Mass distribution and Total Kinetic Energy of Fragments from the Reaction 235U(n_{th}, f) Compatible with Results Obtained Using the 2E and ME Techniques, Respectively

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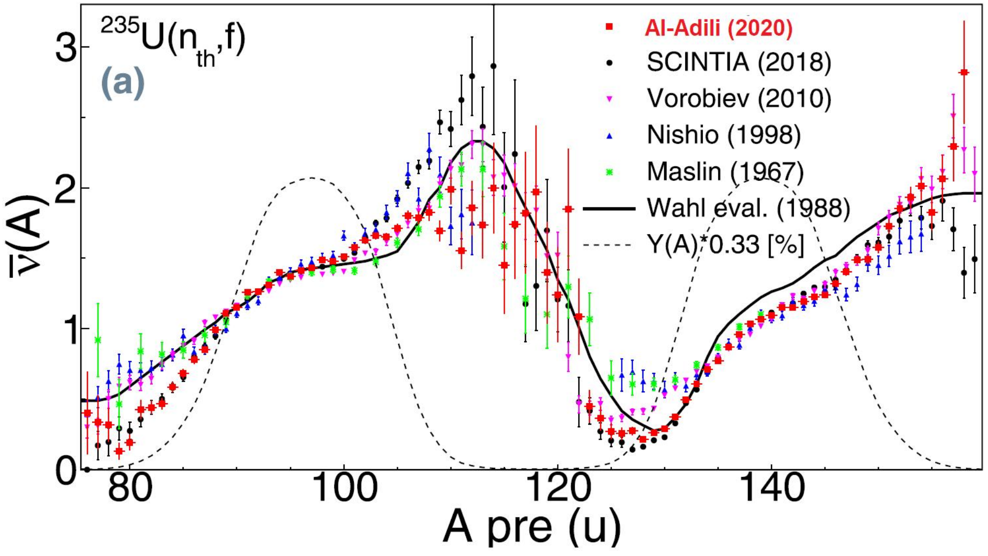
Introduction

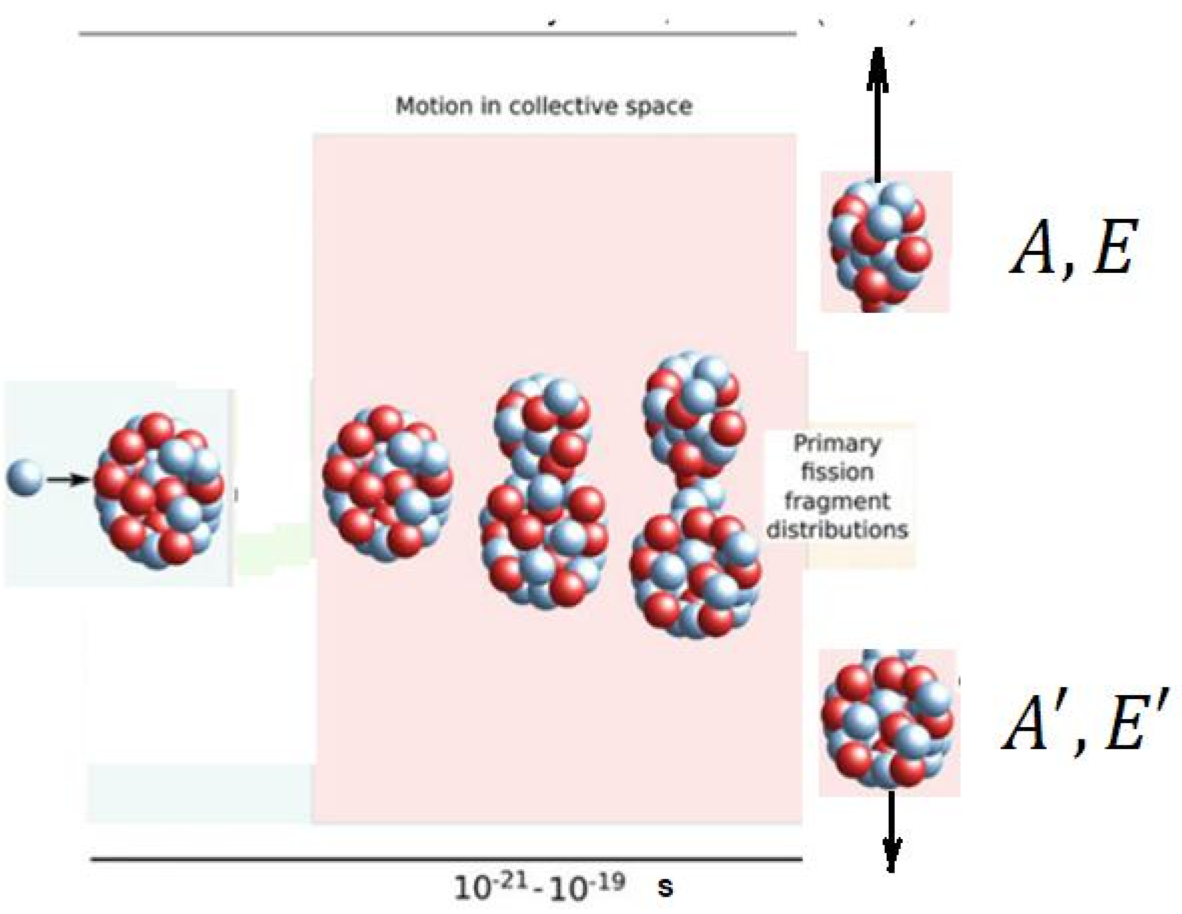
Lack of accuracy in experimental results.



