Benchmarking the Surrogate Ratio Method Using $^{234}U(\alpha,\alpha'f)/^{236}U(\alpha,\alpha'f)$

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The Surrogate Ratio Method

The Surrogate Ratio Method is an indirect technique which makes use of the theory of compound nuclear reactions to determine cross sections in isotopes which cannot be directly measured. Most of these are unstable isotopes which are either too difficult to produce or too short-lived to be used as a target.

The first experiment was performed using STARS at Yale University.

$^{236}U(d,pf)/^{238}U(d,pf)$ surrogate for $^{236}U(n,f)/^{238}U(n,f)$

$^{238}U(d,d'f)/^{236}U(d,d'f)$ surrogate for $^{237}U(n,f)/^{235}U(n,f)$

Demonstrated that the fission probabilities was the same over a wide range of equivalent neutron energies, regardless of whether the nuclei were formed using neutron-capture or the (d,p) reaction.

L.A. Bernstein, *et al.*, AIP Conference Proceedings, vol. 769, 890 (2005).
C. Plettner, *et al*., PRC 71, 051602(R) (2005)

The "surrogate" technique:

$$\sigma_{(n,f)}(E_n) = \sigma_{CN}(E_n)P_{(\alpha,\alpha'f)}(E_x)$$

$$P_{(\alpha,\alpha'f)}(E_x) = N_{(\alpha,\alpha'f)} / N_{(\alpha,\alpha')}$$

$$E_x = E_n + B_n$$

Ratio allows for the possibility to find an unknown cross section. Using ^{234}U & ^{236}U:

$$\frac{\sigma_{(n,f)}(^{233}U)}{\sigma_{(n,f)}(^{235}U)} = \frac{\sigma_{CN}(^{234}U)P_{(\alpha,\alpha'f)}(^{234}U)}{\sigma_{CN}(^{236}U)P_{(\alpha,\alpha'f)}(^{236}U)}$$

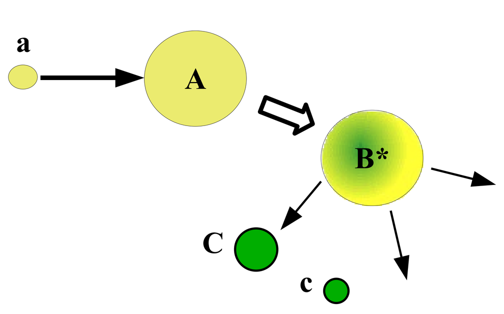
Then the ratio:

$$R = \frac{N_{(\alpha,\alpha f)}(^{234}U)}{N_{(\alpha,\alpha f)}(^{236}U)} = \frac{\sigma_{(n,f)}(^{233}U)}{\sigma_{(n,f)}(^{235}U)}$$

Number of coincidence events

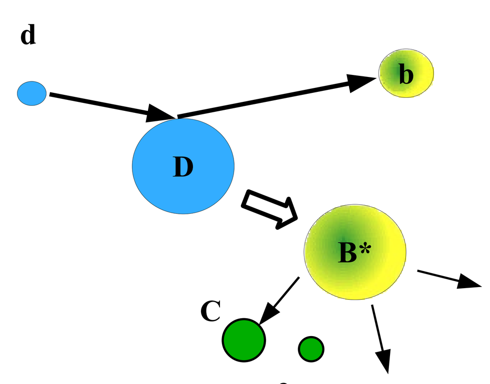
"Desired" Reaction

$a + A \rightarrow B^* \rightarrow c + C$



Surrogate Reaction

$d + D \rightarrow B^* + b \rightarrow c + C$



The first STARS experiment at LBNL:

$^{238}U(\alpha,\alpha'f)/^{236}U(\alpha,\alpha'f)$ surrogate for $^{237}U(n,f)/^{235}U(n,f)$

Able to determine the $^{237}U(n,f)$ cross section for neutron energies ranging from 0 – 20 MeV.

