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Determining the ^{237}Np(*n*,*f*) cross section indirectly: Study of the absolute surrogate method in the 10 to 20 MeV energy range

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Compound Nuclear Reaction Workshop
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Outline

- Overview
- Surrogate technique
- LIBERACE & STARS at the 88-Inch Cyclotron
- Experiment
- Data analysis
- Results and
- Summary

Overview

- In the 70s and recently, some indirect (*n, f*) cross section data were reported using the absolute surrogate method applying (^{3}He,*tf*) reaction
- (*n, f*) cross section data up to 10 MeV equivalent neutron energy were reported
- Comparisons with direct measurements show that in between 1 to ~7 MeV – directly measured data were reproduced well
- (*^{3}He,tf*) reaction is interesting because it provides opportunity to study odd-Z nuclei from a relatively stable even-Z targets

Overview, Cont'

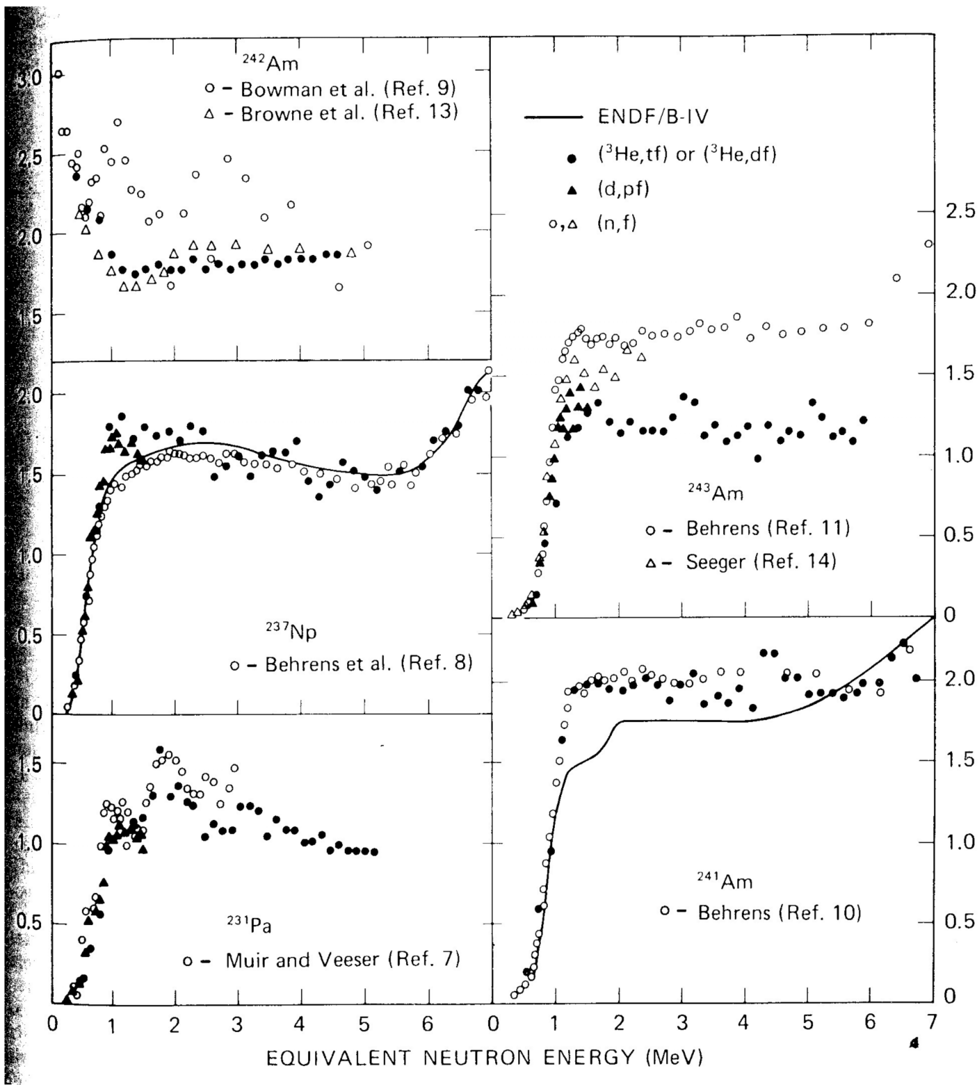
- Absolute surrogate method above 10 MeV is useful to test the effects of pre-equilibrium decay

- In surrogate method equivalent E_n energy depends on various factors, like:
  - beam energy, reaction Q value, particle-nucleus potential height, punch through etc.