"This work clearly proves the lack of accurate correlation between fission fragment and neutron data even in the best-studied reactions. The new results highlight the need of a new evaluation of the prompt-fission multiplicity for 235U(nth, f)." Al-Adili et al., PHYSICAL REVIEW C 102, 064610 (2020)"

In this work we propose a Monte Carlo algorithm to calculate $\bar{\nu}(A)$, a smooth curve of the average prompt neutron multiplicity as a function of pre-neutron fragment mass calculated from the values of post-neutron complementary fission fragment kinetic energies, e and e', as it used in the 2E technique.

The fission process



Relations between pre-neutron fragment mass and kinetic energy.

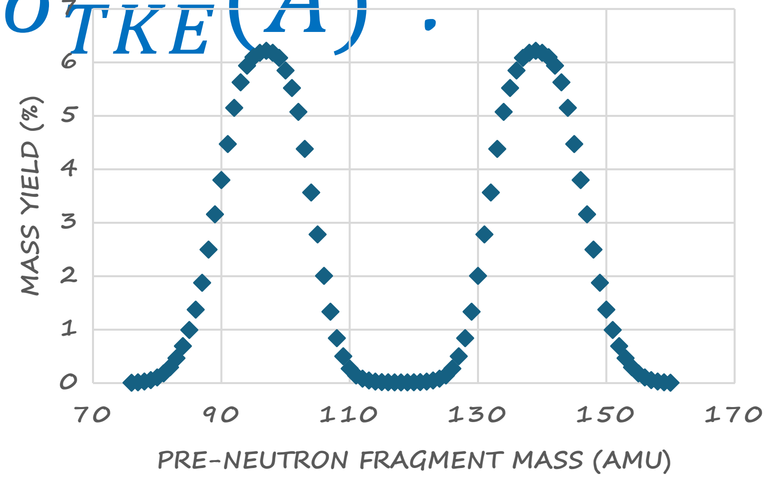
- $A_f = A + A'$,
- $AE = A'E'$,

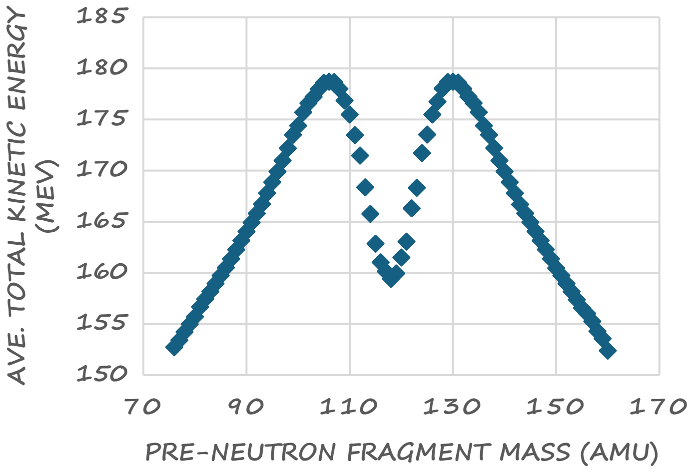
Total kinetic energy

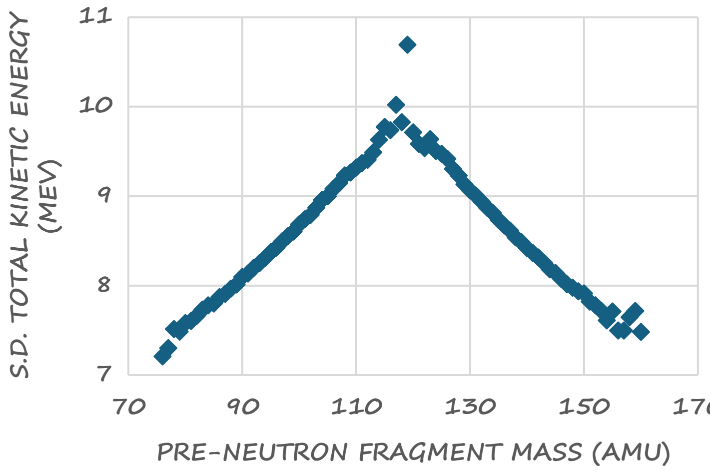
$$TKE = E + E'$$

Simulation of isotropic (relative to fragment CM) emission of neutron

Using a Monte Carlo method we simulate the pre-neutron fragment mass distribution ($Y(A)$) and a total kinetic energy distribution characterized by $\overline{TKE}(A)$ taken from Al-Adili (2020) data, and a smooth standard deviation $\sigma_{TKE}(A)$.







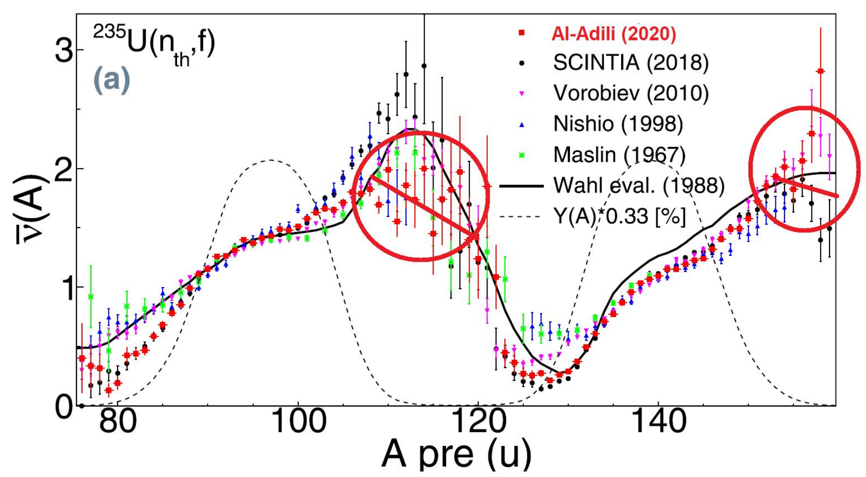
We simulate an isotropic emission of n and n' neutrons from their corresponding fragment having masses A and A', respectively:

