Determining (*n, f*) and (*n, γ*) cross sections: Study of the surrogate method

Collaboration:

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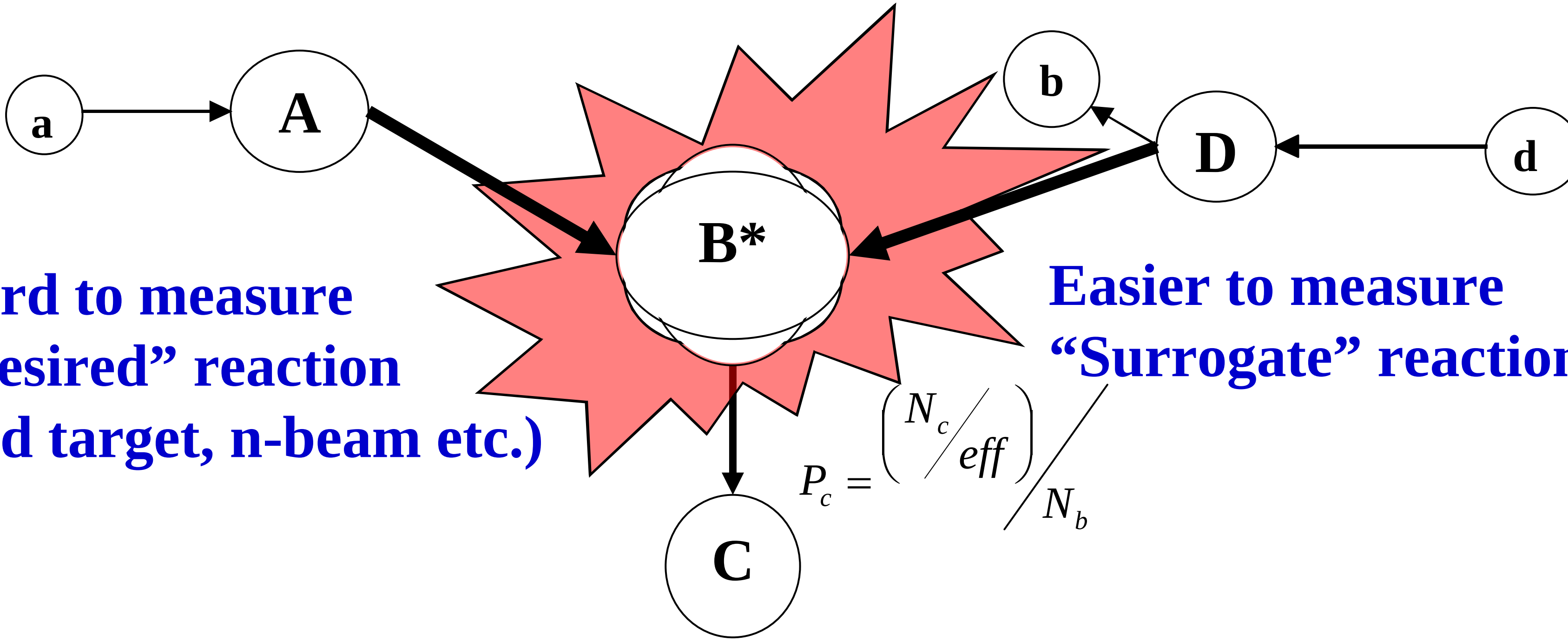
Contents

- The surrogate method provides alternative way to determine nuclear cross section for difficult cases
- Recent experiments provide important cross sections using the surrogate method
  - ^{237}Np(n, f) in the 10 to 20 MeV energy range using ^{238}U(^{3}He, t)^{238}Np: pre-equilibrium effect
  - ^{236}U(n, f) using ^{238}U(^{3}He, α)^{237}U: angular momentum effect
  - ^{153}Gd(n, γ)^{154}Gd cross section using ^{154}Gd(p, p')^{154}Gd: s-process branch-point

The Surrogate Method



Hard to measure
"Desired" reaction
(rad target, n-beam etc.)