- Benchmark study for cross section data in the obtainable equivalent energy range is important

Overview (^{3}He, *tf*)
Brite and Wilhelmy, Nucl. Sci. & Eng., 72, 222, 1979

$E_{beam} \sim 24$ MeV

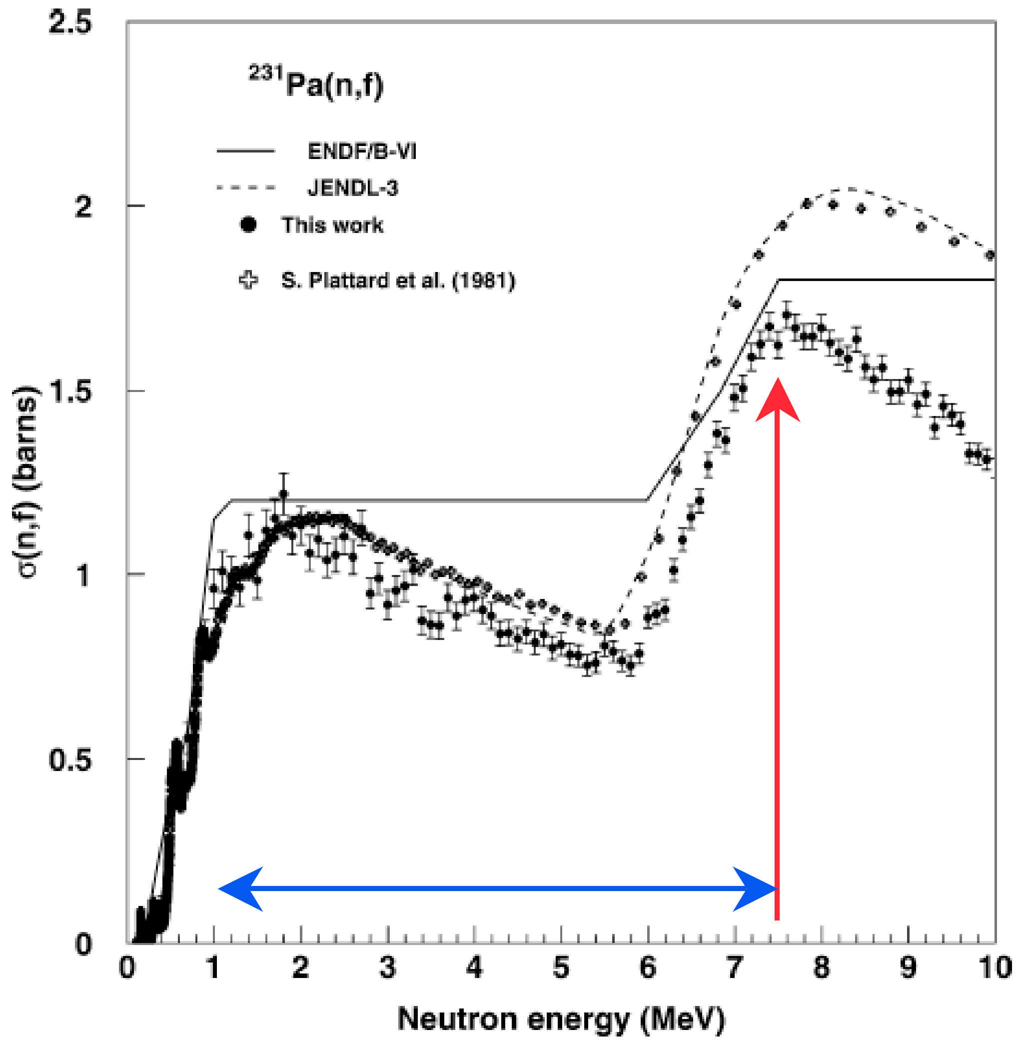


Overview (^{3}He, *tf*), Cont'
Petit *et al.*, Nucl. Phys. A, 735, 345, 2004

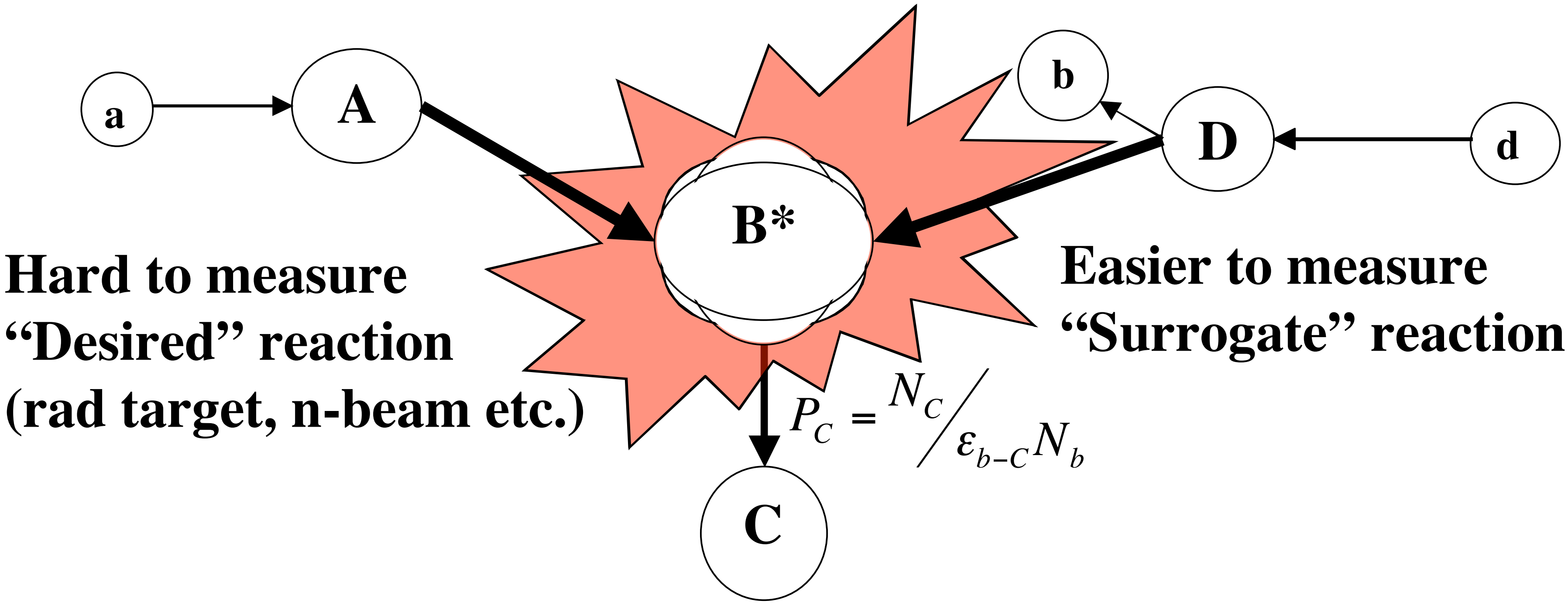
E$_{beam}$~ 30 MeV

Our