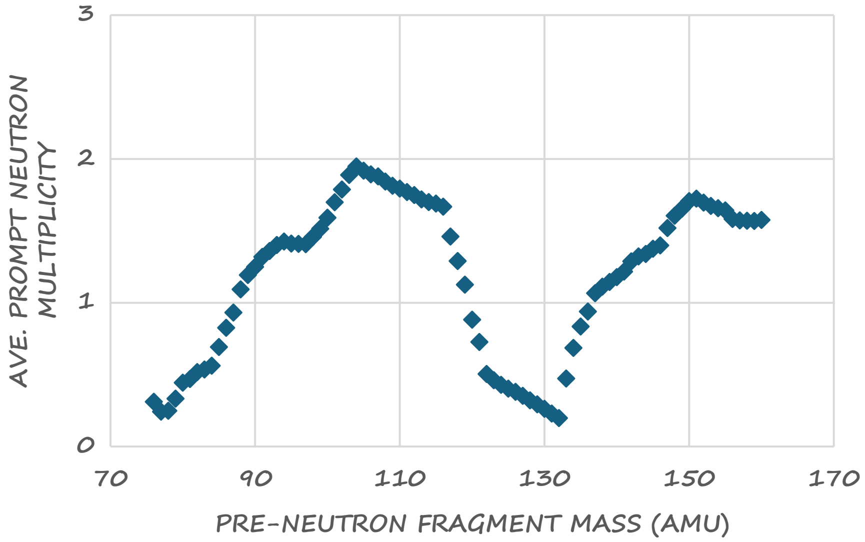
$$n(A, TKE) = \bar{\nu}(A)\left(1 - \frac{TKE - \overline{TKE}}{\alpha(A)} + \frac{r}{3}\right),$$

$$n'(A', TKE) = \bar{\nu}(A')\left(1 - \frac{TKE - \overline{TKE}}{\alpha(A')} - \frac{r}{3}\right),$$

where r has a Gaussian distribution with a mean of 0 and a standard deviation of 1. The value of α is 12 MeV, taken from Al-Adili (2020).

The $\bar{\nu}(A)$ values correspond to an smothed curve based on Al-Adili data (2020).
Our hyphotesis is that the experimental data overstimates values arorund $A = 115$.