Easier to measure
"Surrogate" reaction

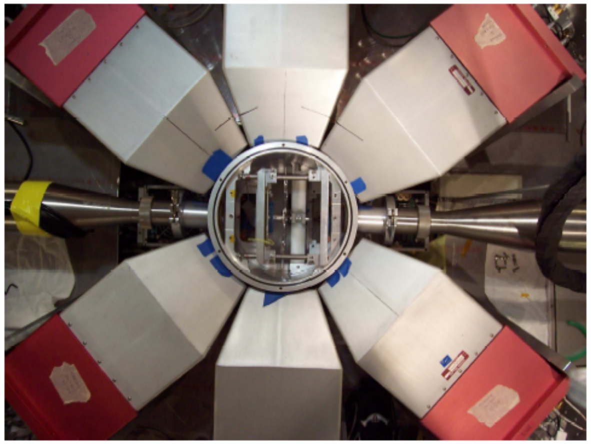
$$P_c = \frac{\left(N_c / eff\right)}{N_b}$$

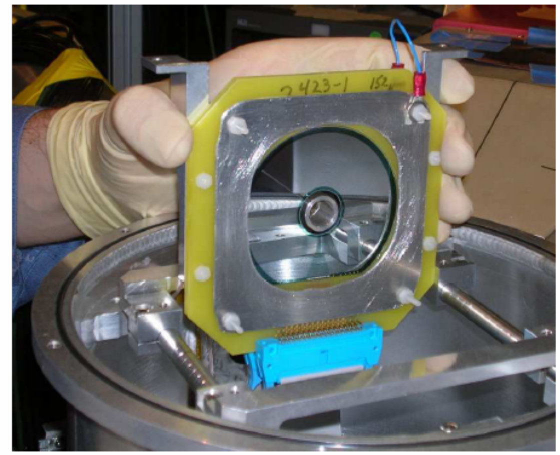
$$\sigma_{A(a,x)C} = \sum_{J,\pi} P_c(J,\pi,E_x)\,\sigma_{a+A}^{comp\ reac}(J,\pi,E_x)$$

$$Weisskopf-Ewing: \sigma_{A(a,x)C} = P_C\ \sigma_{a+A}^{comp\ reac}$$ **If** $P_C \neq P_C(J,\pi)$

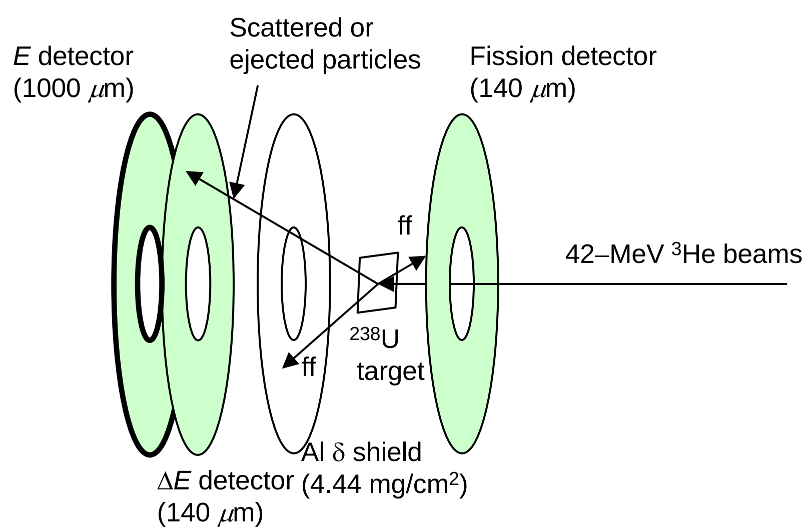
Central assumption: Both reactions form a compound nucleus