E$_{beam}$ ~ 42 MeV

E$_n$ ~ window?



The Surrogate Method

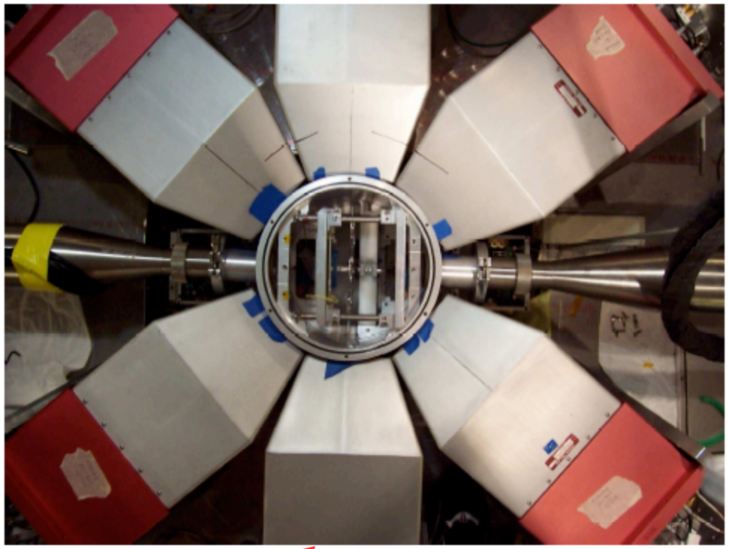


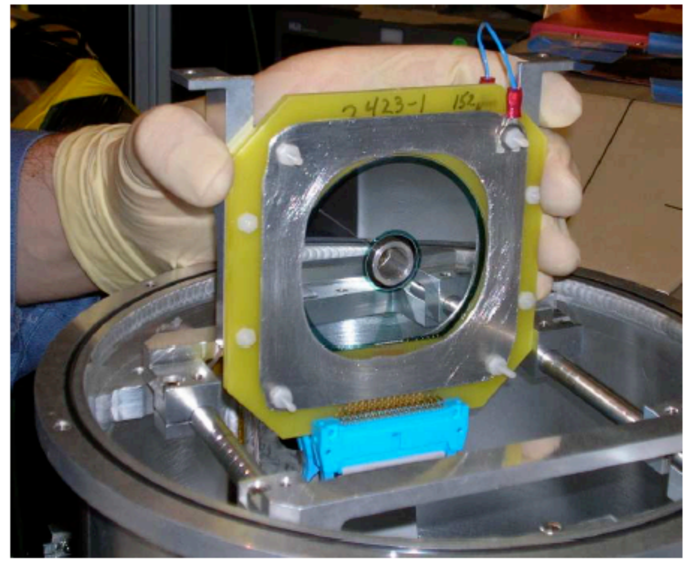
$$\sigma_{A(a,x)C} = \sum_{J,\pi} P_c(J,\pi,E_x)\, \sigma_{a+A}^{compreac}(J,\pi,E_x)$$

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

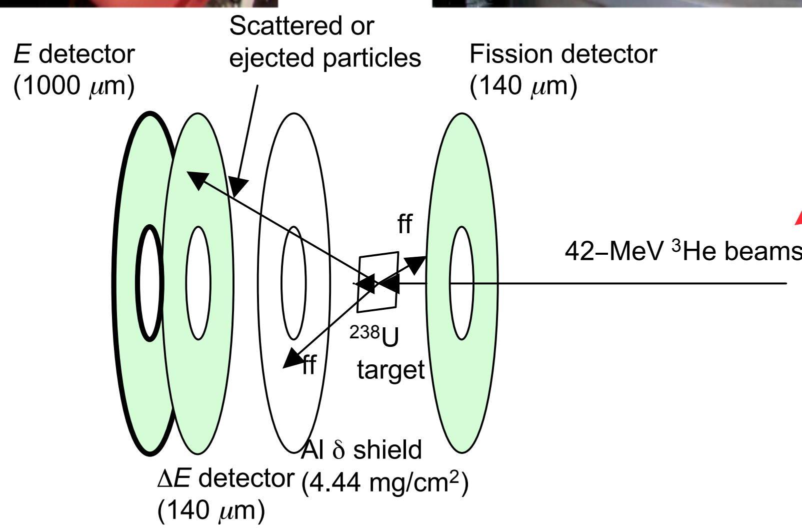
Central assumption: Both reactions form a compound nucleus

