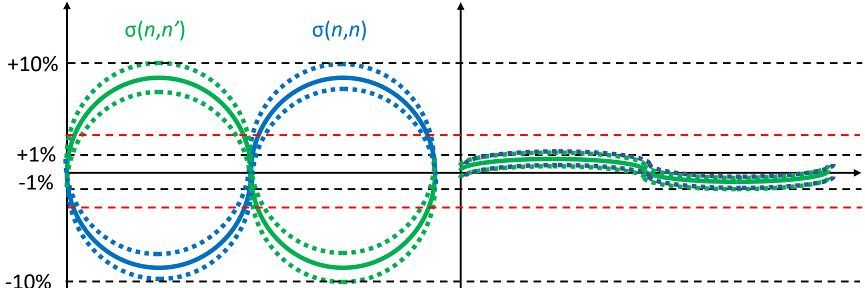
Apart from the total XS, ^{7}Li + n nuclear data are in poor shape

Correlated Measurements are Extremely Powerful

Consider a nucleus with only elastic and inelastic scattering XS's

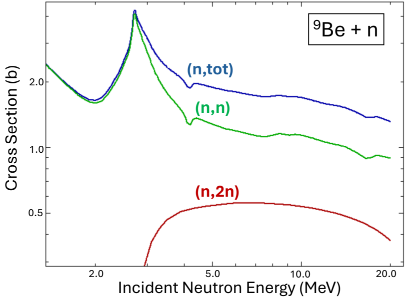
$\sigma(n,n) = 1.0 \pm 0.1$ b (10% unc.)
$\sigma(n,n') = 1.0 \pm 0.1$ b (10% unc.)
} $\sigma(n,tot) = 2.0 \pm 0.04$ b (2% unc.)

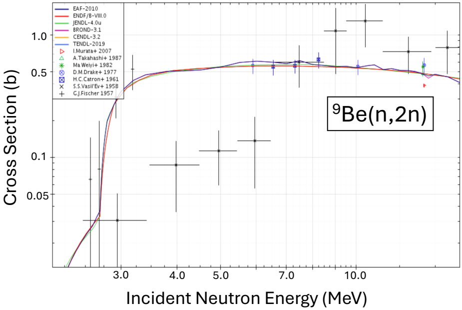
Anticorrelated or No Correlation	Positive Correlation



Cross sections can vary within the entire uncertainty range if the sum is correct	*Cross section must vary in the same direction and sum properly ∴ Variation range severely limited*

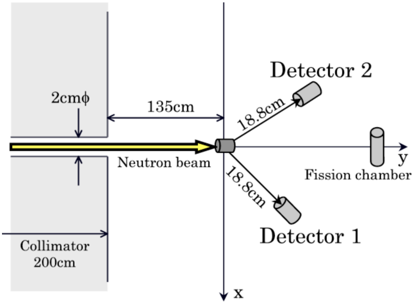
^{9}Be(n,n) Can Refine ^{9}Be(n,$2n$)

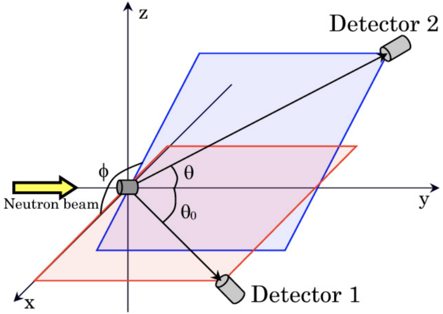




- ^{9}Be(n,$2n$) is unique amongst (n,$2n$) reactions
  - Not accessible via γ rays or activation $\rightarrow$ α breakup
- Luckily, two very precise 14 MeV (n,$2n$) measurements exist
  - Also includes one of the only E_n-E_n differential (n,2n) measurements
- Unluckily, these measurements disagree by about 8 σ

^{9}Be(n,n) Can Refine ^{9}Be(n,$2n$)



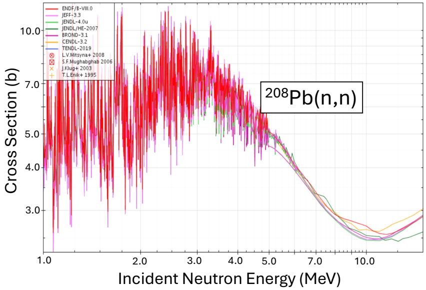


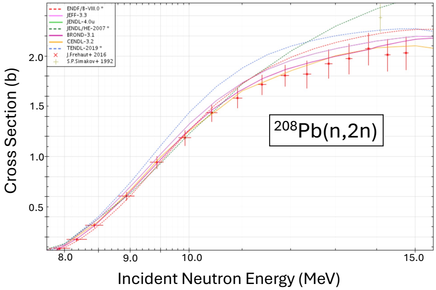
- Murata *et al.* utilized 14 MeV beam for E_n-E_n triple differential measurement of ^{9}Be(n,$2n$)
- NE-213 ⇒ poor E_n resolution ⇒ required mono-energetic beams