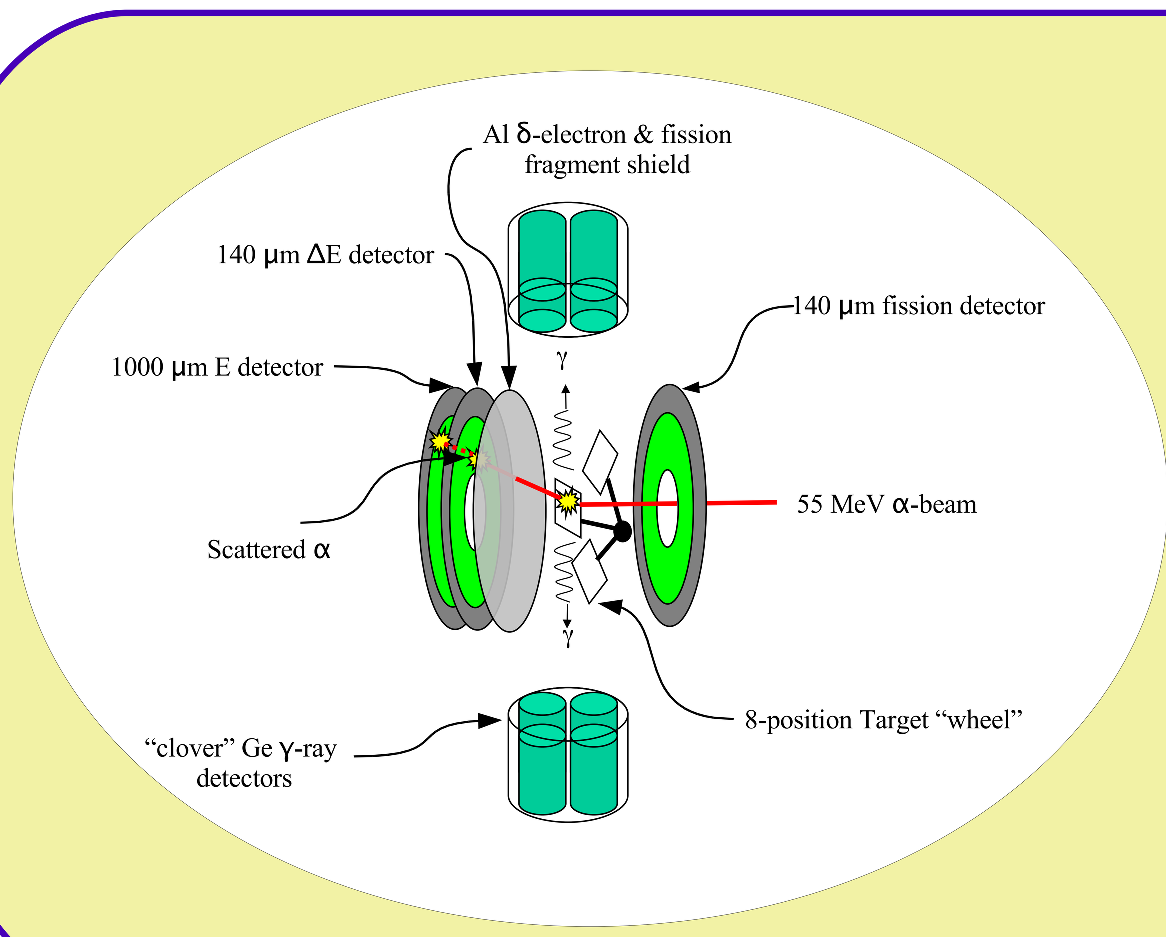
J.T. Burke, *et al*., PRC 73, 054604 (2006)

In this experiment, we obtained the ERSM without implementing theoretical calculations.
Basic equation for fission:

$$N_{\alpha\phi} = N_p \rho_T * \sigma_{\alpha\phi} * \epsilon_{\alpha\phi} * \ell$$

- $N_{\alpha\phi}$: Number of alpha-fission events detected
- N_p: Total number of beam particles ($\Delta t * I$)
- ρ_T: Atomic areal density of target
- $\sigma_{\alpha\phi}$: Alpha-fission cross section
- $\epsilon_{\alpha\phi}$: Detector efficiency
- ℓ: Live time of DAQ