LIBERACE and STARS detectors at the 88-Inch Cyclotron, LBNL



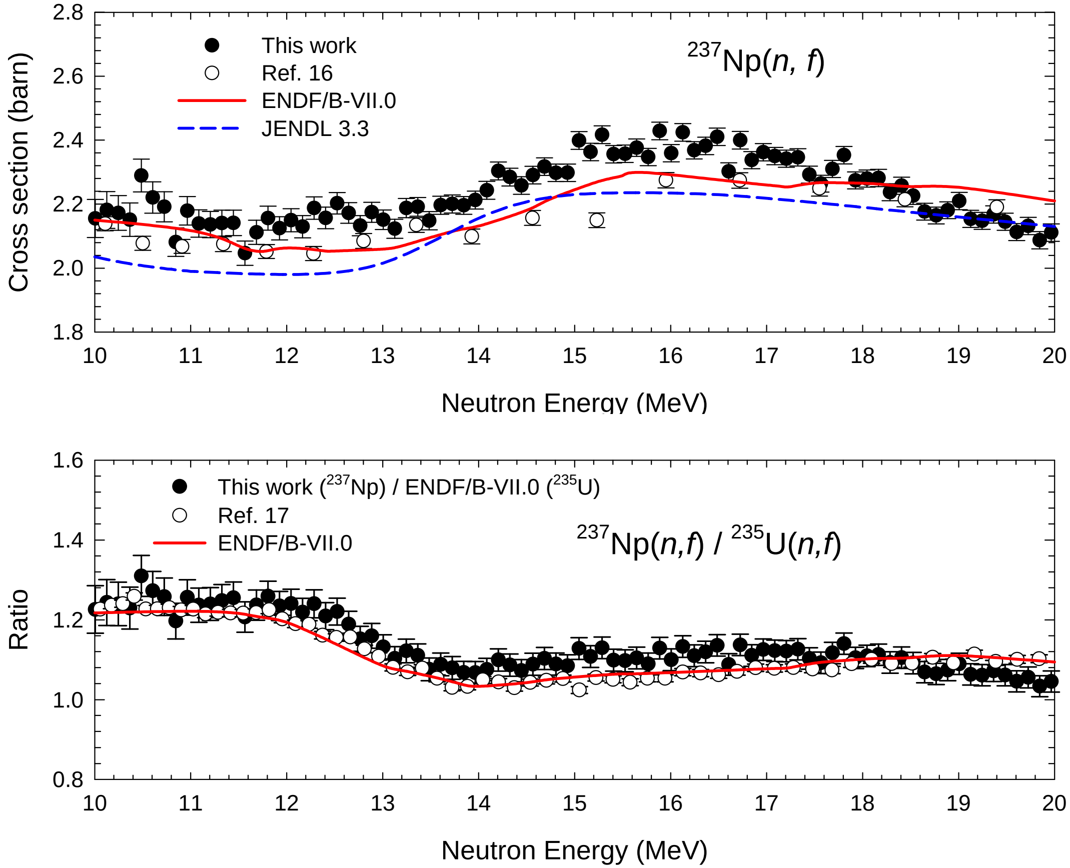


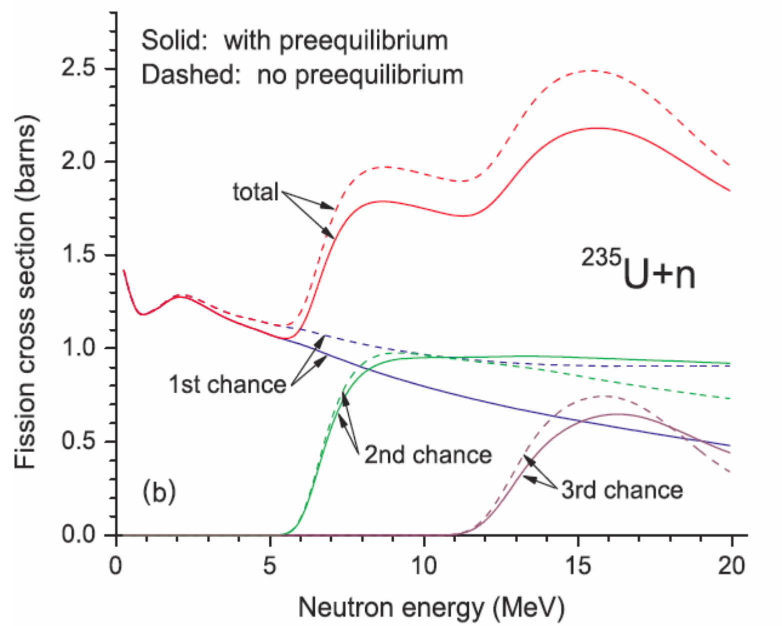
LIvermore
BERkeley
Array for
Collaborative
Experiments