Correlated White-Source (n,n) - (n,$2n$) Measurements Possible with CoGNAC

and with (n,n') when available

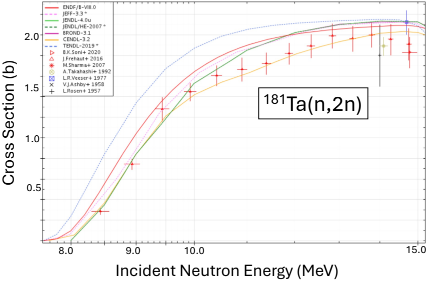
^{208}Pb(n,n): Unmeasured; (n,$2n$): One Data Set

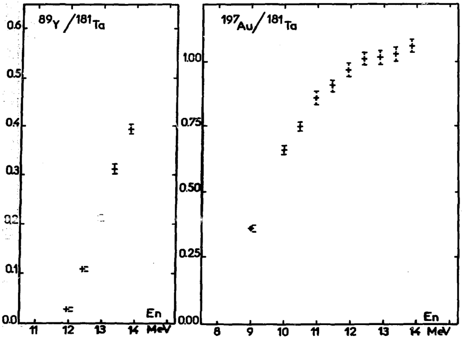




- Great work and updates by P. Brain on Pb evaluations
  - Combined existing differential and integral experiments
- (n,n) measurements are either below 50 keV or above 90 MeV
- (n,$2n$) includes Frehaut 2016, and one 14 MeV Simakov point
- Enriched ^{208}Pb(n,n) and (n,$2n$) measurements are needed

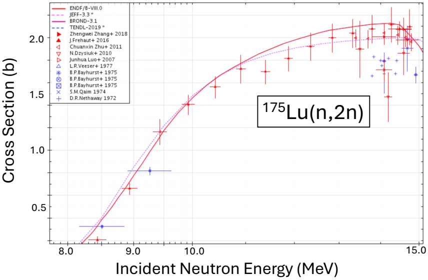
^{181}Ta as an $(n,2n)$ Ref. & Frehaut Correlation

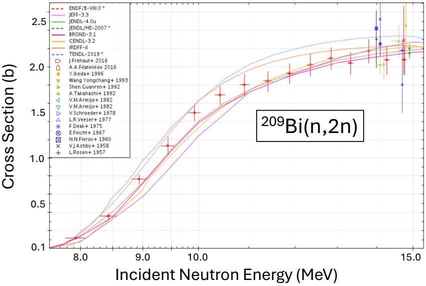




- J. Frehaut measured a myriad of $(n,2n)$ data relative to ^{181}Ta$(n,2n)$
- Later measured $(n,2n)$ cross sections relative to ^{238}U with efficiencies based on calculations and ^{252}Cf(sf)
  - Results were “refurbished” in 2016 by T. Granier and CEA
- Still dominant data for ^{175}Lu, ^{209}Bi, ^{56}Fe, and many more

^{181}Ta as an $(n,2n)$ Ref. & Frehaut Correlation





- A truly impressive collection of nuclear data measurements
- Also a highly-correlated collection of essential nuclear data
- Independent validation of Frehaut $(n,2n)$ and $(n,3n)$ results for many important nuclei is needed

Key Take-Home Points

1. While different agencies focus on specific pieces of nuclear data, all are interested in any improvements in nuclear data for an isotope of interest
   – If a program is interested in γ-production, elastic scattering is still of interest
2. Correlated, simultaneous measurements of multiple channels are powerful because they can force the range of variation to be limited by more precisely-known quantities (e.g., total cross section)
3. New measurements on Li, Be, Pb, and a long list of $(n,2n)$, $(n,3n)$ reactions are valuable across funding agencies
4. Investment in nuclear data evaluation methods and efforts must keep pace with nuclear data needs in order for us to meet our goals

THANK YOU!

CoGNAC γ-production measurements for ^{12}C, ^{16}O, and ^{28}Si funded by Defense Nuclear Nonproliferation Research and Development (NA-22). Elastic scattering development and application to ^{9}Be(n,n) funded by Office of Experimental Science (NA-113). CoGNAC $(n,2n)$ and $(n,3n)$ development funded by DOE Office of Science Early Career Research Program.

Direct questions to kkelly@lanl.gov