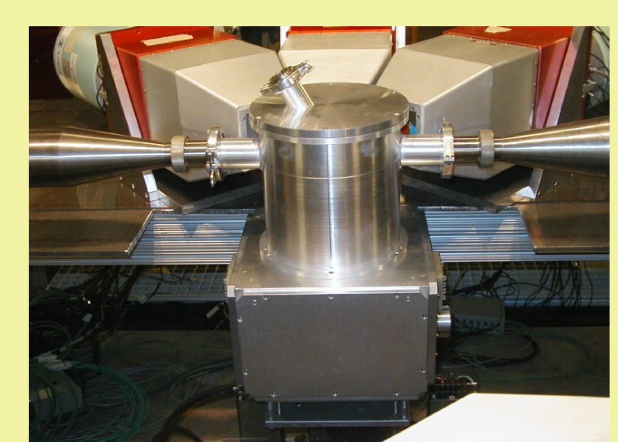
Experimental Set Up



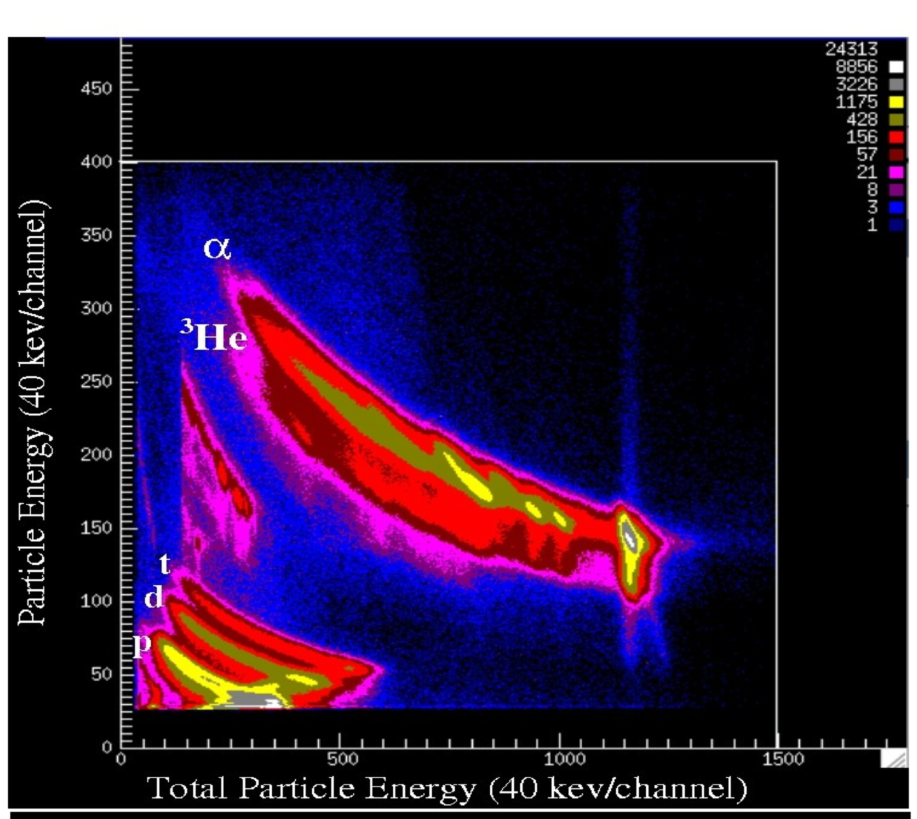
This experiment was performed using the 88-inch cyclotron at Lawrence Berkeley National Laboratory using the Silicon Telescope Array for Reaction Studies (STARS). In this experiment excited ^{234}U and ^{236}U nuclei were formed via inelastic α-particle scattering and the ratio of their fission probabilities was compared to the known $^{233}U(n,f)/^{235}U(n,f)$ cross section ratio.

The ^{234}U and ^{236}U targets were bombarded with a 55 MeV α-beam and the fission fragments in coincidence with outgoing α-particles were measured. The STARS array consisted of a particle telescope comprised of two Micron S2 detectors, a 140 μm ΔE and a 1000 μm thick E detector located downstream from the target coupled to a third 140 μm fission fragment detector located upstream from the target.