Silicon
Telescope
Array for
Reaction
Studies

^{237}Np(*n, f*) from ^{238}U(^{3}He, *t*)^{238}Np surrogate reaction: pre-equilibrium effect





J. E. Escher and F. S. Dietrich, Phys. Rev. C 74, 054601, 2006

Ref. 16: O. Shcherbakov *et al.*, J. Nucl. Sci. & Tech., Supp. 2, 230, 2003

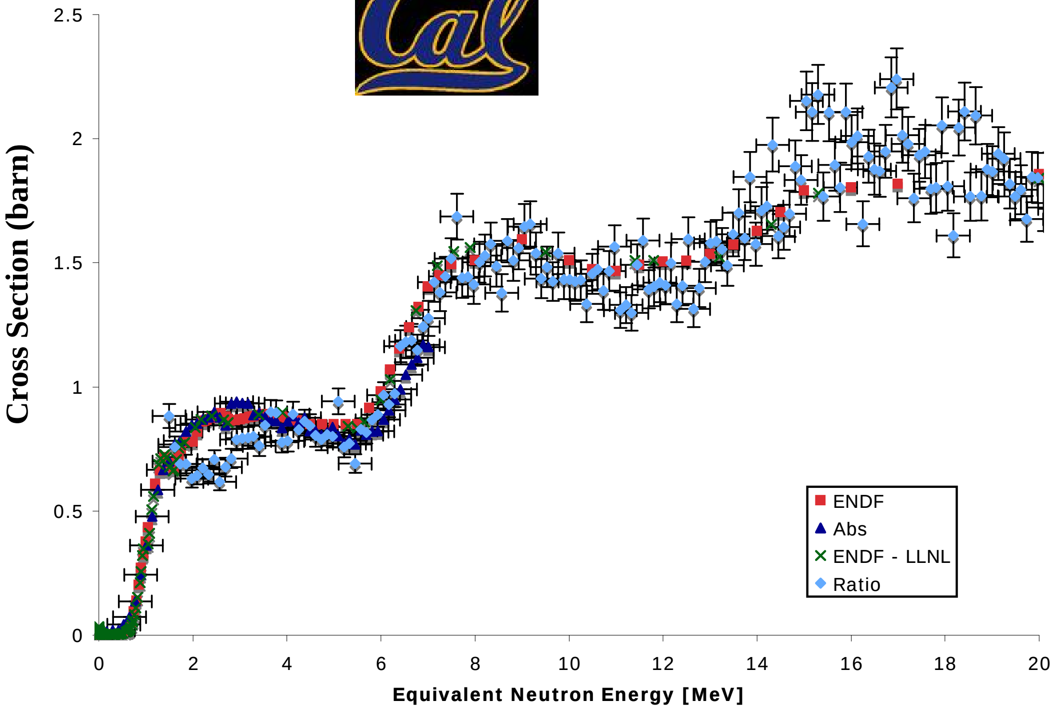
Ref. 17: F. Tovesson and T. S. Hill, Phys. Rev. C 75, 034610, 2007