LIvermore BERkeley Array for Collaborative Experiments (LIBERACE) + Silicon Telescope Array for Reaction Studies (STARS)





LIvermore
BERkeley
Array for
Collaborative
Experiments

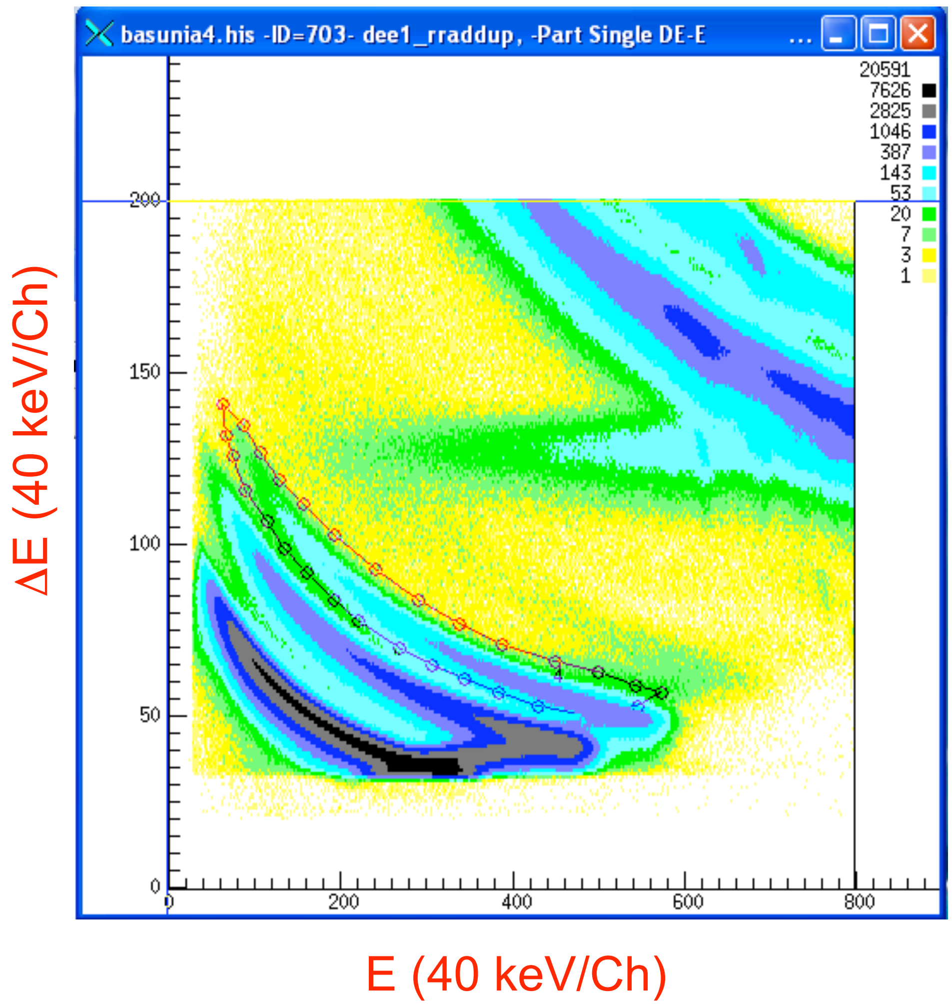


Silicon
Telescope
Array for
Reaction
Studies

Experiment

- Goal: Determination of $^{237}Np(n, f)$ cross section
- Surrogate: $^{238}U(^{3}He, t)^{238}Np$
- ^{238}U metallic target (self supported)
  - 99.99% pure
  - Thickness ~0.9 mg/cm^2
- 42-MeV ^{3}He beam
- Beam current: 2 - 3 pnA
- Irradiation time – 8 days - shared with another ^{235}U target
- A total of ~10^7 triton-fission coin events were recorded