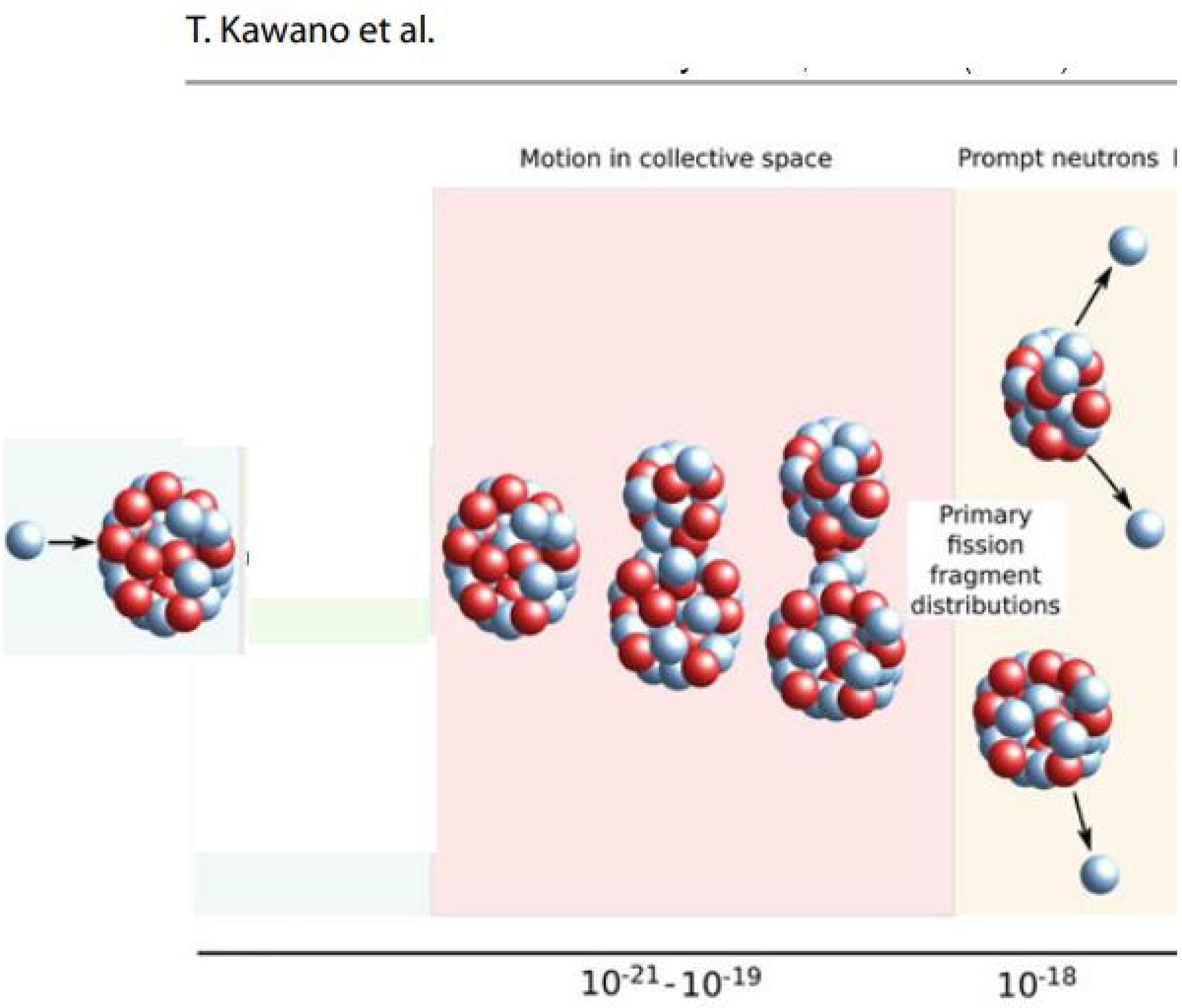


The fragments emit (n, n') neutrons, isotropically with kinetic energies $(\eta_1, \eta_2, \ldots \eta_n; \eta'_1, \eta'_2, \ldots \eta'_{n'}.)$ relative to their corresponding center of mass. The η values obey the relation

$$\eta = \bar{\eta}(A)\left(1 + \frac{r}{3}\right),$$

where r has a Gaussian distribution with a mean of 0 and a standard deviation of 1.
The values of $\bar{\eta}(A)$ are taken from Al-Adili (2020).

Post-neutron kinetic energy of detected fragments



Taking into account the recoil effect in each neutron emission, we calculate the final kinetic energy of fragments e and e', which is associated with the measured by the 2E technique.

Assuming that n and n' neutrons are detected and counted, the provisional mass (A^*) and the aproximative values of E and E' are calculated from equations:

$$A_f = A^* + A^{*\prime},$$
$$A^* e = A^{*\prime} e',$$

$$e = E(1 - \frac{n}{A^*}),$$
$$e' = E'(1 - \frac{n'}{A^{*\prime}}),$$

The last two equations are based on the relation

$$e = E(1 - \frac{n}{A})$$

for which it is assumed that the fragment mass is lower by n amu but its velocity does not change.

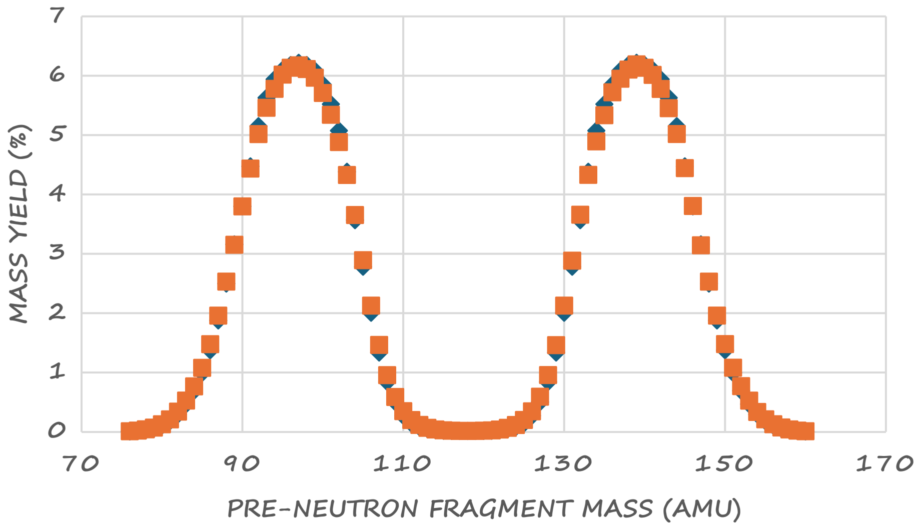
From mass and momentum conservation relations

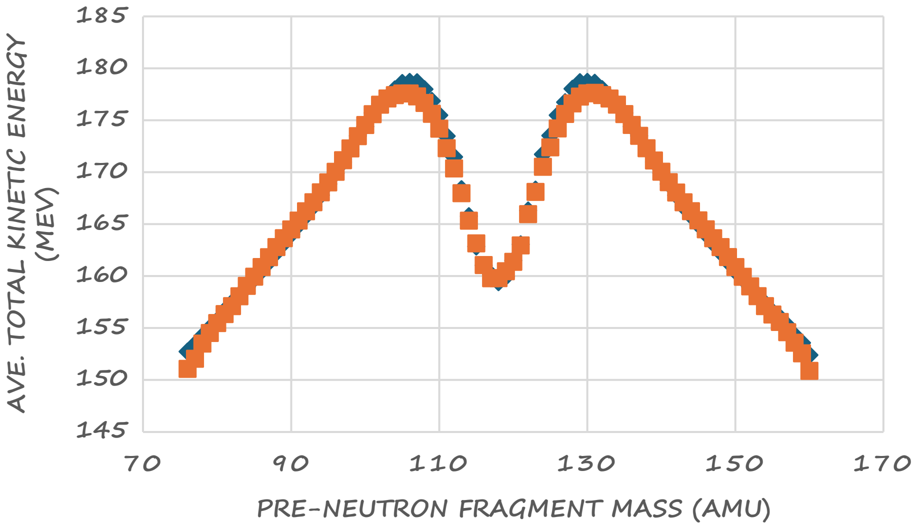
- $A_f = A + A'$,
- $AE = A'E'$,

using the aproximative values of pre-neutron E and E', the aproximative value of pre-neutron A is calculated.