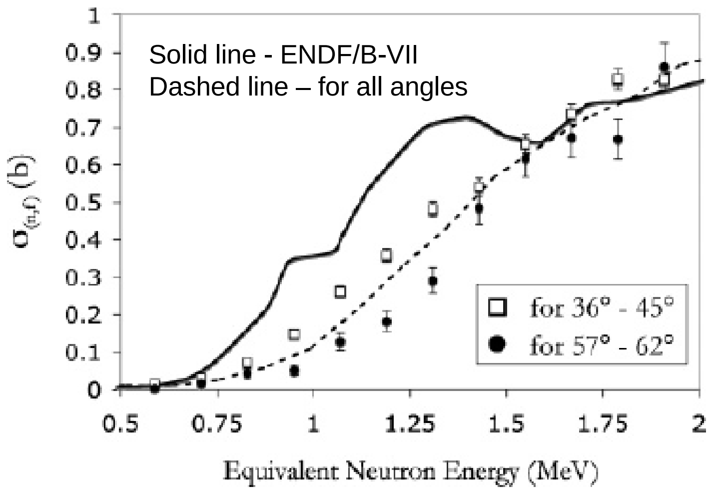
M. S. Basunia *et al.*, submitted to PRC

$^{236}U(n, f)$ from $^{238}U(^{3}He, \alpha)/^{235}U(^{3}He, \alpha)$ ratio and absolute: angular momentum effect