Particles Identification Plot



Analysis

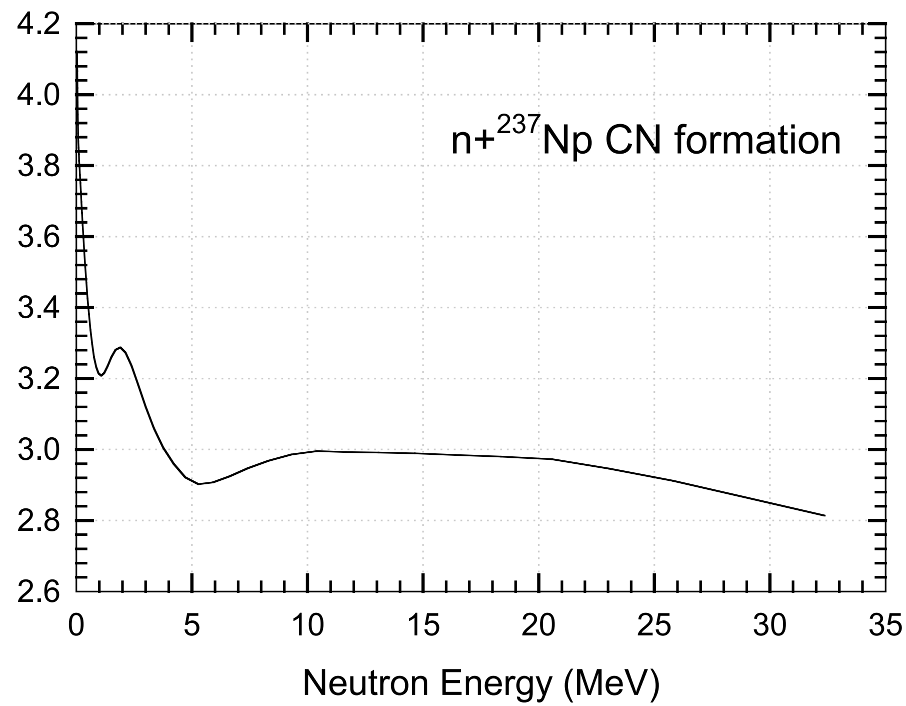
- Tritons were gated for each ring
- Corrected for the energy loss
  - Al δ shield
  - Au layer of the Si detector and
  - For recoil
- Sorted for fission events in coincidence with the gated tritons (Bkg corrected)

Analysis

- Fission probability

$$P_f = \left(N_{c-f} \Big/ eff \right) \Big/ N_t$$

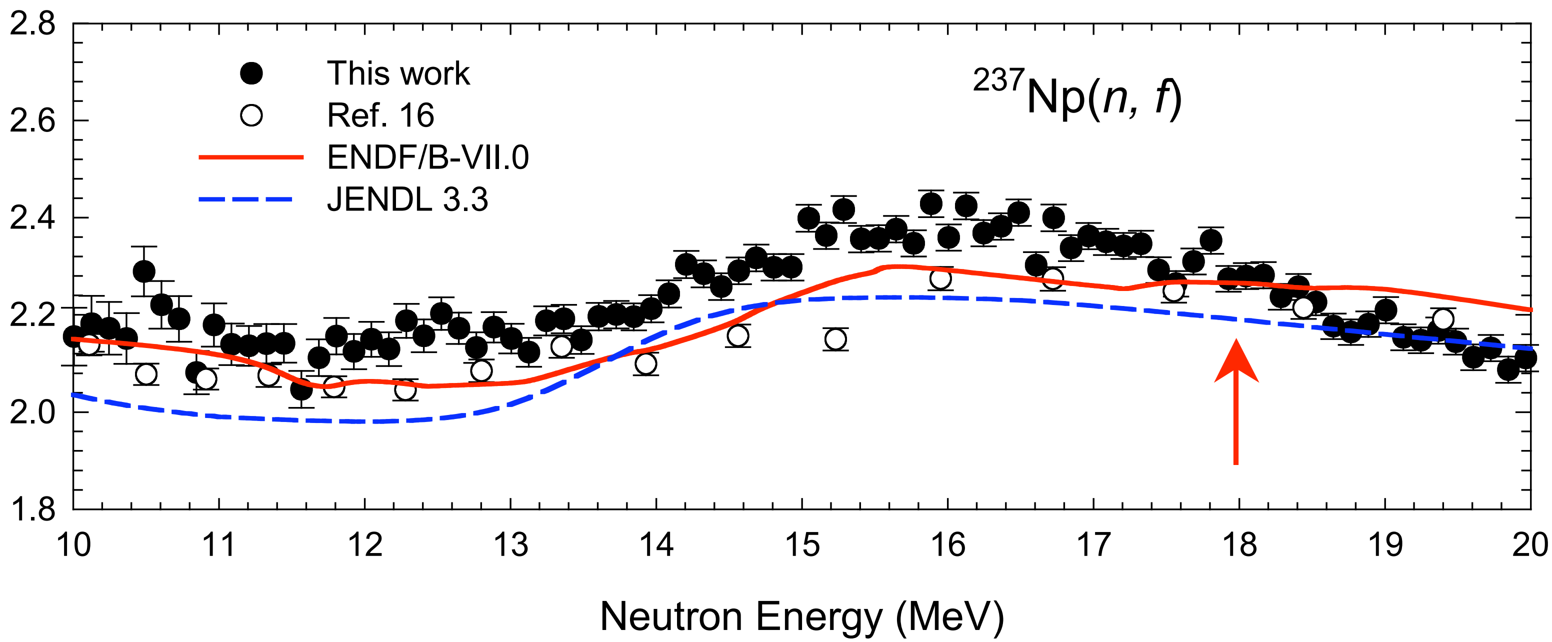
- $^{237}Np + n$ CN formation cross section