Results

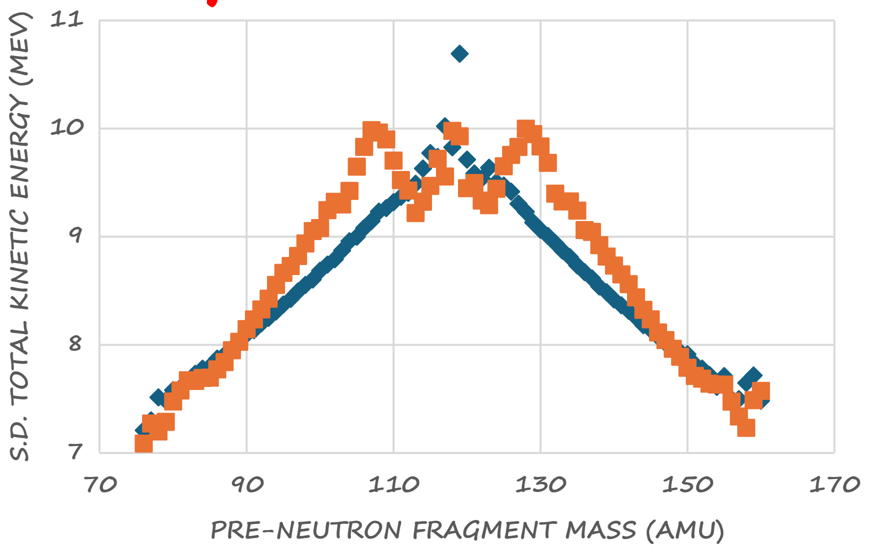
Pre-neutron mass yield and average total kinetic energy of fission fragments.

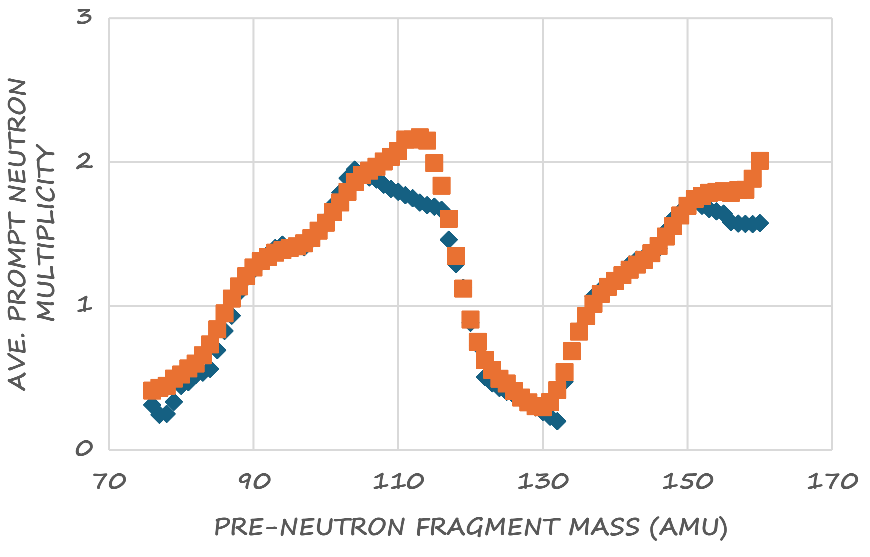




- Diamonds: assumed as "true" values, taken from Al-Adili data (2020)
- Squares represent output data from the measuring simulation. Raw data is corrected using the number of emitted prompt neutrons (n and n').

Standard deviation of the total kinetic energy and the average prompt neutron multiplicity as a function of the pre-neutron fragment mass.





- Diamonds: assumed as "true" values, taken from Al-Adili data (2020)
- Squares represent output data from the measuring simulation. Raw data is corrected using the number of emitted prompt neutrons (*n* and *n'*).

The 2E technique

Assuming that only the $\bar{\nu}(A)$ values are known, the approximative values of pre-neutron fragment kinetic energy are calculated using the relations

$$E = \frac{e}{1 - \frac{\bar{\nu}(A^*)}{A^*}},$$

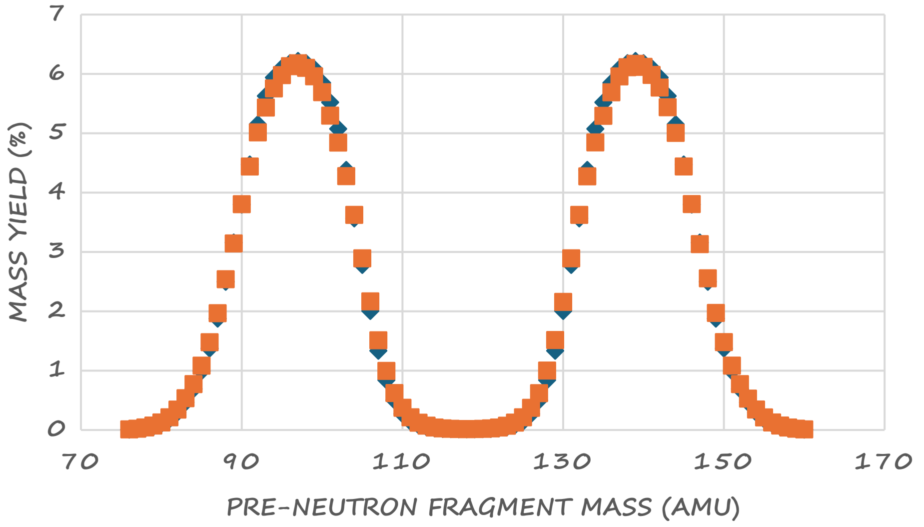
$$E' = \frac{e'}{1 - \frac{\bar{\nu}(A^{*\prime})}{A^{*\prime}}}.$$