Ph.D. thesis project

Courtesy of
B. F. Lyles, LLNL, UCB

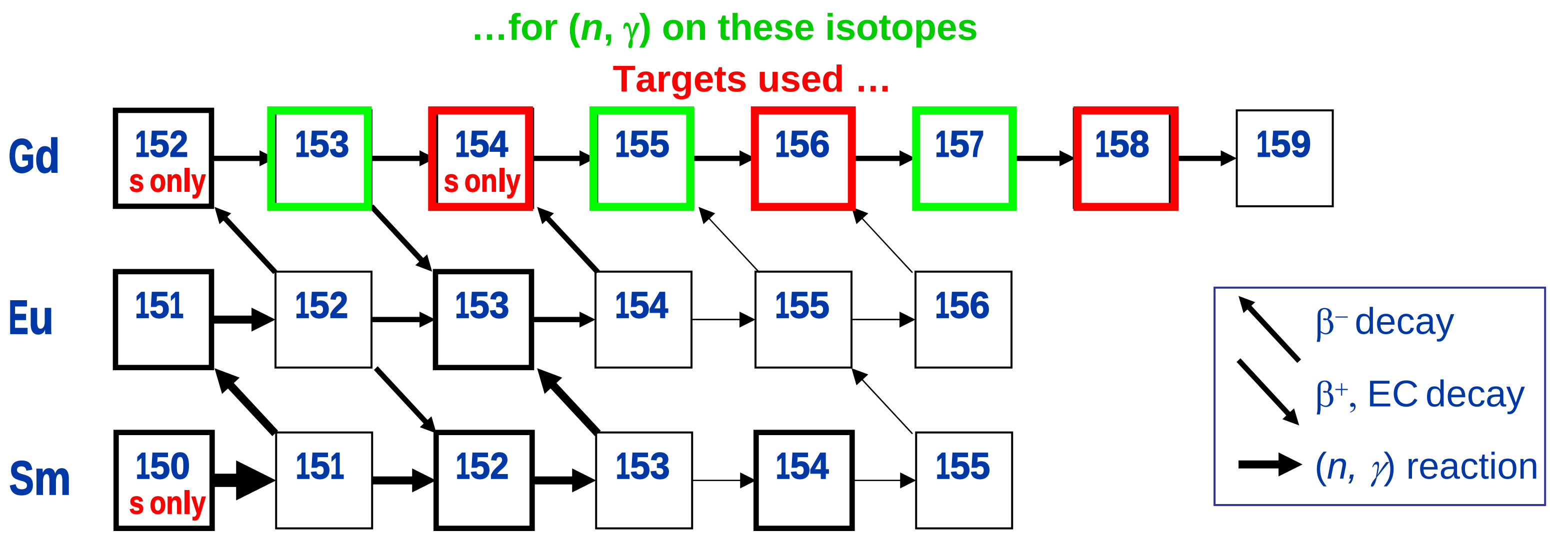




B. F. Lyles *et al.*, PRC 76, 014606, 2007

s-process branch-point nucleus ^{153}Gd

Courtesy of N.D. Scielzo, LLNL



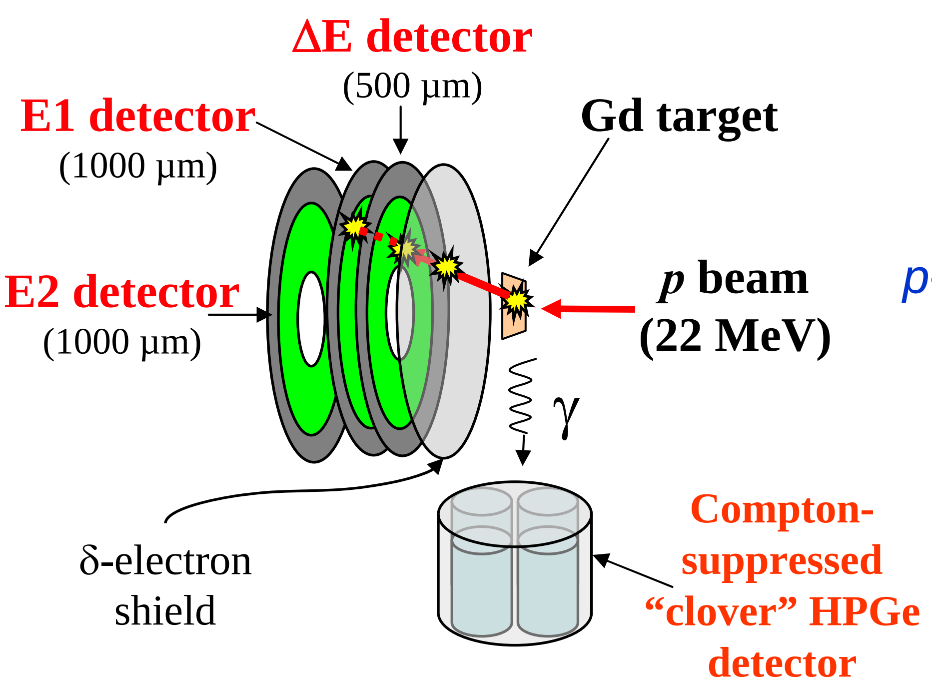
- ^{152,154}Gd cannot be produced by the *r*-process and therefore these abundances can be used to investigate the *s*-process
- (*n*, *γ*) cross sections at energies 0-200 keV in branch-point nuclei such as ^{153}Gd (for which the time scales for *n* capture and β-decay are comparable) are needed
- ^{153}Gd is radioactive ($t_{1/2}$=240 days), making direct measurements very difficult
- Well-suited for surrogate measurement because of neighboring stable Gd isotopes that can be used as targets for measurement and benchmarks.

(n, γ) cross section for ^{153,155,157}Gd isotopes from (p, p')

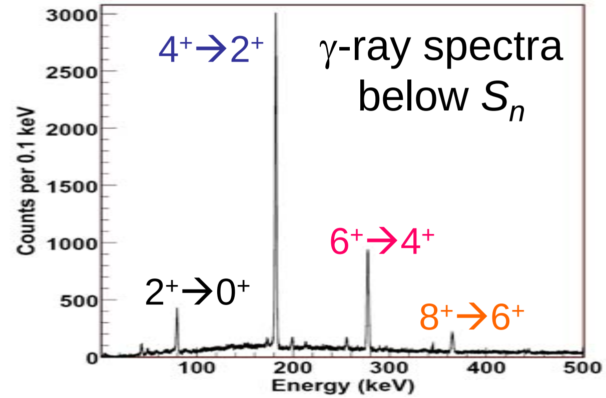
Courtesy of
N.D. Scielzo, LLNL

Excite Gd nuclei ($S_n \approx$8-9 MeV) through inelastic (p, p') scattering

Detect scattered p in segmented silicon detector array in coincidence with characteristic γ-rays from lowest excited states of Gd



^{154,156,158}Gd(p,$p'\gamma$) experiment finished 6/4/07



p-γ coincidence vs. ^{158}Gd* excitation energy shows drop as S_n is crossed