From - Frank Dietrich (LLNL)

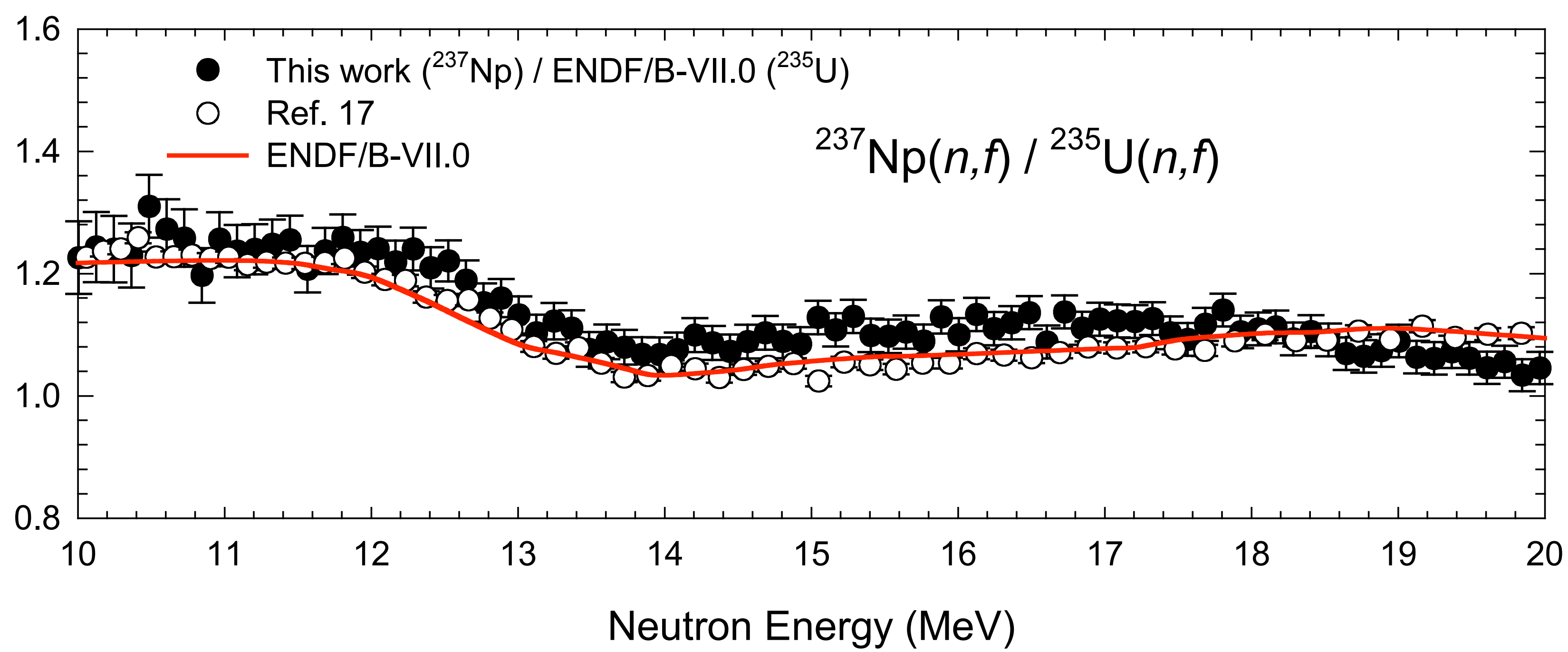
- Finally $\sigma(n, f) = \sigma_{CN} * P_f$

Results



Statistical uncertainty

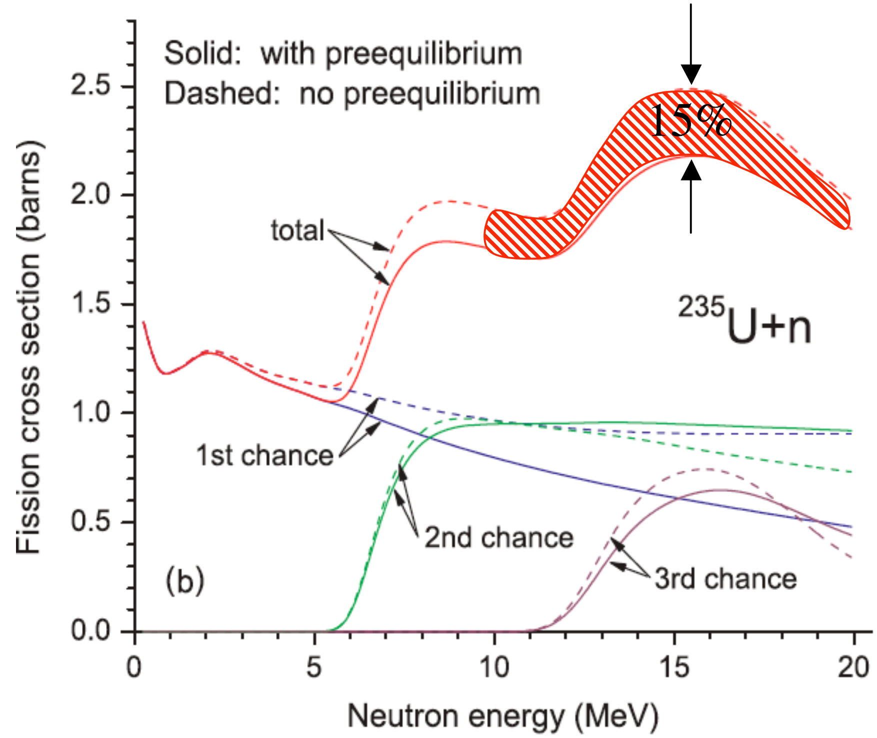
Ref. 16. J. Nucl. Sci. & Tech., Supp. 2, 230, 2003