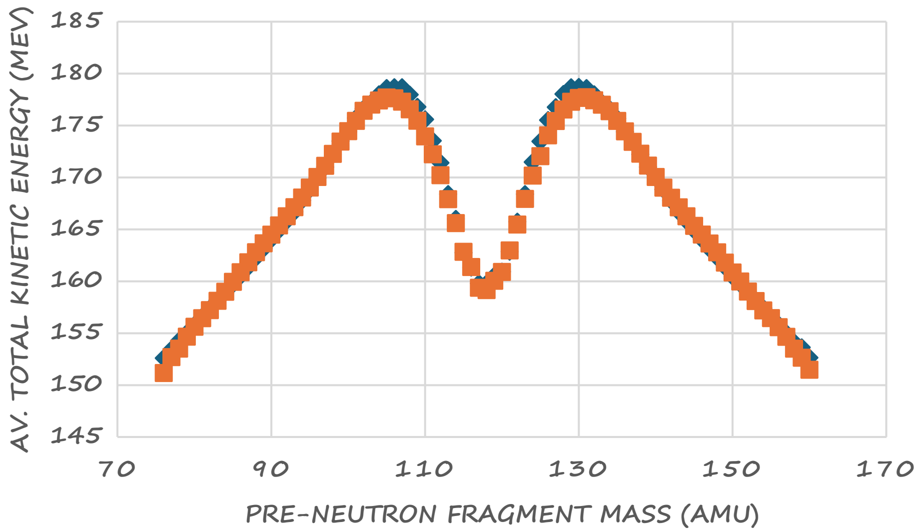
With these values of E and E', the pre-neutron masses are calculated using the relations

$$A_f = A + A'.$$

$$AE = A'E'.$$

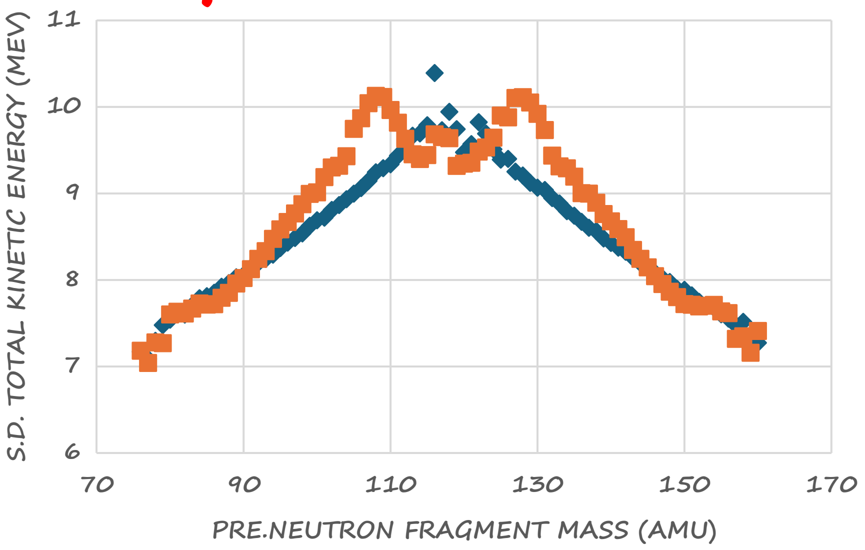
Pre-neutron mass yield and average total kinetic energy of fission fragments.

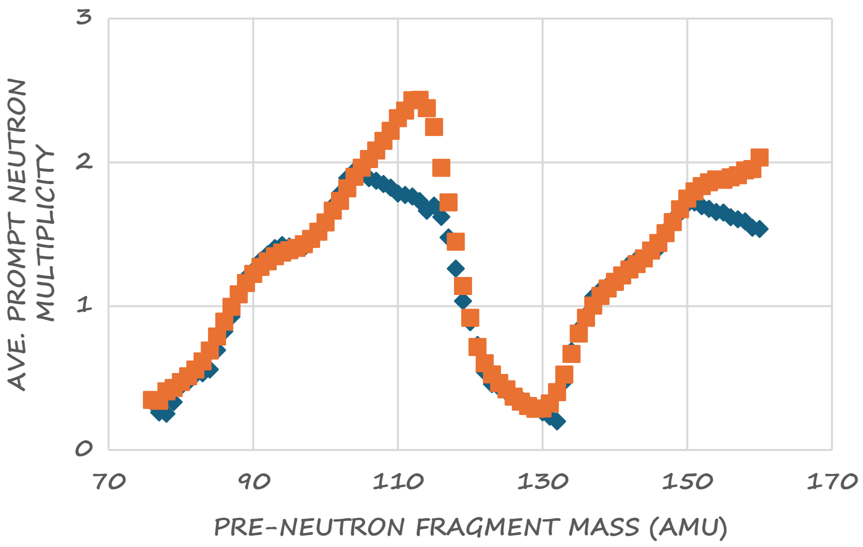




- Diamonds: assumed as "true" values, taken from Al-Adili data (2020)
- Squares represent output data from the measuring simulation. Raw data is corrected using the average prompt neutron multiplicity $\bar{\nu}(A)$.