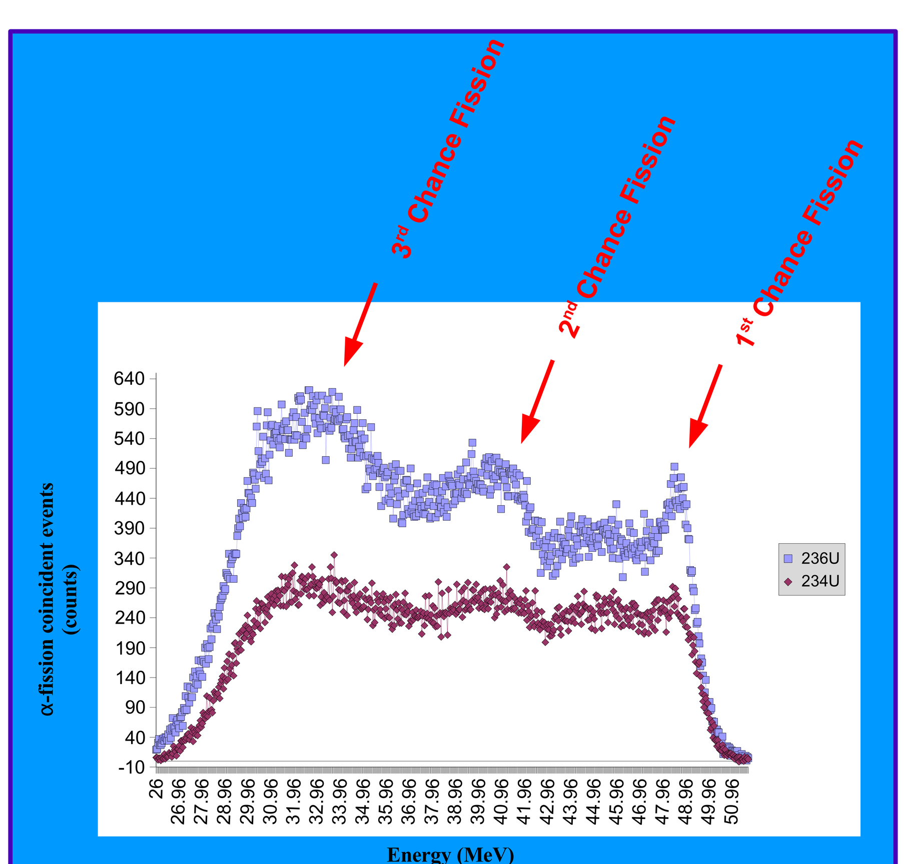
STARS +Liberace



(above) A picture of the STARS chamber, sealed, attached to the beam line at the Lawrence Berkeley National Laboratory. Also shown are half of the Liberace detectors which surround the chamber at varying angles. A schematic drawing of the inside of the chamber is shown on the left.

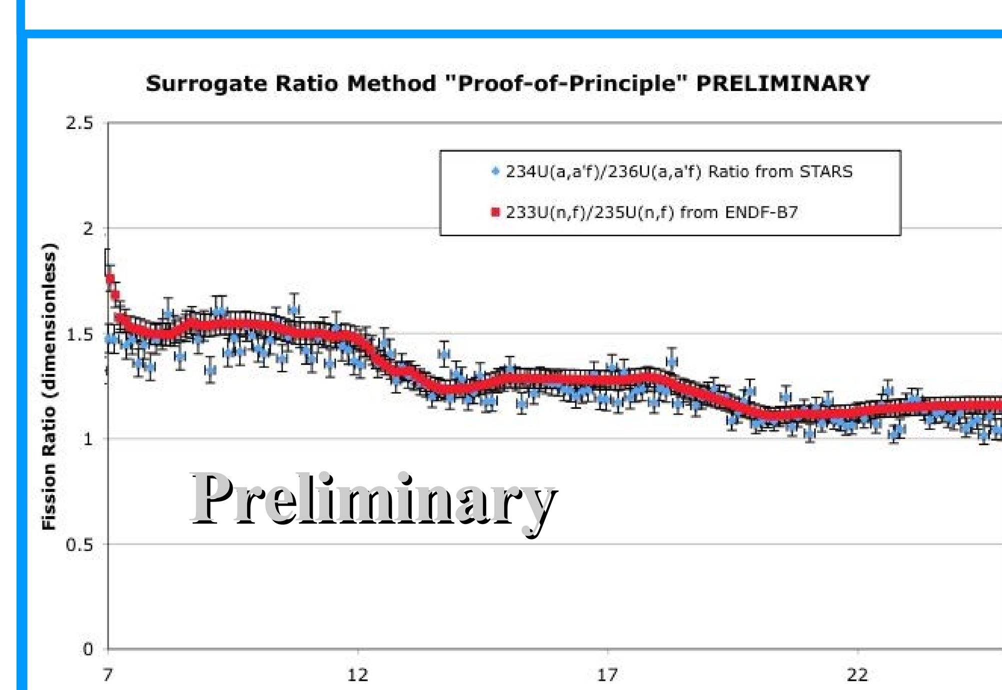


Delta E versus E plot from 55 MeV α particles incident on ^{234}U in coincidence with fission events. Protons (p), deutrons (d), and tritons (t) are seen in the lower region of the graph. In the upper portion of the graph, ^{3}He and alphas are observed. The alpha particles are then gated on using a banana gate for analysis.



The number of $(\alpha,\alpha'f)$ events as a function of energy for both ^{236}U and ^{234}U. This data is then used to make the ratio between the two isotopes.

The graph displays an arbitrary normalization which shows the shape of the experimental curve matches the known cross section. A variety of methods are being considered and analysis is underway to accurately take the normalization into account.



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