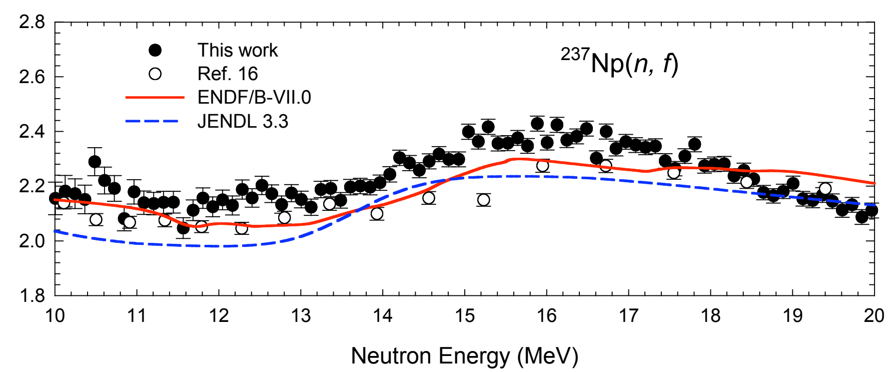


- **Ref. 17:** **F. Tovesson and T. S. Hill, Phys. Rev. C 75, 034610 (2007).**

Pre-equilibrium effect

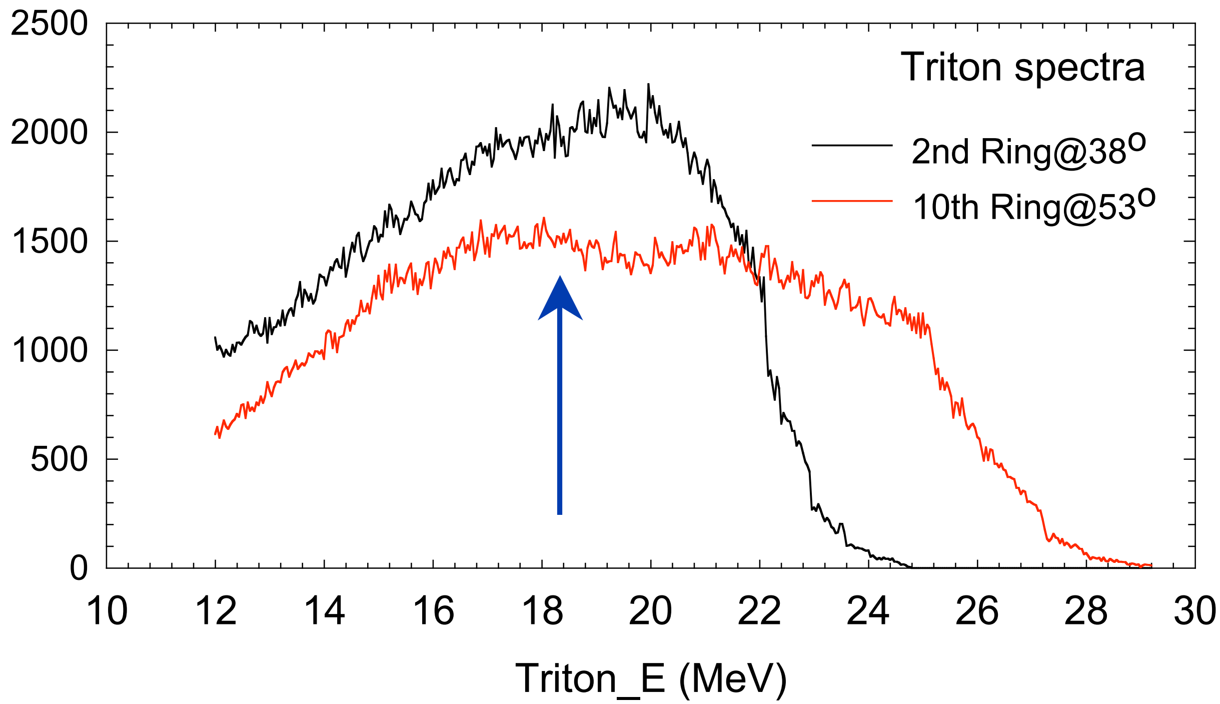
- Pre-equilibrium (*n, n'*) emission bypasses CN formation and reduces the CS
- Surrogate method would be unable to reveal the pre-equilibrium contribution
- J. Escher & F.S. Dietrich PRC74 054601 (2006)
- Our results indicate that the difference between the direct and surrogate reactions data due to pre-equilibrium effect is lower than the model predictions