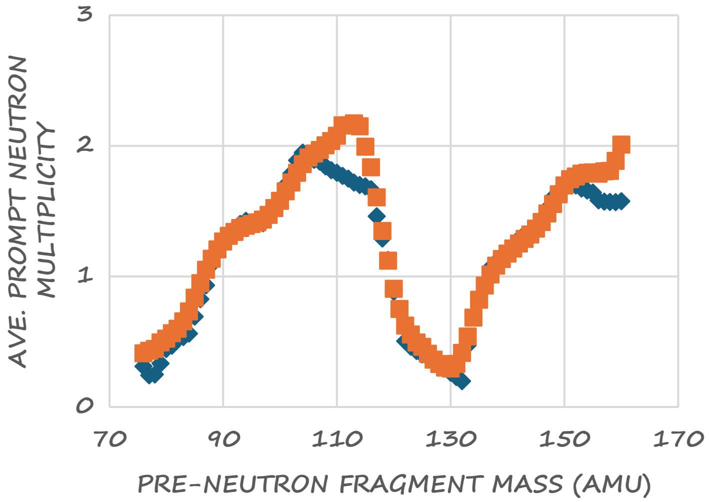
Standard deviation of the total kinetic energy and the average prompt neutron multiplicity as a function of the pre-neutron fragment mass.

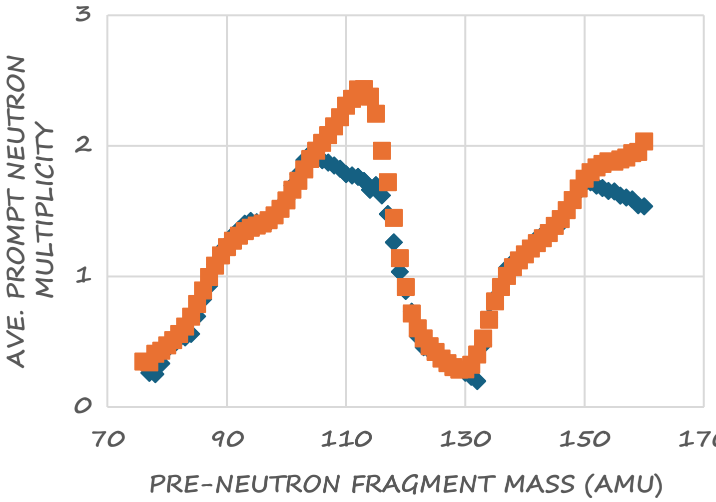


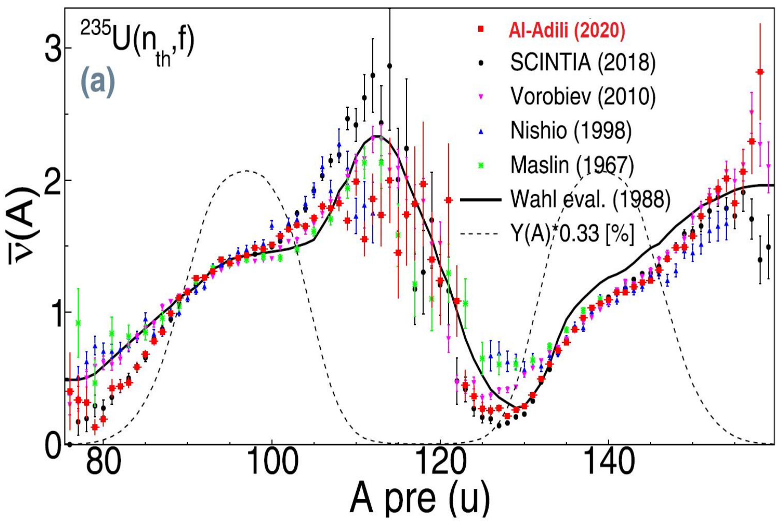


- Diamonds: assumed as "true" values, taken from Al-Adili data (2020)
- Squares represent output data from the measuring simulation. Raw data is corrected using the average prompt neutron multiplicity $\bar{\nu}(A)$.

Comparaison between results based on n and $\bar{\nu}(A^*)$ values. The experimental data is shown.







- Left: output data from the measuring simulation. Raw data is corrected using the exact number of emitted prompt neutron.
- Right: output data from the measuring simulation. Raw data is corrected using the average prompt neutron multiplicity.

The 1M1E technique

In 1979, at the Lohengrin ILL spectrometer, Brissot et al measured the final fragment mass (m) and kinetic energy (e). The standard deviation of e as a function of m shown a peak around m=109. In this work, a similar result was obtained, with input data taken from a 2E technique result.