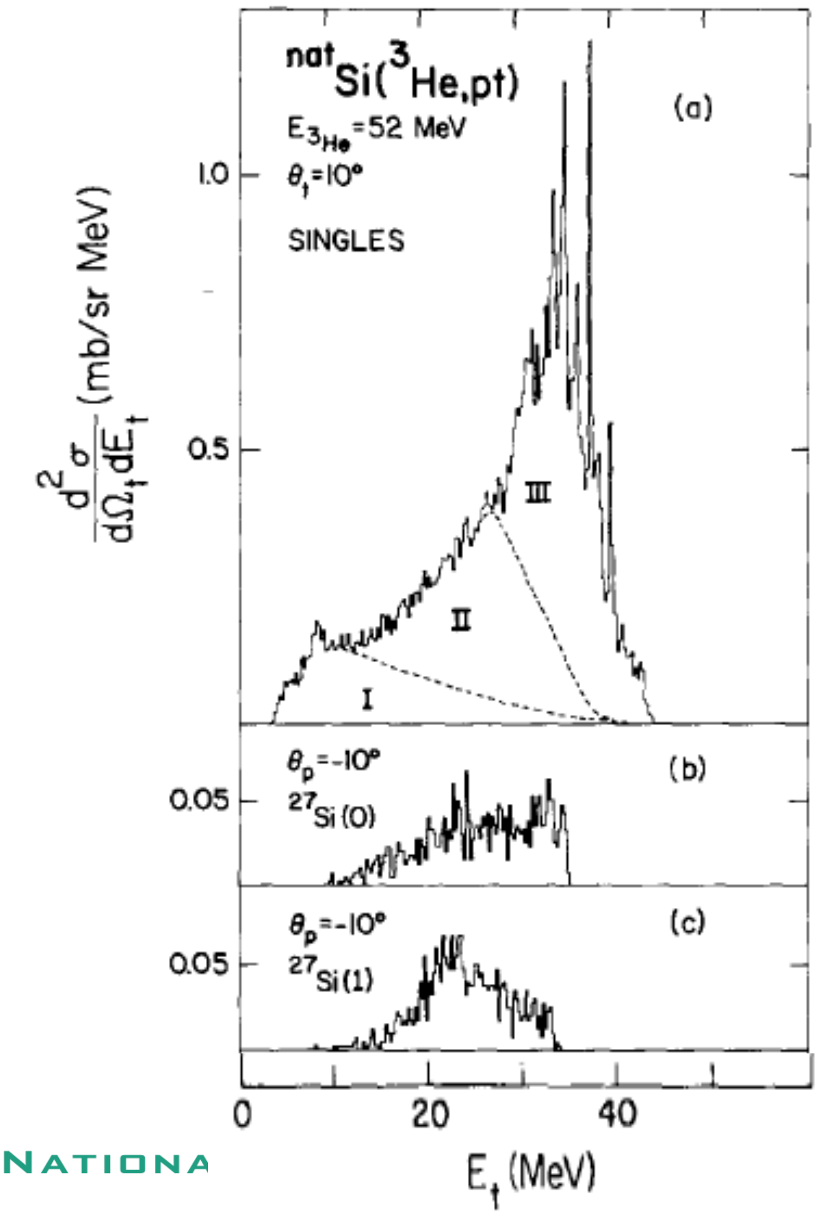
Effects of oxygen?

- Surrogate: $^{238}U(^{3}He, t)^{238}Np$
- $^{16}O(^{3}He, t)^{16}F$, Q = -15.4 MeV, $E_{threshold}$ = 18.3 MeV
- E_{beam} = 42 MeV



Physics Letters 102B (1981) 307

- Study of inclusive (^{3}He,*t*) spectra @E_{beam}= 52 MeV
- Break up
  - $^3He \rightarrow p + d$
  - $d + n \rightarrow t$
- Resultant reaction: (^{3}He, *pt*) and resultant tritons at the lower energy tail
- Break-up tritons are suppressed at backward angles



Summary

- Absolute surrogate method using (^{3}*He, tf*) worked well to deduce the ^{237}Np(*n, f*) cross section in between 10–18 MeV
- Our results indicate that the difference between the direct and surrogate reactions due to pre-equilibrium effect is lower than the model predictions from the (^{3}He, *t*) surrogate reaction in the 10 to 20-MeV range
- Uncertainty remains within 10% for (*n, f*) cross sections including systematic uncertainty
- Absolute surrogate method using (^{3}*He, tf*) reaction provided the opportunity to study pre-equilibrium decay at higher E_n: that would have been lost in the surrogate ratio method

Collaborators

- **LBNL** - R. M. Clark, L. Phair, D. Bleuel, P. Fallon, J. Gibelin, M. A. McMahan, E. Rodriguez-Vieitez, and M. Wiedeking
- **LLNL** - L. A. Bernstein, B. F. Lyles, J. T. Burke, and F. S. Dietrich
- **U of Richmond** - C. W. Beausang and S. R. Lesher