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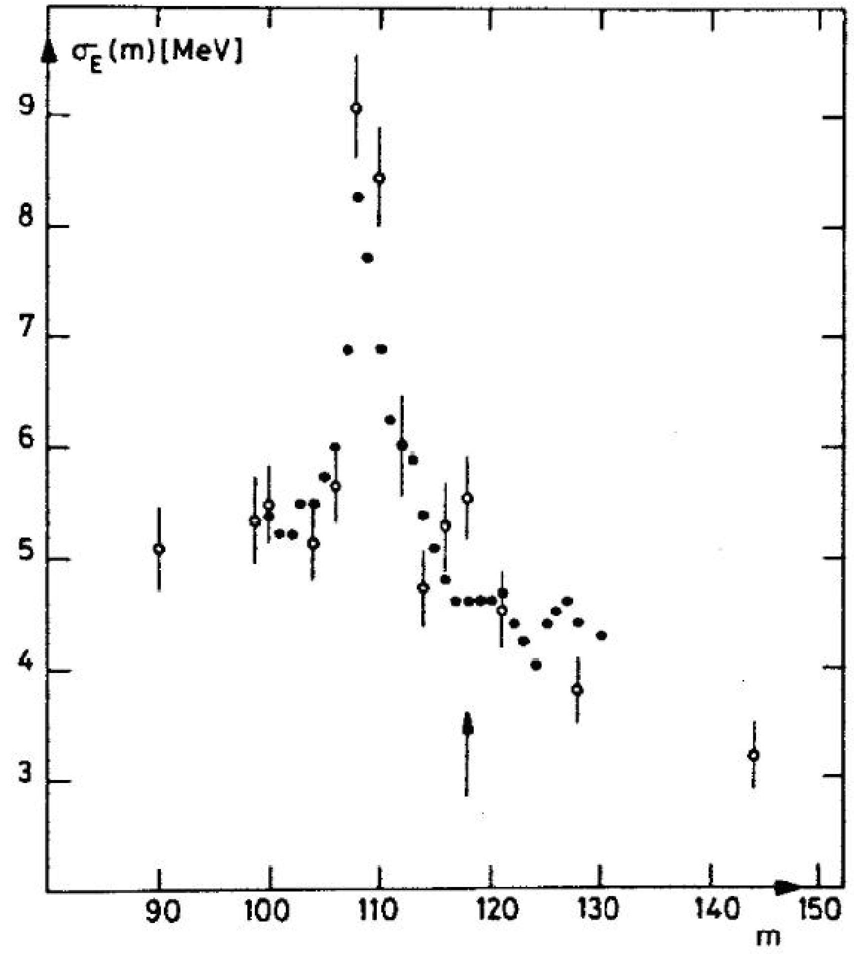

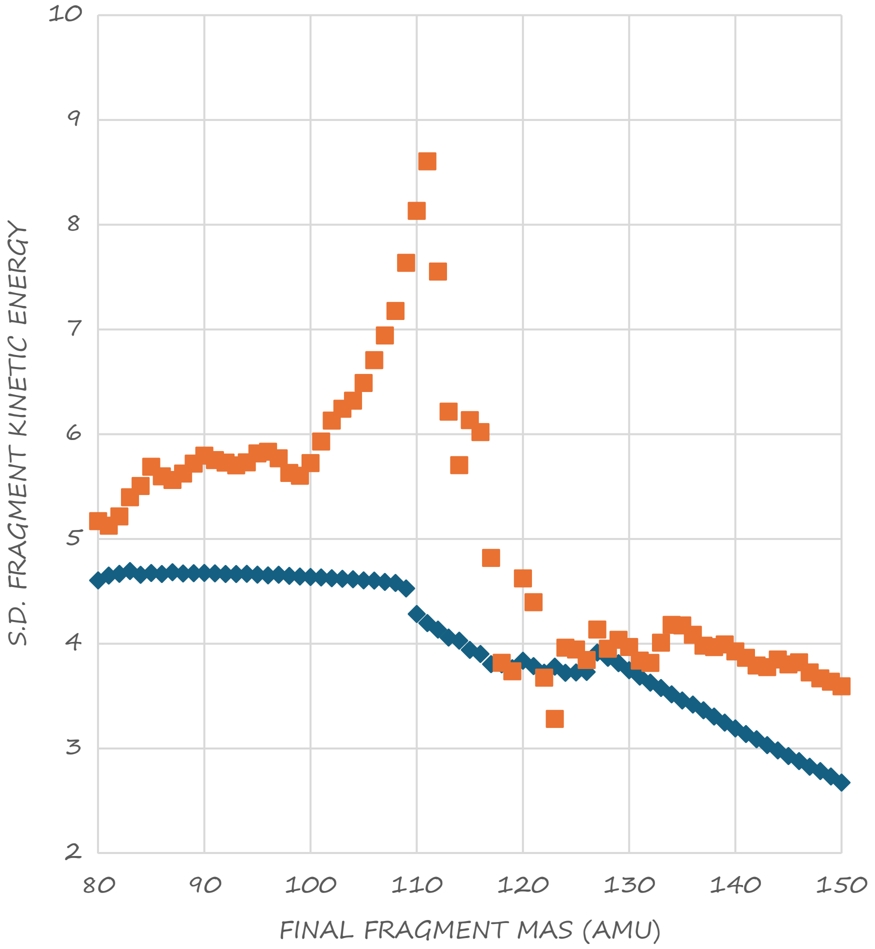

Discussion

- The first source of inaccuracy in the simulated $2E$ technique lies in the fact that formulas applied to calculate the pre-neutron fragment kinetic energy (E_{c}), do not account for the complete recoil effect on the fragments due to neutron emission. Only the drop of mass is considered. Consequently, the calculated pre-neutron fragment mass A_{c} is not necessarily equal to the true value:$A_{\mathrm{c}} \neq A$.
- The dispersion of the values of A_{c} relative to the values of A generates dispersion in the calculated average prompt neutron multiplicity $\overline{n}(A_{\mathrm{c}})$ relative to the simulated as "true" values $\overline{n}(A)$.
- Using the same input data, results from an experiment using the ME technique.
- Furthermore, $\overline{n}(A_{\mathrm{c}})$ is a multivariable function dependent on the mass distribution, the kinetic energy of the fragments, the number of emitted neutrons, and the kinetic energies of each of these neutrons. To trace back to the curve $\overline{n}(A)$, one would need to simulate this distribution as an input to the simulation algorithm so that $\overline{n}(A_{\mathrm{c}})$ reproduces the experimental values of the $2E$ and other techniques.

Thanks for your attention